Roadmap for decarbonisation of the maritime sector

Proposed action plan to decarbonize the French maritime sector and ensure France's sovereignty of supply

EDITION 2

NOVEMBER 2024

Direction générale des affaires maritimes, de la pêche et de l'aquaculture

Cluster Maritime Français

EVOLEN

Armateurs de France

GICAN

MARITIME ENERGY AND ENVIRONMENTAL TRANSITION 2050

CONTENTS

Opening remarks from the co-chairs

Since our roadmap was initially published in April 2023, the Directorate General for Maritime Affairs, Fisheries and Aquaculture (DGAMPA) and the French Maritime Cluster (CMF) have continued to mobilise and unite all stakeholders of the value chain, to accelerate the energy transition of the maritime sector. This updated version marks yet another turning point in this approach.

Thanks to this close collaboration between all players in the industry, we have been able to look deeper into the specific needs of each fleet category, thereby considerably improving the quality of data available and targeting technological, energy-related and operational solutions that are as close as possible to the specific characteristics of the fleets in question. With this fine-tuned knowledge, we will be able to put forward the combination of levers to roll out in order to meet the decarbonisation trajectories imposed by IMO regulations, and identify the pitfalls of this exercise and the long road ahead before we reach the much talked-about goal of net zero by 2050.

Of the work carried out, we applaud the commitment of the shipowners and the shipbuilding and design industry, who have all been highly proactive and innovative in the search for solutions. The French shipowners' association coordinated all the work done by the working groups for each fleet category, while the new tool developed by GICAN visualises French expertise in terms of decarbonisation. Energy providers drew up a situational analysis of sustainable fuels adapted to the maritime sector. Finally, Meet2050 decarbonisation institute’s renowned expertise made it possible to test and illustrate the different strategies per fleet category, translating them into CO2 emission reduction trajectories, and therefore fine-tuning the associated energy requirements for the revised SNBC.

This roadmap was revised collectively by a group of maritime experts to draw up a coherent, structured document to illustrate the technical, technological, industrial, financial, administrative and legal issues the sector is facing.

In setting clear goals and with a modified action plan, this revision sets out long-term decarbonisation goals that are based on a concerted strategy that must continue to be challenged and adapted to any future regulatory, technological, financial and geopolitical evolutions.

A major challenge lies in acquiring French energy sovereignty when it comes to marine fuels. Domestic production of biofuels or synthetic fuels is considered a strategic solution to reduce our energy dependency, maintain the competitiveness of our ports, ensure the operation of a strategic fleet and accelerate the transition. At the same time, we will be proactive in terms of energy diplomacy to guarantee a complementary supply of sustainable fuels.

In conducting this work, our goal has always been to ensure the competitiveness of our maritime industries, design offices and research centres that all play a key role in decarbonising the maritime sector, by guiding shipowners towards the most effective and competitive decarbonisation solutions.

This roadmap, led by the French government and the industry, remains an ongoing document that will continue to be updated periodically to meet the needs of maritime players as closely as possible, adapt to technological progress and to any changes in regulations. It provides a solid baseline and compass that will guide us towards a maritime future that is more sustainable and more environmentally friendly.

Nathalie Mercier-Perrin

President of the French Maritime Cluster

Eric Banel

General Director for Maritime Affairs, Fisheries and Aquaculture

Executive summary

The decarbonisation roadmap for the maritime sector, drawn up under Article 301 of the Climate and Resilience Act, is the French stakeholders in this sector's vision for meeting the decarbonisation targets set at international, European and national level. The result of a collective effort led by the DGAMPA and the CMF, and involving all the stakeholders in the value chain - shipowners, energy providers, ports, shipyards, equipment manufacturers, architects and design offices - it feeds into the work of the French Strategy for Energy and Climate (SNBC and MEP) which will help make decisions on the energy choices for our country.

This roadmap is all the more important as the maritime sector fulfils essential roles in the national economy, which it would no longer be able to carry out without a successful energy transition. With 4,080,000 people directly employed and a highly export-oriented industry, the maritime sector makes a major contribution to:

- **France** and Europe's **sovereignty of supply and transport** (some 85% of European imports and exports by volume enter or leave via the sea);
- **Food independence through fishing and aquaculture**;
- **Reducing national energy dependency** by developing the use of marine energies.
- **Strategic independence** to preserve the ability to act at sea, and to ensure the safety and security of transport, operations and infrastructure at sea.

As the most efficient means of transport in terms of energy consumption and greenhouse gas emissions per tonne transported per kilometre (a factor of 20 compared to road transport and 100 compared to air transport), maritime transport also presents an **opportunity to reduce the energy requirements and emissions for domestic transport,** with greater use of maritime transport and increased use of river and rail transport.

However, despite this efficiency, the quantities of goods transported by sea are so large that its overall impact is significant. It contributes approximately **3% of global greenhouse gas emissions** and, without decarbonisation, this figure could represent 90 to 130% of 2008 emissions by 2050. The maritime sector should account for a similar share of France's emissions, even if it is difficult to quantify these figures at the domestic level, given the international nature of maritime transport. The emissions data reported annually by France to the UNFCCC comply with international regulations but seem to be underestimated because they are calculated on only a part of the energy that is bunkered in French ports, the rest being attributed to international emissions. Moreover, bunkering in French ports is low in comparison with major European ports, which also creates **a risk of increased reliance on foreign bunkering for less abundant low-carbon energy.**

Ambitious decarbonisation targets have been set Internationally and for Europe, in line with the Paris Climate Agreement. The International Maritime Organisation (IMO) therefore declared its commitment in July 2023 to reaching net zero GHG emissions by 2050, with intermediate goals of at least a 20% reduction in emissions by 2030 versus 2008, aiming to reach 30%, and at least 70%, aiming to reach 80% by 2040 versus 2008. To reach these goals, a series of medium-term measures are currently being negotiated within the IMO and are expected to be adopted in 2025, to come into force in 2027. At the European level, the texts from the European "Fit for 55" package aim to reduce the continent's emissions by 55% in absolute terms by 2030 versus 1990 levels, and reach climate neutrality (net zero) by 2050. Several of these texts apply to the maritime sector, either directly or indirectly. The first of these is the FuelEU Maritime regulation which sets out a progressive reduction in the carbon intensity of the energy used on board ships, and the revised ETS directive which includes the maritime sector in the European Emissions Trading Scheme (direct action), as well as the AFIR regulation on port infrastructure and the revised RED 3 Renewable Energy Directive (indirect action). Although the regulatory objectives currently target only the largest ships, the roadmap takes into account all fleet categories, including smaller ones such as fishing and pleasure craft, in a global vision, from the ship's construction to its end of life, and including its operation.

To meet the targets set by the regulations, the maritime sector can take action on three categories of levers: energy efficiency (technological, operational), energy switching (use of less carbon-intensive energies, in particular biofuels, e-fuels but also wind propulsion, electrification and even nuclear propulsion), and sobriety (mainly the reduction in ship speed, but also sobriety in the design phase with eco-design and eco-construction techniques). The roadmap describes in detail the main levers belonging to these categories, which are at varying levels of development. Each is applied with different levels of effectiveness depending on the fleet category under consideration (small to very large vessels, new or existing ships). They also present technological, operational, energy-related, regulatory and financial obstacles and barriers that limit the effective implementation of these levers. The work done within the sector also involves developing and characterising the current range of French industry solutions which comprise 380 decarbonisation solutions led by French industry, from more than 250 players.

Unlike other sectors, such as the automotive industry which relies on massive electrification, none of the levers currently stands out for the maritime sector. Only an **optimal combination of levers**, by fleet category or by vessel according to its use profile, will enable the sector to successfully decarbonise.

To define its decarbonisation strategy, the sector will use the modelling tool developed by the MEET2050 Institute. In the first version of the roadmap, it allowed some **ten decarbonisation strategies to be compared and a benchmark to be selected.** This is the revised version. It is based on the implementation of ambitious technological and operational efficiency measures, the use of moderate speed reduction, the use of less carbon-intensive fuels and the ambitious widespread deployment of wind propulsion. It highlights three major factors:

- The **estimated significant need for biofuels** (around 5 TWh by 2035) **and e-fuels** (20 TWh by 2050), despite the considerable efforts to reduce energy consumption. With the electrification and hybridisation of some ships, the electrification of docks to minimise emissions during stopovers and the production of low-carbon fuels, the upstream electricity needs are estimated at 3.5 TWh by 2030 and 45 TWh by 2050, i.e. the equivalent of 25 wind farms such as the one in Saint-Nazaire;
- The **need to meet significant energy efficiency gains** to limit the use of decarbonised energies, which are costly to produce and whose stocks will be limited;
- The considerable cost of the transition for the sector's stakeholders, estimated at between 75 and 110 billion euros over the period 2023 - 2050, values which are consistent with the conclusions of international studies.

Decarbonisation represents a real challenge for the maritime ecosystem on which a significant part of the French economy depends. France must rise to the challenge, otherwise the sector will be exposed to major operational, industrial and financial risks, resulting in a loss of competitiveness, business and employment that will be detrimental to the economy as a whole and to national sovereignty.

To this end, France has key players throughout the value chain, capable of innovating and committing to decarbonisation: first-rate shipowners, leading shipyards and equipment manufacturers in high value-added technologies, design offices and service companies with a high level of expertise, world-class energy companies, ports located on all the coasts of mainland France and overseas, and academic and scientific players who are highly regarded in France and internationally. Several initiatives and projects are already contributing to the sector's decarbonisation, but we need to do more and change scale.

To achieve this, the industry proposes the implementation of an ambitious, balanced and economically viable **action plan**. Because beyond the environmental challenges, the energy transition also represents a real opportunity for economic development and the creation of domestic industrial jobs. This action plan is broken down into five main strands and 33 actions: Improving the energy efficiency of ships, energy and infrastructure, sobriety, enhancing the regulatory framework and the operational implementation of the roadmap.

Finally, this transition will only be possible through collaborative work between the sector's players and the State, focused on both the medium and long term. The State's support, in particular its financial support and guidance from public policies, are necessary for the implementation of this action plan.

1. Presentation of the roadmap for decarbonisation of the maritime sector

1.1. The roadmaps of Article 301 of the Climate and Resilience Act

Article 301 of Act No. 2021-1104 of 22 August 2021 on combating climate change and strengthening resilience to its effects, known as the "Climate and Resilience Act", state that for each sector that emits large amounts of greenhouse gases, a roadmap must be drawn up by representatives of the relevant economic sectors, the Government and representatives of the local authorities for the sectors where they have jurisdiction.

These roadmaps coordinate the actions implemented by each of the parties to achieve the greenhouse gas emission reduction targets set by the national low carbon strategy. The preparation of each of the roadmaps provided for by the law follows an iterative approach in order to involve the relevant economic sectors in ecological planning:

- During 2022, each sector drew up a decarbonisation roadmap proposal listing their preferred decarbonisation levers, the obstacles present, the actions proposed to implement and the proposals for changes in public policies that submitted to the public authorities to support this transition;
- These decarbonisation roadmap proposals from the various sectors were submitted to the Government at the beginning of 2023. They will provide useful insight for the decisions and directions that will be taken in the context of ecological planning (distribution of emission reduction targets between sectors, financing plans, intersectoral trade-offs to distribute scarce resources, changes in use and the role of sobriety);
- Once the ecological planning guidelines have been decided, the roadmaps will be reworked by each sector jointly with the State and representatives of local authorities to integrate the targets set by the national low-carbon strategy and, more generally, ecological planning. They will then be submitted to Parliament and will form the joint action plan between the public authorities and the economic sectors to ensure that the climate objectives are met.

1.2. The roadmap for decarbonisation of the maritime sector

According to the International Maritime Organisation (IMO), maritime transport accounts for almost 3% of global greenhouse gas emissions. Given its highly international nature, it is difficult to give a precise figure to the domestic contribution of maritime transport to greenhouse gas emissions. Depending on what country's ports the ships are based in, the flag the ships fly and the time spent in territorial waters, the figures vary greatly.

Although an energy-efficient means of transport in relation to the volumes transported, maritime transport is nonetheless almost exclusively dependent on fossil fuels. It must now make an unprecedented energy transition in order to meet the commitments set at international and European levels, but also to contribute to the national decarbonisation effort. The sustainability of the national maritime industry and France's sovereignty of supply are also at stake.

This document responds to Article 301 of Act No. 2021-1104 of 22 August 2021 and constitutes the revised roadmap for the stakeholders in the maritime sector to decarbonise their operations, particularly in relation to the statutory objectives to which they are subject.

As for other sectors with high greenhouse gas emissions and affected by Article 301, the approach adopted for the roadmap integrates the whole value chain. Effectively, this means taking into account the environmental impact in terms of greenhouse gases from the construction of the vessel to its dismantling, via its operation, the associated port infrastructures and the various forms of energy required to operate the vessel (the so-called "life cycle" approach).

A proposed roadmap for decarbonisation of the maritime sector was therefore finalised in January 2023 to then be presented to the Minister of Transport and the Secretary of State for the Sea in April 2023.

This is a revised version of that document, enriched with analyses and consultations that were not included in the original version. The roadmap for decarbonisation of the maritime sector will be revised on a regular basis to ensure the strategy is adapted to any technological and regulatory progress, fine-tuned to take into account access to new data or to address economic evolutions.

1.2.1. *Governance and working approach*

The tight schedule within which the initial roadmap was drawn up led the co-chairs of the roadmap, the Directorate General for Maritime Affairs, Fisheries and Aquaculture (DGAMPA) and the French Maritime Cluster (CMF), to work using a group of recognised experts from industry and public authorities, meeting at regular intervals. In addition to the DGAMPA and the CMF, this steering committee included representatives from the following bodies:

- The teams of the MEET 2050 Institute for Maritime Decarbonisation;
- Association of shipbuilding and naval industries (GICAN), rapporteur on *"shipbuilding and end-of-life"*;
- EVOLEN, rapporteur on *"energy and infrastructure"*;
- MAURIC, rapporteur on "*ship design*"; The French shipowners' association (ADF), rapporteur on the "*ship operation*" section.
- General Commission for Sustainable Development (CGDD), General Secretariat for Ecological Planning (SGPE) and General Directorate for Energy and Climate (DGEC), as the project team for the decarbonisation roadmaps of Article 301 of the Climate and Resilience Act;
- Directorate General for Enterprise (DGE);
- Directorate-General for Infrastructure, Transport and Mobilities (DGITM)

The work on the initial version was organised into four stages:

- Using the expertise of the rapporteurs and their networks of experts, the first stage consisted of identifying the various possible decarbonisation strategies for the maritime sector and the associated levers;
- A second stage enabled the initial elements to be shared with all the players in the ecosystem, through four extended meetings, each of which was attended by between forty and eighty stakeholders, demonstrating the great interest in the sector for the process. Additional thematic meetings were also organised on specific topics, for example with port representatives.
- In parallel with these meetings, modelling work was carried out to quantify strategies based on the strategies and levers identified. This work was based on a model developed by members of the MEET2050 Institute and included data provided by industry, experts and research centres.

– The last step consisted of drafting an action plan to meet the statutory decarbonisation objectives and to finalise the proposed strategy for the sector. The action plan is based both on the implementation of actual projects mobilising public authorities and private players, and on a facilitative framework for collaboration between the stakeholders in the value chain.

  The revised version, which focuses above-all on adapting the initial analysis to fleet category, is based on:

- Working groups for each fleet category led by the French shipowners' association, involving representatives of shipowners from each maritime company concerned by the fleet category, and where appropriate, the GICAN and Meet2050 Institute for modelling.
- A project team comprising the players previously mentioned, co-led by the DGAMPA and the CMF.

1.2.2. *Projects and documents on which Roadmap 301 is based*

Reducing ship emissions is not a new issue. There has been significant work and studies, both internationally and nationally. These include:

- Numerous reports and analyses available in the literature, published by research centres, research centres dedicated to decarbonisation, classification societies, consultancy firms. In particular, the fourth study on greenhouse gas emissions published by the International Maritime Organisation (IMO) in July 2020[1] s a reference.
- The *Green Ship* et *Smart Ship* technology roadmaps of the Strategic Committee for the Maritime Sector (CSF), which were drafted by the Brittany-Atlantic and Mediterranean Maritime Clusters and which present a list of technological and operational levers and solutions.
- The work carried out as part of the Coalition for the Maritime Eco-Energy Transition (T2EM) initiative, led by the CMF since 2019 with the support of some fifty value chain stakeholders, which led to the development of benchmark deliverables that served as an important working framework for the roadmap: Summary report, information platform, Zero Emission Ships and Ports programme, modelling tool for decarbonisation strategies, project for the creation of an institute for maritime eco-energy transition to foster collaboration between the stakeholders in the value chain.

1.2.3. *The challenges to be met in order to establish a "national" roadmap*

Several unique features of the maritime sector, making the roadmap exercise complex, must be highlighted:

- A very **heterogeneous fleet** made up of ships of all sizes operating nationally and internationally, with diverse activities and operating constraints, and with purchase values ranging from a few hundred thousand euros to more than a billion euros for the most technologically advanced ships;
- Ships are **not uniformly constructed on a production line.** Each ship must be both a prototype, a working model of new technology as well as a working tool with unlimited

[1] Fourth Greenhouse Gas Study 2020, www.imo.org

availability to shipowners, making the integration of breakthrough technologies complex;

- The need, in a sector that is very competitive internationally, to have **solutions that are harmonised on a European or even international scale and that do not result in competitive distortions** that could penalise national interests;
- A **diversity of levers** (energy, technological, operational) whose deployment requires the synchronisation of the entire value chain (decision of a shipowner, ability to develop the ship and its sub-systems, energy production units and distribution infrastructures, adaptation of regulations, etc.);
- A large number of the available levers are at quite an l**early stage of development**, making it impossible at this stage to be confident about the solutions to be implemented or their real effectiveness;
- A **large number of stakeholders in the value chain** (shipowners, charterers, shipyards, equipment manufacturers, architecture and naval engineering offices, ports, river transport, energy companies, financial and insurance services, regulations, etc.), represented by some twenty professional federations;
- **Stakeholders in the value chain who are international leaders** but who do not necessarily have customer/supplier relationships at national level, thus not favouring direct collaboration such as between a main industrial client and its network of subcontractors.

2. The maritime sector: a key economic role and major challenges in the context of the energy transition

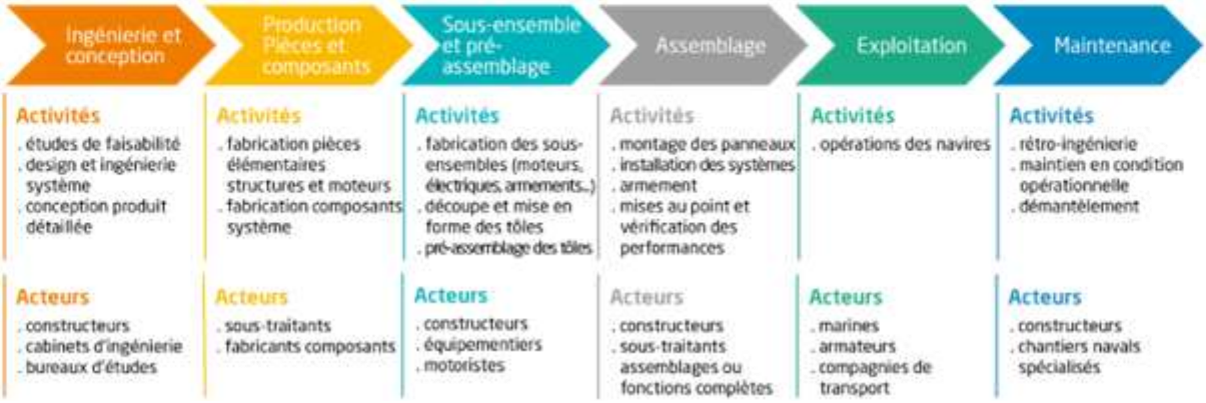
2.1. A key role in the national economy

With production value of over 119 billion euros for approximately 486,000 people employed in 2023, the maritime sector is a major player for the national economy. Maritime transport of goods contributes to the dynamic nature of French exports for example. In **2022**, the export of goods continued to grow, particularly thanks to the significant increase in exported goods transported via boat. **More than 341 million tonnes of goods passed through French ports that year**, confirming France’s position as a maritime power. The sector’s strength is reflected in the performance of French ports, whose turnover went up in 2022 versus 2021, exceeding even the 2019, pre-pandemic levels. The sector's development potential is strong in a country with a first-class coastline and the second largest maritime area in the world.

2.2. The key sectors to be decarbonised in the French maritime sector

Eco-design is very advanced within the French shipbuilding industry, along with the development of low-carbon technologies (including wind propulsion) and the integration of high environmental performance ships. The French shipbuilding industry surpassed the 15 billion euro milestone for turnover in 2023. Over the past decade, business for shipbuilders increased by 5% on average per year, mainly thanks to export, thereby demonstrating the stability of the sector despite fluctuating external factors. The number of people employed in the sector rose by 8%, exceeding 56,400 people. Over the past decade, more than 15,000 jobs have been created, and the industry is planning on creating 15,000 more by 2030. More than

90% of the civil sector is driven by export. The growth of the civil sector is mainly attributed to the substantial orders for cruise ships made by the Chantiers de l'Atlantique shipyard. For smaller civil ships, the various players use their infrastructures to build ships for the military market, for government action at sea, or for civil vessels such as offshore maintenance and service vessels, dredgers, tugboats, special vessels, monitoring and rescue vessels, cable-laying vessels, hydrographic and oceanographic research vessels. The value chain is comprised of a number of industrial players, systems engineers, equipment suppliers, component and sub-assembly manufacturers.

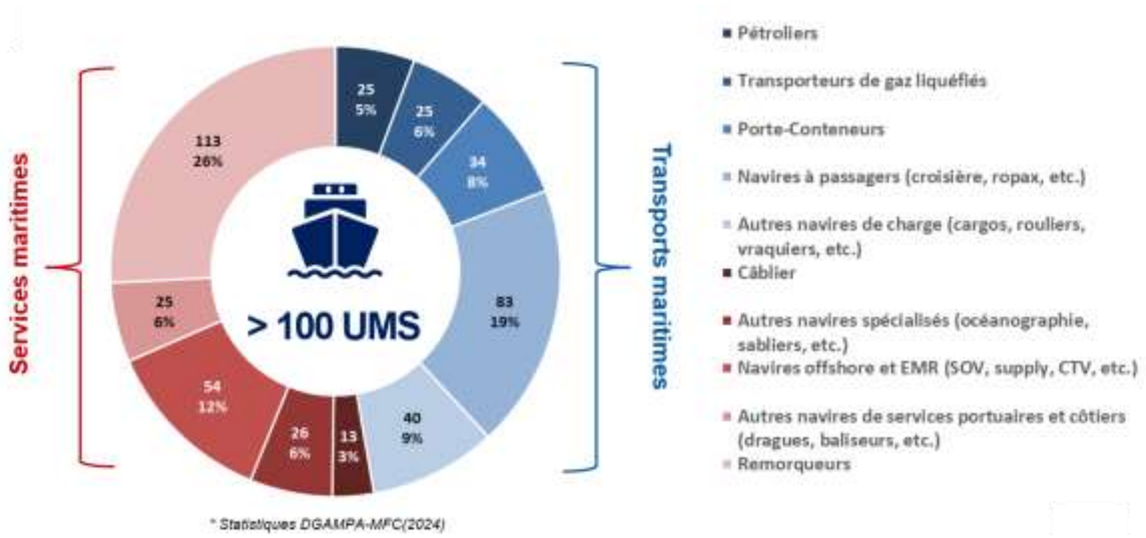


Source: Solutions & co from the Pays de la Loire region

The shipbuilding industry value chain

The maritime transport and services sector

The French merchant fleet is distinguished by its diversity, strength and renowned excellence (on matters related to the environment, social, and security). It is made up of ships with a wide range of designs and uses: oil tankers (crude oil, refined products), bulk carriers, chemical tankers, gas tankers (LNG, LPG, etc.), container ships, cargo ships, ro-ro (vehicle) and ro-ro passenger ships, liners, passenger launches, cable-laying vessels, hydrographic and oceanographic vessels, offshore maintenance and service vessels, dredgers, tugboats, special vessels, monitoring and rescue vessels.



Graph source: French shipowners' association based on Merchant Fleet Division (MFC) data

French fleet under the French flag (2024)

Such diversity is due to very engaged domestic shipowners who are true world leaders in their respective segments (CMA-CGM for container transport, Bourbon in offshore) or groups with multiple activities (LDA Group for submarine cable laying, transport of Airbus aircraft sections or maintenance of wind farms). They are also highly specialised shipowners (SOGESTRAN - MN, Jifmar) or deeply rooted in their regions (Brittany Ferries, La Méridionale, DFDS and Corsica Linea for passenger transport) or even innovative in the cruise segment (Ponant for luxury cruises). It should also be noted that new shipowners such as Néoline, Zephyr & Borée, TOWT, Grain de Sail, Sailcoop specialising in carbon-free transport using wind propulsion and other initiatives currently being created (VELA, HISSEO, etc.) are emerging in France. The strength of the French merchant fleet is particularly evident in certain segments such as marine renewable energy services (with a dozen companies operating) and for the transport of gas which is experiencing significant growth and the number of French vessels could even double between 2024 (32 LNG ships) and 2050 (60 units) (Gazocéan, Geogas, Knutsen LNG France and Orion LNG France).

The fisheries and aquaculture sector

The French fishing and aquaculture sector represents production value of around twelve billion euros, employing 64,000 people[2], and is ranked third in Europe. Mainland France, with its 5,500 km of coastline, boasts sixty or so fishing ports and 4,417 fishing vessels. French overseas territories play a key role in the sector, with 3,438 fishing vessels[3]. However, the fishing fleet is ageing with an average age of 31 years, much higher than that of French-flagged merchant vessels. The renewal of this fleet and the transition to low-carbon energy, which is more expensive than fossil fuel, is a real challenge.

The yachting and pleasure boating sector

The number of regular recreational boaters has now reached four million and **the registration of recreational boats is increasing by about 12,000 units per year.** There are more than one million registered boats in France in 2020, of which almost 78% are motor boats. On the coast, there are almost 473 port facilities designed to accommodate pleasure craft. The economic stakes in this sector are high: France is the leading manufacturer of pleasure boats in Europe and the second largest in the world. Water sporting activities are carried out all over France and its overseas territories.

The port sector

French ports employ some 213,000 people directly and create more than 17 billion euros of added value. There are 66 commercial ports in France through which approximately 350 million tonnes of goods and 30 million passengers pass annually[4]. As land-sea interfaces, ports are key players in the smooth operation of ships, providing a place for bunkering, loading and unloading cargo, transfer to other transport modes, crew relief and routine repairs.

2.3. Potential of the players in the value chain

Faced with the technical and economic challenges presented by the ecological and energy transition, in a highly competitive sector, **France has leading companies in the main components of the value chain**, who are able to respond to the majority of decarbonisation solutions:

[2] 2023 French Maritime Cluster figures.

[3] Panorama de la pêche française", 2024, CNPMEM

[4] https://www.statistiques.developpement-durable.gouv.fr/edition-numerique/chiffres-cles-transports-2024/18-transport-maritime-de-voyageurs

- First class **shipowners** committed and willing to green their fleets, and covering all segments of maritime transport and services, as well as fishing and recreational activities. The renewal of 90% of the existing French-flagged merchant fleet over the next 10 years is estimated at between 14 and 18 billion euros, depending on the technology used (1.5-2 billion/year).
- World-class **energy companies** and industrialists involved in the production and distribution of marine fuels, and able to produce and distribute the decarbonised or low-carbon fuels of tomorrow, and to develop production, transport and storage infrastructures.
- Leading **shipyards** in the most high-tech segments: cruise ships and naval vessels, with a strong capacity for innovation and the ability to tackle complex issues, as well as medium-sized shipyards that position themselves for intermediate and small ships with low or zero emissions.
- **Equipment manufacturers** who are leaders in key technologies and have the capacity to develop them or to form new industrial enterprises, with some companies already positioned in the maritime sector and others capable of providing innovative solutions
- **Ports** along the main European maritime routes (mainland France) or on international routes and logistics hubs (overseas), capable of becoming energy hubs, developing coastal shipping routes suited to the advances in shipping and promoting a shift to inland waterway transport.
- **Companies providing** leading maritime-related **services**, including engineering firms, design offices, a classification society, banks and insurance companies.
- **Academic and scientific** partners who are recognised in the maritime and energy sectors, in France and internationally and are in a position to provide expertise, resources and training to support the transition and the technologies of tomorrow.

2.4. Categorisation of the national fleet

So as to best articulate the decarbonisation levers, the roadmap's actions gradually take into account the specific operating characteristics of the various types of vessel, as much as possible. The following categories have been determined, it being understood that the same fleet category may include various types of vessels:

- Large ferries (ferries and vessels for passenger transport);
- Small passenger vessels;
- Container ships;
- LNG ships;
- Tankers (chemicals or liquid petroleum products);
- Large service vessels (Special offshore vessels, dredgers, ocean-going tugboats, oceanographic research vessels, cable-laying vessels, *etc.*) ;
- Cruise ships;
- Cargo and ro-ro ships;
- Small service vessels (port tugboats, pilot crafts, offshore services);
- Fishing and shellfish vessels.

This roadmap sets out the work that has been carried out and finalised for the ferries, gas tankers, container ships and large service vessels fleet categories, and decarbonisation trajectory modelling will also be presented alongside this work.

Due to the very specific levers to roll out, the work on decarbonising the recreational and sailing fleet is done as part of the sailing and recreational boating roadmap.

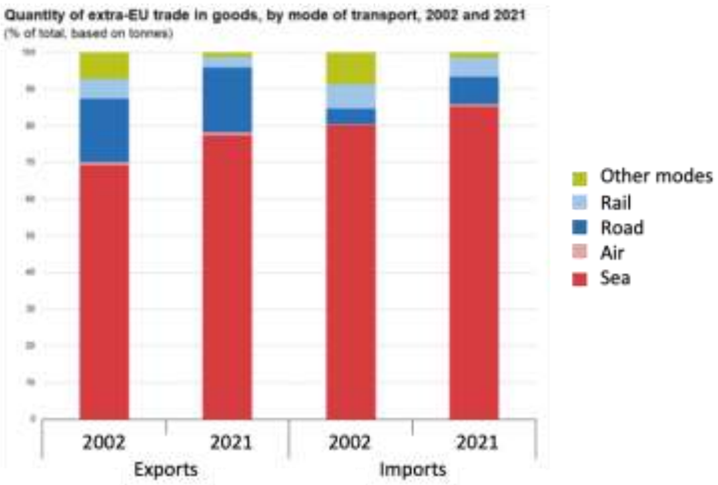
Work on the fishing fleet is underway.

2.5. Challenges for the maritime sector's energy transition

2.5.1. *Issues of sovereignty and independence in the maritime sector*

National and European sovereignty is a priority, especially in the context of post pandemic geopolitical instability and tensions over energy needs. Although often poorly understood, the maritime sector is at the heart of this issue:

1. **Essential role in France's and Europe's sovereignty of supply**
   With almost 85% in volume of imports to Europe arriving by sea, the sovereignty of supply is highly dependent on domestic shipping companies' ability to ensure the transport of goods and people. This is particularly true for strategic supplies of energy, food, raw materials and manufactured goods to France and its overseas territories.
   This sovereignty requires ships that are able to operate in compliance with the regulations, with access to low-carbon energy under viable economic conditions and without being forced to significantly reduce their speed, which would significantly reduce trade.



Distribution of European import and export volumes by mode of transport [5]

2. **Major dependence on foreign bunkering**
   Reliance on bunkering in foreign ports currently accounts for more than 80% of international transport. This means that four out of five ships carrying goods or people fill their bunkers in a foreign country. This heavy reliance holds potential risks for the French economy. Some countries may not be able to meet the needs of shipowners for decarbonised energy and reserve this energy for uses other than international shipping. Furthermore, if French ports are not able to supply sustainable fuels in the future, they will have to rely on fossil fuels, which will be highly taxed and therefore expensive in the near future, and on significant speed reductions, with the risk of losing competitiveness compared with countries that have secure supplies.

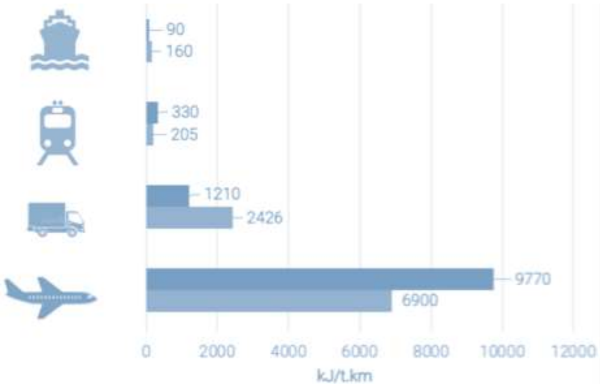
[5] *International trade in goods by mode of transport*, 2022, Eurostat (link).

Sovereignty thus requires, on the one hand, a relocation of bunkering and loading/unloading operations to French ports, and on the other hand, the capacity of French ports to supply decarbonised energy.

3. **Contribution to the decarbonisation of the national energy mix**
   The maritime sector makes a significant contribution to the energy transition in France, primarily with the development of offshore wind power (with the goal of supplying 45 GW to the national mix in 2050) and the goals for the development of hydro-power (5 GW by 2050). Offshore wind power accounts for more than 320 players in the maritime sector, including a dozen shipowners (and 180 available vessels).

4. **Reducing domestic energy requirements through modal shift**
   On a per-tonne basis, sea and river transport are the most energy-efficient means of transport by far, along with rail (a factor of 20 for road transport and 100 for air transport). These means of transport are therefore to be encouraged in the interests of energy efficiency. Combining them with rail and then with trucks for the last few kilometres is also a way of optimising energy requirements.

Comparison of the energy requirements of different modes of transport per tonne transported, from two international studies (shades of blue)



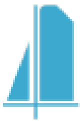
5. **Food independence through understanding and exploitation of marine resources**
   The capacity of maritime operators to develop aquaculture production and to exploit the oceans in a responsible manner through a decarbonised fishing fleet under economically feasible conditions plays an important role in sovereignty.

6. **Technological and digital capacities**
   French leadership in the expertise and production capacity of technologies and equipment for the construction and retrofitting of high-performance ships, the production of low-carbon energy for the maritime sector, and the laying, maintenance and monitoring of the submarine cables that are essential for the exchange of data flows is an issue of national sovereignty.

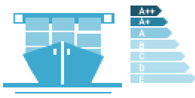
2.5.2. *Capacity challenges and opportunities for economic development*

There are major capacity challenges associated with the decarbonisation of the maritime sector by 2030 and 2050 targets, in terms of producing decarbonisation technologies, shipbuilding and retrofitting of vessels, the availability of alternative fuels and the development of port infrastructure. However, maritime operators are convinced that the energy transition represents a tremendous economic and industrial development opportunity for France.
The table below shows examples of products and services that could be developed by French operators in relation to the maritime transition.

- **Production of low-carbon technology**: the industrialisation and scale-up of low-carbon technology requires the adaptation and creation of factories capable of meeting needs in the years to come

	**Fuel Cells & Marine High Power Batteries** Fuel cells (MEC, SOFC, ...) and medium and high power marine batteries.
	**Electric motors or motors for use with new fuels** Low to high power electric motors, internal combustion engines for use with alternative marine fuels.
	**Storage / bunkering** Decarbonised energy storage tanks (liquefied hydrogen, liquefied methane, methanol, ammonia), bunkering systems on board ships, on-board gas systems, etc.
	**Wind Propulsion** Wind propulsion systems: sails, wings, kites, rotors, etc. and control systems.
	**Energy and operational efficiency** Sensors, data analysis and decision support tools (routing, energy management, etc.)

- **Fleet renewal and adaptation**: To reach the decarbonisation targets, a major share of the global fleet must be renewed or adapted. The French shipowners' association estimates that 90% of the French-flagged merchant fleet will need to be replaced or retrofitted over the coming ten years, with investment estimated at between 14 and 18 billion euros.
- **Shipyard capacity**: The annual shipyard production capacity is limited. With 40,000 or so merchant vessels to replace or retrofit by 2030, the time needed to renew this fleet is estimated at 32 years, unless shipyard production capacity is significantly increased.

	**Zero emission ships** Design and manufacture of eco-efficient ships. Energy use reduction systems, CO2 capture and storage systems, heat/cold recovery, performance optimisation, etc.

- **Production and distribution of alternative fuels**: A huge increase in production and distribution infrastructure is needed if we are to transition to low-carbon fuels such as biofuels, hydrogen and synthetic fuels. The investment this requires is estimated at between 75 and 110 billion euros for French shipowners over the period 2023-2050, not-to-mention operational costs.

	**Energy production** Decarbonised energy production units for the maritime sector
	**Energy hub port** Port infrastructures, distribution of decarbonised energy and diversified port activity.

2.5.3. *The challenges of competition and public policies to support countries*

Decarbonisation technologies have become key in ensuring competitiveness for maritime companies with regards the energy transition, with the following objectives in mind:

- **Reduced energy costs** by decreasing energy consumption and operational costs
- **Access to favourable funding** to address environmental, social and governance (ESG) criteria,
- **Anticipating regulations** to limit CO_2 emissions (carbon taxes or emissions quotas) and increased resilience in the face of regulatory constraints
- Meeting the **expectations of certain clients** and consumers
- **An improvement in innovation** and efficiency to reduce their carbon footprint
- A preference for supply chain players committed to decarbonisation
- Positioning in new vessels, services and green transport markets

Major powers in the global shipbuilding and maritime industry are addressing this with industrial support policies. As an example:

- **The "Made in China 2025" strategy**: This initiative was launched in 2015 with the goal of modernising the Chinese manufacturing industry, including shipbuilding, by putting the focus on innovation, quality and sustainability. The strategy encourages the development of green technology and the production of low-emission vessels. To follow on from this initiative, China developed an ambitious strategy to decarbonise its shipbuilding industry, set out in the "Green Development Action Plan for the Shipbuilding Industry (2024-2030)[6]" published on 26 December 2023 which included support measures for:
    1. Developing a system of green shipbuilding products: equipment, design and integration for vessels
    2. Transforming the manufacturing system through digitalisation and standardisation
    3. Transforming the supply chain system for decarbonisation, particularly through data management across the industry
    4. Strengthening regional coordination and international cooperation for decarbonisation
- **The Korean shipbuilding strategy** "K-Shipbuilding Strategy for Next-Generation Market Dominance"[7] published at the end of 2023 aims for domination of the next-generation shipbuilding market. A budget of 710 billion wons (around €500 million) has been allocated up until 2028, and 3,000 technical experts will be trained to ensure Korea's global competitiveness in this sector. It is based on three policy directions:
    1. Cutting-edge technology: Development and rapid commercialisation of crewless vessels and carbon-neutral fuel technologies (LNG, ammonia, hydrogen).
    2. Advanced manufacturing system: Investment in smart shipyards and robotics to optimise productivity, while adapting the visa requirements to address foreign labour needs.
    3. Legal and financial initiatives: Financial support and increased cooperation with SMEs and large businesses, and the roll-out of initiatives to promote export and industrial innovation.

[6] https://www.gov.cn/zhengce/zhengceku/202312/content_6923175.htm
[7] http://english.motie.go.kr/eng/article/EATCLdfa319ada/1534/view

3. Presentation of the climate objectives set for the sector

3.1. Global targets and initiatives

The international and globalised nature of maritime transport led the United Nations Framework Convention on Climate Change to entrust the International Maritime Organisation (IMO) with the task of accounting for and regulating the sector's greenhouse gas (GHG) emissions.

The IMO began to take action on GHG emissions from ships in earnest in the 2010s, with the introduction in 2015 of the *Energy Efficiency Design Index* (EEDI), which requires new ships of 400 UMS or more to comply with a certain minimum energy efficiency value based on their design, becoming more stringent in five-year increments. This was followed in 2018 by a requirement for the 30,000 ships of 5,000 UMS or more in the world fleet to report their fuel consumption data annually. However, these market based measures are limited in scope and the adoption of the Paris Agreement in 2015 has prompted the IMO to accelerate its efforts in this area.

In July 2023, the IMO adopted a **revised strategy on the reduction of greenhouse gas emissions from ships**. This revised strategy is more ambitious than the initial one from 2018, and it requires countries to reach **net zero GHG emissions by 2050**, with intermediate goals of at least a 20% reduction in emissions by 2030 versus 2008, aiming to reach 30%, and at least 70%, aiming to reach 80% by 2040 versus 2008.

To reach these goals, the strategy envisages the adoption of short-term (effective from 2023), medium-term (after 2023) and long-term (after 2030) measures.

The short-term measures (EEXI, CII), adopted in 2021 and which came into force in 2023, include targets for each ship of 5,000 (UMS) or more to reduce its actual carbon intensity relative to a benchmark calculated from the carbon intensity of its category in 2019: -5% by 2023, -7% by 2024, -9% by 2025 and -11% by 2026. Targets for the period 2027-2030 will have to be enacted by 2026 at the latest, but alignment with the current target of -40 by 2030 in relation to 2008 would require a level close to -3% per year between 2027 and 2030.

In addition, a series of medium-term measures is currently being negotiated within the IMO and is expected to be adopted in 2025, to come into force in 2027. The EU promotes a series of measures including a technical or regulatory measure to reduce the carbon intensity of the energy used on board vessels, known as the GFS (*GHG Fuel Standard*) with a Flexibility Compliance Mechanism (FCM) and an economic measure for universal GHG contribution. These two measures (technical and economic) are complementary and provide a real drive for the sector to invest in solutions to lower the carbon intensity of their activities.

These measures are presented in more detail in Appendix 2.

3.2. Targets and measures at European (EU) level

The European "Climate Law", enacted on 9 July 2021, enshrines in European law the European Union's 2050 carbon neutrality target and a new, more ambitious intermediate target of **reducing net greenhouse gas emissions to -55% by 2030** compared to 1990 (from -40% previously).

The legislative package for meeting these targets (**"Fit For 55" package**), includes two key legislative proposals for the maritime transport sector:

- The revised **ETS Directive** of January 2024 provided for the inclusion of maritime transport in the existing European Emission Trading Scheme (ETS) which already covers emissions from industrial facilities, power generation and aviation, with a cap on quotas for the sectors involved resulting in a 62% reduction in emissions by 2030 compared to 2005;
- The new **FuelEU Maritime** Regulation will impose, from 2025, carbon intensity targets for energy used on board ships, taking into account the whole life cycle of fuels. The reduction targets, taking into account the whole life cycle of fuels (from "well to wake"), are -2% by 2025, -6% by 2030, -14.5% by 2035, -31% by 2040, -62% by 2045 and -80% by 2050. The regulation also allows for shore-side connection obligations from 2030 for passenger and container ships at European ports mentioned in article 9 of the AFIR regulation.

These schemes and their expected impacts are described in Appendix 3.

3.3. National

The National Low Carbon Strategy (SNBC) is France's roadmap for its climate change mitigation policy. It stipulates GHG emission reductions in all GHG-emitting sectors (transport, building, industry, etc.) and consequently provides strategic sectoral guidelines for implementing the transition to a sustainable low-carbon economy in France. The current SNBC (SNBC-2) aims to achieve carbon neutrality by 2050 and reduce France's carbon footprint.

In particular, it plans to make **maritime and river transport entirely carbon-free for domestic emissions by 2050 and 50% carbon-free for international bunkers.** These targets will be reviewed when the SNBC is revised in 2023-2024, in line with the increased European climate target, which commits us to increasing our efforts to decarbonise our economy and society at a large scale. The future SNBC will also set short/medium term targets (in the form of carbon budgets) for international maritime transport, as required by the Energy and Climate Law.

3.4. Categories for which there are no targets

There are blind spots in the legal requirements for international, European and national climate targets. Among the sectors that are not currently covered by mandatory reduction targets include:

- Commercial ships of less than 5,000 UMS for domestic navigation,
- Commercial vessels of less than 400 UMS,
- Pleasure craft,
- Fishing vessels.

These categories represent a significant part of the French maritime sector in terms of the number of vessels concerned. Although they face specific constraints and challenges, they must be included in the efforts to achieve national climate objectives.

4. Maritime sector emissions and energy requirements

4.1. Inventory of emissions from the French maritime sector

Energy consumption and its associated emissions must be accurately measured to get a clear picture of the sector's needs.

In France, the centre for interdisciplinary studies on atmospheric pollution (CITEPA) carries out an annual inventory of national emissions in accordance with France's commitments under international conventions and European reporting obligations. Emissions from maritime and inland waterway transport, published in the CITEPA SECTEN report, represent 0.6% of emissions for the domestic account[8], and less than 2% if emissions from international transport are included[9], which is lower than the percentages of maritime emissions at European or world level, estimated at 3 and 4%.

There are several reasons for these differences:

- The calculation method is based on the volume of marine fuels bunkered by **French-flagged ships in French ports**, which, as mentioned above, are low in proportion to other maritime countries.
- Following the international accounting method, only a proportion of bunkers are included in the calculation, namely those of small ships and fishing vessels on the one hand, and only a **proportion** (6%) **attributed to heavy fuel oil emissions.** Liquefied natural gas, which is more recently used as a fuel, is also excluded.

Moreover, while not included in CITEPA's calculations, emissions related to the construction and recycling or dismantling of a ship may be significant. Moreover, while not included in CITEPA's calculations, emissions related to the construction and recycling or dismantling of the ship may be significant[10]).

Type of ship	Build-Dismantle Footprint / Total Emissions
Cargo ship	3 to 5%
Liner	10 to 20%
Mega-yachts and pleasure craft	15 to 20%

The relative share of this footprint is expected to increase as the operational energy efficiency of vessels improves. For example, a ship powered mainly by wind will have a much higher relative share of its carbon footprint at construction than a standard ship due to its low fuel consumption in operation.

4.2. Energy requirements calculation scope, chosen benchmark scenario scope

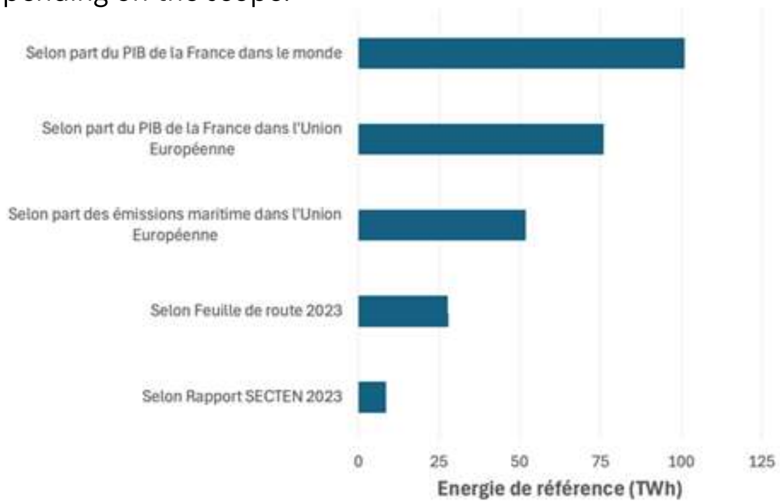
To account for the actual emissions of the French maritime sector and not to underestimate the energy requirements for its decarbonisation, several methods of calculation were studied,

[8] Inland waterway freight transport, domestic maritime transport, other shipping, i.e. mainly inland waterway vessels, fishing vessels and pleasure craft.

[9] International river transport, international maritime transport, i.e. mainly container ships, bulk carriers, oil tankers entering French ports

[10] Data provided by GICAN and Fountaine Pajot members and international studies (Jian Hua et al (2019), Pham Ky Quang et al (2020), Favi et al (2017).

other than the calculation method set out in §4.1. The graph below illustrates how the baseline energy differs depending on the scope:



The following is illustrated in this graph, from top to bottom:

- **P1: Extended scope, based on decarbonised energy requirements in proportion to French GDP compared to global GDP** (3.1%), representing around 100 TWh and 30 Mt CO_2 (around 6% of domestic emissions)[11];
- **P2: Extended scope, based on decarbonised energy needs in proportion to French GDP compared to European GDP (17.0%)**, which would lead to around 75 TWh of fossil fuel energy representing 25 Mt CO_2.
- **P3: Scope** considering that national maritime emissions account for the same percentage as the EU emission (3.7%), representing 51.9 TWh and 17.0 Mt CO_2;
- **P4: Intermediate scope covering the decarbonisation of all fuels bunkered in French ports** (small share at European level), i.e. around 27.7 TWh of fossil fuel energy (based on CITEPA bunkering data without weighting factor and addition of LNG), i.e. around 9.1 Mt CO_2.
- **P5: Scope of CITEPA inventory report** of national emissions, which would be extremely limited considering the reasons mentioned in the previous paragraph, accounting for around 8.4 TWh of fossil fuel energy, representing 2.8 Mt CO_2 annually[12];

In the 2023 roadmap exercise, P4 was the chosen approach in developing the benchmark scenario. This choice is not entirely based on the CITEPA French benchmark emissions calculation scope (P5) but was considered to be a balanced approach, justified by:

- The need to take into account the IMO resolution calling on each State to act locally to facilitate meeting the international targets[13];
- The economic and industrial development objectives of French stakeholders, regardless of the nationality of the intermediate or final client.

Since then, discussions on this topic have been more thorough, analysing other scopes to quantify energy requirements (and the associated emissions), especially in the case of the work done for the fleet categories within the French fleet (see §7) which covers all French-flagged vessels, regardless of their bunkering location.

---

[11] The values presented are different to those set out in the 2023 roadmap because the CITEPA 2023 data is considered (2022 in the previous calculation) and the MEET2050 modelling tool calculation parameters have been fine-tuned.
[12] SCETEN 2023 Report from CITEPA.
[13] Resolution MEPC.327(75) of 20 November 2020 encouraging its Member States to develop "national action plans" to reduce GHG emissions from ships.

The table below compares several methods to illustrate the impacts on emissions.

Method	Flag	Bunkering	Shipowner	Sailing zone	Depending on import/ export needs	P4 benchmark method
Principle	Consideration of emissions from French-flagged vessels	Sales of fuel, excluding LNG, for maritime, inland waterway transport, fishing and recreational boating with weighting factor	Consideration of emissions from vessels, whose owner is registered in the country in question	Consideration of emissions from vessels sailing in the economic zone of the country in question	Based on the maritime transport requirements for the economy of the country in question	Bunkering in French ports, also including LNG bunkering
Comment	Chosen method for the work per fleet category in the revised 2024 roadmap.	CITEPA method chosen for emissions inventory reports in line with UNFCCC declarations, according to the IPCC directives [2006].	Method put forward by the OECD for the maritime sector (currently a forecast).	Method addressed in the analysis reports ordered by the United Kingdom [2024] or Singapore [2022] on the impact of the maritime sector.	-	Method chosen for the roadmap to quantify the energy requirements for the maritime sector
Emissions	Working group for container ships **2.6 Mt**; Working group for large **ferries 1.8 Mt**; Working group for gas tankers **1.3 Mt** – Total of these three segments: **5.7 Mt**	Domestic emissions: 2.7 Mt; + International emissions 3.5 Mt - Total: **6.2 Mt**. Representing 0.7% of French emissions across all sectors.	According to OECD, a total of **27.4 Mt in France in 2022** (29 Mt declared by CMA CGM in 2023, corresponding to the maritime scope of the company).	No data available at national level (CITEPA is conducting a study on the topic).	In allocating a proportion of emissions to France that is in line with its impact in the economy: at European level: **25.0 Mt** at global level: **33.3 Mt**.	27.7 TWh of fossil fuel energy **9.1 Mt CO_2**

Developing an indicator that is representative of the actual share of each country in this global account is a challenge for maritime decarbonisation. For example the current method of calculation (the so-called "bunkering" method, 2nd column) estimates France's national maritime emissions as 0.7% of the total emissions for the country, considered "green" in terms of emissions, with an economy that is however highly dependent on the maritime sector. This tells us that **the impact of emissions from the national maritime sector is likely to be significantly underestimated in relation to its actual impact.** This method also means that the energy required for the country to achieve economic sovereignty is underestimated.

If we take a look at two major maritime nations (the United Kingdom[14] and Singapore[15] which is the world's largest bunkering port) that recently published an analysis of the methods used to calculate emissions, showing that the current method introduces a considerable bias in the estimation of a country's emissions. These nations have called for the current approach to be updated, for a more accurate representation of these emissions allocated to each country.
Summary:

- The intermediate P4 method was chosen for the estimation of energy requirements for the decarbonisation of the maritime sector.
- To study the decarbonisation trajectories per fleet category, the "flag" method was chosen, based on the consumption data for French-flagged vessels operated by national companies.

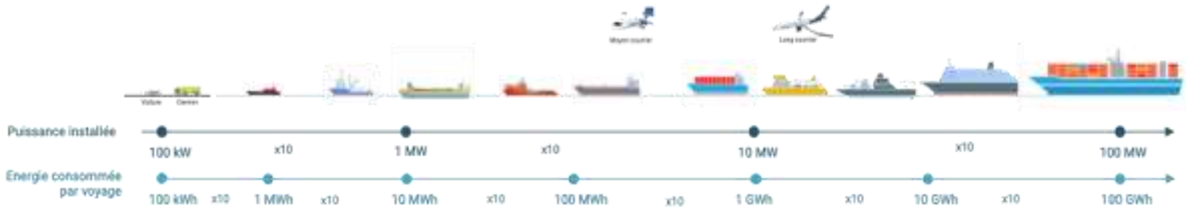
[14] House of Commons / Environmental Audit Committee – Net zero and UK shipping (2024) – https://committees.parliament.uk/publications/45178/documents/223685/default/.
[15] International Council on Clean Transportation – Exporting emissions: Marine fuel sales at the port of Singapore (2022) – https://theicct.org/publication/marine-singapore-fuel-emissions-jul22/.

5. Presentation of decarbonisation levers

5.1. Specific levers and technologies to group by type, range and size of vessel

Decarbonisation of vessels is quite distinct and has been recognised as one of the most complex to achieve, given the many combinations of power and range requirements. The power of a container ship is actually 1,000 times higher than a car and the energy requirements for a trip are 1 million times higher.

The graph below gives estimates for power (main engine and auxiliaries) and energy consumed for a trip, on a logarithmic scale, in comparison with other forms of transport.



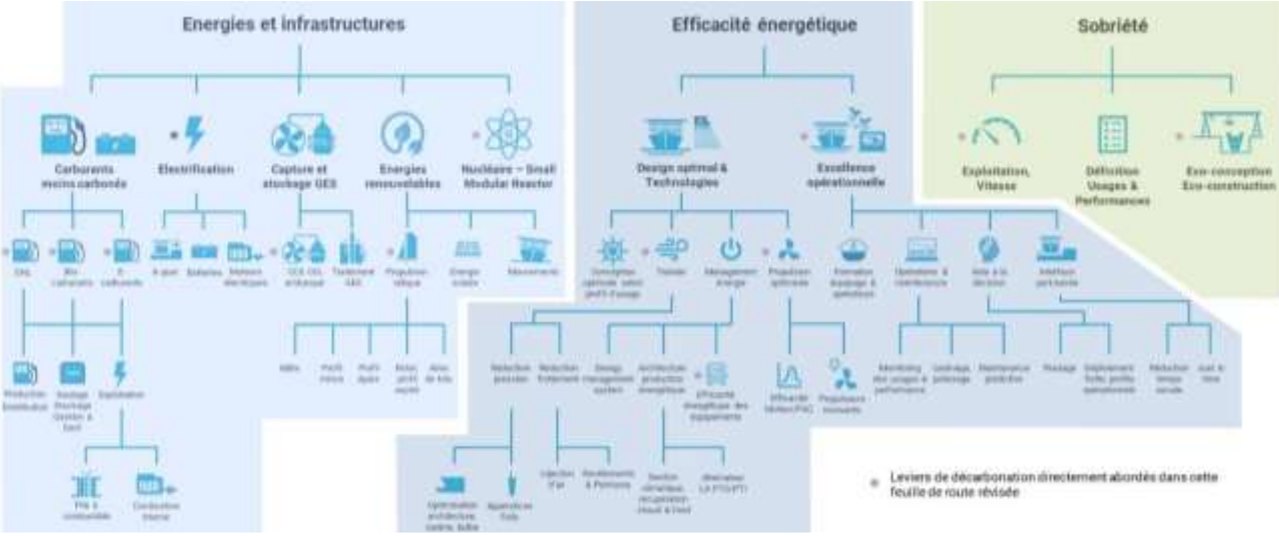
Generally speaking, the technologies developed in other fields, such as the automotive sector, are not directly transferable and need to be adapted for marine use (batteries, fuel cell stacks) or require specific developments (wind).

This also applies to energy carriers. Diesel and heavy fuel oil mainly used by the maritime sector today will need to be replaced by molecules used in other methods of transport such as methane and hydrogen, but others are more specific such as methanol and ammonia.
There is not and will never be one single solution to decarbonising the maritime sector. A combination of different solutions will always be required, and will vary significantly depending on the type of vessel and its use. Some solutions are at the concept stage, others at the prototype stage and some have been in use for several years. It is estimated that the energy performance of ships today is 10-20% better than it was 20 years ago.

Each solution has its advantages, but also **disadvantages of different kinds** which have limited their deployment so far:

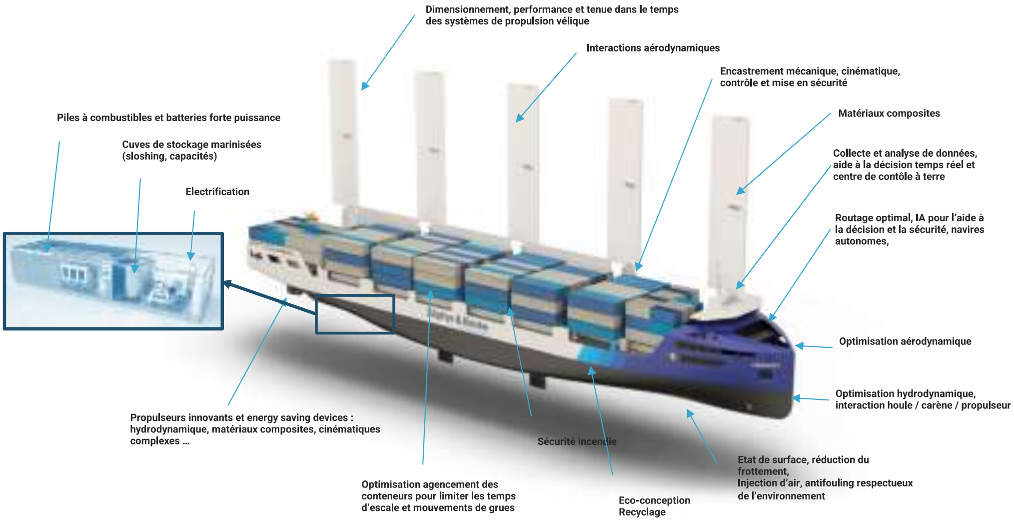
- **Technological**, due to the complexity of the solutions still to be developed or made reliable;
- **Regulatory**, for safety reasons (batteries, ammonia, new materials etc.);
- **Financial**, because decarbonised solutions are usually more expensive in terms of investment (CAPEX) and sometimes in terms of operation (OPEX);
- **Energy**, as resources are limited with regard to the significant needs for the production of alternative fuels;

The diagram below illustrates the main levers to be used, by type of vessel, to achieve decarbonisation.



The main levers for decarbonising the maritime sector (source MEET2050)

The three concept ships discussed below make use of these different levers.



Container ship moving towards zero emissions (Credits: Zephyr and Borée)

Neoline sailing cargo ship (Credits: Mauric / Neoline)

Hydrogen-powered fishing vessel (Credits: Mauric)

5.2. Overview of the main decarbonisation levers

In this updated version of the roadmap, 13 main levers have been studied, described in detail in Appendix 4 and summarised here. The descriptions include the advantages and the current obstacles to their implementation. Illustrations of actual projects accompany this description.

Group of levers no. 1: The vessel's energy efficiency in technical or operational terms *Improvement in the design of vessels, at the design phase for new or retrofitted vessels, to optimise the energy requirements depending on the programme (range, use)*			
Lever & Description	**Advantages**	**Disadvantages**	**Potential gains and maturity**
1.1 Drag reduction Optimise the shape of the vessel to minimise its wave and frictional resistance, for new or retrofitted vessels (bow, canopy, appendages, injection of air under the hull)	• All vessels • New or retrofit • Mature, proven solution • Quick ROI (1 to 3 years for retrofitting)	• Studies considered unnecessarily long and costly. • Lack of data on operational characteristics, required as a baseline for studies • A balance needs to be struck between maximum efficiency and excessive new design specifications	5 to 20% reduction in energy consumption and associated emissions Maturity: ●●●
1.2 improvement of propulsive efficiency Optimise the vessel's entire propulsive chain (efficiency, innovative thrusters, integrated propulsive chain, energy saving device)	• All vessels • New or retrofit • Quick ROI (1 to 3 years for retrofitting) • Breakthrough innovations in development (inspired by biomimicry)	• Studies considered unnecessarily long and costly. • High cost of efficient thrusters (5 to 25% of the ship's cost) • Need to scale up	3 to 10% reduction in consumption Maturity: ●●●
1.3. Improving the energy efficiency of ship equipment Optimise the energy consumed on board to avoid unnecessary consumption (heat or cold recovery, efficiency of deck equipment, fishing equipment and other gear)	• All vessels • Easy to implement • Reduced cost, energy savings guaranteed	• Energy modelling and vessel monitoring systems still under development • Results are varied depending on the type of vessel	Maturity: ●●○
1.4. Operational excellence Optimise the energy consumption of the ships in	• Potential for considerable benefits from solutions that are sometimes very easy to implement	• Availability of bandwidth for ship/shore satellite communications • Lack of quality, standardised, shared data • Weak technical skills among some ship operators	Maturity: ●●○

their interaction with their environment (eco-piloting, optimised routing, optimised stopovers and turnaround time in ports, etc.)	• Development of increasingly powerful IT tools	• Sharing of investments and benefits between shipowners and charterers	

Group of levers no. 2: Energy and infrastructure Ships are currently powered by heavy fuel oil and diesel, and so the energy source must be changed. 21% of current vessel orders are compatible with alternative fuels. For France, the energy bunkered in ports represents 30 TWh/year, and the availability of such a volume in alternative fuels is a major issue.			
Lever & Description	**Advantages**	**Disadvantages**	**Potential gains and maturity**
2.1. Less carbon-intensive and transient fossil fuel (LNG) Transitional energy towards biofuels and e-fuels, thanks to the compatibility with bio-LNG and e-LNG engines.	• Mature technology and supply chains • Compatible with air pollution regulations for ECA areas • Pre-existing international regulations • Compatible with bio-LNG and e-LNG engines • High energy density	• Fossil fuel energy, risk of fugitive methane emissions • Use limited to large vessels (>100m) • Requires crew training to handle cryogenic fuel on board	Reduction of CO_2 emissions up to 17% depending on the type of engine and the origin of the LNG (+6% to -17% in the draft FuelEU regulation) Maturity: ●●●
2.2. Biofuels Alternative fuels made from biomass: liquid biofuels, biomethane and bio-LNG	• Fuels already available in some ports • Can be used without major retrofitting, blended with traditional fuel • High energy density	• Limited stocks and competition for use from other sectors • Emissions reductions vary between biofuels • R&D required to develop advanced biofuels	Maturity: ●●○
2.3. E-fuels Fuels manufactured using electricity, obtained from electrolysis of water (for H_2) and then transformed. They can be low-carbon as long as they are derived from low-carbon electricity. They include e-hydrogen, e-methane (and e-LNG), e-methanol and e-NH_3. As it stands, none of them has been singled out as the preferred option.	• Great potential for the reduction of GHG emissions • Diversity of e-fuels, suitable for different uses • Reduction of SO_x, NO_x and fine particulate emissions	• Massive needs for low-carbon electricity due to low energy yields, and in competition with other uses • Prices highly dependent on the price of electricity, much higher than the fossil fuel equivalents. • Low energy density • Industrial economy and infrastructure to be built • NH_3 and H_2 are dangerous/toxic	Maturity: ●○○

2.4. CO2 capture and utilisation (CCUS) On-board capture of engine output CO2 and its subsequent use or sequestration	• In addition to carbon-based alternative fuels, can be stored at very low temperatures • Potential new market for French ports	• Costly, can only be considered for large vessels • Energy intensive on board • Regulatory uncertainties regarding CO2 • Numerous modifications required on vessels, space requirements	Maturity: ●○○
2.5. Nuclear propulsion Convert to nuclear propulsion using pressurised water reactors or by installing SMRs	• Zero emissions • French expertise in pressurised water technology • Excellent density/power ratio	• Only suitable for large ships with a power of at least 20,000 to 40,000 kW • SMRs have not been proven reliable at sea • Difficult to ensure a safe environment given the current operational profile for merchant ships • High construction, operating and dismantling costs • Acceptance	Maturity: ○○○
2.6. Electrification of ships and docks Electrification of modes of propulsion for ships with low energy requirements per trip, electrification of auxiliaries, hybridisation of the thruster, electrical operation when docked	• Reduction in GHG emissions on board • Mature battery technology • Retrofitting possible for certain vessels • Potential for hybridisation of combustion engines	• Efficiency in terms of the reduction in GHG emissions depends on the source of electric power • Electrification infrastructure costly for ports • Not suitable for short distances or small vessels	Maturity: ●●○
2.7. Wind propulsion Installation of wind propulsion systems to assist the main engine systems	• Wind is a renewable, free and abundant source of energy • For new or retrofitted vessels • Numerous French pioneers in wind propulsion systems • Does not require any transformation on land • Compatible with all modes of propulsion	• Efficient for low ship speeds • Suitability varies depending on maritime links • Sturdiness and sustainability of equipment has not yet been proven • Requires modification of the hull and appendages to effectively move upwind • Impacts on cargo deck, stability and visibility	Maturity: ●○○

Group of levers no. 3: Sobriety *These are intentional measures taken with a sustainable approach to energy use in mind, to reduce the ship's emissions across the entire value chain, beyond the imposed regulations. In optimising the design, the use of the vessel, the way it is built and the materials used*			
Lever & Description	**Advantages**	**Disadvantages**	**Potential gains**
 **3.1. Speed reduction** Speed reduction	• Technically straightforward to implement • Efficient solution if the speed reduction is sensible (up to 30%) • Can be combined with wind propulsion	• Offsetting risk with the commissioning of new vessels • Risk of modal shift to more carbon-intensive solutions to increase speed • Complex in operational terms for certain categories (particularly ferries)	Maturity: ●●●
 **3.2. Sobriety in design and use** Encourage the design of more economical vessels in terms of functionalities and the use of raw materials, particularly by using eco-design methods throughout the entire life cycle of the vessel	• Constraints linked to the end of a ship's life already integrated by French shipyards • First life cycle assessments already carried out • Regulatory obligation regarding the end-of-life of ships can help boost self-sufficiency by means of the circular economy • National eco-organisation APER approved to manage the dismantling and recycling of recreational and sports boats • Industrial capacity in France and know-how of French players (4 ship recycling facilities in France)	• Upstream and downstream environmental performance criteria for ships either not or barely taken into account by regulations, and therefore by the market. • No shared LCA methodology • Restrictive regulatory requirements for materials approval, hampering innovation • Availability of low-carbon raw materials at competitive prices in Europe: the carbon adjustment mechanism at EU borders makes access to raw materials more expensive for European manufacturers, creating a distortion of competition on imported finished products (ships and equipment).	Maturity: ●●○

5.3. Key role of naval architecture and integrating solutions at shipyards

The naval architect is a crucial link in decarbonising the maritime sector, acting across the different levers to ensure their integration and coordination, from the design to the implementation phase. This profession binds and coordinates the effective development of decarbonised ships.

There are two stages to this mission: first of all, a precise definition of the ship's uses and expected performance, then, depending on the use profile, the application of a combination of optimal decarbonisation levers to guarantee the best possible environmental performance for the ship, with coherent overall architecture adapted to the seafarer and compliant with safety and performance requirements.

5.3.1. *Defining Uses & Performances*

The **programming** phase for a ship is when the **intended use is considered** for the **entire life cycle** of the vessel, as well as **associated performances**, to **satisfy the need that has been expressed**. This can be done with help of the skills of a naval architect, whose experience and expertise can help define and optimise a ship's uses and the associated performances and profitability, to reduce the ship's impact on the environment. The goal is to define the uses and performance by exploring the appropriate balance between speed and proportions, range and space requirements for fuel and modes of propulsion.

This phase is crucial as it defines the architecture of the ship over its entire life cycle which is often expected to be 20 to 30 years, sometimes more.

5.3.2. *Optimal design according to use profile*

The project manager is in charge of designing a ship that is tailored to the operations programme, as well as their role as **integrator of innovative, low-carbon solutions**. They adopt an overall approach and make sure **coherent and coordinated innovative solutions are put forward, drawing on optimisation tools to find the best balance**, and therefore defining the overall architecture, **optimising the ship's use according to its operational profile**, and reducing its impact on the environment.

These innovative solutions can involve the hull profile and dimensions, technologies, systems, on-board equipment, fittings, etc. The success of a low-carbon ship lies as much in the thought and implementation of the overall design of the ship as in the integrated solutions, to balance the ship's proposals, its loads and uses and the equipment on board.

6. Types of decarbonisation depending on the nature of the fleet

Based on the analyses carried out for the roadmap for decarbonisation of the maritime sector, working groups were set up to fine-tune the various levers identified, as closely as possible to the operational and technical characteristics of each fleet. Only four of them will be presented in this revised version. The next categories will be published in the subsequent revision of this document.

These working groups were coordinated by the French shipowners' association and led by a representative of the shipowners of each fleet. Here is a summary of the working groups for container ships, gas tankers, large service vessels and large ferries. A detailed account of the work done is presented in Appendix 7.

6.1. Container ships

The container ships fleet category includes around 650 ships managed by two French maritime companies: CMA CGM and Marfret. Of these ships, around 90 of them bunkered some of their fuel in France in 2022, representing a total of 411 kt fuel oil equivalent (176 kt in Fos, 39 kt in Marseille, 53 kt in Montoir, 46 kt in Le Havre, 5 kt in Dunkirk, and 92 kt in Pointe-à-Pitre).

6.1.1. *Container ships characteristics and special features*

There are several distinctive characteristics of the container ships sector that have a direct influence on the decarbonisation strategies of shipowners. Given the industry's highly international nature, with maritime links involving numerous countries, applying decarbonisation measures across the board is highly complex. The fleet is optimised on a worldwide scale, ensuring effective management of resources but complicating the implementation of local solutions. Shipowners enjoy great flexibility in their choice of bunkering ports, influencing the adoption of alternative fuels according to their geographical availability. Setting up regular routes can nevertheless allow for long-term strategies in terms of energy supply.

MARFRET container ship

LNG-powered container ship from CMA CGM

The vessels serving France are renewed frequently, offering regular opportunities to integrate greener technology. The size of the vessels varies considerably, from 500 to 23,000 TEU, meaning that decarbonisation solutions tailored to different scales are required. The average age of the fleet differs between companies: 13 for CMA CGM and 17 for Marfret. This average age influences modernisation and replacement strategies.

6.1.2. *Suitability of the various decarbonisation levers*

Energy and infrastructure	
Less carbon-intensive fuels & carbon capture	The energy transition is at the core of the **long-term decarbonisation strategy** for this fleet category. **LNG and methanol are being adopted** for new builds, and the majority of new orders are equipped with dual-fuel LNG or methanol engines (18 billion USD invested by CMA CGM for a fleet of more than 130 ships with dual-fuel LNG or methanol engines). **Biofuels are to be incorporated gradually**, with objectives of up to 10% for heavy fuels, 20% for methane and 25% for methanol by 2030, subject to availability and competitive prices. **E-fuels are expected to be used from 2030**, and e-methanol and e-methane will be given priority.
Renewable energy sources, electrification, other sources of energy	**Wind propulsion** offers a potential gain of 5-6% (retrofit) to 12% (new build) on a small proportion of the fleet over the next 15 years (5%). **Marfret** has already conducted **trials** with this type of technology. The **CMA CGM** group is involved in the **NEOLINE** project to develop a sail cargo ship that will be used for **transatlantic crossings. Shore-side power** is under development, to comply with European regulatory requirements for container ships over 5,000 GT, under the FuelEU Maritime regulation (compulsory from 2030). The first studies on **hybridisation** were **inconclusive** in terms of a reduction in GHG emissions for this type of ship. Taking **fuel cells** on board for electrical consumption is currently being considered for new builds.
Energy efficiency	
Operational efficiency	Operating measures offer **significant short- and medium-term gains** for the container ship category. Operational excellence could generate a **5% gain for 40 to 50% of the fleet**, including measures such as the optimisation of routes and effective management of energy on board. CMA CGM has invested more than 20 million dollars in the ***Smartship* programme** to improve energy efficiency on board. The **hull and propellers are regularly cleaned**, providing potential gains of 2 to 3% in fuel consumption.
Optimal design & technologies	This lever is **crucial** for the decarbonisation strategy. **Hydrodynamic optimisation** (shape of the bow, hull coating) and optimisation of propulsive efficiency are **already in place**, with considerable investment from CMA CGM in particular (200 million USD over 10 years). The CMA CGM group has for example trialled and validated several solutions, including the **windshield**, which demonstrated the ability to reduce a ship's CO2 emissions, or the **alternator** equipment attached to the main propulsion engine of 10 new container ships, to produce the energy needed to power the electrical equipment on board.
Sobriety	
Sobriety in operation & design	Reducing speed is a **major strategy**, with a reduction of 15% in mind for 80% of the fleet, offering substantial fuel savings to be made.

6.1.3. *Review*

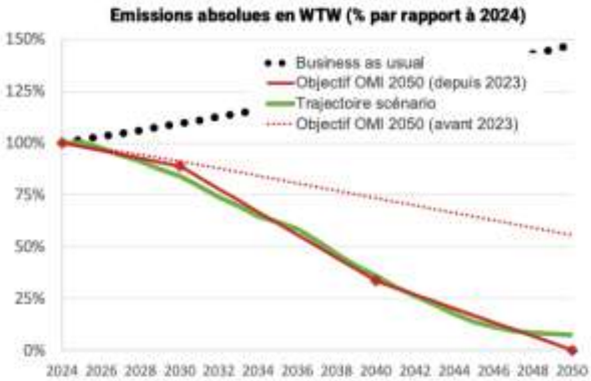
The emissions reduction targets for the container ships fleet category are ambitious and align with international targets, even though the regulations are not currently restrictive on an international scale. The transition towards less carbon-intensive and renewable energy sources is a gradual one, and the use of biofuels and e-fuels is expected to increase, subject to availability and competitive prices. For the moment, the workload is at a standstill and the lack of international regulatory ambition is distorting competition and penalising some of the sector's pioneers. Energy efficiency and operational excellence remain essential, with ongoing investment in these areas.

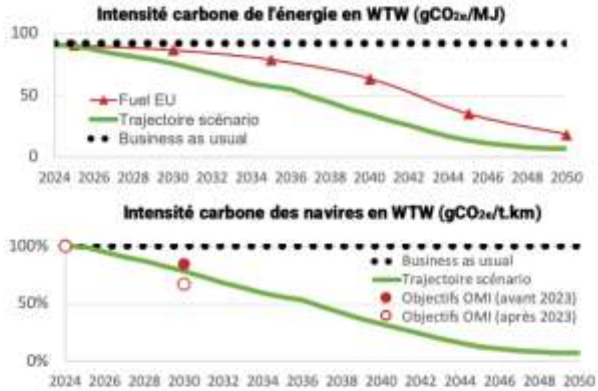
Several areas require closer attention to facilitate an energy-efficient transition of this fleet category:

- The **development of renewable and low-carbon fuels** in France and worldwide is crucial, especially for biodiesel, bio/e-methane, bio/e-methanol and e-ammonia, and there needs to be either **a beneficial tax arrangement for these low-carbon fuels or a low-carbon bonus.**
- In order to validate the effectiveness of these fuels on a widespread basis, **prototypes for new technology need to be rolled out,** illustrating wind propulsion and on-board CO2 capture for example.
- **Subsidies** shall be made available for **shore-side power and the renewable origin** of this power guaranteed.
- **Standardisation of the various European and international regulations**, particularly in terms of how they take into account new fuels (emission factors, certification) and wind power.
- **Financing of the research** and the developments required for the transition must be ensured, in particular through the redistribution of taxes collected in the maritime sector.

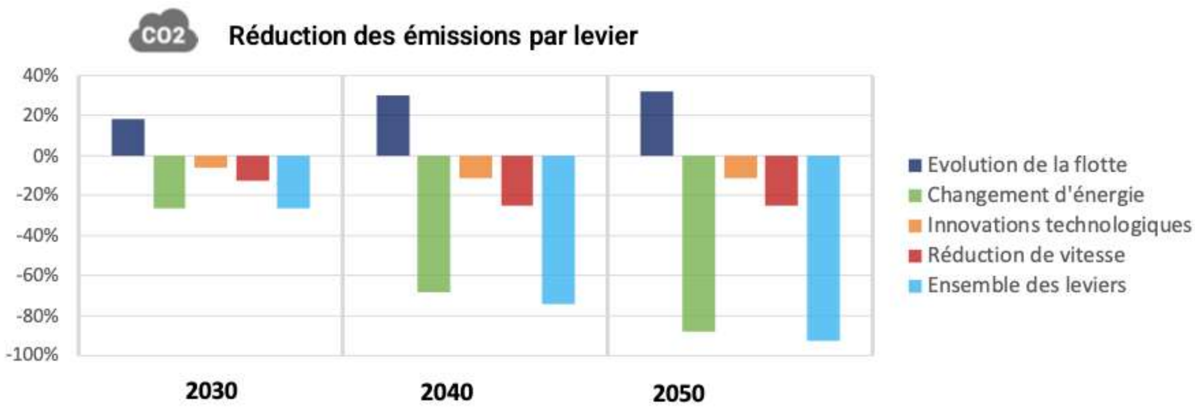
6.1.4. *Decarbonisation scenario*

For the "container ship" category, the scenario is based on moderate growth (+1.5% per year), and the use of an energy mix that gradually incorporates biofuels and e-fuels, as well as the introduction of technological innovations and a possible adaptation of ships' sailing speed. The combination of these levers will allow us to stay on track to meet the decarbonisation targets for 2030, and gradually decrease absolute emissions and the overall carbon intensity of vessels. However, the availability of sufficient quantities of biofuels and e-fuels, as well as their cost, remain major obstacles to decarbonisation, and a solution to overcome these obstacles has still not been found.





The change of energy source appears to be a major decarbonisation lever for this category, helping to offset the increasing emissions due to fleet expansion. This lever will be boosted in equal measure by the introduction of innovative technology and operational measures.



6.2. Gas tankers

The French fleet of gas tankers consists mainly of 32 LNG tankers, representing 3% of the global fleet, an LNG bunker vessel and 4 LPG vessels. This is a relatively young fleet, with an average age of less than 4 years for LPG vessels and 3 years for LNG tankers. Forecasts predict significant growth over the next decades, with an estimated 45 LNG tankers in 2030 and 60 in 2050 (approximately 100% growth over 25 years). This development highlights the growing importance of these types of vessels in a context where LNG is widely considered as a bridge fuel.

Gas tanker operated by Knutsen LNG France

Gas tanker operated by Orion LNG

6.2.1. *Characteristics and special features of LNG tankers and LPG carriers*

LNG tankers make up a homogeneous fleet with an average transport capacity of around 175,000 m3. They are equipped with low speed 2-stroke engines that can run on natural gas, MDO or VLSFO. They are intended solely for the transport of liquefied natural gas. An important feature of these vessels is the use of **boil-off** gas - which is the natural evaporation of cargo - as fuel, allowing SOx, NOx and fine particles emissions to be eliminated and to reduce CO2 emissions by 15 to 20%. Nevertheless, this fuel source can cause methane slip and fugitive emissions.

LPG tankers are distinguished by a transport capacity that varies between 35,000 and 90,000 m3. They are equipped with propulsion systems with low speed 2-stroke engines. These vessels are of the refrigerated type and some of them are able to use their cargo (LPG) as fuel, which also eliminates SOx, NOx and fine particles emissions and reduces CO2 emissions by 15 to 20%.

Gas tanker operated by GEOGAS

6.2.2. *Suitability of the various decarbonisation levers*

Energy and infrastructure	
 **Less carbon-intensive fuels & carbon capture**	For the LNG and LPG tankers category, **fuel cells** (PEM and SOFC) are estimated to potentially reduce emissions by 20%. However, they face **major challenges**, such as the **volume lost on board for hydrogen storage**, the absence of stable maritime **regulations** and the **cost**. Biofuels meanwhile offer a **reduction potential that is limited to 5%** for gas-powered vessels, mainly by replacing pilot fuel. The roll-out of biofuels is hampered by limited availability and high cost. Ammonia presents a **high reduction potential** of up to 80%, but its **technological readiness remained low** in 2024, and there are considerable challenges in terms of safety and toxicity. Methanol, while not green, offers a **reduction potential of 10%**. It has the benefit of storage at room temperature and has already proven effective for transport, but its high cost and toxicity remain obstacles to overcome. **CO2 capture** offers a **very high reduction potential** of up to 90%, but this technology is still **not mature enough.** It faces major challenges in terms of on-board storage, offloading logistics and high costs associated with captured CO2.

Renewable energy sources, electrification, other sources of energy	**Wind propulsion** is a promising option for LNG and LPG tankers with an **estimated reduction potential of 25%.** It presents the advantage of using a renewable energy source and improves the EEDI of these vessels, many of which will be built in the coming years. However, the efficiency of this energy source is largely dependent on weather conditions and the associated routing, and there are challenges in terms of maintenance and operation (suited to certain routes, limited use offshore, etc.).
Energy efficiency	
Operational efficiency	Optimised **routing**, trim optimisation and other techniques (reduced speed, optimising ballasting, etc.) have a **combined potential to reduce emissions by up to 15%.** The advantage of these measures is that they can be rolled out at **short notice** and at a **relatively low cost** for new or existing vessels.
Optimal design & technologies	**Optimising the shape of the hull** can lead to a reduction in emissions for LNG and LPG tankers of **up to 15%**, but this measure is mainly applicable to **new vessels**. Air lubrication offers a reduction potential of 8% but requires considerable electrical consumption. Attached alternators are promising with an estimated reduction of 15%, eliminating emissions and methane slip from using generators at sea. Finally, **reducing methane slip offers a potential reduction of 10%, making it particularly important for LNG tankers** (possible extra 3% for two-stroke engines and 10% for four-stroke engines), and it will be included in the Emissions Trading Scheme (ETS) in 2026.
Sobriety	
Sobriety in operation & design	The sector is considering a reduction in speed.

6.2.3. *Review*

Operational measures and certain design measures that are relatively easy to implement can provide short-term gains for the LNG and LPG tanker category. However, alternative fuels and advanced technology such as CO2 capture and wind propulsion systems offer greater potential over the long term, but require significant developments in technology and regulations. Therefore, a multi-faceted approach is required in decarbonising the gas tanker sector, combining progressive short-term improvements and breakthrough innovations over the long term.

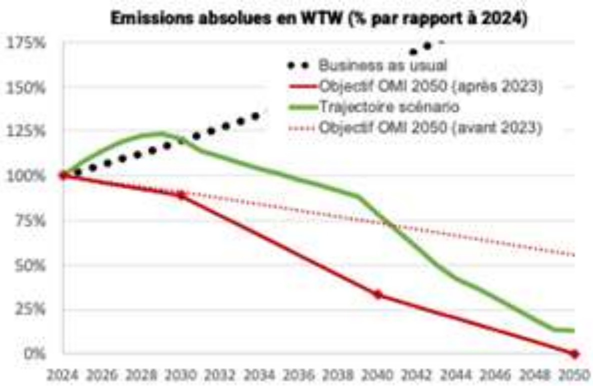
Besides developing the range of French solutions and training operators on the various levers deemed to be relevant, the gas tanker working group insisted on the necessity to facilitate exceptional depreciation for the implementation of technologies, and established the following development guidelines:

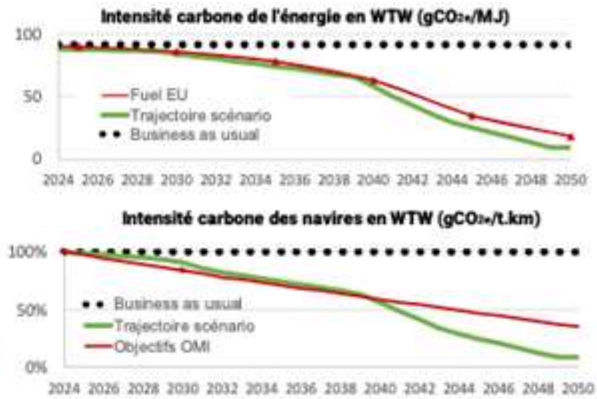
- **Fuel Cell PEM**: develop technologies, hydrogen storage and bunkering solutions;
- **Wind propulsion**: introduce on-board prototypes for gas tankers, combine with an effective routing solution;

- **Carbon Capture**: introduce on-board prototypes for gas tankers, develop on-board storage solutions and infrastructures for CO2 offloading;
- **Alternative fuels:** continue technical developments for engines, ensure the availability of fuels at competitive prices, develop the supply chain and bunkering, amend regulations to facilitate the use of these fuels in complete safety, work on reducing methane slip.

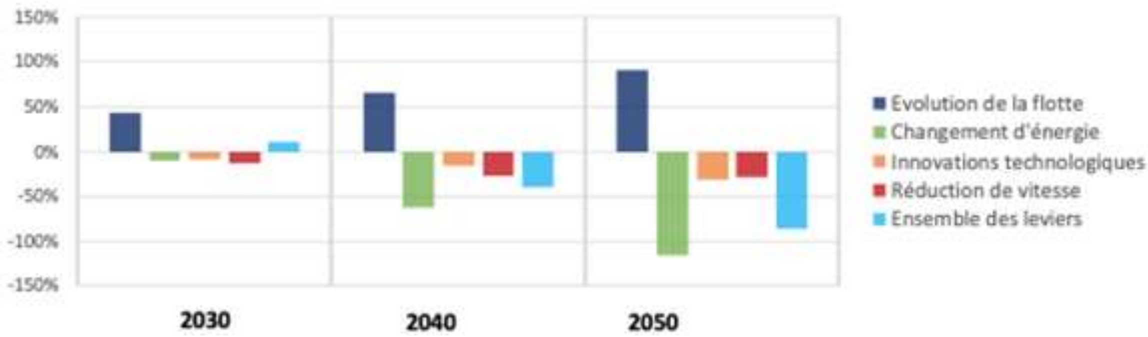
6.2.4. *Scenarios*

For the "gas tanker" category, the scenarios are based on strong growth in the number of vessels in service (+10% annually over the next five years), followed by moderate growth (+1.5% annually): on a short-term basis, this trend leads to an increase in emissions (the expanding fleet causes an increase of 45% by 2030, 65% by 2040 and 90% by 2050). However, the evolution of demand for alternative fuels will mean that this category of vessels can transport and consume energy that is, as a result, less carbon-intensive (bio-gas, e-fuels).





The change of energy source will be a major decarbonisation lever for this category, allowing for a decrease in emissions of 10% by 2030, 65% by 2040 and 120% by 2050. This lever will be boosted in equal measure by the introduction of innovative technology and operational measures (contributing to a 25% reduction by 2030, 45% by 2040 and 60% by 2050. The trajectory of this scenario aims to reach a reduction in emissions of 60% by 2040 and 10% by 2050 of the IMO targets (post 2023 curve), the expected reduction being 40% by 2040 and 90% by 2050.



6.3. Large service vessels

The large service vessels category includes a wide variety of specialised vessels: 4 rescue and assistance tugboats, an anchor handling tug supply vessel, an anti-pollution vessel, 5 oceanographic research vessels of varying size, a research and supply vessel (the Marion Dufresne), 16 cable-laying vessels and a survey vessel. The offshore wind farm sector is represented here by 3 service vessels (SOV), and the diverse range of vessels in this category is rounded off with a trailing suction hopper dredger.

Sophie Germain cable layer from Orange Marine

Le Pourquoi Pas ? by GENAVIR for IFREMER

6.3.1. *Characteristics and special features of large service vessels*

These vessels are distinguished by their highly specialised functions. They are designed to carry out complex underwater work, for scientific or specific technical surveys, and for the majority of them, to maintain high-precision dynamic positioning. Their propulsion system differs significantly from that of standard transport vessels. Some of the vessels have diesel-electric propulsion systems, which illustrate how technology has evolved in the sector.

The highly specialised nature of these vessels puts them in a distinct category in terms of energy regulations. The EEDI, EEXI and CII indexes which are often used to assess the energy efficiency of merchant vessels, cannot be applied to this fleet. These vessels are currently not concerned by EU and IMO regulations for the maritime sector. However, work is underway to include them in the EU's Emissions Trading Scheme (EU ETS), which would mark a turning point in the management of their impact on the environment.

The large service vessels fleets have varied consumption profiles, which reflect the diversity of their missions and operation zones. In 2022, consumptions varied between 7,001 m3 for Les Abeilles and 78,700 m3 for LDA - ASN, 5,850 m3 for Genavir - Ifremer and 18,155 m3 of MDO for Orange Marine. For dredging operations, the Grand Port Maritime Nantes-St Nazaire consumes a combination of 1,200 m3 of MGO and 380 m3 of LNG. The geographic distribution of these consumptions varies considerably: Les Abeilles and Orange Marine operate along the Channel/Atlantic and Mediterranean coastlines, while Genavir - Ifremer and LDA - ASN operate worldwide. GPM Nantes-St Nazaire operates between Nantes/St Nazaire and Rouen/Le Havre.

The French large service vessels fleet comprises ships of varying age and characteristics. The rescue tugboats have an average age of 17 years, while the oceanographic research vessels have an average age of 26 years. The cable-laying vessels are younger, with an average age of 10.6

years, and the trailing suction hopper dredger is 22 years old. This great difference in age reflects the different renewal and investment cycles for each sub-sector.

This diversity highlights the complex range of decarbonisation challenges this sector faces and the necessity to take an approach that is tailored to each type of vessel.

6.3.2. *Suitability of the various decarbonisation levers*

Energy and infrastructure	
Less carbon-intensive fuels & carbon capture	The spectrum of options in terms of energy source for these vessels is vast and constantly evolving. **LNG**, while promising, presents **challenges linked to the volume of storage required** to ensure range that is comparable to traditional fuels. **Biofuels** are undergoing extensive testing in this fleet category, focused particularly on B30 and B100. There is growing interest in **e-fuels** such as methanol and ammonia but they also present difficulties in terms of supply and risks.
Renewable energy sources, electrification, other sources of energy	**Electrification and hybridisation** are gaining ground. **Shore-side connections** can help make savings of up to 35% of the diesel consumption considering the fairly long periods that some of the vessels in this fleet remain docked, particularly for rescue vessels and cable-laying vessels, while batteries, especially for the SOV, reach capacities of several MWh. **Wind propulsion using kite systems** offer a **significant** reduction potential. Finally, some promising studies have been carried out on hydrogen, with demonstrated feasibility for 2-day range on an SOV, and it could be considered as an on-board solution for shore-side connections. Each of these options presents its own challenges in terms of storage, supply and compliance with regulations, meaning that a nuanced approach is required, tailored to each type of vessel.
Energy efficiency	
Operational efficiency	Operational levers are crucial in reducing the energy consumption of large service vessels. Operational excellence, which includes optimising the speed/consumption ratio, porosity, weather routing, and optimising dynamic positioning systems, is a key goal of this approach.
Optimal design & technologies	Improving the energy efficiency of these vessels is reliant on several key levers. It is crucial to improve propulsion efficiency and this involves the adoption of innovative propulsion technology (particularly variable-pitch propellers) and hybridisation of propulsion systems. Several measures must be rolled out to optimise on-board energy consumption, such as the use of LED lighting, installing batteries for peak shaving, to absorb the fluctuations during dynamic positioning operations, and replacing hydraulic systems (hoisting facilities for example, which are sometimes quite imposing on these vessels) with alternative electrical systems. It should be noted that the applicability and effectiveness of these levers varies considerably depending on the type of vessel, as each category comes with its own challenges and specific opportunities. **Regularly cleaning the hull and propellers, with 5 years to 2.5 years between hull fairing** for some vessels, also helps ensure energy efficiency. Combining these different measures can lead to a significant reduction in consumption.

Sobriety	
Sobriety in operation & design	Energy sobriety, particularly by reducing speed for transit or patrol operations, offers significant gains.

6.3.3. *Review*

This category's shipowners develop varied strategies to address the decarbonisation challenges. For tugboats for example, Les Abeilles have chosen to focus on shore-side connection for their entire fleet, and are involved in an innovative partnership for the use of kites, with trials on sails that vary in size between 50 m2 and 400 m2. Genavir - Ifremer are adopting a long-term approach with the new MSRV vessel, designed with the possibility of jumboization halfway through its life cycle in 2045, and the Atalante is expected to be replaced for 2030-2032. Orange Marine has turned to hybridisation with a new diesel/electric vessel and the improvement of the René Descartes cable-laying vessel with a land power connection. GPM Nantes St Nazaire is planning for a new construction by 2032, while LDA - ASN is looking into ambitious retrofitting scenarios for its cable-laying vessels and SOV, including the use of biofuels, shore-side connection, an increase in battery capacity and the integration of hydrogen fuel cells. These diverse strategies reflect the complex nature of the large service vessels category and the necessity to adapt the solutions to the specific operational and regulatory issues to face for each type of vessel.

Tugboat from the company LES ABEILLES

Pilot craft being refuelled with HVO

To transition to a greener fleet, several development areas need to be addressed as a priority:

- It is crucial to **develop the electrical infrastructure** for shore-side connection, and the ports of Calais and Brest are priorities here.
- **Adapting technical regulations** to new technologies is essential if they are to be rolled out on a widespread basis.
- The **distribution of new fuels** is a major challenge in terms of logistics and requires precise mapping of the distribution of LNG, methanol, ethanol, bio-diesel and H2, over the short and medium term.
- Finally, **financing solutions must be sought out** to support these technological transitions and allow shipowners to invest in these new solutions. With the industry calling for ETS revenues to be redistributed for the decarbonisation of the maritime

sector, shore-side electricity projects and electrification of vessels in certain ports could therefore be financed.

The success of these projects requires close collaboration between shipowners, port authorities, regulators and technology suppliers, underlining the importance of a concerted, multi-sector approach to decarbonising this specialised fleet.

6.4. **Large ferries (GFE in French)**

The French fleet of large ferries comprises 31 vessels operated by four shipowners in France. The fleet is divided between two major maritime coastlines: Channel/Atlantic and Mediterranean

A Galeotta LNG vessel from Corsica Linea launched in 2023

The Brittany Ferries Saint-Malo LNG/electric ferry

6.4.1. *Characteristics and special features of large ferries*

Large ferries have an average length of around 180 m, and are very powerful, with between 25,000 and 31,500 kW for the main engines. With a gross tonnage of 31,935 on average, they boast a significant transport capacity, both for vehicles and passengers. The average age of the fleet varies considerably depending on the shipowner, ranging between 14 and 25 years, for an average of 18.5 years, which is evidence of the long lifespan of this type of vessel, and therefore the necessity for gradual modernisation.

These vessels boast a relatively high speed compared to other fleet categories, which creates specific challenges in terms of energy efficiency. In terms of design, they are short and with high superstructures, making them less energy efficient. The fact that they are operated on fixed routes according to a specific timetable between two or more ports, and in maritime areas with multiple uses, also limits the possibilities to optimise routing.

The renewal of the fleet is made complicated due to the high cost of these vessels, estimated at several hundred million euros per unit, and the difficulty for large-scale production. Passenger transport also involves more stringent safety regulations than for other types of vessels, which can be a hindrance for some decarbonisation solutions. The restricted space on-board and the high superstructures limit options for retrofit and the installation of new technologies.

6.4.2. *Suitability of the various decarbonisation levers*

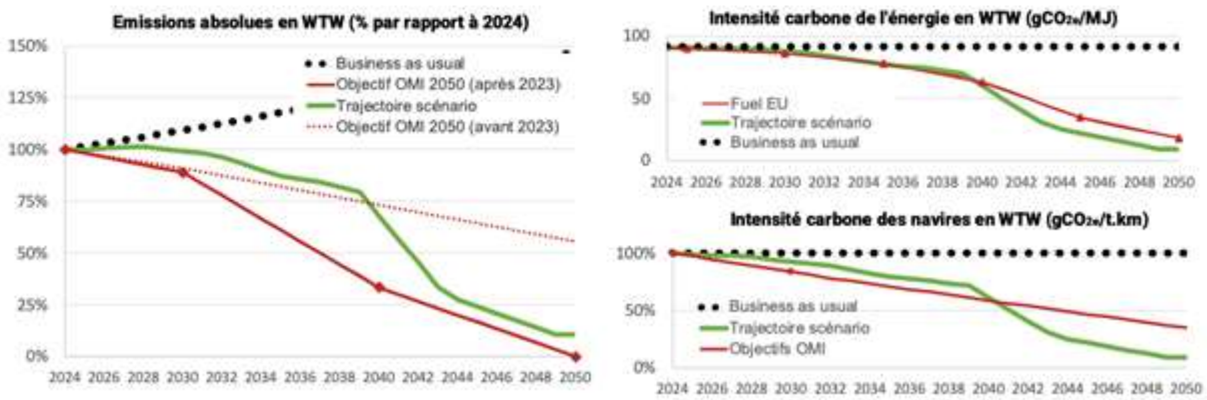
Energy and infrastructure	
 **Less carbon-intensive fuels & carbon capture**	**LNG** is **currently either used or being considered by 3 of the 4 shipowners** in the large ferries fleet category, with 3 of the vessels that use this fuel already in operation and another 3 being built. However, the **issue of methane slip**, which can reduce any environmental benefits, is still to be overcome. *Biofuels* show promise, and it is **possible to incorporate biodiesel in current engines immediately.** There is growing interest in **biomethane**, which could reduce CO2 emissions as compared to fossil LNG. While e-fuels have been recognised as necessary in the long-term, they are still hampered by insufficient technological readiness and challenges relating to cost, compared to conventional fuels.
 **Renewable energy sources, electrification, other sources of energy**	**Electrification** shows great potential when it comes to **manoeuvres and stopovers**, with battery systems that can reach a capacity of 10 MWh. However, for **long trips, the weight of the batteries and the battery life remain major obstacles to overcome.** Other limiting factors have also been identified for this type of technology, including the ability of ports to supply sufficient power, connection standards, frequency issues, as well as economic concerns and a number of technical challenges (connection points, connection automation). **Wind propulsion** may be promising for other types of vessels, but it appears **difficult to implement for ferries due to their sailing speed.**
Energy efficiency	
 **Operational efficiency**	Optimising operations is crucial in reducing emissions from large ferries. **Optimising turnaround times** is particularly important and every minute saved can help make significant fuel savings. **Weather routing**, although applicable on a case-by-case basis according to the area of operation, can deliver variable gains in fuel consumption, saving more fuel for longer crossings. Shipowners are investing in decision support tools that are still being studied, which could improve operational efficiency. Performance monitoring is already widespread and is being constantly adapted, with systems gradually capable of tracking consumption and emissions in real time. Staff training is currently being developed and the goal is to increase awareness of eco-piloting practices among crews.
 **Optimal design & technologies**	A certain number of technical improvements offer promising prospects for the large ferries category. **Coating hulls with innovative paints** can help to gain up to 10% in efficiency. **Modifying the bow** may be a more complex task, but it can help gain a few percentage points. **Optimising the shape of the vessel** is mainly feasible only for **new ships**, and can produce gains of between 5 and 20% according to hydrodynamic studies. Optimising the propulsive efficiency, particularly by replacing the propeller blades, can lead to impressive gains of between 8 and 18%, as long as the operational requirements of the vessel are modified at the same time. Finally, **optimising energy usage on board**, by installing Organic Rankine Cycle (ORC) systems, waste heat boilers and switching to LED lighting, can reduce a vessel's overall energy consumption.
Sobriety	
 **Sobriety in operation & design**	The sector is currently considering a reduction in speed.

6.4.3. *Review*

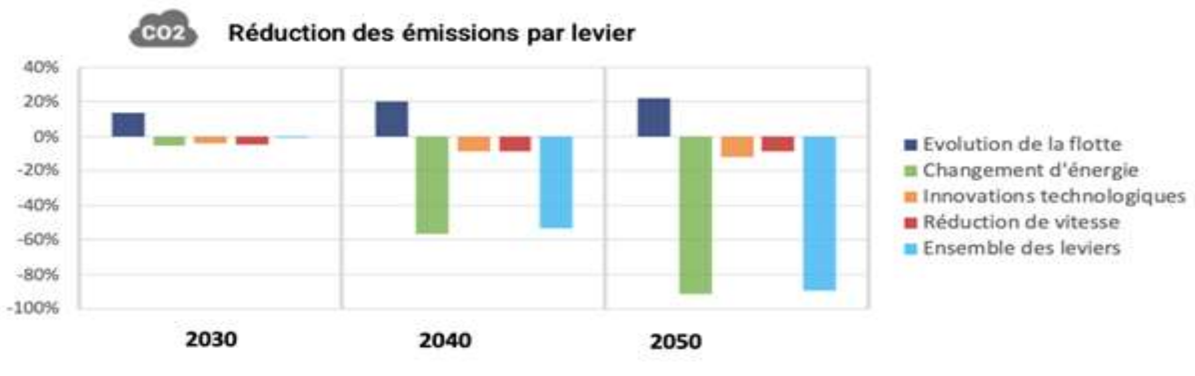
Decarbonising large ferries presents challenges that are complex but can be overcome. Shipowners are actively exploring various solutions, with a focus on operational optimisation, energy efficiency and the gradual adoption of alternative fuels. Partial electrification and the use of LNG have been singled out as short-term solutions. In the medium term, an increasing use of biofuels could help reduce emissions even further. E-fuels are considered for the long term. Collaboration between shipowners, ports and the development of adapted infrastructure will be crucial, and will require investments estimated at several billion euros over the next decades, to reach the ambitious decarbonisation targets for the sector.

6.4.4. *Scenarios*

For the "large ferries" category, the scenario is based on moderate growth in the number of vessels in service (+1.5% per year), and the use of an energy mix that gradually includes biofuels and e-fuels, the electrification of certain uses, as well as the introduction of technological innovations and a possible adaptation of ships' sailing speed. The combination of these levers will allow us to stay on track to meet the decarbonisation targets for 2030, and gradually decrease absolute emissions and the overall carbon intensity of vessels. Considering the service life of vessels which is longer than those in the container ships and gas tankers categories, the vessels using fossil fuel energy sources will remain in the fleet for longer, which explains why the levels of carbon intensity and emissions are slightly higher than in other categories. However, this longer service life offsets the carbon emissions linked to the construction of new vessels.

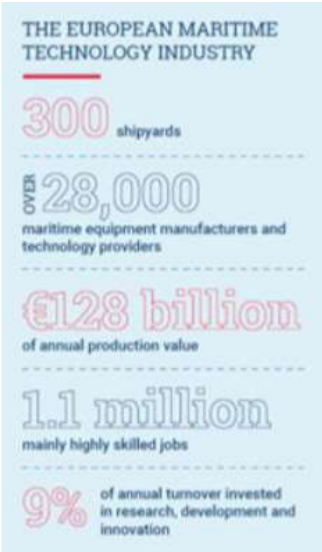


The change of energy source is considered a significant decarbonisation lever for this category, as it will help reduce emissions by 5% by 2030, 57% by 2040 and 91% by 2050, offsetting the increasing emissions due to fleet expansion (+13% by 2030, +20% by 2040 and +22% by 2050). This lever will be boosted in equal measure by the introduction of innovative technology and operational measures (helping to reduce emissions by 9% by 2030, 17% by 2040 and 20% by 2050), therefore guiding emissions to 10% below their current level.



7. The range of solutions and industrial capacity for decarbonisation

7.1. European industrial capacity for a European maritime policy[16]



European shipyards stand out for their expertise in building complex and technologically advanced vessels, both civil and military. Thanks to an industrial capacity of around 300 shipyards specialising in the construction, repair, maintenance and conversion of various types of vessels, European shipyards are renowned for their ability to build vessels with high added value such as cruise ships, ferries, specialised ships and military vessels.

Ship repair covers all types of vessels, and can provide retrofitting for the entire fleet, even those built in Asia. Retrofitting includes, for example, the installation of auxiliary wind propulsion, bow and propulsion replacement, engine replacement, installation of battery or smoke treatment systems, or jumboization techniques to add decarbonisation modules.

European equipment manufacturers are global leaders in the shipbuilding industry. There are around 28,000 companies of varying size, from large firms to small and medium-sized enterprises (SMEs). These companies provide a diverse range of materials, systems, equipment and services, particularly related to engineering and guidance.

In terms of capacity, these equipment manufacturers generate annual production of around 70 billion euros and employ more than 320,000 people directly. They are responsible for around 50% of the global market in their field, which illustrates just how competitive they are and the extent of their technological expertise.

Despite these strengths, European shipyards and equipment manufacturers have challenges to face, such as the increasing competition from Asian shipyards and the necessity to adopt sustainable and digital technologies. To help boost their leading position, SEA Europe is calling for a European strategy to build 10,000 sustainable, digital vessels by 2035, highlighting the importance of innovation and cooperation within the European maritime industry.

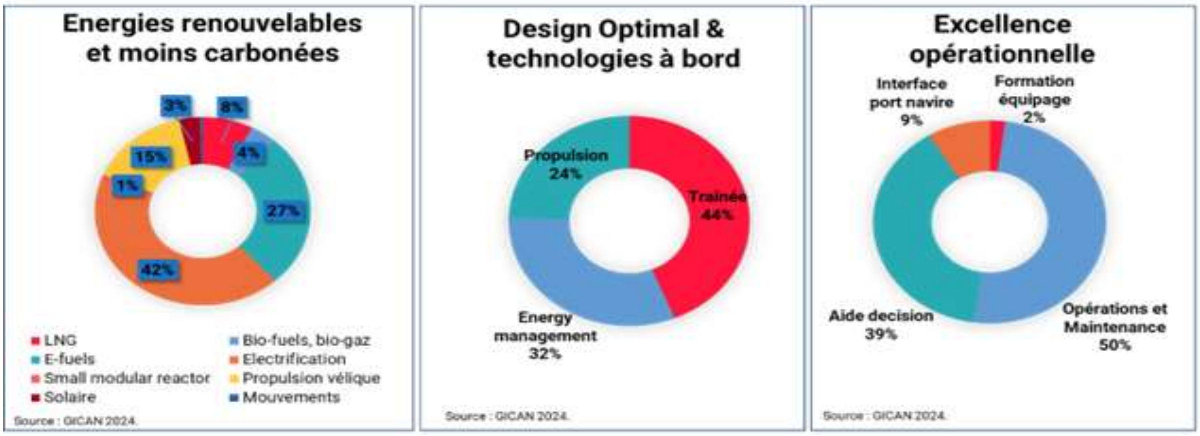
[16] Source SEA Europe

7.2. Overview of industrial solutions

Drawing on available open sources[17], the French Maritime Industry Group (GICAN) has developed an detailed overview of the French solutions devoted to the decarbonisation of the maritime sector that are in line with the levers set out in the roadmap for decarbonisation of the maritime sector. This overview features the technologies and solutions developed by French companies to reduce greenhouse gas emissions in the shipbuilding industry. By the end of 2024, more than 380 proposals for solutions had been put forward by over 250 sources.

These proposed solutions mainly concern less carbon-intensive energy sources stored on-board (53%), design technologies (17%), operational excellence (13%), the use of renewable energy sources on-board (12%, mainly wind propulsion).

The energy sources mentioned in the various solutions put forward by French companies are mainly linked to electrification, e-fuels and wind propulsion. The technologies suggested to increase energy efficiency linked to the design of the vessels are concerned with drag (44%), managing on-board energy (32%) and propulsion (24%). The information technology cited allows for the development of operational excellence solutions, mainly by optimising operations and maintenance (50%), decision support for seafarers and fleet managers (39%) and the port/ship interface.



[17] Media, websites, innovative projects from competitiveness and work clusters

This diverse range of French solutions is supported by an industrialisation of solutions and the roll-out of the first factories for wind propulsion equipment manufacturers (Saint Nazaire, Lanester, Caen) and more generally devoted to green technologies (batteries, fuel cells, etc.). It is now necessary to work alongside shipowners, for the required additional visibility in terms of needs and potential markets, for the first orders to come in, to follow up R&D projects.

7.3. French solutions in line with the results of fleet categories studied

The work done by the working groups for each fleet category for the updated version of this road map summarises the vision and requirements of French shipowners for their specific fleets. The French shipbuilding industry is looking to seize this opportunity to ensure there is a good match between supply and demand

The summary of requirements for large ferries calls for 100% electric ferry prototypes, wind propulsion solutions adapted to the structural constraints of ferries and their operations, and shore-side connection solutions for small ports and island ports. The French range of solutions to meet these needs is particularly abundant with a great number of players working on the topic.

The summary for gas tankers highlights specific solutions for shipbuilding in this category, including the use of fuel cells, wind propulsion, carbon capture and calls for prototypes to be built with these technologies. This vision only accentuates the need to bring the French industry closer to these shipowners as the French proposals are becoming increasingly aligned with these topics.

For large service vessels, the priorities identified in the scenarios for fleet development linked with shipbuilding technologies include electrical infrastructure and shore-side connections, hybrid propulsion, compatibility with new fuels, the use of kites for auxiliary propulsion and weather routing.

8. Transition of energy carriers: biofuels and e-fuels

The transition to less carbon-intensive and even decarbonised fuels is one of the cornerstones in the decarbonisation of the maritime sector. While **LNG**, already a mature solution, is considered to be a transitional fossil fuel, the use of **biofuels** in the maritime sector is likely to increase rapidly, before they are then replaced with **e-fuels**, which are not yet mature enough, and not available in sufficient quantity.

These alternative marine fuels **require a transformation of the value chain**, but can also represent a real **opportunity** for the French energy sector.

8.1. Biofuels for the maritime sector

Biofuels, whether liquid or gaseous, provide a solution to initiate the process of decarbonising maritime transport. They are easy to use and can generally be incorporated without requiring any major modifications to existing infrastructure and engine systems, and they are already available for widespread use. Biofuels allow greenhouse gas emissions to be reduced, in variable proportions depending on the type of biofuel, and also, subject to certain conditions, to support the local economy through agricultural production and the transformation of waste.

8.1.1. *Types of biofuels suitable for the maritime sector*

Two major categories of biofuels can be used in the maritime sector: liquid biofuels and gaseous biofuels. They are generally added to fossil fuels.

Liquid biofuels

FAME (fatty acid methyl esters), more commonly known as biodiesel, can be produced using several inputs. The so-called 1st generation FAME are obtained from vegetable oils such as rapeseed, sunflower or soy, and then transformed by transesterification. The "advanced" FAME biofuels are obtained through the recovery of raw materials intended for destruction, such as animal fats or waste oils. According to the life cycle assessment approach, the potential of GHG emissions reduction can vary between 50 to 60%[18] for the 1st generation biofuels and over 80% for "advanced" FAME.

HVO (Hydrotreated Vegetable Oil) can be produced using vegetable, residual or waste oils, but by using a different process, that of hydrogenation. This process involves adding hydrogen compounds to oils using high pressure, which eliminates oxygen and produces a very high-quality fuel similar to fossil diesel or kerosene, but with less of an impact on the environment. Unlike FAME, HVO contains little or no oxygen, therefore improving its stability and performance in engine systems. As for the reduction in greenhouse gas emissions, HVO can reach up to an 80% reduction in CO_2 emissions compared to fossil fuels, depending on the origin of the raw materials and the efficiency of the production process.

[18] Life cycle assessment of first generation biofuels used in France, ADEME (2010)

Other types of so-called 2nd generation biofuels, are currently under development (in the industrial R&D phase). Produced from non-food raw materials, such as crop residues (straw, husks, wood) or organic waste, using processes such as "Biomass to liquid" (BtL), they do not compete directly with food crops and could eventually be an interesting solution for the decarbonisation of maritime transport.

Gaseous biofuels

Biomethane is another alternative to decarbonise maritime transport. In chemical terms, biomethane is the equivalent of liquefied natural gas (LNG). It is interchangeable with LNG, and can be used in existing infrastructures without requiring modifications to the tanks or engines of ships already running on LNG. It is currently the only biofuel capable of decarbonising the growing fleet of LNG-powered vessels. Today, biomethane is mainly produced by anaerobic digestion. This is a biological process whereby organic matter (agricultural waste, food waste, manure, sludge from water treatment plants) is broken down in the absence of oxygen, producing a methane-rich biogas. Once treated, this biogas can be injected into the natural gas system as biomethane.

In terms of carbon intensity, recent studies by GRDF[19] show that the biomethane injected in France represents an average carbon footprint of 23.4 g CO_2eq/kWh according to a Life Cycle Assessment (LCA), compared to 227 g CO_2eq/kWh for natural gas from fossil sources. This carbon intensity varies depending on the inputs and processes used. When combined with carbon capture technology, anaerobic digestion can even allow for negative carbon emissions. Anaerobic digestion also generates another product called digestate which can be used as a fertiliser, adding organic matter and nutrients to soils.

New technologies such as pyro-gasification and hydrothermal gasification also provide alternative ways to diversify biomethane sources. Pyro-gasification is a process whereby dry matter such as forestry residue is recovered, while hydrothermal gasification is a way to transform specific waste such as refuse-derived fuel (RDF), into biogas.

8.1.2. *Biofuels production potential*

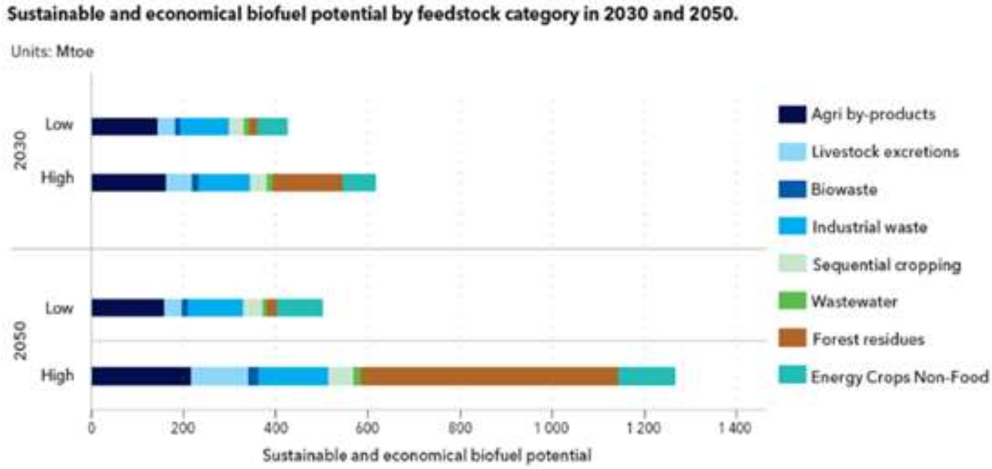
Worldwide and in Europe

Any means of producing biofuels relies on biomass resources, which are by definition limited. Numerous studies have attempted to estimate the production potential of biofuels on a global scale, often with divergent results. According to the Net Zero by 2050 report from the International Energy Agency (IEA), the production of liquid biofuels could be multiplied by four, while biogas could be multiplied by six between 2020 and 2050. These forecasts depend on the development of sustainable biomass supply chains.

These estimations are nevertheless considered to be optimistic and do not take certain obstacles into consideration, such as those relating to European regulations such as the RED directive (Renewable Energy Directive). The latter restricts the use of biomass to only the biofuels capable of considerably reducing greenhouse gas emissions compared to fossil fuels (see chapter 4). In its 2023 white paper entitled "Biofuels in Shipping", DNV estimates the global biomass potential between 400 and 600 Mtoe by 2030 and between 500 and 1,300 Mtoe

[19] Brief summary of the GHG emissions study on the development of injected biomethane

by 2050 (all sectors combined). These figures take into account regulatory constraints, the availability of resources (agricultural and waste), the efficiency of different production technologies, as well as economic viability by excluding fractions that are profitable in other markets.



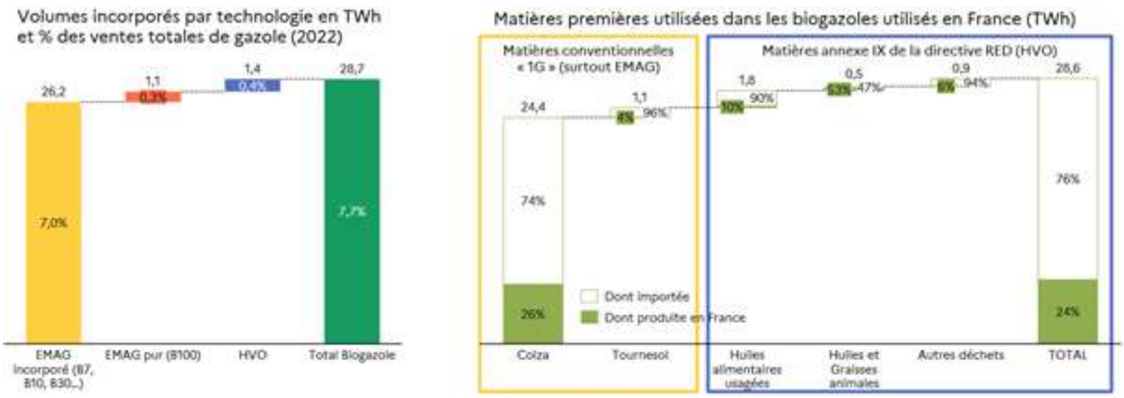
Biofuels in Shipping, DNV (2023)

It should be noted that biomass allocation depends on the categories and sectors, with variable conversion rates (ratio between the volume of inputs used and the fuel produced) depending on the type of inputs (dry or wet) and the addition of hydrogen in the production process. As described in Chapter 1, the various biomass categories are more or less suited to different production processes.

On a European scale, the European Commission estimates[20] that the biomass available for the production of biofuels could reach between 150 and 200 Mtoe by 2030 and between 160 and 350 Mtoe by 2050.

In France

In France, biofuel production was given a boost by the Multiannual Energy Plan (MEP), reaching around 3.5 million tonnes of liquid biofuels in 2023, mainly for the road sector and to a lesser extent, the air sector.



Figure

biomass prioritisation of use: challenges and guidelines, SGPE (July 2024)

[20] European Commissions Impact Assessment for the 2030 Climate Target Plan (EC, 2020)

The 3rd edition of the MEP is currently being drawn up, and these targets might be revised upwards as a result. In 2022, biodiesel incorporated in France - mainly FAME for road transport - represented 7.7% of diesel volumes, or around 30 TWh. The materials used are still mainly from crops such as rapeseed and imported.

For biomethane, France has set ambitious targets, with current production exceeding 12 TWh/year, compared to a target of 44 TWh by 2030. There are currently 674 facilities injecting biomethane into the natural gas systems using inputs comprised of 80% inputs of agricultural origin and 20% from non-hazardous waste storage facilities (ISDND). The gas industry is expecting greater production potential with 57 TWh of biomethane by 2030, and 275 TWh by 2050.

	Potentiel	Trajectoire de production réalisable		
		2030	2040	2050
Methanisation	190 TWh	49 TWh	100 TWh	135 TWh
Pyrogazéification	180 TWh	6 TWh	30 TWh	90 TWh
Gazéification Hydrothermale	100 TWh	2 TWh	25 TWh	50 TWh
Total	**>> 430 TWh**	**57 TWh**	**155 TWh**	**275 TWh**

France Gaz "A vision of the gas industry by 2050" (2022)

8.1.3. *Use of biofuels in maritime transport today*

The use of biofuels has always been limited to road transport and, to a lesser extent, air transport, due to incentive-based regulations. Recently however, their use in the maritime sector has started to accelerate. As an example, in 2023, fuels combined with biodiesel represented more than 7% of total bunkering at Rotterdam port[21] and around 1% at Singapore port[22], for a total of approximately 0.4 Mtoe pure bio-based diesel, up from around 0.3 Mtoe in 2022.

In France, ports do not currently offer bunkering solutions for marine fuels containing liquid biofuels, because there isn't enough demand. Nevertheless, a number of one-off operations have been carried out, such as the LDA-operated vessel Ciudad de Cadiz, which underwent several HVO bunkering operations by truck in the port of Nantes-Saint Nazaire.

In the short term, however, the incorporation of FAME (for the most part) and HVO appears to be an appropriate solution for shipowners to decarbonise their fleets and comply with regulatory requirements. These so-called "drop-in" liquid biofuels are an excellent fuel base for marine engines, and present few technical and operational constraints. Tests carried out by several shipowners have confirmed that marine engines are well adapted to these fuels, with results that are often satisfactory in terms of greenhouse gas reductions, as well as reductions in pollutant emissions (sulphur oxides and nitrogen oxides).

---

[21] https://www.portofrotterdam.com/sites/default/files/2024-04/bunkersales-2021-2024.pdf
[22] https://www.mpa.gov.sg/docs/mpalibraries/mpa-documents-files/stratpol/port-statistics/bunker-sales3e276db0565c4f94bdd764da59396395.xls?sfvrsn=c7b22b1_0

However, the volumes of these fuels will remain limited, even though they might be reallocated in Europe with the announced end of sales of new combustion-powered cars, to other sectors, including the marine sector. The main reasons for this are the limited availability of vegetable oils and deliberately restrictive regulations on 1st-generation biofuels. However, there may be a move towards 2nd-generation diesels, bioalcohols (methanol and ethanol) or residual fuels. In addition to broadening the resources used, these processes would make it possible to meet the decarbonisation targets imposed by regulations for 2040 or 2050.

As far as biomethane is concerned, its use in the maritime sector is linked to the rapid development of the global fleet of LNG-powered vessels. It should be noted that LNG is now by far the leading alternative to traditional liquid fuels.

In the majority of cases, biomethane intended for the maritime sector will be derived from biomethane injected into the gas system, made available in the form of bioLNG at European LNG terminals, thanks to the appropriate certification schemes (regulation implementing the RED directive). It can be distributed by bunker vessels, or by tank lorries for ferries.

There are a number of regulatory uncertainties surrounding the use of the biogas guarantee of origin certification system, and particularly in recording these fuels for decarbonisation obligations, without physical bunkering of the molecules. Only French projects not subsidised by the State would be eligible. Bear in mind that the regulator's objective is to ensure physical bunkering of the molecules.

The use of bioLNG by shipowners is only just beginning, but there are companies that are actively committed to integrating this lever. CMA CGM has just signed an agreement with SUEZ to produce up to 100,000 tonnes of biomethane per year by 2030[23].

8.1.4. *Projects that illustrate the dynamic nature of the biofuels industry in France*

Biofuels production projects in France could be beneficial to maritime transport. Initiatives such as Salamandre and other advanced biofuels production facilities could eventually offer adapted solutions for marine fuels. With the needs of the maritime sector evolving towards more sustainable fuels, these facilities could be gradually either transformed or expanded in response to the specific demand in the maritime sector for biofuels.

Salamandre project

The Salamandre project was launched in 2021 with the aim of producing biomethane by pyro-gasification in the region of Le Havre, solely for maritime use. This initiative, led by ENGIE and CMA CGM, involves the installation of a synthetic renewable gas production facility powered by wood waste and refuse-derived fuel (RDF). Salamandre is the result of 10 years of R&D on pyro-gasification and methanation and the facility will have the capacity to supply 11,000 tonnes of biomethane per year by 2027, or 177 GWh/year. CMA CGM will acquire bioLNG, which emits 80% less than its fossil equivalent.

---

[23] [1]cmacgm-group.com/fr/actualites-media/le-groupe-cma-cgm-et-suez-signent-un-protocole-daccord

Converting refineries, such as La Mède (TotalEnergies)

La Mède refinery near Marseille is one of the biggest biofuel production facilities in France, and is run by TotalEnergies. This former fossil oil refinery was converted into a biorefinery in 2019, and boasts a production capacity of 300,000 tonnes of HVO biodiesel per year. La Mède uses a diverse range of feedstocks, including vegetable oils (such as rapeseed or sunflower oils), waste oils and animal fats. The refinery's annual production is mainly used by the road sector, but it is likely to turn to the maritime sector in the future due to the gradual electrification of road vehicles and the close proximity to the port of Fos-sur-Mer.

La Mède is not the only facility concerned by these changes, the Grandpuits platform is also being transformed to supply biofuels, here mainly devoted to aviation.

BioTfuel facility in Dunkirk

BioTfuel is a pioneering project in Dunkirk, specialised in the production of advanced 2nd-generation biofuels derived from lignocellulosic feedstocks (agricultural and forestry waste and residues). This pilot project is led by a number of partners, including IFPEN, Axens, CEA, TotalEnergies, and ThyssenKrupp Uhde, and has demonstrated the success of Btl (biomass to liquids) technology on a pre-industrial scale. Even though this technology is still in the industrialisation phase, the BioTfuel project offers great potential for supplying biofuel with a low carbon footprint to the aviation and maritime sectors. Incidentally, this process has been leveraged for an industrial project, entitled BioTJet, from Elyse Energy, which aims to build and operate an e-biofuel commercial plant for the aviation sector in France.

8.1.5. Outlook for the roll-out of marine biofuels in France

To develop biofuels for the maritime sector, the competing uses must be taken into consideration. Demand for biomass is growing in a number of sectors, especially aviation, industry, residential and also for electricity production. For the maritime sector, the existing infrastructure and engine systems allow for direct and efficient integration of liquid and gaseous biofuels, therefore providing a potential for an immediate reduction in greenhouse gas emissions. However, a strategy aiming to guide the volumes of biofuels towards this sector will be needed if the maritime sector is to benefit from this opportunity. This could involve directing resources towards the industries that are the most difficult to decarbonise, and specific regulations. SGPE's work on the prioritisation of biomass uses is linked to this, in that a list of priority sectors were identified as having access to biomass resources.

Giving priority to maritime transport in terms of accessing biofuels should also involve encouraging stakeholders to create and develop production capacity that is adapted to the specific characteristics of this sector.

Ports, shipowners and energy providers all have a key role to play in developing biofuels production models based on local supply chains. These initiatives can only be rolled out if the French government and local authorities are proactive in creating suitable economic and regulatory conditions for the roll-out of such projects in France.

The transition to advanced biofuels in the maritime sector can also boost local economies and the competitiveness of certain French ports. Faced with competition from other European hubs, if ports can provide bunkering for sustainable biofuels, they will attract shipowners looking to reduce their carbon footprint, while anticipating increasingly demanding international environmental requirements. Boosting these production capacities will help to be less vulnerable to the fluctuations of the fossil fuels market and ensure greater energy resilience.

8.2. Synthetic fuels and the maritime sector

Synthetic fuels, or e-fuels, are fuels derived from chemical processes using decarbonised hydrogen and captured CO2, or nitrogen for ammonia, that can be introduced over the medium and long term. These fuels come in liquid or gaseous form and along with biofuels derived from biomass, they provide a suitable alternative to reduce the dependency of maritime transport on fossil fuels, and therefore pave the way for the decarbonisation of the sector by 2050.

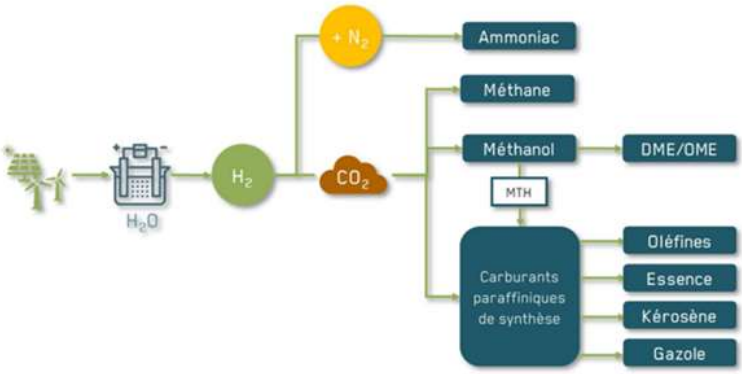
E-fuels are not as mature as biofuels, but they are one of the solutions needed to be able to reach the decarbonisation goals for the maritime sector.

8.2.1. *Types of synthetic fuels suitable for the maritime sector*[24]

At atmospheric pressure, hydrogen is gaseous and has a high energy density per mass, but a low energy density per volume. To be stored in reasonable-sized tanks, it must be compressed at very high pressure (between 300 and 700 bar) or liquefied at -252°C. Both of these methods require a high energy consumption and pose technical challenges for on-board equipment.

Its transformation into e-fuels, by reaction with CO_2 or nitrogen, is an indirect method of providing vessels with electricity. Whether gaseous or liquid under ambient conditions, e-fuels are generally easier to transport, store and use than pure hydrogen. This is an interesting solution for air and maritime transport, as pure hydrogen is difficult to use for long distances.

There are several types of e-fuels that can be used in the maritime sector, and each one presents specific characteristics suited to the different needs of vessels. The main e-fuels being considered for the maritime sector are e-methanol, e-ammonia and e-methane.



Main types of synthetic e-fuels (IFPEN)

According to the well-to-wake life cycle assessment methodology, the potential for synthetic fuels to reduce greenhouse gas emissions depends, among other things, on how carbon-intensive the inputs used are, primarily electricity.

---

[24] https://www.evolen.org/wp-content/uploads/2023/03/15-03-2023-EVOLEN-Note-de-synthese-sur-les-e-fuels.pdf

Liquid synthetic fuels

E-methanol, the production of which has already been industrialised in small proportions, particularly for the chemicals industry, is a promising fuel for the maritime sector. This fuel is already known among manufacturers, relatively dense in energy and is in liquid form at room temperature. E-methanol can be rolled-out quickly as it can easily be added to the petrol used for existing vehicle engine systems and used in "duel fuel" engines in the maritime sector. However, methanol presents a certain level of toxicity and so precautions must be taken when using it as fuel.

Paraffinic e-fuels: These fuels are produced according to the Fischer-Tropsch process and can be used with properties similar to their fossil equivalents.

Gaseous synthetic fuels

In liquid form at around -163°C, **e-methane** has the major advantage in that it can be incorporated into LNG (Liquefied Natural Gas) and can therefore be used at existing facilities and in compliance with existing regulations.

E-ammonia is being looked into more closely for maritime transport as it is an economical synthetic fuel that is simple to produce, using the Haber-Bosch process. It is also the only zero-carbon e-fuel. However, its high level of toxicity and the threat it poses to the environment remains an obstacle to its widespread use as a fuel, particularly in confined spaces such as ships. E-ammonia also aims to lower the carbon intensity of the production of chemicals such as nitrogen fertilisers. It is also a possible solution for transporting hydrogen long distances (ammonia cracking).

8.2.2. *Potential for synthetic fuels production*

As it stands, synthetic fuels production is almost non-existent across the globe. The availability of renewable, low-carbon hydrogen is extremely limited for the moment, even though it is crucial for the production of e-fuels.

Production technologies for these fuels may have been mastered by manufacturers, but the cost of e-fuels is still a hindrance to their large-scale development as it is estimated 8 times higher than the fossil equivalents. Changes in the regulatory framework, aiming for carbon neutrality by 2050, should nevertheless facilitate their gradual introduction.

Worldwide

The International Energy Agency (IEA) estimates[25] that due to decarbonisation requirements, global production of synthetic fuels for transport could reach 56 Mt of e-fuels (excluding ammonia) and 44 Mt of ammonia by 2050, with a significant share devoted to sectors that are difficult to decarbonise, such as maritime transport. These figures are estimations based on scenarios involving large-scale development of renewable electricity.

A study carried out by the company MGH on behalf of CMF offers an estimation of the global potential for synthetic fuel production, taking into consideration geographical aspects. The study reveals that, in the most competitive geographic areas, i.e. those with favourable wind

[25] https://www.iea.org/reports/net-zero-by-2050

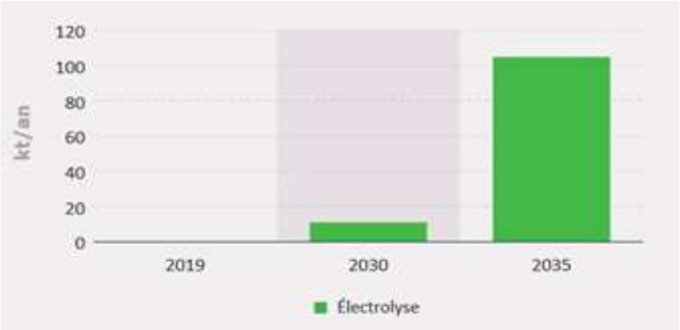
and sun conditions, the potential for e-fuels production is high (estimation of the minimum potential for the most competitive areas), exceeding even the needs of the maritime and air transport sectors. The analysis demonstrated the leading role of Africa, the relative importance of Australia and, to a lesser extent, America. Europe however, where a significant share of the demand is located, does not have the optimal weather conditions for widespread roll-out of renewable energy sources, and consequently, widespread production of e-fuels. This distribution could redesign fuel trade on a global scale, by introducing a new model for trade between producing and importing countries. Certain ports could therefore become specialised and position themselves as strategic supply hubs.

In France

The Multiannual Energy Plan (MEP) currently being revised, does not set targets for the production of synthetic fuels, but instead aims to support the development of hydrogen produced by water electrolysis. In the planning documents currently out for consultation (SNBC and MEP), the target set is 6.5 GW in electrolyser capacity by 2030 and 8 GW.

France is also bound by European goals, particularly the integration of 1.2% of renewable fuels of non-biological origin delivered to ports and 1% in bunkers by 2030.

As for electricity requirements, RTE anticipates the needs for[26] electricity to be around 10 kT/year by 2030 and 100 kT/year by 2035.



Supply of hydrogen to meet sustainable fuel needs for maritime transport (RTE, July 2024)

8.2.3. *Use of synthetic fuels in the maritime sector*

Even if synthetic fuels are not yet available, they are being closely examined by shipowners, shipyards and equipment manufacturers, as well as ports.

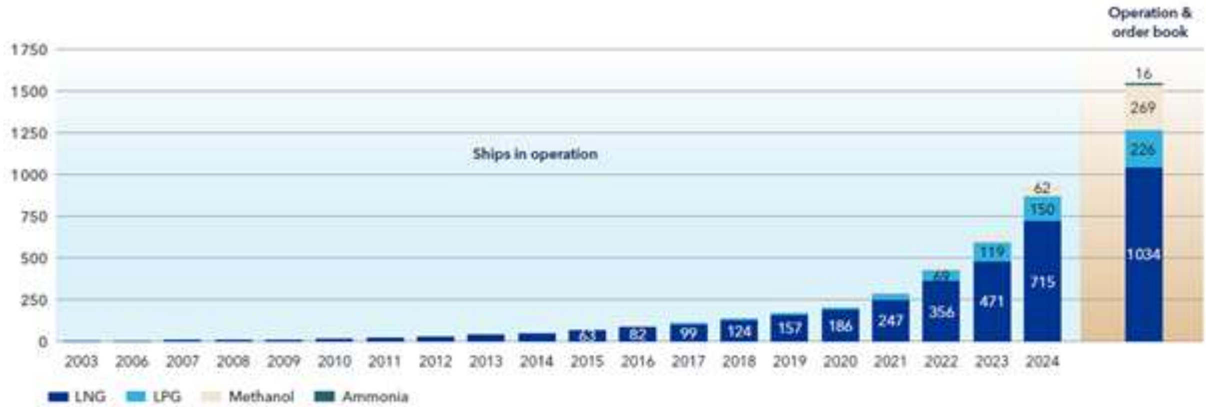
LNG is already used in the maritime sector, particularly for certain fleet categories (LNG tankers, container ships, ferries, cruise ships), and already boasts marine infrastructure and equipment - engines, storage, etc. - suited to this fuel, but there is still progress to be made, especially to limit methane slip. If there were to be a switch to synthetic LNG, this would not require any specific adaptation compared with conventional LNG.

There is a lot of interest in **e-methanol** from the world's shipowners and they are investing in "methanol-ready" vessels. These vessels are usually designed to be able to run on methanol as soon as this fuel becomes available at a competitive price, but they are also able to run on conventional fuel. There are also plans to retrofit existing vessels to adapt them to methanol, and the first duel-fuel methanol vessels are now in operation. In terms of bunker infrastructure, the majority of ports do not have suitable facilities, although a few pioneers are initiating

[26] https://assets.rte-france.com/prod/public/2024-07/2024-07-12-chap11-hydrogene.pdf

projects. The development of infrastructures will depend mainly on how demand evolves and on the clarification of international rules on the safety and bunkering of this fuel.

There is growing interest in **ammonia** in its liquid form at -33°C in the maritime sector, but there are technical challenges to overcome. The main one is concerned with designing vessels, equipment and bunker facilities that can be used with ammonia in complete safety. This extremely toxic and corrosive fuel calls for strict handling protocol. Aftertreatment of the NOx (pollutant) and N2O (powerful greenhouse gas) emissions generated by its combustion is also a major challenge, and R&D on the topic is currently underway. Added to this is the lower energy density of ammonia, which requires bunkers 3 to 4 times larger than for fuel oil, both of which provide the same range. Despite the lack of maturity, orders for new ammonia-powered vessels have begun to take off, and a first Japanese vessel has been converted to an ammonia-fuelled vessel (Sakigake tugboat).



Growth in the number of vessels capable of using selected alternative fuels, excluding LNG carriers (DNV, May 2024)

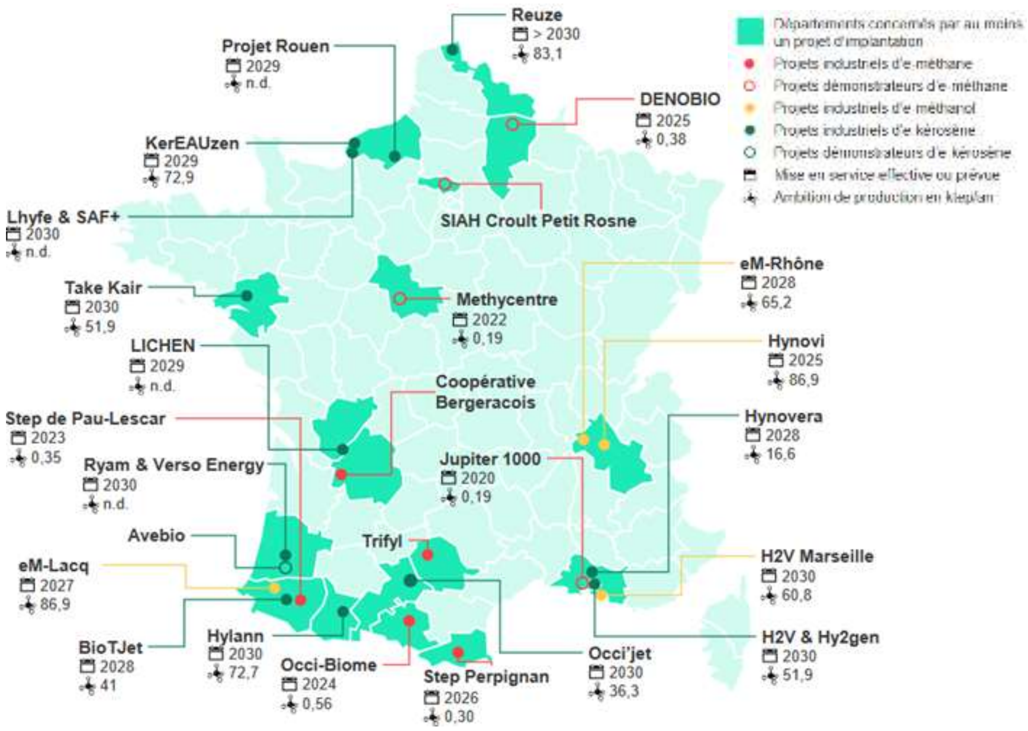
8.2.4. Key projects in France for synthetic fuels

In France, demand for e-fuels for the maritime sector is likely to remain low between now and 2030, as shipowners opt for more mature, less costly technologies. However, due to regulatory requirements, demand could rise to over 9 TWh (774 kToe) by 2040 The structuring of a French e-fuels production sector from 2030 should help to anticipate this change in demand.

France boasts a vast network of proactive players involved in the development of synthetic fuels. The French E-fuels Bureau, which represents all these players, publishes an annual observatory which provides a comprehensive overview of current projects. The 2024 edition[27] of this observatory, published in July, featured 26 projects (covering all stages in progress) across 17 departments in mainland France, devoted to the production of various molecules, including e-methane, e-methanol, e-kerosene and by-products.

More than a quarter of the projects are either near the river Seine or close to Fos-sur-Mer. These locations near major industrial areas offer project leaders the advantage of being close to CO_2 deposits that can easily be captured, and also to the end consumers of e-fuels. These locations offer the possibility of transporting e-fuels towards Le Havre and Fos-sur-Mer.

[27] https://www.bureau-efuels.com/wp-content/uploads/2024/10/Observatoire-francais-des-e-fuels_edition-2024_Fr.pdf



Map of projects announced either within the scope of the study or related to it, according to public data provided by project leaders or reported in the media (Sia Partners, June 2024)

If all the projects for e-fuel production in France go ahead as planned, they will be able to cover the needs in France between 2030 and 2035. It should be noted that no plans to produce e-ammonia for the maritime sector have been reported to date. This can be explained due to the lack of readiness in ammonia technologies for the maritime sector.

The French e-fuels observatory also states that these projects would require 24 TWh of low-carbon electricity, i.e. 3.4% of the production capacities planned by the SNBC (corresponding to around 3 GW, the equivalent in power of 2 EPR-type nuclear reactors), as well as 2.6 million tonnes of biogenic or fossil CO_2 to be captured and recovered, i.e. 2.2% of the current volume produced by the most carbon-intensive industrial sites (sites with emissions in excess of 30 ktCO_2/year).

If national e-fuels production sectors are not developed, France will have to import e-fuels or ships will have to use bunkering facilities outside France to meet their regulatory obligations and the needs of the maritime sector.

8.2.5. *Obstacles to the introduction of synthetic fuels in the maritime sector*

Over the medium term, the development of synthetic fuels in France presents an opportunity to ensure the decarbonisation of the maritime sector while boosting France's energy sovereignty. However, there are several major challenges to overcome for a large-scale roll-out of projects, and these challenges require strategic choices and huge investments to be made.

The production of synthetic fuels relies on the widespread availability of competitive, low-carbon electricity, required to produce hydrogen by water electrolysis. France is in a favourable position thanks to its nuclear and hydroelectric power plants, which already produce low-carbon electricity, but it will have to significantly increase its renewable electricity production capacity to meet the various needs. Indeed, the electrification of uses in several sectors of the French economy could make it even more difficult for projects to access low-carbon electricity at competitive prices. The French government will have a key role to play in the first phase of developing the sector, to ensure that a portion of low-carbon electricity production can be allocated to projects at competitive rates. Investment in electrical infrastructure and network management will also need to take into account the requirements for e-fuel production.

With the exception of future projects for ammonia production that could arrive on French soil, projects for carbon-intensive e-fuels will require a stable supply of CO_2. These needs can be met through the capture of biogenic, fossil and potentially, over the long term, atmospheric CO_2. As European legislation currently stands, industrial fossil CO_2 recovered for the production of RFNBO-type e-fuels will be considered as avoided emissions, up until 2040. After 2040, there may be issues in biogenic CO_2 supply and this must therefore be anticipated from the design stage of the first projects, in view of their projected lifespan (>20 / 25 years).

Developing the sector will also require considerable funds. Financing is now needed to carry out technical and engineering assessments for projects, and in the coming years, for the construction and development of industrial sites. To date, 8.1 billion euros of investments have been announced between now and 2030 for 15 of the 26 projects mapped out, representing a total production capacity of 552 kToe, or around 76% of the capacity of the projects in figure 3 (maritime and air sectors combined). These investments will greatly benefit the regions in which they are located, boosting the local economy.

To ensure the economic viability of this new sector, commitment from end buyers, particularly shipowners, will be crucial. These commitments will guarantee outlets for synthetic fuel production, thus reinforcing the economic stability of the projects. Shipowners have a central role to play in providing their support for e-fuel consumption over the long term, which will encourage investors to get involved and secure financing for the necessary infrastructure. Long-term partnerships between e-fuel producers and end consumers will also be key in boosting the development of the sector in France.

Finally, depending on the type of fuel, developing synthetic fuels also involves adaptations of varying extent to French port infrastructure. The ports are major refuelling and transit sites for maritime transport, and they could also be developed to be able to receive, store and distribute these new fuels. This would require investment to transform the existing facilities or build new ones such as production, storage and supply units for vessels.

Finally, it should be mentioned that the e-fuels supply from countries that boast favourable production conditions such as certain regions of Africa or Australia, with potentially more competitive prices, could also be exploited for French and European projects, to be able to meet the high demand for low-carbon fuels in the maritime sector. Considerable quantities are required to decarbonise maritime transport and domestic production alone will probably not suffice to meet all these needs.

9. Decarbonisation strategies for the domestic maritime sector

The decarbonisation of the maritime sector can only be achieved through a combination of different levers. By comparing different decarbonisation scenarios that take into account different ways of combining the levers, it is possible to assess the quantitative aspects of the solutions to be considered and to prioritise the actions to be taken.

9.1. Energy transition model and associated data

Modelling software has been developed by the maritime industry as part of the MEET2050[28] project. This tool provides an overview of a given fleet (defined by a number of vessels, age distribution, overall consumption). In describing the evolutions of this fleet (newly built or retrofitted vessels, new technologies and energy sources available, operational optimisations, etc.) and taking into consideration the gains achieved through these changes in terms of reduced consumption and emissions, the model enables:

- The development of decarbonisation trajectories for this fleet (absolute emissions, carbon intensity of bunkered energy, of operated vessels);
- An estimation of the energy requirements for the fleet (or a combination of fleets).

The model can be adapted to take into account specific data from international, national or multi-national fleets, on the basis of "average" descriptions. More specifically, the modelling provided by the tool is based on:

- The quantification and description of a group of vessels in operation;
- The evolution of a group of vessels in operation;
- The evolution of on-board consumption for the fleet in question;
- The evolution of emissions associated with consumption;

Assessment of primary energy source needs and transition costs.

MEET2050 teams and value chain actors have worked together to define the data and parameters used in the model: emission factors, technical data associated with new energy sources (volume, yields, etc.). It is important to note that the data used show some scattering associated with the sources used, especially due to the uncertainty of future forecasts (medium- and long-term energy costs, cost per tonne of CO2) or the lack of a shared frame of reference (emission factors for certain biofuels, for example).

9.2. Previously studied scenarios

Some ten scenarios were developed in the 2023 roadmap around a core scenario (scenario S3) in which the decarbonisation objectives were met by a balanced implementation of all the levers: technological and operational efficiency available to date and expected by 2050, wind propulsion, a 15% reduction in speed with the addition of ships to maintain the volumes transported, gradual deployment of biofuels before integrating e-fuels from 2030. This core scenario also assumes a 3% growth in energy needs. This 3% corresponds to a 1.5% increase in the volumes transported, in line with international projections, and 1.5% linked to an increase in bunkering in French ports with a view to reducing dependence on foreign bunkering.

[28] J.F. Sigrist, E.Jacquin, "A comprehensive energy transition model to assess the decarbonisation trajectories of the maritime sector", annual conference of the *Association Technique Aéronautique et Maritime*, Paris, 8 October 2023.

9.3. Revised benchmark scenario (S3 revised) - national maritime sector

The scope for the benchmark scenario remains unchanged. However, following discussions between representatives of maritime sector stakeholders and the French government, a modified scenario was agreed upon, with the following characteristics:

- Numerous hypotheses have been made and reviewed concerning the reduction of energy requirements through an optimistic combination of different technical and operational levers: design gains, contribution of wind power, CO2 capture, retrofit plans, etc. A gradual, linear reduction in sailing speed of around 15% by 2050 was also applied. These two elements maintained the energy consumed by the fleet at a stable level, and the twofold increase in needs linked to growth was offset in equal measure by these two types of measures;
- The gradual deployment of biofuels before the integration of e-fuels from 2030;
- Initially considered at 3% in the S3 scenario of the 2023 roadmap, the increase in maritime emissions has been reduced to 1.5% up until 2035 to take into account fleet growth and the repatriation of domestic bunkering, then considered as zero after 2035. This factor was reviewed against a background of obstacles to the distribution of French biomass and electricity between the various industrial sectors to be decarbonised.

This "revised" benchmark scenario set out in Appendix 5 therefore details the following modelling hypotheses:

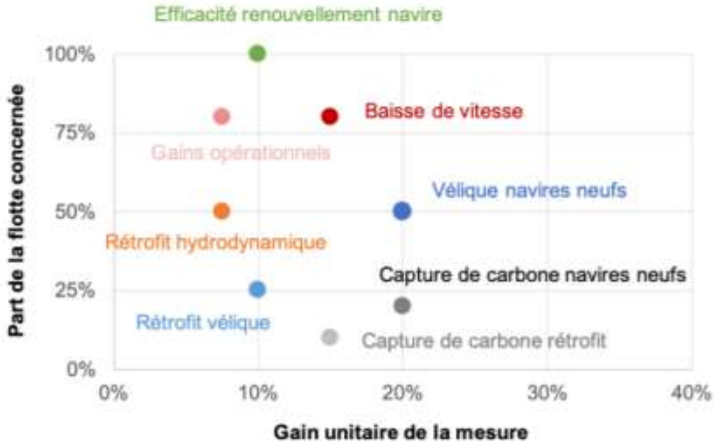
- Initial energy consumed: 27.7 TWh;
- Total growth: 1.5% over 15 years, including equal shares of fleet growth and growth related to repatriation of bunkering to France, then 0% after 15 years;
- Average lifespan of vessels: 25 years;
- Introduction date of e-fuels: 2028;
- E-fuel deployment time period: 15 years.

We also assume that:

- 100% of new vessels will offer gains of 10% in consumption reduction (gradual decrease to 50% over 15 years);
- 50% of new vessels will be equipped with wind propulsion systems over the next 10 years, reducing their consumption by 20%;
- 20% of new vessels will be equipped with a CO2 capture system, allowing for a 20% reduction in emissions;
- 80% of the fleet will reduce fuel consumption by 7.5% through operational efficiency measures (routing, eco-piloting, etc.);
- Two retrofitting plans will be introduced for the fleet: 50% of the fleet will reduce fuel consumption by 7.5% thanks to hydrodynamic improvements to the hull, bow, etc. and 25% of the fleet will reduce consumption by a further 10% thanks to wind propulsion; 10% of the fleet will reduce emissions by 15% thanks to on-board CO2 capture.
- 80% of the fleet will reduce speed immediately to gradually (and in linear fashion) reach a 15% reduction by 2035.
- The fleet of fuel or diesel-powered vessels will undergo retrofitting over the next 15 years, to gradually replace these fossil fuels with synthetic fuels (mainly e-methanol).

The following table and graph summarise the main points of this benchmark scenario.

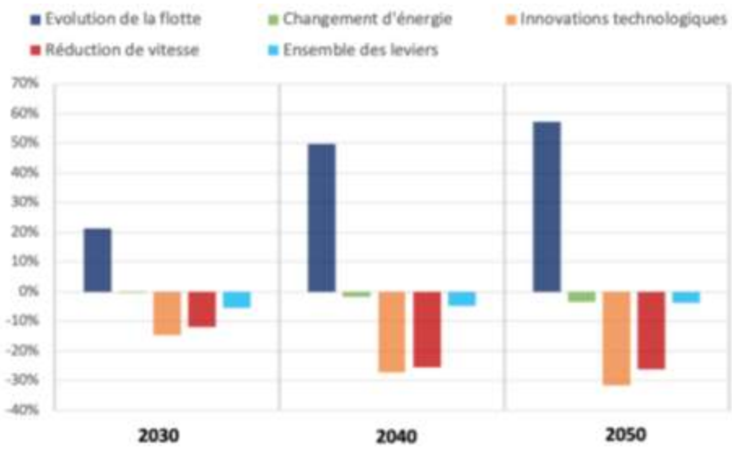
Gains in energy consumption	Gain	Percentage of the fleet	Deployment time period	Average 2023-2050
Efficiency gains upon renewal	10 %	100 %	-	6.4 %
Gains from wind assistance for new vessels	20 %	50 %	7	7.6 %
Operational gains	7.5 %	80 %	5	5.4 %
Speed reduction	15 %	80 %	15	8.7 %



According to these assumptions, the quantity of energy consumed by the fleet will decrease from 27.7 TWh in 2022 to 26.6 TWh in 2050 (a 4% reduction) - as shown in the following table.

	2023	2030	2040	2050	2023-2050
Energy consumed by the fleet (TWh)	27.7	26.2	26.4	26.6	774
Energy consumption trends	Benchmark	-5 %	-5 %	-4 %	-
Fossil fuel	26.9	22.0	7.1	0.0	393
Bio-sourced energy (blend only)	0.9	3.1	6.2	7.2	136
Energy from e-fuels	0.0	3.2	30.6	43.7	571
Electrical energy (shore/on-board)	0.0	0.1	0.6	1.2	13

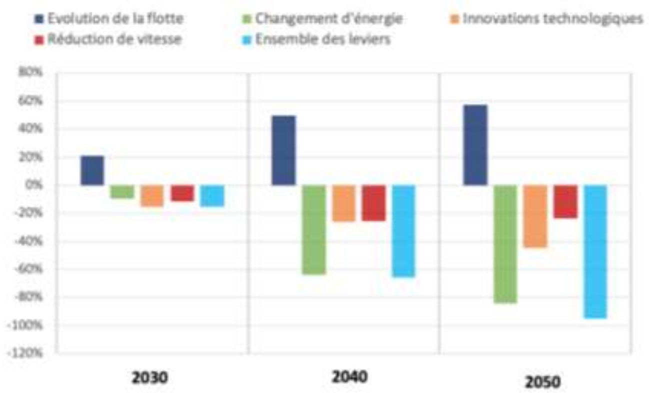
The evolution of consumption is dependent on various levers, as shown in the graph below: the 4% decrease in consumption observed in 2050 is broken down into +57% for fleet evolution (increase in quantities transported, bunkered energy and construction of additional vessels to maintain transport capacity following the reduction in speed), offset by various levers: -32% for technological efficiency (including wind propulsion); -26% for speed reduction; -3% for the change of energy source.



The table below shows the evolution of CO2eq emissions in the benchmark scenario: in this scenario, emissions fall from 9.0 million tonnes in 2023 to 0.4 million tonnes in 2050, representing a drop of almost 95%.

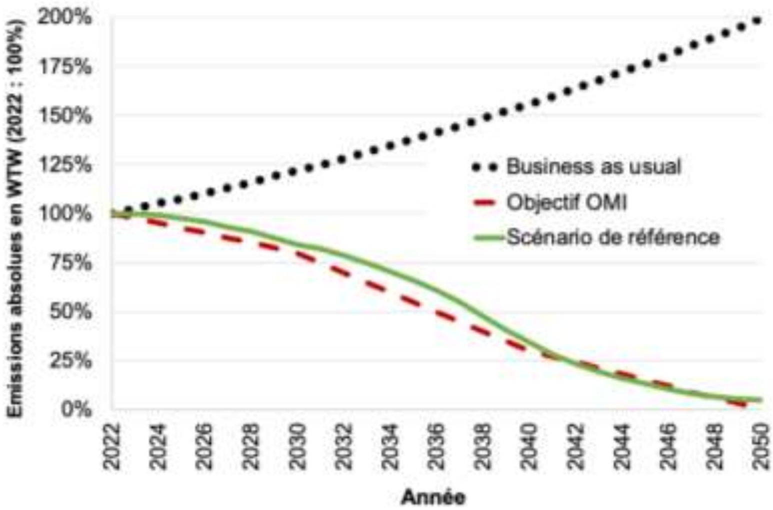
	2023	2030	2040	2050	2023-2050
CO2eq emissions WTW (Mt)	9.0	7.6	3.1	0.4	143
Emissions trend	Benchmar k	-16 %	-66 %	-95 %	-
Evolution of the fleet	0 %	21 %	50 %	57 %	35 %
Change of energy source	0 %	-15 %	-26 %	-45 %	-21 %
Efficiency	0 %	-12 %	-26 %	-23 %	-18 %
Speed reduction	0 %	-10 %	-64 %	-84 %	-41 %

As shown in the graph below, this reduction is broken down into an increase of 57% linked to the evolution of the fleet, offset by a decrease cause by the various decarbonisation levers: -45% for technological efficiency (including wind propulsion), -23% for speed reduction and -84% for the change of energy source.

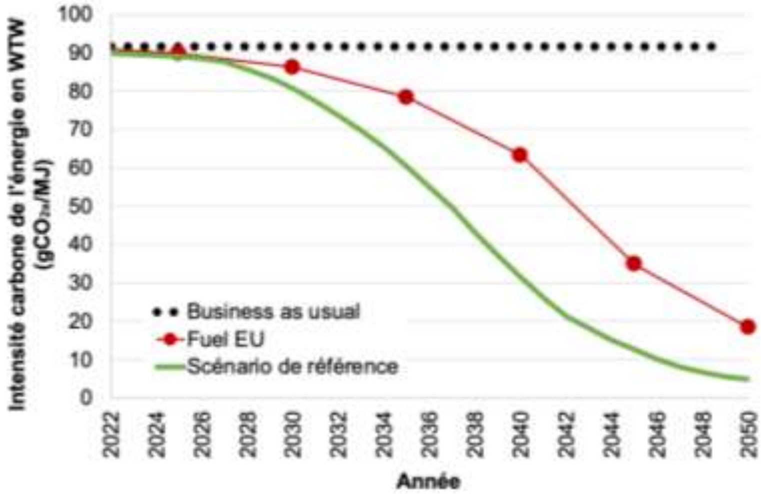


The decarbonisation trajectories for this benchmark scenario are illustrated in the following three graphs:

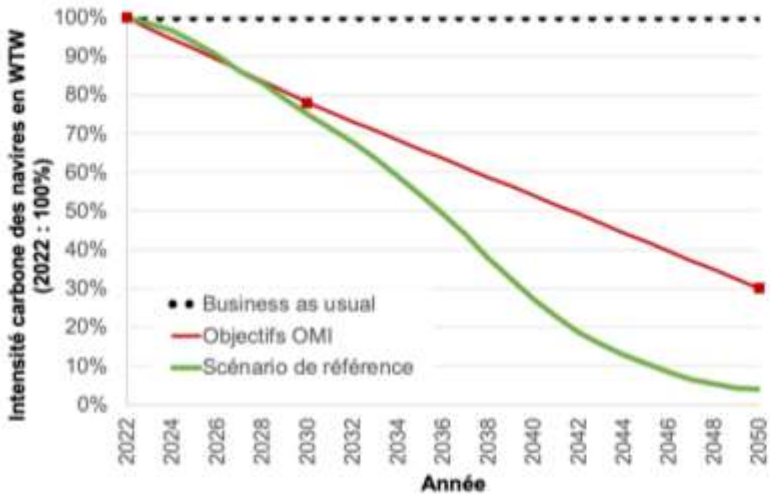
Absolute emissions of the fleet (benchmark 2022, base: t CO2eq WTW), compared to the current IMO goal (-50% - dashes on the graph);



The carbon intensity of the energy consumed by the fleet (benchmark 2022, base: gCO2eq WTW/MJ), compared to the levels established by FuelEU;



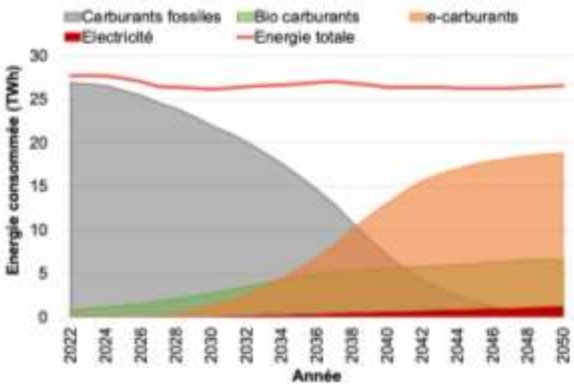
The carbon intensity of vessels in the fleet (benchmark 2022, base: gCO2eq WTW/t.km), compared to the IMO reduction targets.



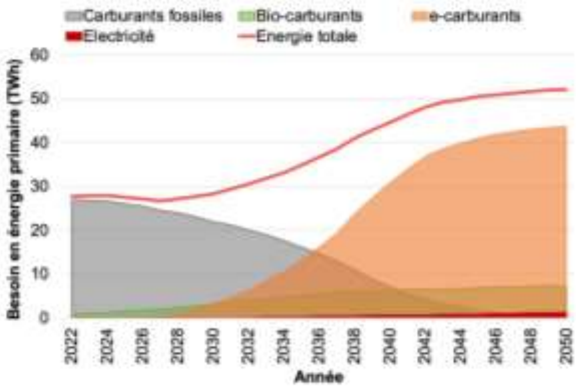
The following table presents the input energy requirements[29] in the benchmark scenario: they are 27.8 TWh in 2022, increasing to 52.2 TWh in 2050 (including 43.7 TWh to produce e-fuels).

	2023	2030	2040	2050	2023-2050
Energy consumed by the fleet (TWh)	27.7	26.2	26.4	26.6	774
Input energy (TWh)	27.8	28.3	44.6	52.2	1162
Fossil fuel	26.9	22.0	7.1	0.0	393
Bio-sourced energy[30]	0.9	3.1	6.2	7.2	136
Energy to produce e-fuels[31]	0.0	3.2	30.6	43.7	571
Electrical energy (shore/on-board)	0.0	0.1	0.6	1.2	13

The graphs below summarise, for this "revised" benchmark scenario, the energy requirements of the fleet (top) and the primary energy requirements to produce this energy (bottom).



(a) Energy consumed by the fleet



(b) Primary energy requirements

The model also allows for a cost estimate based on the extra cost of decarbonised vessels, retrofit plans, energy costs (bio and e-fuels) and estimates, albeit with a high degree of uncertainty, the extra cost linked to the ETS depending on expected market trends and various regulatory measures. It does not include the cost of distribution or port infrastructure.

The result of this scenario, compared to a Business As Usual scenario, is presented below, with a breakdown by origin and considering whether or not the addition of new vessels is planned to compensate for the speed reductions.

	Extra cost in relation to the Business As Usual scenario (billion euros)

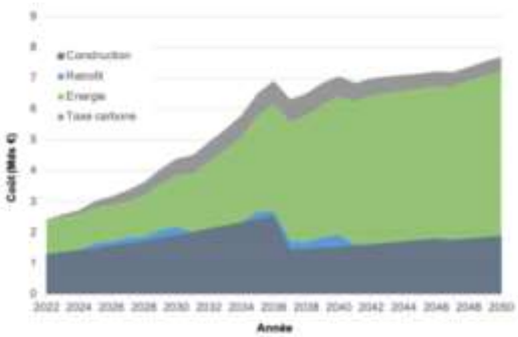
[29] This is the energy required to manufacture synthetic fuels or bio-fuels. It is considered that a factor of 1.5 to 2 in input energy is required to produce one unit of e-fuel, compared to the same unit of fossil fuel energy.

[30] The energy consumed on-board includes the biofuels blend, with 30% for bio-fuel and bio-diesel and 100% for bio-methane and bio-methanol, and an extra 10% that corresponds to the energy required to produce biofuels.

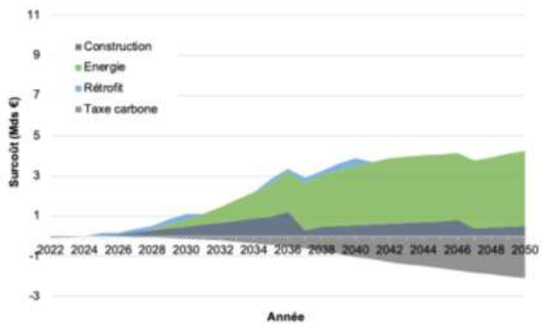
[31] Depending on the e-fuel production efficiency assumptions made in the model and the chosen mix.

	With additional ships to compensate for speed reductions		Without additional ships to compensate for speed reductions
	2023-2030	2023-2050	2023-2050
Total additional cost of this scenario	2	45	28
Shipbuilding	0.89	13.75	7.82
Retrofit plan	0.94	2.81	2.55
Energy source change	0.08	48.63	38.71
Carbon tax	-0.20	-20.00	-21.00
Ports and Infrastructure	Not quantified		Not quantified
R&D and Demonstration Programme	Costed separately		Costed separately

This scenario indicates that shipowners will face very high additional costs in the coming years, with increased costs for ships (and possibly require more ships to compensate for lower speeds) and energy. The carbon tax (ETS mechanism) is presented as a negative in the additional cost compared with the Business As Usual scenario, but will represent an additional cost for shipowners, of the order of one billion euros per year from around 2030, depending on the quotas and the value of CO2, which is still difficult to predict.



Total cost of the scenario



Extra cost in relation to the "Business As Usual" scenario

These estimates, which still need to be refined by further research, are comparable to the projections made in the context of international studies, which estimate the cost of the transition at 3,000 billion globally, i.e. 92 billion euros based on the proportion of French GDP. The model estimates an additional cost, excluding carbon tax, of between 77 and 110 billion Euros.

9.4. Conclusions

To meet the decarbonisation targets and reduce dependence on foreign bunkering, the proposed scenario ("revised" S3) highlights the following estimates:

- Annual biofuel requirement estimated at 4.7 TWh by 2030 and 5.2 TWh between 2040 and 2050;
- Annual e-fuels requirement estimated at 2.5 TWh by 2040 and 19.7 TWh by 2050;
- Total need for decarbonised upstream electricity to produce decarbonised fuels and allow direct shore-side and ships electrification of 6.4 TWh by 2030, 37.4 TWh by 2040 and 53.1 TWh by 2050, i.e. the equivalent of 0.3, 2.9 and 4.2 nuclear reactors or 2.2, 21.3 and 30.9 wind farms like the one in Saint-Nazaire respectively over these three years;
- The annual additional costs for the sector are around one billion euros from 2025, 1.5 billion by 2030, 3.8 billion euros by around 2040 and 4.7 billion euros by 2050. The total additional cost for 2023 to 2050 is estimated at between 30 and 45 billion euros.

It should be noted that these requirements are based on a highly optimistic application of technical levers on vessels:

- The implementation of technological and operational efficiency measures to reduce energy needs by 30% over the period 2023-2050, which is very optimistic, will only be achieved by the implementation of a coordinated and financed national maritime decarbonisation programme,
- The extremely fast development of wind propulsion has a significant impact on the reduction of emissions. According to these highly optimistic deployment hypotheses, wind propulsion could save between 25 and 30% of energy by 2050, which is the equivalent of two nuclear reactors or about fifteen wind farms like the one in Saint-Nazaire.

It should also be noted that the reduction in ship speed hypotheses are limited to values acceptable to ship operators (10 to 20%) so as not to impact too much on the national economy through a reduction in import/export volumes, but also to limit the increase in the number of ships in order to maintain the volumes transported.

10. Decarbonisation scenarios for each fleet category

10.1. Chosen methodology

Each fleet category strategy has been modelled according to the following principles:

- The following data was provided by the working groups representing each category:
  - The considered fleet (number of ships, initial age distribution, energy consumed);
  - The likely evolutions for this fleet - according to growth forecasts;
  - Future vessel performances, depending on their potential to integrate innovative technology

  This data collected provides the most realistic view possible of the emissions/consumption gains that the innovations allow for, as well as the expected availabilities and degree of adoption expected.

  The scope considered corresponds to the "flag" method set out in §4.2.
- The chosen methodology involves complying with the most stringent regulatory constraints on short-term measures, and to aim for "net-zero" by 2050. The proposed scenarios are therefore subject to compliance with three regulatory indexes, in the following order of priority:
  - The reduction of the carbon-intensity of the bunkered energy, in accordance with the Fuel-EU regulatory targets;
  - The reduction of the carbon-intensity of the fleet in question, in accordance with IMO targets;
  - The reduction of absolute emissions of the fleet in question, in accordance with IMO targets.

With this, an "average and realistic" energy mix is defined (in terms of integrating biofuels and synthetic fuels), to respect as closely as possible the Fuel-EU regulations by 2040, then for 2040-2050, working towards the IMO targets. This baseline energy mix can be marginally adapted to the specific features of each fleet category.

Of the three categories - container ships, large ferries and gas tankers - the modelling is set out for three scenarios defined as follows.

	Evolution of the fleet	Roll-out and performance of innovations
Scenario 1 "Realistic transition"	Historic growth in line with the forecasts for each category (market studies, trends, etc.).	Normal development of innovations and their roll-out, realistic technological and operational gains
Scenario 2 "Technology"	Historic growth in line with the forecasts for each category (market studies, trends, etc.).	Increased gains and speed of deployment of efficiency solutions: gains doubled, early roll-out and higher percentage of fleet concerned.

Scenario 3 "Sobriety"	Decrease in maritime traffic (modal shift to road and air transport or overall reduction in transport demand). Speed reduction (and reduction in the quantity of transport).	Normal development of innovations and their roll-out, realistic technological and operational gains but on smaller percentages of fleets.

These scenarios, set out in Appendix 6, are modelled for each of the fleet categories. It should be noted that:

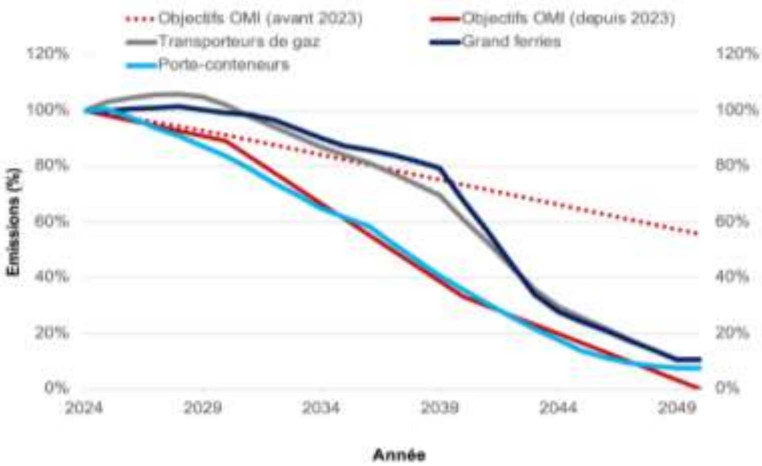
- The Fuel-EU regulations are encouraging an energy mix with an increasingly higher concentration of biofuels from 2030, and of synthetic fuels from 2040. Additional hypotheses have been drawn up for specific categories:
    - For gas tankers, using the energy transported for propulsion;
    - For large ferries, more widespread use of electric batteries (both for new vessels and retrofits, more expansive in this fleet category than others).
    - For container ships, it was decided to go beyond the Fuel-EU targets, with more and safer bunkering of e-fuels (subject to available supply), in accordance with the conversions planned for this category.
- There are specific rates of adoption and performance (gains in emissions and consumption) for each fleet category to consider for the roll-out of technological innovations that accompany these changes of energy source.
-

10.2. Summary of results

A detailed account of the results is provided in Appendix 6.

Regarding regulatory indexes, the modelling outcomes highlight similar trends for the three categories studied.

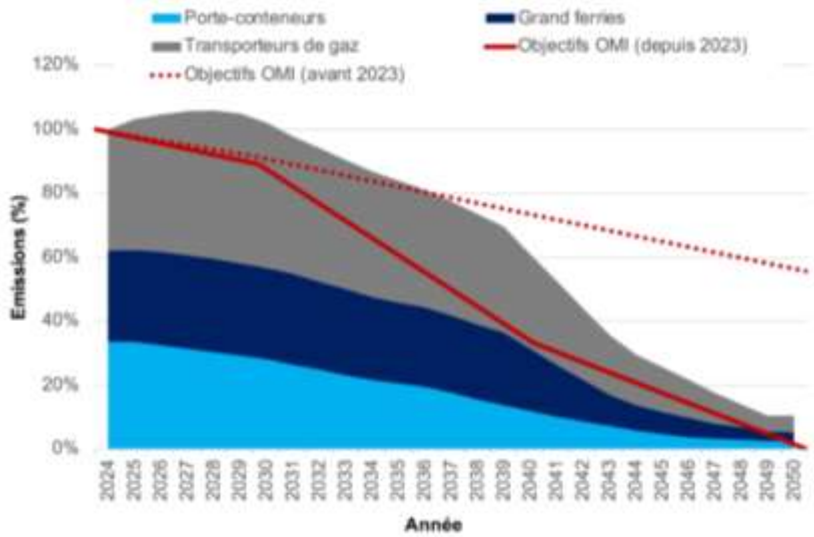
- **The emissions from each fleet, recorded separately, are all moving towards net zero by 2050** (with an asymptote at 10% due to the operating inertia of the least eco-efficient vessels and the non-zero WTT emissions associated with synthetic fuel production), as shown in the graph below.



On the graph, the emissions are compared to the first year of modelling (2024, 100% baseline). IMO regulations, particularly the milestones for 2030 and 2040, define a reduction target compared to the year 2008. The trajectories presented therefore take into account the reductions already seen between 2008 and 2024, of between 10% and 15%.

More significant bunkering of synthetic fuels from 2040 will accompany a trend towards the IMO targets (from 2023). Before 2040, the downwards trend in emissions is in line with the IMO targets prior to MEPC 80 in July 2023 (except for gas tankers, due to the significant growth expected for this category between 2025 and 2030). The pace of reaching net zero by 2050 is more sustained for the "Sobriety" scenario, then for the "Technology" scenario, which achieves greater decarbonisation performance.

The same trends are observed for cumulative fleet emissions, as shown in the graph below for the "Realistic transition' scenario. It is important to note that the **simulated trajectories do not take into account the effects of the ETS and the way in which this mechanism may influence vessel operating choices or the integration of innovations allowing shipowners to reach key targets** (such as the 2030 and 2040 IMO regulatory milestones).

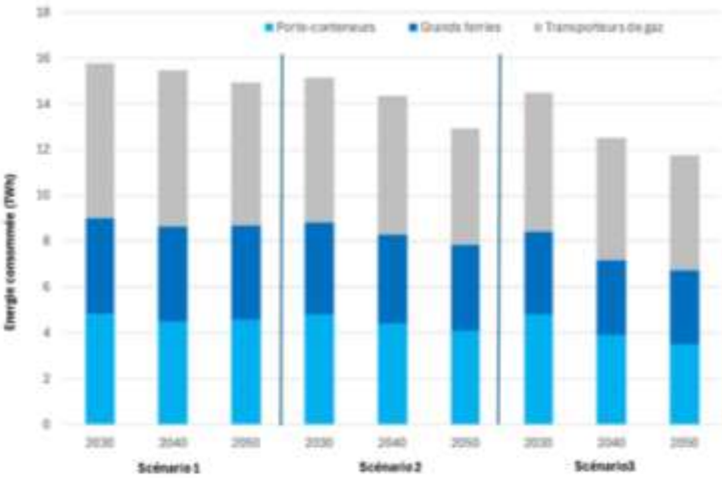


The combined efforts in developing and rolling out innovations ("Technology" scenario trends) and, possibly, in terms of sobriety ("Sobriety" scenario trends) will no doubt help to reach the regulatory targets.

- By developing scenarios, **the carbon intensity of energy sources** respects the Fuel-EU regulations, which are less ambitious than the emissions reduction targets set by the IMO, as illustrated by the example of the container ships category, for which large-scale conversions are planned for vessels that can bunker more synthetic fuels.
- **In the three scenarios, the carbon intensity of all fleets is in line with the trends imposed by IMO regulations.** There are some notable differences between the three categories (the carbon intensity of the large ferries fleet is slightly below target, while that of the gas tankers and container ships fleets is closer to target). This can be explained by differences in the initial age distribution of the fleets, which operate for different lengths of time, and are more or less "rapidly" integrating innovations that help become more energy efficient (it should be noted, however, that in the case of

large ferries, the longer operational life of the vessels compared with the others offsets the carbon emissions linked to shipbuilding).

- **The energy consumed by the fleets evolves over time, for the three categories considered, towards an overall reduction by 2050** versus the 2024 level. The energy consumed is obviously less for the "Sobriety" scenario, followed by the "Technology" scenario, versus the "Realistic transition" scenario. However, differences were recorded between categories
  - For container ships, the energy consumed by the fleet remains relatively constant, with a "Realistic transition' scenario of 4.8 TWh by 2030 to 4.6 TWh by 2050 (and 4.5 TWh by 2040). This can be explained by the efficiency measures (energy, innovation, speed reduction) which can limit an upward trend in requirements due to the growth of the fleet;
  - For gas tankers, the energy consumed by the fleet begins with an increase due to the significant growth expected for this category in 2030. For the "Realistic transition" scenario, the energy increases from 5.5 TWh by 2025 to 6.6 TWh in 2030, then remains stable between 2030 and 2040, to go down to 6.2 TWh by 2050;
  - For large ferries, the energy consumed by the fleet remains relatively stable up until 2050, around 4.2 TWh in the "Realistic transition" scenario. As the vessels in this category are in operation for a longer period of time, the fleet does not experience a improvement in efficiency (as is the case for container ships), and the reduction in energy consumed is less significant.



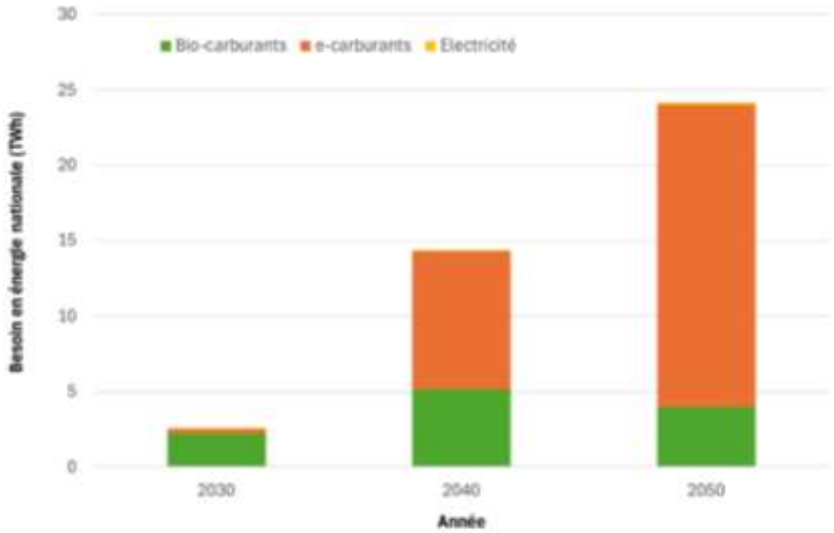
- **The "national energy requirement"** (i.e. the decarbonised energy needed to produce alternatives to fossil fuels in France) **increases for all three categories between 2030 and 2050** (this increase is lower in the "Sobriety" scenario, followed by the "Technology" scenario, compared to the "Realistic transition" scenario). The increase is relatively moderate between 2030 and 2040 and it becomes more significant between 2040 and 2050, due to the widespread use of synthetic fuels. More specifically, the trends observed in the "Realistic transition" scenario are as follows:
  - For container ships, the requirements increase from 4.8 TWh in 2030, to 5.2 TWh in 2040 to reach 7.4 TWh by 2050;

- For gas tankers, the requirements increase from 6.2 TWh in 2030, to 9.2 TWh in 2040 to reach 11.9 TWh by 2050;
- For large ferries, the requirements increase from 4.2 TWh in 2030, to 5.0 TWh in 2040 to reach 6.1 TWh by 2050.

In total, the cumulative energy requirements for the three categories is:

- In the "Realistic transition" scenario: 15.9 TWh by 2030, 19.1 TWh by 2040 and 25.1 TWh by 2050;
- In the "Technological" scenario: 15.2 TWh by 2030, 17.4 TWh by 2040 and 22.0 TWh by 2050;
- In the "Sobriety" scenario: 14.6 TWh by 2030, 15.2 TWh by 2040 and 20.1 TWh by 2050.

The evolution of cumulative "national energy" requirements for the three categories studied (we have provided the average for the three chosen scenarios) for 2030, 2040 and 2050 is provided below.



For theoretical comparison, production is as follows:

- A nuclear unit is around 10 TWh (using the last PWR plant built in France as an example);
- A wind farm is between 1 and 2 TWh (using the Saint-Nazaire site as an example).

Therefore, as an example, e-fuels production for the three fleet categories for 2050 would require two nuclear units.

10.3. Conclusion

Hypotheses and modelling outcomes for decarbonisation trajectories for three fleet categories (container ships, gas tankers and large ferries) were presented for three different scenarios (reflecting different transition rates and energy resource requirements).

The approach adopted for the study involved:

- Collecting the data required for the modelling from the working groups for each category. This data concerned the fleet itself (number of vessels, age, consumption) and the technical and operational gains expected for each category (reductions in emissions and consumption);
- Deciding on an energy mix in line with the Fuel-EU regulations;
- Assessment the evolution of other indexes (overall emissions and overall carbon intensity);
- Identifying the energy requirement.

The main conclusions of the study were focused on the following points.

- Evolution of emissions
  - **The carbon intensity of the fleets** considered from an overall standpoint is in line with the trends imposed by IMO regulations;
  - **The emissions from each fleet**, recorded separately, are all **moving towards the IMO target of net zero by 2050**, but individually they are not in line with the reduction targets for 2030 and 2040. The simulated trajectories do not take into account the effects of the ETS and the way in which the mechanism may influence vessel operating choices or the integration of innovations, and as such, the trends may be considered "pessimistic". In taking these effects into account, trajectories in line with the 2030 and 2040 milestones are likely to be observed.
- Evolution of energy consumption
  - **For the three categories considered, the energy consumed by the fleet is evolving towards an overall reduction by 2050** versus the 2024 level, and depending on the scenarios it is showing a level of 14-15 TWh for 2030, 12-15 TWh for 2040 and 11-13 TWh for 2050.
  - **The national energy requirement** (i.e. The decarbonised energy required to produce alternatives to fossil fuels in France) is showing **an upward trend for the three categories between 2030 and 2050.** In total, the cumulative energy requirement for the three categories, depending on the scenario, is between 14-15 TWh for 2030, 15-19 TWh for 2040 and 20-25 TWh for 2050.

10.4. Outlook

The chosen scope here is French-flagged vessels, and the decarbonisation goal for these vessels highlights the significant national energy requirements. French-flagged vessels do not cover all the transport services required by the country's economy, and so to consider the decarbonisation goal for the whole economy, a wider scope must be considered, and so the energy requirements are much more significant.

To add to the present study and draw up a consolidated estimate of the energy required for the national maritime sector, it appears necessary to:

- **Come up with transition scenarios for other fleet categories**, built on the same hypotheses, to ascertain the total energy requirement for French-flagged vessels;

- **Ensure the reliability of the data on the evolution of the requirement in maritime transport**, alongside the various analyses carried out by government departments and by academic and economic experts, for a realistic representation of the country's energy supply requirements.
- **Engage in a comprehensive study on the definition of a national maritime scope**, to provide a more accurate representation of the impact of a country's maritime sector - this study, to be carried out initially at national level, could be based on assessments carried out by maritime nations (United Kingdom, Singapore) and then continued in an international context, via an international working group;
- **Produce updated trajectories that take into account the effects of the ETS**, based on feedback from shipowners and data to be integrated into current modelling;
- **Work on prioritising maritime energy with regard to energy availability**, in the event that demand is not met, in order to quantify the impact of allocation choices and suggest making decisions by fleet category.

11. Proposed action plan to decarbonise the maritime sector

This chapter sets out a revised action plan compared to the 2023 version of the roadmap that has been simplified and takes into account changes in governance, in sector strategies and a handful of decisions and guidelines issued by the French government.

It is still developed with the following four objectives in mind:

1. **To meet the regulatory targets** defined by the IMO, EU and nationally;
2. **To minimise the energy consumption of the maritime sector** in order to contribute to national efforts to reduce energy consumption and to encourage the use of maritime and river transport in order to reduce transport's overall energy requirements;
3. **Ensure the economic development of national maritime stakeholders** and use the opportunity of technological and energy changes to relocate industries and jobs to France;
4. **Enhance France's sovereignty of supply** in a context of major changes to come for transport and logistics stakeholders (regulations, taxation, speed reduction, investments).

This action plan is underpinned by the expertise of French stakeholders who have the skills and resources to implement it, subject to support from the State, with the collective ambition of making France a leading nation in the area of maritime decarbonisation.

The revised action plan is now broken down into five strands.

- Strand 1: ENERGY EFFICIENCY (optimal design, technologies and operational excellence)
- Strand 2: ENERGIES AND INFRASTRUCTURE (Production, storage, transport and distribution of energy sources and low-carbon energy carriers, etc.)
- Strand 3: SOBRIETY (Sobriety in use and design, decarbonising the production phase and circular economy)
- Strand 4: Complete, enhance and stabilise the regulatory framework for greenhouse gas emissions from ships
- Strand 5: Operational IMPLEMENTATION and MONITORING

11.1. Strand 1: ENERGY EFFICIENCY (optimal design, technologies and operational excellence)

Optimal design & technologies

The goal of this component is to deploy technological solutions on-board new or existing vessels that are adapted to the operational characteristics of the vessel, and based in particular on the work done by the working groups for each fleet category.

Action 1.1	**Enable rapid and accurate evaluation of decarbonisation solutions identified for each fleet category on technological platforms, and bench tests on land or at sea, and promote the development of standards for key technologies**

	Set up technological and test platforms (test benches and software) to support the development of technological building blocks identified particularly by the fleet category working groups, and associated standards[32] Cost: €150 million for 3 to 5 platforms Leaders: MEET2050, national research centres, industry
Action 1.2	**Set up developmental projects to promote the growth of industrial sectors in the main technological and operational decarbonisation levers by aiming to pool the fleet categories.** Encourage the establishment of domestic equipment manufacturers and service providers for the main decarbonisation levers for which France has companies in a position to take a significant market share, by supporting the development of solutions, their industrialisation (factories) and support for their commercial deployment (first orders, initial additional costs, etc.) Examples of industrial technologies: wind propulsion systems[33] (sails, kites, rotors, etc.), electric hybridisation (marine batteries and high-power fuel cells, hybrid architectures)[34], storage tanks for new fuels, management of liquid hydrogen on board ships, innovative propulsion systems, heat/cold recovery systems, decision support software (energy management, routing). Cost: €150 to 300 million per development project, 5 projects, i.e. €1 billion over 5 years Leaders: CSF, GICAN, Wind Ship, the State (DGAMPA, DGE)
Action 1.3	**Encourage the creation of prototype vessels moving towards zero emissions, based on feedback from decarbonisation working groups for each fleet category** Set up a dozen or so full-scale concept ships per fleet category, capable of operating in real conditions, using the technological building blocks developed. These vessels will adopt a global eco-design approach (complete life cycle assessment, design and technology optimisation for its use, etc.). Local economic impacts, in particular in the manufacturing of innovative materials, will also be considered. Cost: €2 billion over 5 years, of which €600 million associated with innovations Leaders: DGAMPA, DGE in partnership with CORIMER, shipowners, shipyards, design offices, equipment manufacturers, ports, the State

Operational excellence:

This strand seeks to improve the operational efficiency of ships by implementing real-time performance monitoring tools, evaluating potential improvements linked to the interfaces

[32] The necessary platforms are associated with electric ship hybridisation, wind propulsion, hydro and aerodynamic performance, performance data, testing facilities, etc.

[33] An early development project is being set up by the MEET2050 project teams, the Wind Ship association and the IRT Jules Vernes, for a budget of around €200 million over 5 years.

[34] The Helena project led by the CEA is currently being set up, with a budget of around €150 million over 5 years

between port terminals and ships, studying the relevance of reducing the speed of certain ships and developing large-scale modal transfer.

Action 1.4	**Basic and continuing training of seafaring staff** Set up basic and continuing training courses to help seafaring staff improve their skills by training them in the use of decarbonisation technologies and eco-piloting. <u>Cost</u>: not quantified at this stage <u>Leaders</u>: DGAMPA, CINav, maritime engineering schools, ENSM, maritime college
Action 1.5	**Improve the instrumentation for vessels and the collection and analysis of performance-related data** Support ship owners with the installation of performance and consumption monitoring tools for their vessels, including the installation of measurement systems, analysis tools and decision-making aids, as a follow-up to the AMMARREE programme for fishing vessels. <u>Cost</u>: €30M over 5 years (€30K per ship, for a fleet of 1,000 of the highest emitting ships in the various fleet categories) + €10M for the development and deployment of analysis tools. <u>Leaders</u>: Shipowners, software companies, equipment manufacturers, shipyards
Action 1.6	**Study the potential for optimising ship / port interfaces** Assess the possible solutions and gains linked to the optimisation of interfaces between ships and ports / terminals at national level (optimisation of loading / unloading, shore-side connection, "just-in-time" arrival solutions, etc.) in line with the “improvement of port passage performance” of the 2021 National Port Strategy (SNP) and identify the initiatives and solutions implemented or being deployed internationally (e.g. international association for ICT4.0 standardisation) <u>Cost</u>: €300k over 2 years <u>Leaders</u>: State (DGITM, DGAMPA) MEET2050, ports, terminal managers, shipowners
Action 1.7	**Encourage modal shift to reduce the overall energy footprint of transport and logistics** Encourage modal shift to reduce the overall energy footprint of transport and logistics through the energy efficiency of maritime and river transport in relation to other transport modes, in line with other national strategies (SNP, SNDFF, SNF) Cost: not quantified <u>Leaders</u>: State (DGITM), ADEME, local authorities, shippers, logisticians, ports, multimodal platform operators, high-volume land transport operators, rail and waterway infrastructure managers

11.2. Strand 2: ENERGIES AND INFRASTRUCTURE (Production, storage, transport and distribution of energy sources and low-carbon energy carriers, etc.)

The availability of low-carbon energy will be one of the cornerstones of the energy transition in maritime transport, which is currently completely dependent on fossil fuels. As mentioned earlier, decarbonised fuels will be significantly more expensive and have greater usage constraints than their fossil fuel equivalents.

The energy transition is a real opportunity to relocate energy production to our territory, to improve the attractiveness of our ports through a unique supply of low-carbon and renewable energy, to secure our bunkering facilities, and to make energy providers, manufacturers and French ports the true champions of tomorrow's energy carriers and energy. The goal is to develop new economic and industrial activities, guaranteeing the country's maritime sovereignty, creating value and jobs in the region, enabling French ports to contribute to the decarbonisation of the sector and reducing the sector's energy dependence.

This aspiration, which is shared by maritime stakeholders, requires heavy investment in production, storage, transport, distribution and refuelling infrastructure. It requires real planning in terms of the availability of low-carbon fuels (in time and on a given region) with regard to the needs of the maritime sector, to ensure the rapid implementation of the first demonstration vessels before being able to fully deploy the solutions, through major investments by the energy companies, in which the State must also participate, and which will require commitments from shipowners.

Ports are multimodal, energy and industrial nodes located at the interface between land and sea and host shipping-related operations. They often accommodate an industrial and logistical network. Securing port land, supporting the decarbonisation of port ecosystems and investments in port infrastructure and the equipment required for the decarbonisation of the national economy must be factored into the discussions, in addition to the topics relating to the supply of decarbonised energy to ships.

Action 2.1	**Decide on the energy source for the maritime sector and the roll-out of a sustainable maritime fuel production sector in France** Aim for a certain level of maritime energy sovereignty Leaders: The State
Action 2.2	**Start a planning process and then implement the deployment of the energy distribution infrastructure required for maritime needs** Implement a national planning process, broken down by maritime division, for the requirements and availability of decarbonised marine fuels (produced in France or imported). Ensure the deployment of the associated energy infrastructure -construction of jetties in the major maritime ports-, development of storage and bunkering infrastructure (supply ships, truck to ship solutions, etc.) in the ports, including the smaller ports Cost: to be estimated, for example €200M for the construction of a multi-purpose jetty (multi-energy) Leaders: The State, local authorities, ports

Action 2.3	**Produce liquid and gaseous biofuels in accordance with development project §2.1 of the Strategic Committee for the Sector (CSF) of maritime industries, work in the aviation field and the decisions from action 2.1** Support the deployment of industrial projects for sustainable liquid and gaseous biofuels, in sufficient quantities to meet the statutory targets. Cost: as an indication, a liquid biofuel plant can cost up to €1.5 billion for a production of 200,000 tons per year Leaders: Energy companies, the State, shipowners and ports
Action 2.4	**Develop and test liquid biofuels for the maritime sector - in accordance with development project §2.1 of the Strategic Committee for the Sector (CSF) of maritime industries** Support a research and development programme for the testing and deployment of new generation liquid biofuels for maritime use (e.g. requirements for use with marine 2-stroke engines) and develop French production facilities. Cost: €15 million for the R&D / prototypes component, €40 million for the demonstration vessel component, €10 million for carrying out on-board tests, without factoring in the deployment through the setting up of production units included in actions 3.1 and 3.2. Leaders: CSF, Energy providers, Shipowners
Action 2.5	**Develop the marine e-fuels production sector - in accordance with development project §2.1 of the Strategic Committee for the Sector (CSF) of maritime industries, work in the aviation field and the decisions from action 2.1.** Support commercial projects for the construction of the first sustainable marine e-fuel production units. In addition to land-based facilities, this also involves the development of a hydrogen production industry based on marine renewable energies, particularly offshore wind power, to accelerate the production of e-fuels in the medium term and the decarbonisation of port industries. Cost: as an indication, an e-methanol or e-methane plant can cost up to €2 billion for a production of 1TWh/year. Leaders: CSF, Energy providers, Shipowners
Action 2.6	**Improve infrastructure for importing new energies** Build a French import and export sector for e-fuels and their inputs (specifically import-export hubs). Include this consideration in the French legislation in preparation (LPEC, PPE, SNBC, etc.). Regulatory implications: Modify the *RePowerEU* plan to allow the import of e-fuels Leaders: The State (DGEC), industry, ports
Action 2.7	**Develop the CO2 sector for maritime use and in partnership with ports, and develop CCS technologies in accordance with the development project of the Strategic Committee for the Sector (CSF) of maritime industries**

Develop, like northern European countries, a French CO2 economy and industry, from capture on ships or in port industries to the transfer of CO2 to the quayside, then its use to produce e-fuels.

Regulatory implications: Allow the capture of fatal and non-compressible CO2 for the production of e-fuels beyond 2041

Leaders: Energy providers, Ports

Action 2.8 **Enable the electrification of quays and electric charging of ships**

Accelerate the deployment of port infrastructure for connecting ships to shore power and sustainable fuels. The power requirements involve major electrical modifications.

Cost: €5 million per connection point. Study of the potential for multi-mode charging (electricity + fluid) in ports: €200k. to be defined for sustainable fuels

Leaders: Ports, Local authorities, the State (DGITM, DGAMPA), Industry (GICAN)

11.3. Strand 3: SOBRIETY (Sobriety in use and design, decarbonising the production phase and circular economy)

French shipyards and ship equipment manufacturers contribute first and foremost to decarbonisation by innovating to reduce emissions during the operations phase and by working on the ships of tomorrow. The production and end-of-life phase of ships should also be considered, as should the ability to anchor shipbuilding operations in the region in the long term. For all the regulatory areas, care should be taken to ensure that this does not impose a constraint on French shipyards alone.

Action 3.1 **Eco-design**

Generalise the use of eco-design methods for any new vessels and develop common methodology and set of guidelines for the life cycle assessment (LCA) of vessels - in accordance with the development project §1.3 of the Strategic Committee for the Sector (CSF) of maritime industries

Define an LCA methodology and integrate the main inventory data (energy, materials, etc.) specific to the naval, river and nautical sectors (engine emission profiles, composite materials, welding processes, etc.).

Cost: €1 million over 5 years

Leaders: CSF, GICAN, IFAN, ADEME, DGAMPA

Action 3.2 **Materials and processes for the green shipbuilding industry - in accordance with the development project §1.3 of the Strategic Committee for the Sector (CSF) of maritime industries**

Support innovation and experimentation with new materials and industrial processes by French stakeholders to reduce the carbon footprint and improve circularity at the end of a vessel's life, with a view to recycling 100% of a dismantled vessel.

Leaders: CSF, GICAN, IFAN, ADEME

Action 3.3	**Access to low-carbon inputs by ensuring competitiveness** Ensure access to low-carbon raw materials by guaranteeing the competitiveness of French industry and fair international competition conditions. As a first step, impact studies on the CBAM (Carbon Border Adjustment Mechanism) would appear to be necessary to document the impacts on competitiveness and the risks of relocation. Leaders: The State Regulatory implications: Ensure the consistency of European legislation (e.g. carbon adjustment mechanism at borders) to guarantee the competitiveness of the French naval industry and combat distortions in the internal market while decarbonising the production of raw materials.
Action 3.4	**Develop dismantling operations in the region** Consolidate the boat and ship dismantling sector to guarantee its growth and improve the recycling rate. Increase the share of the TAEMP allocated to the APER eco-organisation to 5%, increase the use of French dismantling capacity Cost: not quantified at this stage Leaders: The State, shipbuilding dismantling yards

11.4. Strand 4: REGULATION (Complete, enhance and stabilise the regulatory framework for greenhouse gas emissions from ships)

To ensure that all the ships involved contribute to meeting the decarbonisation targets and that French ports are competitive in the decarbonisation value chain in comparison with their European competitors, it is necessary, in conjunction with the market based measures mentioned above, to continue to build, consolidate and stabilise the long-term regulatory framework relating to GHG emissions from ships at sea and at berth, at global, European and national levels.

Action 4.1	**Take a leadership role in international regulatory bodies** Continue to play a leading role within the European and IMO bodies for the implementation and consolidation of the most ambitious regulatory framework possible while ensuring fair international competition. Leaders: The State (DGAMPA, DGEC)
Action 4.2	**Optimise the implementation of the international and European regulatory framework at a national level** Study the potential and feasibility of the broadest possible application of international regulatory instruments such as the IMO's energy efficiency measures or the dockside connection obligations that will be provided for by the European regulations at the national level, while ensuring fair international competition.

	Leader: The State (DGAMPA, DGEC) in consultation with the stakeholders concerned (professional federations, ports, etc.)
Action 4.3	**Explore national regulatory measures for fleet categories not covered by international regulation** Investigate, if necessary using special funding, the potential and feasibility of national regulations (normative and/or incentive type) for the GHG emissions of fleet segments not covered by international and European regulations. Leader: The State (DGAMPA, DGEC) in consultation with the stakeholders concerned.
Action 4.4	**Ensure consistency between regulation, decarbonisation ambitions and decarbonised energy production requirements** Contribute to the establishment of a clear and incentive-based regulatory framework for the rapid deployment of low-carbon and renewable energy carriers. Take into account in public policy documents, in particular the Energy-Climate Programming Law (LPEC), the Multiannual Energy Plan (PPE), the National Low Carbon Strategy (SNBC), the potential for e-fuel production to develop this industry of the future. Leaders: The State (DGAMPA, DGEC, SGPE) – AdF and MEET2050
Action 4.5	**Study the implementation of a mandatory reporting system for bunked fuels in ports** This mechanism would improve the traceability of the fuels (type and quantities) bunkered in ports, to identify the quantities bunkered in France using a direct method. Leaders: The State (DGEC, DGAMPA, DGITM)

11.5. Strand 5: Operational IMPLEMENTATION and MONITORING

This strand relates to the operational implementation and monitoring of the roadmap. It aims to encourage full collaboration between the stakeholders in the sector through a common knowledge base based on reliable data and decision-making tools to guide coordinated public policies and industrial strategies. Operational implementation requires transforming the decarbonisation targets outlined in the scenarios into practical projects to meet them (research, development, demonstration vessels, deployment).

Action 5.1	**Development of reliable information and data on the maritime transition for the benefit of public and private stakeholders in the sector** Undertake technical and economic evaluations and independent analyses to ensure the reliability of information and data related to the maritime transition: gains, yields, costs, availability, emissions, etc. Engage in a comprehensive study with CITEPA on the definition of a national maritime scope. Continue implementation of the roadmap by fleet category. Cost: at least €3.5 million over 5 years Leaders: DGAMPA, CMF, ADF, GICAN, CITEPA, DGITM, DGEC, MEET2050

Action 5.2	**Use of public procurement to support innovations and initial orders for decarbonisation solutions - development project §1.1 of the Strategic Committee for the Sector (CSF)** With the aim of initiating and supporting: – Systematically include the eco-design approach following the most advanced standards for the design of ships for the State or local authorities. – Include the integration of decarbonisation equipment in public calls for tender for the purchase of ships, with a minimum amount of 20% of the value of the ship. Cost: €200 million over 5 years (20% extra cost on over €200 million of investments per year) Leaders: SGMer
Action 5.3	**Development of decision support tools to support public policies and industrial strategies** Develop the necessary decision support tools to guide public policies and industrial investment strategies (e.g. CAP2050). Cost: €2 million over 5 years Leaders: MEET2050, national research centres, CITEPA, DGAMPA, DGITM
Action 5.4	**Training and increasing the awareness among decision-makers in the maritime world of the challenges of transition** Set up a training and awareness-raising campaign for private and public decision-makers in the maritime sector regarding energy transition issues throughout the region: boards of directors of professional federations and competitiveness clusters, company directors, department managers, etc. Cost: €300k over 2 years Leaders: The State
Action 5.5	**Encourage academic players and research centres to carry out and distribute research on the decarbonisation of the maritime sector** Combine all the academic and research centres that can provide expertise into a joint programme to remove the barriers and obstacles identified by industrial stakeholders, launch developments on breakthrough technologies and meet the needs of industry to accelerate the development of their products and services. Cost: €50 to 100 million over 5 years (programme to be drafted and accurately costed) Leaders: MEET2050, national laboratories and research centres
Action 5.6	**Support plan for retrofitting and renovation of operational ships** Implement a plan to support shipowners in retrofitting or renovating their vessels in priority fleet categories with regard to national emissions, while ensuring that the French market is fully engaged. Specifically, a study of the capacity of shipyards and equipment manufacturers to respond to this renovation plan should be carried out in advance. Support for the

	modernisation of industrial equipment could then be considered as a sub-action. This plan might include specific action such as support for the electrification of vessels as part of the shore-side connection plan, and draw on existing French and European schemes, as well as the ETS credits allocated to the decarbonisation of the maritime sector. Cost: preliminary study necessary for costing per fleet category Leaders: The State, MEET2050, shipowners, consultancy firms, shipyards

Action 5.7	**Tailor maritime financing methods to the challenges of decarbonisation** Carry out a detailed audit of the financing requirements of stakeholders in the context of the energy transition (type, amount) and of public (at national and European level) and private resources that can currently be made available at the various levels of development (from research to support for first orders). This audit will suggest potential areas for improvement and optimisation (clarity, speed and access to finance, leverage), following on from the report on Blue Finance[35]and may make recommendations on finding the best possible match between the sums that can be raised, whatever their origin, and the support needs of stakeholders to invest in decarbonisation. Develop a comprehensive financing strategy for decarbonisation, based on French and European public financing levers and private financing. Cost: €75 to €200k depending on the level of detail required Leaders: The State
Action 5.8	**Seek a balance between the revenues generated by the new regulations and the support to stakeholders for investing in decarbonisation** Seek to optimise the use of revenues generated by the new European regulations (FuelEU penalties, ETS revenues, etc.) so that they support the development of decarbonisation solutions. Leader: The State
Action 5.9	**Establish and boost the role of the Meet2050 institute in decarbonising the maritime sector.** Growth of the institute created early 2024 and which provides support for the State (SGAMPA, local authorities), the French shipowners' association and certain industry players and energy providers. Leaders: The State, Shipowners, Energy providers, Ports, etc.

[35] https://www.mer.gouv.fr/finance-bleue-decouvrez-le-rapport

Appendix 1 - List of acronyms and abbreviations

Acronym or abbreviation	Meaning
SFAES	Support for fishermen to achieve energy savings
ADEME	Agency for Ecological Transition
AFIR	Alternative Fuels Infrastructure Regulation
LCA	Life cycle assessment
ADF	French shipowners' association
APER	French Association for Eco-responsible Yachting
BAU	Business As Usual
CAPEX	Capital expenditure
CCUS	Carbon capture use and storage
CII	Carbon Intensity Index
CITEPA	Technical Reference Center for Air Pollution and Climate Change
CEE	Energy Saving Certificate
CMF	French Maritime Cluster
CO2e	CO2 equivalent
CSF	Strategic Committee for the Sector (of Maritime Industries or New Energy Systems)
CITEPA	Centre for interdisciplinary studies on atmospheric pollution
UNCTAD	United Nations Conference on Trade and Development
CORIMER	Research and Innovation Steering Committee for the Maritime Industries
CORIMER	Research and Innovation Steering Committee for the Maritime Industries
CGEDD	General Council for the Environment and Sustainable Development
UNFCCC	United Nations Framework Convention on Climate Change
UNFCCC	United Nations Framework Convention on Climate Change
DCS	Data Collection System
CO2	Carbon Dioxide
DGAMPA	Directorate general for Maritime affairs, Fisheries and Aquaculture
DGE	Directorate General for Enterprise
DGITM	Directorate-General for Infrastructure, Transport and the Sea
ECA	Emission Control Area
ECA	Emission Control Area

Acronym or abbreviation	Meaning
ETS	Emissions trading scheme
MRE	Marine Renewable Energy
EEDI	Energy Efficiency Design Index
EEXI	Energy Efficiency eXisting ship Index
ESD	Energy saving device
ETS	European Trade System
GHG	Greenhouse Gas
LPG	Liquefied Petroleum Gas
LPG	Liquefied Petroleum Gas
CNG	Compressed Natural Gas
CNG	Compressed Natural Gas
LNG	Liquefied Natural Gas
LNG	Liquefied Natural Gas
gCO2e/MJ	Grams of CO2 equivalent per megajoule
gCO2/t.km	Grams of CO2 per tonne per kilometre
IPCC	Intergovernmental Panel on Climate Change
GICAN	French Maritime Industry Group
LOM	Mobility Orientation Law
LTECV	Law for Energy Transition and Green Growth
MEET2050	Maritime Energy and Environmental Transition towards 2050
MWh	Megawatt hour
MRV	Monitoring – Reporting - Verifying
MRV	Monitoring, reporting and verification
OPEX	Operational expenditure
IMO	International Maritime Organisation
IMO	International Maritime Organisation
NOx	Nitrogen oxides
SOx	Sulphur oxides
SME	Small and medium-sized enterprises
FC	Fuel Cell
FC	Fuel cell (MEC: membrane exchange cell, SOFC: solid oxide fuel cell)
MEP	Multiannual Energy Plans

Acronym or abbreviation	Meaning
RED	Renewable Energy Directive
ROI	Return on investment
SGPI	General Secretariat for Investment
SECTEN	Economic sectors and energies
SEEMP	Ship Energy Efficiency Management Plan
SFEC	French Strategy for Energy and Climate
SNBC	National Low-Carbon Strategy
SNBC	National Low-Carbon Strategy
SAILS	Sustainable Actions for Innovative and Low-impact Shipping
SEQE	Emissions Trading Scheme
TtW	Tank-to-Wake
TAEMP	Annual Tax on Marine Recreational Equipment
TWh	Terra Watt Hour
T2EM	Maritime Eco-Energy Transition
VSE	Very Small Enterprise
EU	European Union
WtW	Well-to-Wake

Appendix 2 The Short and Medium Term IMO Measures

Short-term measures

The short-term measures adopted by the IMO in June 2021 have two components:

- The **Energy Efficiency Existing ship Index (EEXI)**, a technical component, is a nominal energy efficiency index based on the same model as the Energy Efficiency Design Index (EEDI) but applied to all existing ships of 400 tonnes or more (UMS) and no longer just to new ships. The reduction factors required on 31 December 2023 in relation to the benchmark value (reflecting the average nominal energy efficiency for each category of ship for the 2000-2009 period) are in different steps ranging from 0 to 50%, depending on the type of ship and its size. To achieve this, ships will have to adopt solutions from a wide range of technical options: limitation of engine power, optimisation of the engine, heat recovery, optimisation of propellers, installation of wind propulsion assistance systems, etc.
- The **Carbon Intensity Indicator (CII)**, an operational component, is an indicator of carbon emissions (efficiency-related emissions) applicable to ships of 5,000 tonnes or more (UMS). It is calculated by dividing the greenhouse gas emissions by the transport capacity of the ship and the distance travelled in a year, thus taking into account the actual emissions of individual ships and not just their theoretical energy efficiency (unlike the EEDI and EEXI). Its aim is to ensure that the world fleet achieves a 40% reduction in carbon intensity by 2030 relative to 2008. To achieve this, each ship is required to meet targets for reducing its carbon intensity relative to a benchmark that is calculated based on the carbon intensity for its category in 2019: -5% by 2023, -7% by 2024, -9% by 2025 and -11% by 2026. Targets for 2027-2030 will need to be established by 2026 at the latest, but to achieve a target of -20% by 2030, it will be necessary to maintain a trend of around -3% per annum between 2027 and 2030.

Ships will be required to plan measures to meet the target within the **Ship Energy Efficiency Management Plan (SEEMP).** Depending on how well the "achieved CII" compares to the "required CII" (corresponding to the target), the ship will be given a score ranging from **A** (low carbon intensity) to **E** (high carbon intensity), with **C** being approximately the required intensity.

While at present, the scheme does not include sanctions or withdrawal of certificates for poorly performing ships, it does require that ships with a **D** rating for three consecutive years or **E** for a single year implement a corrective action plan to be approved by their flag State, and it calls on industry stakeholders (States, ports, financial institutions, etc.) to put in place incentives for ships with **A** and **B** ratings. Finally, the implementation of the SEEMP may be subject to checks and audits by the flag State.

Potential impacts of the IMO short-term regulatory measures on the national fleet

Energy efficiency and carbon intensity measures will have a differentiated impact on the various fleet segments, vessel operations and age. The impact of the EEXI is estimated to be relatively limited, especially for a relatively young fleet such as the French fleet. In its study of the impact of short-term market based measures, a DNV study estimates that the EEXI alone could reduce the carbon intensity of the world fleet by 6% to 10% in 2030 compared to 2019, but would not prevent an increase in emissions in absolute terms (+3%) due to the projected increase in demand for maritime transport. Bureau Veritas estimates that 30% of ships built from 2015 onwards will have to implement technical measures to comply.

The impact of the CII is expected to be more significant: by requiring ships to reduce their real carbon intensity by at least 2% per year, it requires them to implement planned and ongoing technical solutions (the same as to comply with the EEXI) or operational solutions (speed reduction, routing optimisation, application of "just-in-time", etc.). While this measure is not currently accompanied by harsh sanctions, it should lead to a positive change in practices. For the first time, in a sector that until now has not paid much attention to energy sobriety, it systematically addresses the climate impact of ships in the technical and operational management of fleets. France has chosen to apply the EEXI and CII rules to all its ships over 5,000 UMS, including those used for domestic navigation.

Medium and long-term measures

Currently under discussion at the IMO, these market based measures may include a combination of technical (e.g. a carbon intensity standard for energy used by ships) and economic elements. France and the European Union member States have called for a combination of measures with a regulatory measure for the gradual reduction of the carbon-intensity of the energy used on-board ships, and an economic taxation measure for fossil fuels. These measures aim to compensate in whole or in part for the price differential between fossil fuels and low or zero emission fuels.

In conjunction with short-term measures, these actions should trigger the energy transition over the next 20 to 30 years. France is promoting the consideration of the carbon footprint of fuels over their whole life cycle, including the primary energy source and production methods (the so-called "life cycle assessment" approach), in order to encourage alternative fuels that are truly greener. These measures are expected to be adopted in 2025, to come into force in 2027.

It should be noted that the regulations adopted by the IMO generally observe the principle of technological neutrality, i.e. they leave the choice of technical or operational solutions to the economic players to meet the targets set.

Potential impacts of the IMO medium-term regulatory measures on the global fleet

The DNV study of the impact of medium-term measures on the fleet puts forward several cost intensity measurement for fleets following the introduction of medium-term measures. Cost intensity for fleets is a comprehensive measurement of the total cost of owning, operating, maintaining and managing the fleet in operation. According to the business-as-usual scenario, this is expected to increase from 16 to 47% by 2030, from 56 to 80% by 2040 and from 71 to 85% by 2050.

There are however a number of uncertainties as to the future cost of fuels. If we take the forecast price range of fuels, fuel cost intensity will increase relative to the business-as-usual scenario by 2030, from 12% to 60%. There is even more uncertainty surrounding fuel prices between 2040 and 2050. The range of increase in fuel cost intensity is between 47% and 109% for 2040 and between 46% and 129% for 2050. The total cost per tonne of greenhouse gases reduced, within the forecast range of fuel prices, ranges from 210 to 488 USD/tCO_2eq.

Appendix 3: The European "Fit for 55" package

Maritime ETS

The extension of the **European Emissions Trading System** (**ETS**) to maritime transport. Since the 1 January 2024, 100% of emissions in ports and intra-European journeys and 50% of emissions from journeys between an EU port and a port in a third country must be offset against the corresponding quotas. As it is not subject to delocalisation risks, maritime transport does not benefit from free quotas, but from a progressive implementation (only part of the quotas will have to be offset in 2024 and 2025). The cap on quotas available to the whole market will decrease annually at a rate of about 4.2%.

Initially, it will only apply to ships over 5,000 (UMS) carrying cargo or passengers. Offshore service vessels above 5000 (USM) will be included in the MRV (the EU mandatory reporting system for ship emissions data, in use since 2018) from 2025 and then in the ETS from 2027. From 2025 onwards, offshore service vessels between 400 and 5000 UMS and general cargo ships will be included in the MRV. The inclusion of other categories of ships between 400 and 5000 (USM) in the MRV will be reviewed in 2024. Whether ships between 400 and 5000 (USM) should be included in the ETS will be reviewed before 31 December 2026. Fishing, recreational, public service and military ships are excluded.

As well as CO_2 (already included in the MRV), methane and nitrous oxide emissions are included in the MRV from 2024 and in the ETS from 2026. However, the emissions corresponding to services to the overseas territories (for all ships) and to the additional energy required by "ice class" ships (5% rebate) will be exempt from the offset quotas. The measure includes a review clause for the entire scheme to reflect the potential adoption of a market-based measure by the IMO by 2028.

The maritime sector becomes an official beneficiary of the European Innovation Fund. Furthermore, the European Commission will have to give "special attention" to projects contributing to the decarbonisation of maritime transport in its calls for projects and include themes dedicated to the latter. It has also pledged the revenues from the sale of 20 million quotas by 2030 to this. Project proposals for the European Innovation Fund must have a "clear European added value".

Find out more on the official webpage for the Ministry of Marine Affairs (https://www.mer.gouv.fr/marche-carbone-europeen-ets-transport-maritime).

FuelEU Maritime

Complementing the ETS, which helps to reduce the price gap between fossil fuels and low-carbon fuels, the **FuelEU Maritime regulation** aims to promote the use of sustainable marine fuels by ships, through the adoption of mandatory carbon intensity targets between 2025 to 2050.

The reduction targets, taking into account the whole life cycle of fuels (from "well to wake"), are -2% by 2025, -6% by 2030, -14.5 by 2035, -31% by 2040, -62% by 2045 and -80% by 2050. The regulation also allows for shore-side connection requirements from 2030 for passenger and container ships at the European ports mentioned in article 9 of the AFIR regulation (see the paragraph below).

AFIR

The draft regulation on the deployment of **alternative fuel infrastructure (AFIR)** should include, in addition to FuelEU Maritime, a requirement for the provision of onshore power for passenger and container ships in the European transport network's major ports, as requiring Member States to implement a development plan for alternative marine fuel infrastructure in their ports.

RED III Directive

The revised **Renewable Energy Directive** (RED 3) encourages the use of advanced biofuels and sets greenhouse gas reduction targets for the whole of the transport sector. In particular, article 25-1-3 of the Directive provides an "incentive" mandate for marine fuels, stipulating that Member States should strive to achieve 1.2% synthetic fuels in the energy mix for consumption by 2030.

Potential impacts of the Fit For 55 regulations on the national fleet

The technical and economic implications of the FF55 package on the national fleet will be many and varied depending on the selected segment and the operation. It is difficult to model these impacts, but several elements can be highlighted.

Regarding the impact of the maritime ETS, the average price of the quota for the year 2023 was €85, which was fairly stable compared to the price of €81 on average for the year 2022. This carbon price will be both a financial burden for shipping companies, which until now have benefited from no fuel tax, and an opportunity for those who start to decarbonise their ships in advance of the phase. An adjustment period will be possible due to the phase-in which provides for a gradual integration with the market (40% of verified emissions by 2024, 70% by 2025 and 100% from 2026).

Meanwhile, meeting the carbon intensity reduction targets of the FuelEU Maritime Regulation should encourage a gradual phase-out of fossil fuels. However, the expected price ranges for alternative fuels by 2030 are all higher than for heavy fuel oil (around €15/GJ), with the exception of LNG. They range from €25 to €65/GJ for green ammonia, €15 to €35/GJ for biodiesel, and €25 to €50/GJ for bio-LNG.

Appendix 4: Detailed presentation of decarbonisation levers

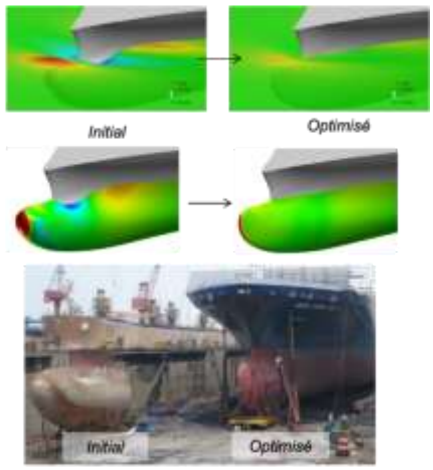
1. Energy efficiency to reduce energy requirements and emissions

There are several solutions to optimise the energy efficiency of ships at the design stage. With the exception of pleasure craft,ships are not usually built on a production line, so separate studies must be carried out on each ship to improve its design and overall energy efficiency. These improvements allow an average gain of 5 to 15% in efficiency, especially by customising the design to the vessel's operational requirements.

Lever 1.1: reducing ship drag

Drag reduction involves optimising the shape of the vessel to minimise its wave and frictional resistance.

It involves complex calculations using specialised software and sometimes tests in a flume tank. These studies may address the general shape of the vessel or of specific parts (bulb, canopy, appendages), following different operational requirements, whether for new construction or retrofit. Some innovative techniques such as the injection of air under the hull or the use of certain surface coatings also help to minimise friction.



Gains de l'ordre de 10% sur la consommation

Credits: HydrOcean / CMA-CGM

BENEFITS	OBSTACLES
• Applicable to all vessels and fleet categories, for retrofit and new construction; • Significant gains of 5 to 20% on energy consumption and emissions • Fully developed and proven solution with extensive positive feedback • Immediate ROI in new constructions and quick ROI (1 to 3 years on large ships) for retrofits	• Limited time allocated to the ship design phase • Studies still seen as an additional cost despite the significant ROI • IMO measures not applicable to smaller ships • Requirement for a technical shutdown when retrofitting • Difficulty in obtaining reliable and accurate information on the actual operational characteristics of vessels, which is required for optimisation studies • Changes to the use of certain vessels which make it difficult to optimise them in too specific a manner, especially in terms of maintaining versatility (for resale of the vessel)

Lever 1.2: improvement of propulsive efficiency

Improving the propulsive efficiency of a vessel consists of optimising its entire propulsive chain (from the engine control to the propeller). The solutions can include:

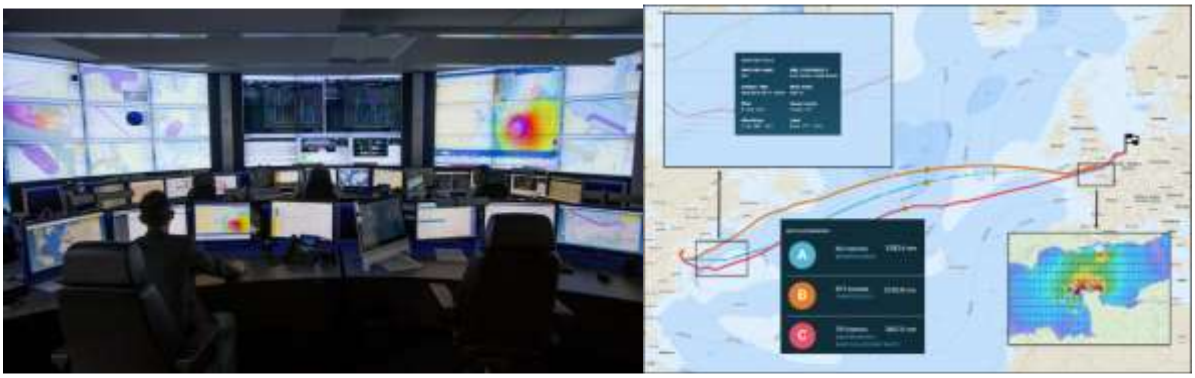
- Optimising the efficiency of the propellers: improved shapes, power matching / cavitation / radiant noise, use of composite and deformable materials;
- The integration of innovative thrusters that may be inspired by biomimicry;
- Optimisation of hull / auxiliary structure / thruster integration: streamlined thrusters, wake / suction, tunnels and optimised aft arcs;
- Development of Energy Saving Device (ESD) systems to improve propulsion efficiency.

BENEFITS	OBSTACLES
• Optimisation for new construction and retrofit to accommodate a vessels new operational conditions • Immediate ROI for new construction and quick (1 to 3 years for large ships) for retrofits • Reliability of design and evaluation software • Gains of 3 to 10%. • Breakthrough innovations in development, especially using biomimicry, with better yields	• Limited time allocated to propulsion performance optimisation in the design phase • Studies still seen as an additional cost despite ROI • Requires a thorough technical study based on the operational requirements of the vessel; • High cost of the most efficient thrusters (between 5 and 25% of the ship's cost dependant on type) • Need to scale up and increase power for innovative biomimicry thrusters

Lever 1.3: improving the energy efficiency of ship equipment

This involves optimising all the energy consumed on board for a given vessel and operating characteristics to avoid unnecessary or redundant consumption. Solutions may include

- Heat or cold recovery for use on board;
- Optimisation of the main engine use compared to that of the auxiliaries as well as the operating conditions;
- Optimal engine power and sea margin;
- Improving the efficiency of deck equipment, fishing equipment and other gear;
- Optimisation of on-board energy consumption: light bulbs, air conditioning, heating.



Example of a ship control centre and routing software (Credit Marine Traffic)

BENEFITS	OBSTACLES
• Can be installed on all ships • Easy to implement with the help of studies at the design stage or through retrofitting • Low cost and energy savings guaranteed	• Requires energy modelling and vessel monitoring systems still under development or not yet fully tested • Optimisation is highly dependent on the operational characteristics of the vessel, which will vary over its lifetime

<u>Lever 1.4: Operational excellence</u>

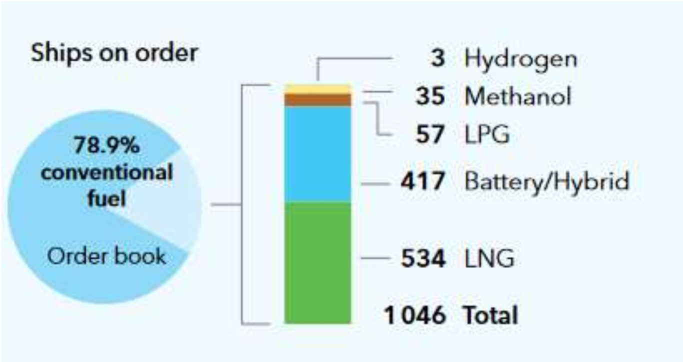
Operational excellence measures include all the steps taken to optimise the energy consumption of currently operational ships and in their interaction with their environment: decision-making and eco-driving tools, routing that takes into account weather conditions (wind, swell, current), optimising interactions with land to reduce transit speeds (just-in-time arrival, reduction of stopover times, etc.), performance monitoring to identify excess energy consumption, and training for crews

These measures, which contribute to the energy efficiency of a ship in its operational phase, are under-deployed.

BENEFITS	OBSTACLES
• Significant gains brought by a better understanding of the ship's operation • Some solutions are easy to implement, without significant modifications to the ship • Increasingly powerful software (routing, for example)	• Bandwidth for ship/shore satellite communications • Data standards and quality • Data ownership disputed between equipment manufacturers, shipyards and shipowners • Weak technical skills among some ship operators • Sharing of investments and benefits between shipowners and charterers

2. Energy and infrastructure

The progressive introduction of energy sources with a reduced carbon footprint, over the entire life cycle, is an essential solution for decarbonising the sector. At present, almost all ships run on fossil fuels, but gradually shipowners are opting for alternative fuel compatible ships (21% of new ship orders according to the DNV).



Orders for ships using alternative fuels (DNV, 2022)

Under the umbrella of alternative fuels, there are a variety of solutions that can be grouped into broad categories: liquefied natural gas (LNG), biofuels, e-fuels and batteries. In addition, CO2 capture and storage (CCS) and diesel propulsion systems can complement ships' systems and reduce their carbon footprint.

At the national level, the energy bunkered in French ports is about 30TWh of fossil fuel energy. The conversion of this 30TWh into other forms of decarbonised energy would require the availability of the equivalent energy in biofuels today, or the equivalent of 60 to 120TWh of electricity to produce e-fuels, taking into account the energy yields associated with each phase of transformation, which are of the order of 12 to 25%. The availability of energy for decarbonisation is therefore a major issue.

Lever 2.1: The use of less carbon-intensive and transitory fossil fuels (LNG)

Liquefied natural gas is a gaseous mixture of hydrocarbons of fossil origin composed mainly of methane. Transported in liquefied form (cryogenic temperature of -161°) in LNG ships, it has been used on these ships as a fuel since the 1960s-1970s, which makes it an established technology. LNG also makes it possible to meet the constraints of air pollution regulations, particularly in emission control areas (ECA areas as defined by the IMO), and is gradually being introduced in new construction of cargo and passenger ships, which cannot be decarbonised solely by electricity and hydrogen.

LNG's greenhouse gas emission reduction is limited given its fossil origin and the fugitive methane emissions (whose global warming power is 28 times greater than CO2 at 100 years) caused by its use, so LNG can only be seen as a transitional energy towards bio-LNG and e-methane, which have the advantage over other forms of energy of a gradual and controllable transition.

For smaller vessels, such as fishing vessels, compressed natural gas (CNG and its derivatives in bio- and e-fuels) may be suitable.

Additionally, the pyrolysis of natural gas on board ships, a process that directly transforms the gas into hydrogen and solid carbon, is currently being developed for maritime use.

BENEFITS	OBSTACLES
• Improved air quality: reduction of SOx, NOx and fine particulate emissions • Established supply chain, growing infrastructure in main refuelling ports • Pre-existing international regulations for LNG use on board ships • Reduction of CO2 emissions up to 17% depending on the type of engine and the origin of the LNG (+6% to -17% in the draft FuelEU regulation) • High energy content in comparison to other alternative fuels • Potential for gradual transition to bio-GNL and e-GNL without changing vessel and infrastructure design	• Fossil fuel • Fugitive methane can lead to an increase of up to 6% in GHG emissions (compared to heavy fuel oil according to FuelEU). • Use limited to large vessels (>100m) • Requires crew training to handle cryogenic fuel on board

Lever 2.2: Biofuels

Liquid biofuels represent a very varied range of alternative fuels produced from biomass from food resources (vegetable oils, sugar plants, cereals, etc.) for so-called first generation fuels, and from lignocellulosic resources (wood, leaves, straw, etc.) for second generation fuels. Some biofuels have already been used for a long time for road transport, but their use in the maritime sector remains in its infancy.

Another type of biofuel, biomethane, is a 100% renewable gas produced from waste from the agri-food industry, collective catering, agricultural and household waste, or even sludge from wastewater treatment plants. This purified biogas has the same properties as natural gas, and therefore the same uses. It can then be liquefied to make bio-LNG and replace fossil LNG.

Relatively easy to use and available now, biofuels have varying greenhouse gas emission reduction potentials related to their origin and level of use. The availability of stocks, given future needs, is a major issue. Biofuels are generally more expensive than fossil fuels.

BENEFITS	OBSTACLES
• Fuels already available in some ports • A "drop-in" solution, biofuels can be blended directly into the ship's bunkers, mixed with fossil fuels, without major retrofitting (sometimes requiring engine modifications) • Similar energy density to fossil fuels	• Limited stocks and competition for use from other sectors (including aviation) • Emissions reductions vary between biofuels • Research needed to enable scaling up, and to develop third generation biofuels (from seaweed) • NOx emissions from these biofuels to be managed

Lever 2.3: Electrofuels (e-fuels)

E-fuels are a class of fuels produced using electricity. They can be a greenhouse gas-neutral solution provided that the production processes, including the electricity used, are greenhouse gas-neutral. Together with biofuels, these are the two major solutions for meeting the energy needs of the maritime sector in the future.

The production of e-fuels requires huge amounts of energy in proportion to the low yields. Their production involves a hydrogen production stage, which can be produced by electrolysis of water (to ensure its decarbonised nature), and this hydrogen can then be transformed into other molecules by various chemical processes.

Several e-fuels are being considered to meet the needs of the maritime sector, although it is not possible to determine at present whether one of them will dominate over others. The following are the main ones:

- **e-hydrogen**, produced by electrolysis of water, which can then be used in a fuel cell or even, in some cases, in a combustion engine. Because of its low energy density per unit volume, hydrogen must be compressed at very high pressures (300 to 700 bars) or even liquefied at about -252°C. Its use will remain limited to certain types of ships that can refuel frequently. The limited lifespan of fuel cells and their cost are also a constraint.

Energy Observer 2 - a multi-purpose electric charging vessel powered by liquid hydrogen (credits: Kader Boucher / Epron Design)

- **E-methane**, produced via the Fischer-Tropsch process, can also be liquefied to produce e-LNG. The latter could directly replace the fossil LNG used in ships built for this energy.

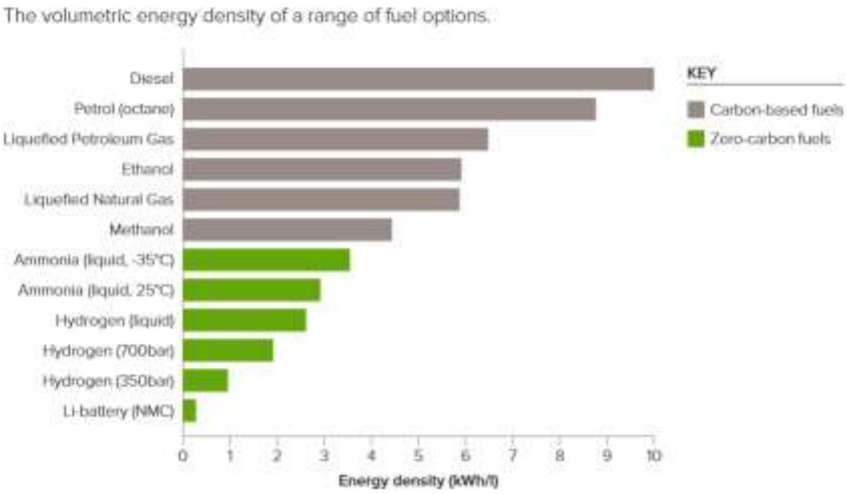
Jupiter 1000 project, industrial Power-to-Gas demonstrator (Credit Jupiter 1000)

- **E-methanol**, the production of which has already been industrialised, particularly for the chemical industry. This fuel is liquid at room temperature, which makes it easier to handle and bunker, and it could be used in retrofits of existing ships. Tankers operating and transporting methanol are already in operation, and the first ships - excluding tankers - using methanol as a fuel will be in operation by 2025-2026. Some container ship owners are counting on this technology.

- **E-ammonia**, also produced in large quantities for industrial purposes (fertiliser industry, explosives) using the Haber-Bosch process. Less established than the two previous e-fuels for maritime use, ammonia has the major advantage of not having a carbon chain and therefore not emitting any CO2 when burned. However, major R&D efforts are needed to ensure its safe use, as ammonia is highly toxic.

The price of e-fuels, the production of which is almost nil to date except for heavy transport, would depend greatly on the price of electricity. It can be estimated that, in the long term and without the carbon tax mechanism, e-fuels will be three to four times more expensive than their fossil equivalents. The necessary investments in infrastructure and the additional costs of ships with a different design from conventional ships must be added to this price.

E-fuels have different physical properties. In particular, their energy density per unit volume varies considerably, with direct implications for the size of the vessel's cargo hold and therefore its payload.



Energy density of marine fuels, excluding storage tanks[36]

Another issue is that e-fuels containing carbon, in particular e-methane and e-methanol, must have a source of carbon, CO2 or CO, for their production. Several technologies are being considered to provide CO2, bearing in mind that the European RED III regulation could restrict the use of certain sources. Biogenic CO2, for example from the production of biomethane, is particularly good in terms of carbon balance, especially when coupled with an anaerobic digestion unit, which doubles the production of gas for the same quantity of biomass input.

36 https://royalsociety.org/-/media/policy/projects/green-ammonia/green-ammonia-policy-briefing.pdf

BENEFITS	OBSTACLES
• Significant greenhouse gas reduction potential • Improvement of air quality: reduction of SOx, NOx (except for ammonia for which there are risks of residual NOx emissions) and fine particulates • Diversity of e-fuels to meet different uses and operating constraints	• Significant need for renewable or low-carbon electricity due to low efficiency • Industrial economy to be built, with major investments in production and distribution infrastructures (especially ports) • Source of CO2 to produce carbon-based e-fuels • Some e-fuels have hazardous properties, notably e-ammonia and hydrogen • Lower energy density than fossil fuels • Ship design to be modified • Lowering of the carbon signature is not recognised due to the fact that the IMO has not yet done the life cycle assessment of marine fuels (work in progress) • Training of crews to use these new fuels • Limited land in port areas

Lever 2.4: on-board CO2 capture

On-board capture of CO2 emitted on a ship, and its subsequent sequestration, would reduce the carbon content of emissions from ships using carbon-based fuel. The technology is already relatively well established on land and deployed in some industrial sites. It still requires R&D efforts and the development of demonstration units in marine conditions.

Its deployment can be considered for the largest ships, but remains costly.

BENEFITS	OBSTACLES
• Technology that can complement alternative fuels • Relevant for ships with a cold source on board, such as LNG ships, to liquefy and store CO2 • Potential new market for French ports	• Numerous modifications required to retrofit existing vessels • Space requirements for on-board CO2 capture and storage systems • Energy intensive process on board • Regulatory uncertainties regarding CO2

Lever 2.5: Hybridisation and electrification of ships and docks

As in other forms of transport, the electrification of propulsion modes is gradually being implemented on ships. The smallest of them, such as aquaculture or pleasure vessels, can choose to use battery-powered electric propulsion. It is also an attractive option for small passenger or service vessels, in rivers or sheltered waters, which benefit from dockside recharging capacity and do not have high range requirements. On larger vessels, these applications are limited to a few specific uses, such as the electrification of auxiliaries, which can still represent up to 20% of the vessel's energy consumption, or for ferries making short crossings that can be recharged frequently at the quayside.

Another option, electric hybridisation of propulsion, decouples the generation of energy on board and electrical propulsion control by relying on on-board electricity storage, with advantages in terms of system sizing, efficiency and technological upgradability. It is aimed at a wider market, ranging from maintenance vessels at sea to passenger ships, some fishing vessels and, more generally, any vessel, for example when approaching a port area.

Shore-side electrification is a necessary condition for the development of electric propulsion, both for the reduction of emissions at quayside and for the recharging of batteries. Some infrastructure already exists in European and French ports for ships to connect to the quay during their stopovers. However, in view of the European requirements of the AFIR regulation[37] and with the future development of the electrification of ships, the roll-out of hook-up infrastructure should accelerate.

BENEFITS	OBSTACLES
• No direct emissions from the ship • Reduced noise pollution • Well established battery technology with good energy efficiency • Relevant for low power vessels (pleasure craft, fishing) but also for higher power vessels as long as they have short trips • Potential for hybridisation with a combustion engine, for example • Reduction of GHG and other pollutants, especially in ports • Decoupling of on-board energy generation, storage and propulsion: adaptation to load variations and optimised operation for each of the components • Power generation retrofit capability	• Efficiency depends on the energy mix used to produce the electrical energy used on board • Large footprint. Not an option for long distance propulsion • Fire risk from batteries • Cost of electrification infrastructure for ports for hook up and charging

Electric oyster barge "François Cadoret"

Vessel "Commandant Charcot" equipped with 4520 kW of batteries

37 Alternative Fuels Infrastructure Regulation, see Appendix 3

Lever 2.6: Nuclear propulsion

The maritime transport sector is on the cusp of a revolutionary switch to clean energy, and nuclear power could be one of the alternatives to traditional fossil fuels.

Today, the propulsion of nuclear ships is covered by Chapter VIII of the SOLAS Convention, a text supplemented by resolution A.491.12 of the Code of Safety for Nuclear Merchant Ships. Since this resolution was ratified by France in 1981, the body of regulations dealing essentially with pressurised water technology has not evolved. Even today, no other technology has demonstrated that it can withstand all the stresses and strains of the maritime environment (platform movements, vibrations and all types of collision, impact, etc.) while remaining capable of operating in complete safety.

Although a few nuclear-powered vessels have been built across the globe since the 1960s, they have all been state-owned and have not really been used for any international commercial trips (icebreakers, experimental ships or research vessels). Privately-owned merchant ships that could be resold, operated by multinational crews and finally dismantled, would pave the way to a new approach for this sector.

While nuclear power has the potential to provide a reliable, high-density source of energy that could significantly reduce the carbon footprint of maritime transport and Offshore Floating Nuclear Plant (OFNP) operations, there are still considerable obstacles to the adoption of nuclear power in the maritime transport sector. Indeed, if the business model is to be adopted over the long-term, a number of considerations must be taken into account, including the challenges associated with nuclear safety, crew qualification, radioactive waste management, and the costs of building, maintaining and dismantling such vessels.

Although the rapid development of Small Modular Reactor (SMR) technologies and their possible use in commercial maritime transport may open up new possibilities, there are still a great number of regulatory hurdles to overcome. From this point of view, a revision of IMO texts seems essential, although this subject is not currently on the Organisation's agenda.

Computer-generated image of the SMR principle studied by the Nuward Consortium. © Nuward Consortium (Source CEA)

While no technological solution to decarbonisation should be ruled out, the implementation of nuclear propulsion systems on merchant ships would require major efforts from public and industrial players, which would have to be sustained over the long term. Such a development would also need to draw on the extensive experience of the military shipbuilding industry, which has been using nuclear reactors for the propulsion of military vessels for several decades. Before any investment decision is made in this field, it would therefore seem necessary to carefully assess the advantages and disadvantages, in terms of the objective to be achieved.

BENEFITS	OBSTACLES
• Zero emissions • French expertise in pressurised water technology • Excellent ratio between density (thanks to SMRs) and power output	• Only suitable for large ships with a power of at least 20,000 to 40,000 kW • SMRs have not been proven reliable at sea • Difficult to ensure a safe environment given the current operational approach for merchant ships • Construction, operation & maintenance and dismantling costs • There seems to be low acceptability for nuclear power

Lever 2.7: Propulsion by wind and other renewable energies

Wind is a renewable energy, free and abundant at sea, especially in certain geographical areas. Its direct use on board ships using dedicated propulsion systems (sails, rigid wings, rotors, kites, etc.) makes it possible to significantly reduce the use of other energy sources. Wind energy can be used to assist the principal propulsion system on new ships or retrofit existing ships, or on specific lines as principal propulsion.

Example of wind propulsion systems under development

(credits Ayro and Airseas)

Wind propulsion is the focus of numerous proposals and patents for innovation at the national level, but the commercialisation of equipment and its installation for large-scale deployment on commercial ships has yet to be accelerated.

Other renewable energies can in some cases be exploited on board ships, especially photovoltaic and hydro-power.

BENEFITS	OBSTACLES
• The energy is free at its point of use on board • No processing, transport, or storage on land • No bunkering, storage on board • Safe routing to optimise use and hybridisation with another propulsion mode • Widely available, including in countries and islands with less access to fuels • An energy source that does not compete with other industries and is compatible with other modes of propulsion • Innovative French industry in this field	• Efficient for low ship speeds • Suitable for some shipping lines and less so for others (low wind) • Performance and reliability of the new generation propulsion equipment which will have to demonstrate sustainability and efficiency with their on board use • Requires modification of the hull and appendages to effectively move upwind • Impacts on cargo deck, stability and also on visibility from the bridge • For strong energy efficiency gains, the whole design must be considered to incorporate wind propulsion with hybridised propulsion means

3. Sobriety in operational terms and design to reduce emissions in the operational phase and for the entire value chain

Lever 3.1: Operational sobriety - speed reduction

Sobriety in operational terms for maritime transport is a complementary measure for reducing GHG emissions in certain fleet categories. Actioning this lever, which is technologically straightforward, is still not without its difficulties.

The main market based measure identified is to reduce the ship's speed, as fuel consumption is a cubic function of its speed. This practice is, actually, already widespread and has been highlighted to the IMO by France. It is also included in the SAILS charter signed by several French shipping companies. However, too great a reduction in the speed of commercial vessels would mean a reduction in total transport volumes and, potentially, an increased need for new vessels to handle maritime trade.

The drop in transported volumes and therefore in international trade is so far quite low. In its annual report published on 29 November 2022, the United Nations Conference on Trade and Development (UNCTAD) projected an annual increase in world maritime trade of 2.1% per year over the next five years, despite rising energy costs.

BENEFITS	OBSTACLES
• Technically straightforward to implement • Efficient solution if the speed reduction is well thought out (up to 30% depending on the type of fleet) • Lower speeds make wind propulsion more attractive	• Impact on the economic performance of operators, • Little room for manoeuvre for certain fleet categories (e.g. ferry schedules) • Potentially offset by the introduction of additional vessels, significantly reducing the expected gains • Risk of modal shift to less energy efficient but faster modes of transport

Lever 3.2: Ecodesign, manufacturing process and end of life to reduce the construction and dismantling carbon footprint

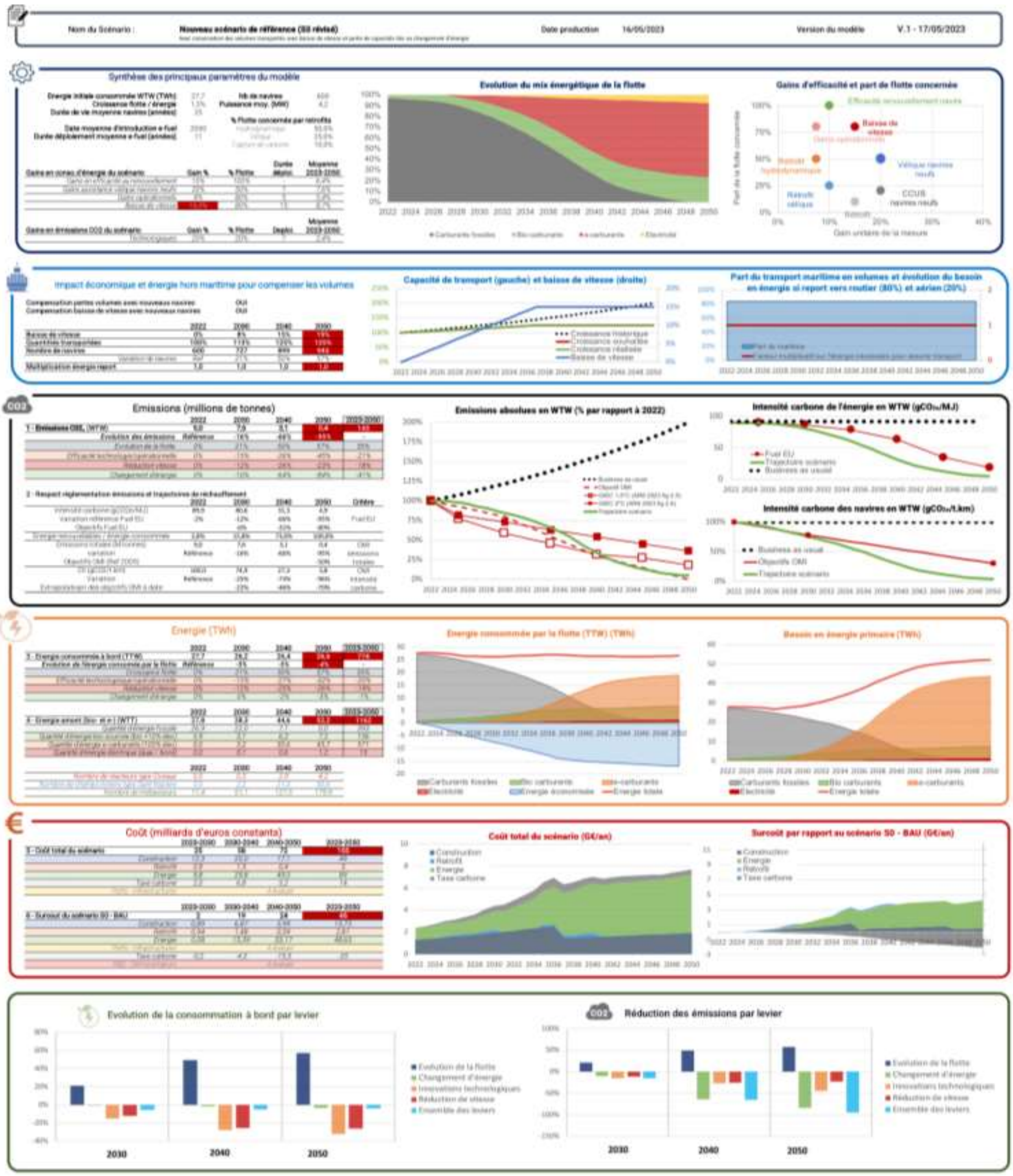
The first step in understanding this lever, which is often overlooked in international regulations and poorly documented, is to agree on a carbon accounting framework for conducting life cycle assessments (LCAs) and to promote its use. The consolidation of the main inventory data (energy, materials, etc.) specific to the naval, river and nautical sectors (engine emission profiles, composite materials, welding processes, etc.) is necessary to initiate an eco-design approach.

Ecodesign then implies finding incentives for shipbuilders and shipowners to work towards vessels with the smallest possible carbon footprint over its entire life cycle. This approach highlights the impact of material inputs, in particular steel, aluminium and composites, which can account for up to 90% of the production carbon footprint. The transition of upstream industries must be achieved while ensuring the competitiveness of European downstream industries.

French shipyards are attempting to integrate the constraints linked to the end of a ship's life into the design stage. The recreational marine sector has already initiated developments to use more environmentally friendly and recyclable materials (e.g. use of flax fibre instead of carbon fibre, and recyclable resin).

BENEFITS	OBSTACLES
• Some technical solutions are well established • First life cycle analyses carried out by key players • Regulatory constraints regarding the end-of-life of ships • National eco-organisation APER approved by the Ministry of Ecological Transition to manage the dismantling and recycling of recreational and sports boats at the end of their life. • Four EU-approved ship recycling facilities located in France • Industrial capacity in France and know-how of French players	• Lack of a shared LCA methodology and lack of data to establish a benchmark • Life cycle environmental performance criteria not taken into account by the market and regulations • European border carbon adjustment mechanism that makes access to raw materials more expensive for European manufacturers, but does not include finished products • Restrictive regulatory requirements for materials approval that does not facilitate innovation.

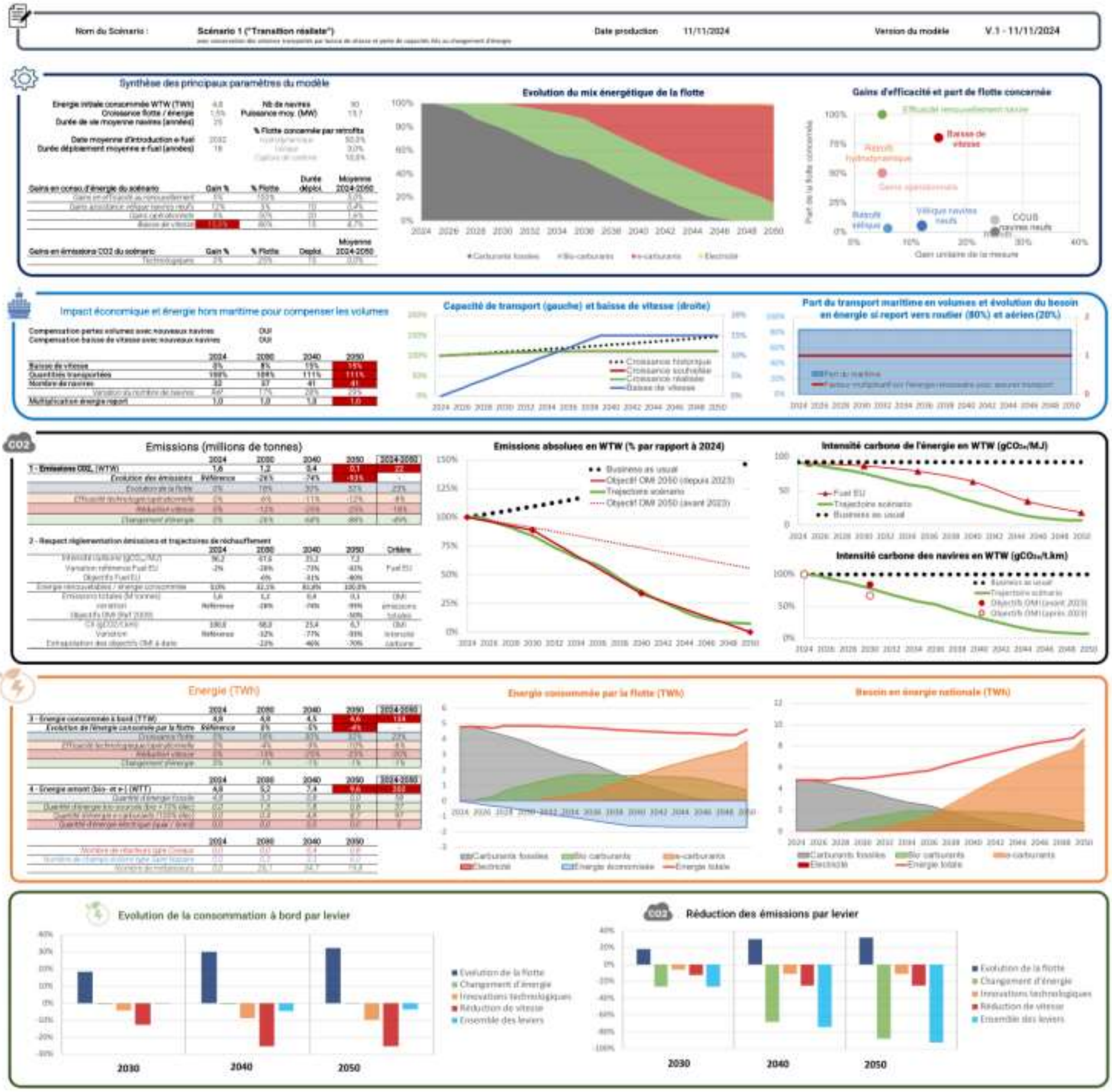
Appendix 5 – Benchmark decarbonisation scenario – Meet 2050



Appendix 6 – Decarbonisation scenarios by fleet category

For each of the fleet categories, “Container ships”, “Gas tankers” and “Large ferries”, 3 decarbonisation scenarios were modelled, according to three scenarios: S1 – “Realistic transition”, S2 – “Technology”, and S3 – “Sobriety”.

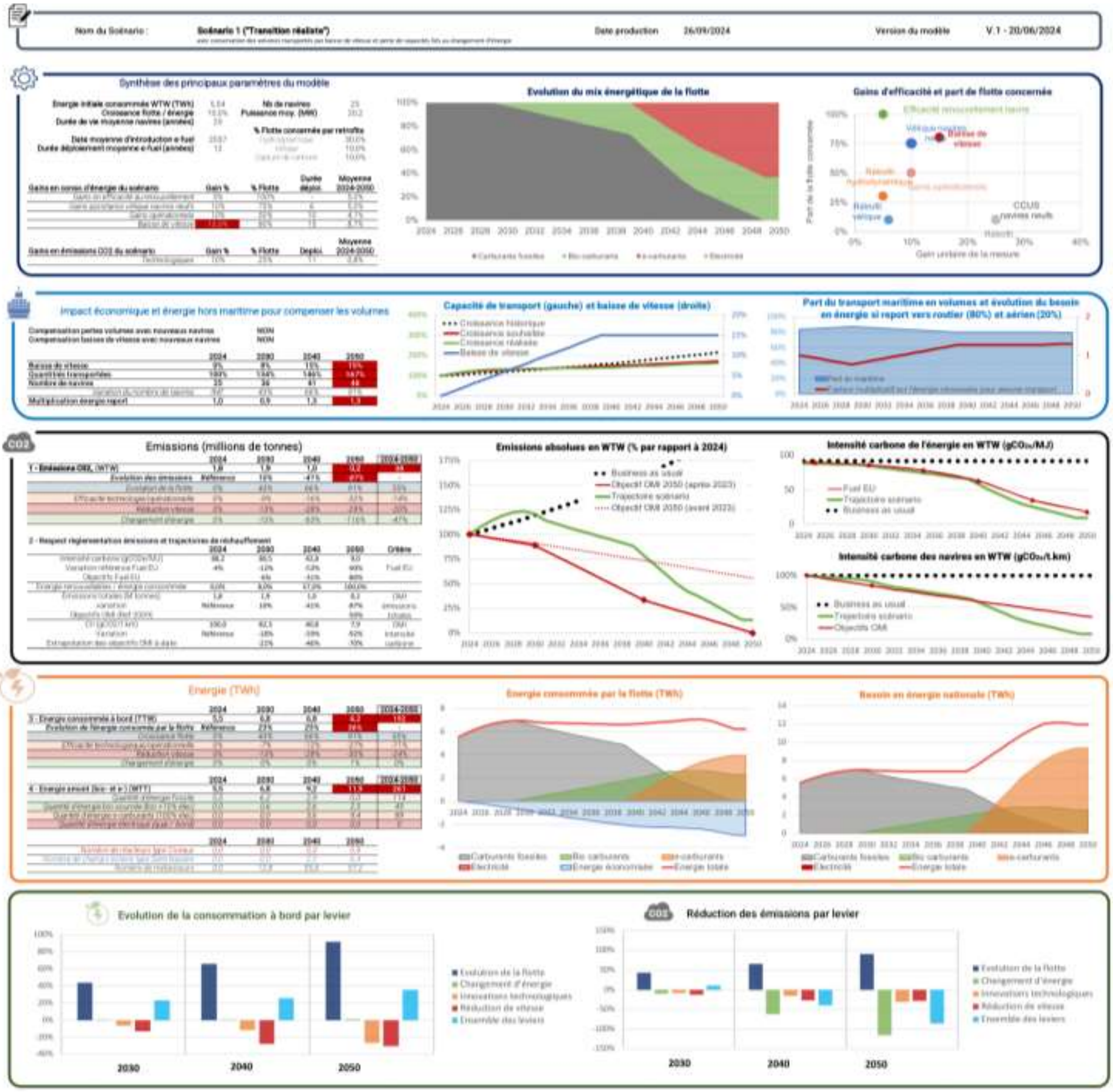
Modelling 1.1: Container ships, “Realistic transition” scenario



Modelling 1.2: Container ships, “Technology” scenario

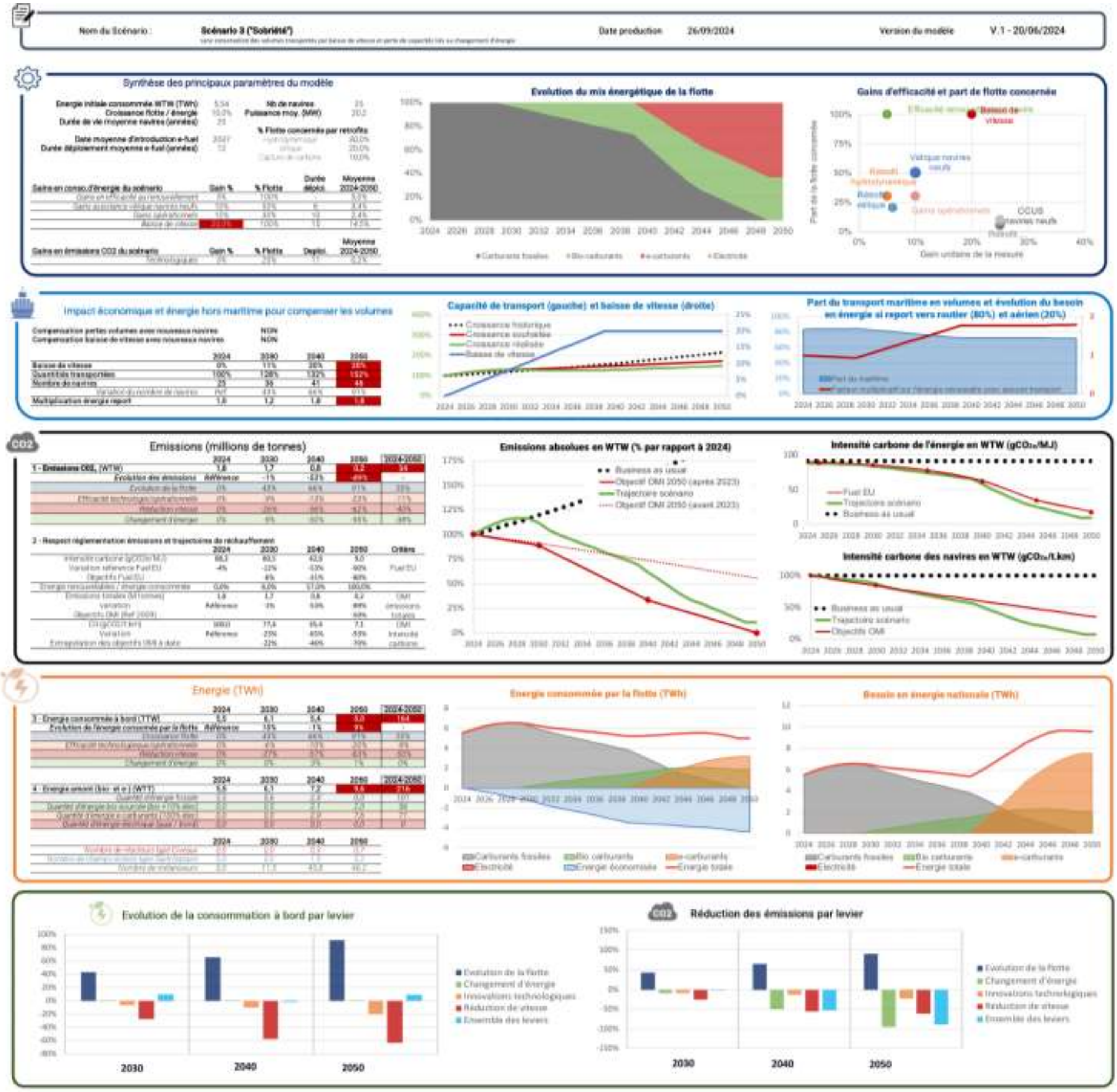
Modelling 1.3: Container ships, "Sobriety" scenario

Modelling 2.1: Gas tankers, "Realistic transition" scenario

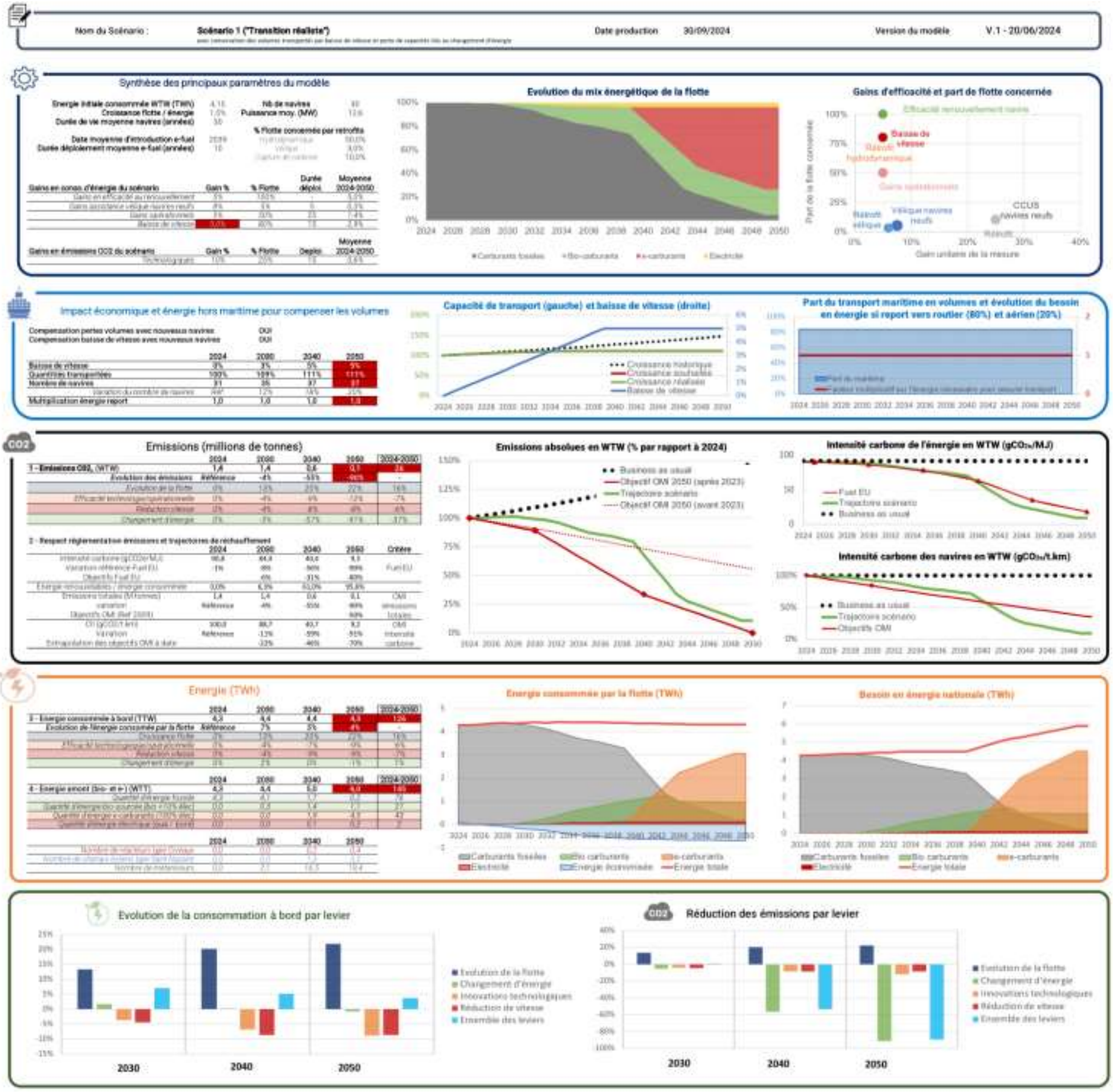


Modelling 2.2: Gas tankers, "Technology" scenario

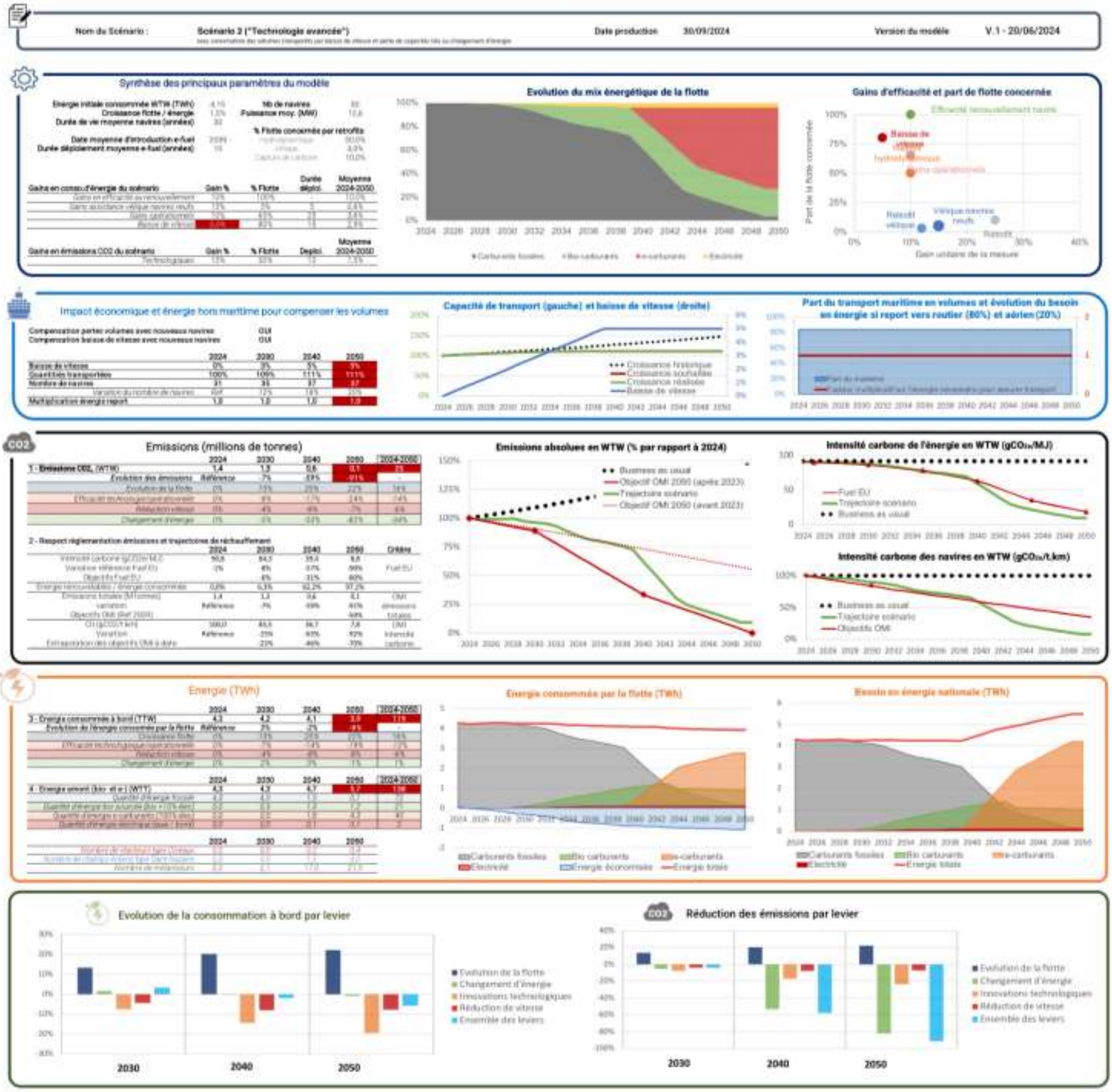
Modelling 2.3: Gas tankers, "Sobriety" scenario



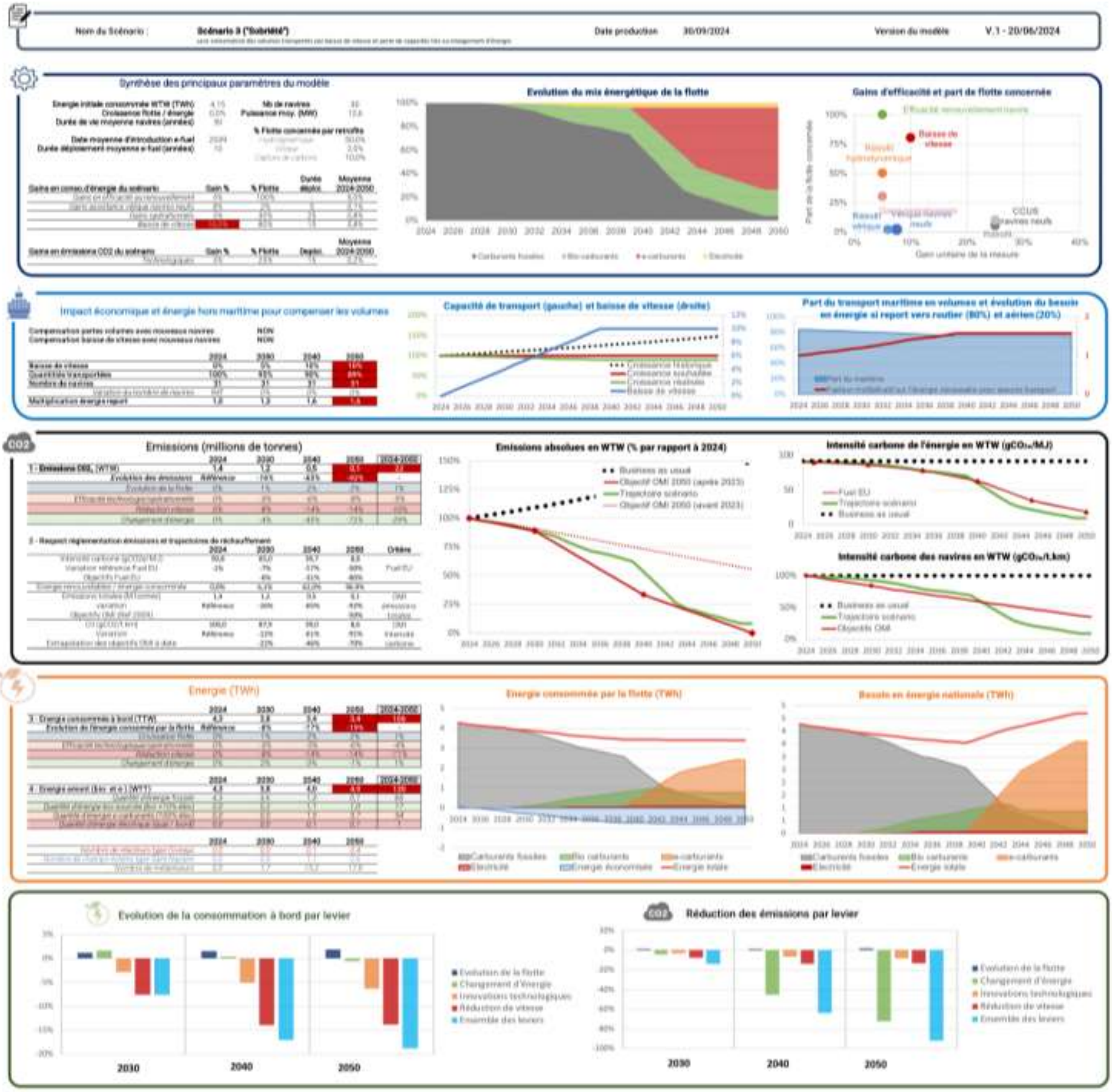
Modelling 3.1: Large ferries, "Realistic transition" scenario



Modelling 3.2: Large ferries, "Technology" scenario



Modelling 3.3: Large ferries, “Sobriety” scenario



Appendix 7 - Summary of the working groups per fleet category

1. "Container ships" working group

Caractéristiques de la flotte

	CMA CGM	Marfret
Type de navire (longueur, puissance, UMS)	~650 navires de 500 à 23,000 TEUs (dont ~170 sur des services touchant la France)	5 navires PC, 1 en livraison 2025, De 500 à 2500 TEUs
Répartition sur la façade	~90 navires ont souté une partie de leur carburant en France en 2022	3 navires ont souté une partie de leur carburant en France en 2022
Moyenne d'âge	13 ans	17 ans
% de Construction française	0% (pas d'offre) mais collaboration avec Chantiers ST Nazaire sur prototype d'assistance vélique	0% (pas d'offre)
Consommation par type de combustible en 2022 (m^3)	France : 408 kt equiv FO (3 kt HSFO, 242 kt VLSFO, 15 kt MDO, 148 kt LNG)	France : 3,2kt de carburant (2,5kt VLSFO, 0,7kt MGO)
Consommation par façade 2022 (m^3 et port)	Fos : 176 kt, Marseille : 37 kt Montoir : 53 kt Le Havre : 45 kt, Dunkerque : 5 kt Pointe-à-Pitre : 92 kt	Marseille : 2,45kt Le Havre : 7kt Dunkerque : 0,05kt

Levier Efficacité énergétique
Réduction de la trainée

		CMA CGM	Marfret
RETROFIT	Revêtement des carènes	Inclus dans un gain global rétrofits hydrodynamiques (5% sur 50% de la flotte) (~ 200M USD de capex consacrés en 10 ans)	Déjà optimisés par peinture antifouling
	Modification du bulbe		Non
	Modification de l'étrave		Non
CONSTRUCTION NEUVE	Optimisation des formes	Inclus dans un gain global au renouvellement (5%)	Inclus dans un gain global au renouvellement (5%)

Nécessaire Envisageable Non applicable

Levier Efficacité énergétique
Optimisation du rendement propulsif

	CMA CGM	Marfret
RETROFIT	Inclus dans un gain global rétrofits hydrodynamiques (5% sur 50% de la flotte)	Ajout appendice (hélice, safran)
CONSTRUCTION NEUVE	Inclus dans un gain global au renouvellement (5%)	Inclus dans un gain global au renouvellement (5%)

Nécessaire   Envisageable   Non applicable

Levier Efficacité énergétique
Optimisation de la consommation d'énergie à bord

	CMA CGM	Marfret
RETROFIT	Inclus dans le gain d'excellence opérationnelle (5% sur 50% de la flotte) (Investissement ~ 20M$ Programme Smartship)	Implémentation des procédures de gestion de l'énergie Tout sauf moteur / propulsion (elec, chaudière)
CONSTRUCTION NEUVE	Inclus dans le gain d'excellence opérationnelle (5% sur 50% de la flotte)	Optimisation des générateurs Implémentation de variateurs de fréquence Procédures de gestion de l'énergie

Nécessaire   Envisageable   Non applicable

Levier Exploitation
Excellence opérationnelle et sobriété

RETROFIT & CONSTRUCTION NEUVE	CMA CGM	Marfret
EXCELLENCE OPERATIONNELLE	Gain de 5% sur 50% de la flotte	Gain de 5% sur 40% de la flotte
SOBRIETE & REDUCTION DE LA VITESSE	Baisse de 15% de la vitesse sur 80% de la flotte (déploiement en 15 ans)	Baisse de la vitesse Just-In-Time Weather Routing Optimisation des consommation à bord (déploiement en 15 ans)

Nécessaire Envisageable Non applicable

Levier Exploitation
Nettoyage de coque et des hélices
Si applicable seulement

RETROFIT & CONSTRUCTION NEUVE	CMA CGM	Marfret
NETTOYAGE DE COQUE	Inclus dans le gain d'excellence opérationnelle (5% sur 50% de la flotte)	Réalisé en cale sèche dans la limite des exigences réglementées à ce jour
NETTOYAGE DES HELICES		Réalisé à intervalle régulier Gain 2 à3 %

Nécessaire Envisageable Non applicable

Levier Energies et Infrastructures

Energies fossiles moins carbonées et transitoires GNL et/ou methanol

	CMA CGM	Marfret
RETROFIT	GNL : non retenu après étude technico-économique Methanol : pilote en cours sur 2 navires. Navires supplémentaires à l'étude.	
CONSTRUCTION NEUVE	La majorité de nos nouvelles commandes sont DF LNG ou methanol	Motorisation et/ou groupes électrogènes « dual fuel méthanol

Nécessaire Envisageable Non applicable

Levier Energies et Infrastructures

Biocarburants liquides - gazeux

	CMA CGM	Marfret
RETROFIT	Incorporation progressive de biodiesel, biométhane et biométhanol sur 2024–2030 (seules solutions disponibles), potentiellement jusqu'à 10% de bio sur le FO, 20% sur le méthane et 25% sur le méthanol en 2030, sous réserve de disponibilité et de compétitivité du prix des molécules	Incorporation progressive de biodiesel sur 2024–2030 (seules solutions disponibles, de FAME ou EMAG), sous réserve de disponibilité et de compétitivité du prix des molécules
CONSTRUCTION NEUVE		Incorporation progressive de biodiesel sur 2024–2030 (seules solutions disponibles, de FAME ou EMAG), sous réserve de disponibilité et de compétitivité du prix des molécules

Nécessaire Envisageable Non applicable

Levier Energies et Infrastructures
E-carburants: Méthanol, Ammoniac, Hydrogène...

	CMA CGM	Marfret
RETROFIT	Incorporation progressive d'e-fuels à partir de 2030, en commençant par e-méthanol et e-méthane	
CONSTRUCTION NEUVE		

Nécessaire Envisageable Non applicable

Levier Energies et Infrastructures
Electrification – Hybridation du navire

	CMA CGM	Marfret
RETROFIT	Hybridation : les premières études ne sont pas concluantes sur le gain GHG	Electrification des navires à quai (On Shore Power Supply, OPS) Hybridation : les premières études ne sont pas concluantes sur le gain GHG
CONSTRUCTION NEUVE	Electrification : envisagé avec des piles à combustibles Hybridation : les premières études ne sont pas concluantes sur le gain GHG	Electrification : envisagé avec des piles à combustibles Hybridation : les premières études ne sont pas concluantes sur le gain GHG

Nécessaire Envisageable Non applicable

Levier Energies et Infrastructures
Propulsion par le vent

	CMA CGM	Marfret
RETROFIT	Gain de 6% sur 3% de la flotte à 10 ans (technologie non aboutie sur les navires à manutention verticale)	Gain théorique 5 %
CONSTRUCTION NEUVE	Gain de 12% sur 5% de la flotte à 15 ans	Gain théorique projetté max. 10% Conception générale du navire au stade de la recherche

Nécessaire Envisageable Non applicable

Levier Energies et Infrastructures
Nucléaire

	CMA CGM	Marfret
RETROFIT	Non envisagé	Non envisagé
CONSTRUCTION NEUVE	Pas envisagé avant 2035-2040	Non envisagé

Nécessaire Envisageable Non applicable

Scénarios d'évolution de la flotte CMA CGM

Trajectoire d'émissions : 2030	Trajectoire d'émissions : 2040	Trajectoire d'émissions : 2050
Scénario 1 : objectif -30% vs 2008 Scénario 2 : objectif -20% vs 2008	Scénario 1 : objectif -80% vs 2008 Scénario 2 : objectif -70% vs 2008	Scénario 1 : objectif net zero Scénario 2 : objectif net zero

Décrire un ou plusieurs scénarios d'évolution de la flotte avec les différentes combinaisons de choix technologiques, opérationnels et énergétiques possibles – identifier les besoins associés en : énergie, technologies, infrastructures, réglementation, financement…
Ce scénario doit être assorti d'objectifs de trajectoire d'émissions à des dates clés (2030, 2040, 2050).

- *Les technologies d'efficience énergétique sont de plus en plus déployées jusqu'à devenir systématiquement implémentées*
- *Les mesures opérationnelles de réduction de la consommation qui n'impactent pas l'offre commerciale sont implémentées au maximum ; celles qui ont un impact commercial (baisse de vitesse, design du réseau) le sont modérément*
- *Tous les nouveaux navires sont dual fuel pour réduire la dépendance à un seul type d'énergie, en se répartissant sur les technologies méthane, méthanol dans un premiers temps et ammoniac dans un second temps, en visant en 2050 un mix équilibré entre ces différentes énergies et des solutions pour les navires encore en opération à propulsion conventionnelle (scrubbers, capture de carbone à bord, piles à combustible sur une partie de la flotte)*
- *Les énergies émettrices de GES sont progressivement remplacées par leurs équivalents bas-carbone (biodiesel, bio/e-méthane, bio/e-méthanol, e-ammoniac) en lien avec l'évolution des réglementations, l'augmentation du nombre de chargeurs acceptant un cout plus élevé pour décarboner leur supply chain, et les politiques volontaristes de certains transporteurs*

Scénarios d'évolution de la flotte Marfret

Trajectoire d'émissions : 2030	Trajectoire d'émissions : 2040	Trajectoire d'émissions : 2050
Scénario 1 : Scénario 2 :	Scénario 1 : Scénario 2 :	Scénario 1 : -50% vs 2008 (OMI avant rev.2023) Scénario 2 : NET ZERO

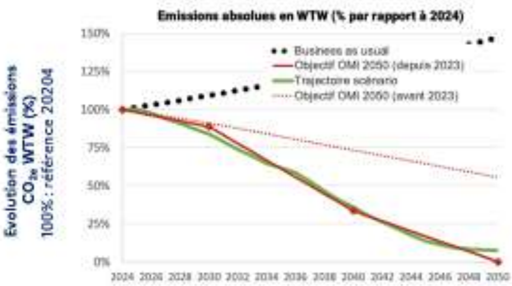
Décrire un ou plusieurs scénarios d'évolution de la flotte avec les différentes combinaisons de choix technologiques, opérationnels et énergétiques possibles – identifier les besoins associés en : énergie, technologies, infrastructures, réglementation, financement…
Ce scénario doit être assorti d'objectifs de trajectoire d'émissions à des dates clés (2030, 2040, 2050).

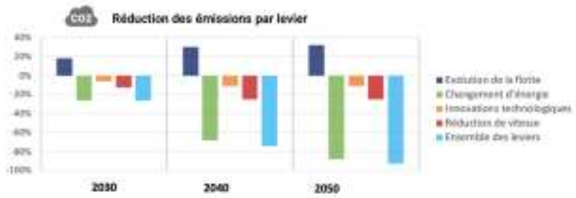
Marfret s'aligne sur les scenarios recommandé par les Hautes Autorités et ses partenaires.
Les estimations de diminution d'émission CO^2 - Tank to Wake – sont mesurées depuis 2023. Nous ne pourrons projeter des chiffres raisonnables par rapport aux références des standards (COP 28: par rapport à 1990, OMI par rapport à 2008, Fuel EU par rapport à 2020) qu'à la suite de calculs conséquents qui sont en cours de réalisation au moment de ce groupe de travail.

Scénario 1 : Just in Time, Réduction de la vitesse , Weather routing : 2 navires déployés +1 en cours pour l'excellence opérationnelle. Moteur dual fuel, Hydrodynamisme. Aérodynamisme.

Scénario 2 : Disponibilité et coûts abordables des ressources énergétiques

Trajectoire de décarbonation





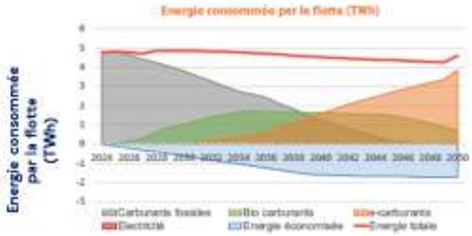
Contribution des différents leviers de décarbonation à l'évolution des émissions (%)

Besoin en énergie primaire (TWh)

	2024	2030	2040	2050	2024-2050
3 - Énergie consommée à bord (TTW)	4,8	4,8	4,5	4,6	124
Evolution de l'énergie consommée par la flotte	Référence	0%	-6%	-4%	-
Croissance flotte	0%	10%	20%	32%	23%
Efficacité technologique/opérationnelle	0%	-4%	-9%	-10%	-6%
Réduction vitesse	0%	-13%	-21%	-25%	-20%
Changement d'énergie	0%	-1%	-1%	1%	-1%

	2024	2030	2040	2050	2024-2050
4 - Énergie amont (bio- et e-) (WTT)	4,8	5,2	7,4	9,6	[illegible]
Quantité d'énergie fossile	[illegible]	3,3	0,8	0,0	55
Quantité d'énergie bio sourcée (bio +10% élec)	0,0	1,3	1,8	0,8	37
Quantité d'énergie e-carburants (100% élec)	0,0	0,4	4,9	8,7	97
Quantité d'énergie électrique (quai / bord)	[illegible]	0,0	0,0	0,0	0

	2024	2030	2040	2050
[illegible]	0,0	0,0	0,4	[illegible]
[illegible]	0,0	[illegible]	[illegible]	6,8
Nombre de méthaniseurs	0,0	25,1	34,7	19,6



Technologies de décarbonation

TECHNOLOGIES EXISTANTES	TECHNOLOGIES A DEVELOPPER
Production de Biocarburants (biofuel, biomethane, biomethanol) (FR, UE et non UE)	Vélique: rotors Flettner, Turbines éoliennes - WindMill (FR, UE et non UE)
Forme de la coque (chantier naval non UE)	Carbon Capture Utilization & Storage (UE et non UE)
	Drone de nettoyage de coque (FR, UE et non UE)
	Production d'e-fuels (FR, UE et non UE)
	Pile à combustible (FR, UE et non UE)

Thématiques particulières à travailler
(infrastructure, réglementation, formation, financement…)

Carburants bas-carbone	Offre de carburants bas-carbone en France, notamment biodiesel, bio/e-méthane, bio/e-méthanol, e-ammoniac avec fiscalité / prix favorables
Carbon Capture Utilization & Storage	Logistique terrestre du CO_2 (déchargement du navire, transport terrestre, enfouissement)
Réglementation	Normes et méthodologie d 'évaluation de gain énergétique à homogénéiser pour l'énergie éolienne (Vélique) Diffusion d'un référentiel des économies de carburants théoriques pour chaque RFNBO
Financement	OPS: l'électricité au port sera-t-il subventionnée?, quelles garanties sur son origine renouvelable sera disponible? Redistribution des taxes collectées pour la recherche et les aménagements

Démonstrateurs à déployer

Démonstrateur 1	**Navire à propulsion vélique**	*Surcoût système vélique : 15-25 M$*
Démonstrateur 2	**CCUS : navire avec capture de CO2 à bord et gestion de la logistique du CO2 à terre**	*Capture à bord : 25 M$ CAPEX + 20 M$ OPEX cumulés* *Logistique CO2 à terre : 10-30 M$ OPEX cumulés*
Démonstrateur 3		
Démonstrateur 4		
Démonstrateur 5		

2. "Gas tankers" working group

GT Navires transporteurs de gaz
Membres du GT

[illegible]	[illegible]	[illegible]
DGAMPA	Corinne Naumer	Adjointe au sous-directeur Sous-direction de la sécurité et de la transition écologique des navires
DGAMPA	Romain Cazzato	Adjoint au chef de bureau, pour les affaires relatives à la transition écologique et à la réglementation environnementale des navires
Armateurs de France	Pierre-Antoine Rochas Pryce Pardo (stagiaire)	Responsable Environnement
[illegible]	Romain Provost	Global Advisor Energy Transition
France Gaz Maritime	Joëlle Yvard	Directrice Générale
[illegible]	Thomas Mouline	Délégué Recherche et Développement, Innovation et Numérique
Union des Ports de France	Mathilde Fortet	Responsable des affaires économiques & européennes
MEET 2050	[illegible] Philippe Renaud [illegible] [illegible] Jean-François	Co-fondateur Directeur Technique
[illegible] Energy	M Montegut Samuel Tremouille	
France LNG Shipping	Véronique Pissier-Alessio	Directrice Générale
[illegible]	Antoine [illegible]	Ingénieur, Chef de projet
[illegible]	David [illegible]	[illegible]
GAZOCEAN	JF Castel	Pilote du GT
GAZOCEAN	C. Gallone	Pilote du GT
GAZOCEAN	M. Antici / J. Samson / F. Lalau	[illegible]
GAZOCEAN	R. Jolivet	Président
GAZOCEAN	Blaise Thomas	Stagiaire
GAZOCEAN	P. Boehler	Directeur technique
GTT	J. Boutard	
[illegible]	Arnaud [illegible]	Directeur de Flotte
[illegible]	Loïc [illegible]	Président
[illegible]	Claude Maurian	Directeur Maritime
[illegible]	Sean McCormack	Directeur Technique
[illegible]	[illegible]	
[illegible]	[illegible]	Superintendante
[illegible]	Claude Maurian	Directeur Maritime
[illegible]	[illegible]	
	Thomas [illegible]	Student [illegible]
[illegible]	Luc [illegible]	

GT Navires transporteurs de gaz
Membres du GT – Présentation du segment

Source statistiques Flotte de Commerce au 01/01/2024

Flotte pétrolière et gazière

	01/01/2024			01/07/2023			01/01/2023		
Catégorie	Nbre	J.B.	TPL	Nbre	J.B.	TPL	Nbre	J.B.	TPL
pétroliers	25	1 661 653	3 093 573	27	1 687 937	3 172 732	27	1 556 724	2 920 004
Tranporteurs de gaz liquéfiés	25	2 366 797	1 912 020	17	1 558 050	1 249 571	15	1 335 556	1 083 706
TOTAL Flotte pétrolière et gazière	50	4 028 450	5 005 593	44	3 245 987	4 422 303	42	2 892 280	4 003 712

GT Navires transporteurs de gaz
Membres du GT – Présentation du segment

ORION GLOBAL

Orion Bohemia	JP MORGAN	JP MORGAN
Orion Gaugin	JP MORGAN	
Orion Hugo	JP MORGAN	
Orion Jessica	JP MORGAN	JP MORGAN
Orion Monet	JP MORGAN	
Orion Sea	JP MORGAN	JP MORGAN
Orion Sinead	JP MORGAN	JP MORGAN
Orion Sun	JP MORGAN	JP MORGAN

FLS/GAZOCEAN

Elisa Aquila	France LNG Shipping	Gazocean
Elisa Larus	France LNG Shipping	Gazocean
HHI NYK 11	France LNG Shipping	Gazocean
HHI NYK 12	France LNG Shipping	Gazocean
HHI NYK 13	France LNG Shipping	Gazocean
HHI NYK 14	France LNG Shipping	Gazocean
HHI Edison 1	France LNG Shipping	Gazocean
HHI Edison 2	France LNG Shipping	Gazocean
LNG Adventure	France LNG Shipping	Gazocean
LNG Endurance	France LNG Shipping	Gazocean
LNG Endeavour	France LNG Shipping	Gazocean
LNG Enterprise	France LNG Shipping	Gazocean

KNUTSEN FRANCE

ALICANTE KNUTSEN	KNUTSEN
EXTREMADURA KNUTSEN	KNUTSEN
FERROL KNUTSEN	KNUTSEN
GORDON WATERS	KNUTSEN
GRAZYNA GESICKA	KNUTSEN
IGNACY LUKASIEWICZ	KNUTSEN
LECH KACZYNSKI	KNUTSEN
MALAGA KNUTSEN	KNUTSEN
PARIS KNUTSEN	KNUTSEN
RAVENNA KNUTSEN	KNUTSEN
SAINT BARBARA	KNUTSEN

VSHIPS FRANCE

Gas Vitality	MOL	VSHIPS

GEOGAS

FREYCINET	GEOGAS MARITIME	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	GEOGAS MARITIME	[illegible]	[illegible]	[illegible]	[illegible]
LA CONDAMINE	GEOGAS MARITIME	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	GEOGAS MARITIME	[illegible]	[illegible]	[illegible]	[illegible]

GT Navires transporteurs de gaz
Propos liminaires METHANIERS

Etat de la flotte française	32 méthaniers - 3% de la flotte mondiale 1 navire souteur GNL (LBV)	Projections : 2030 - 45 navires 2050 - 60 navires
Particularités du segment de flotte	**Flotte homogène : capacité de transport de 175,000 m3 et système de propulsion "Moteur lent "2 temps" (Gaz Naturel/MDO/VLSFO)** **Fonction unique** : transport de gaz NATUREL liquéfié **Boil-off :** utilisation de la cargaison comme carburant.	Enjeux de la réduction des émissions de méthane imbrulé (methane slip) et émissions fugitives Décarbonation étroitement liée à la cargaison utilisée comme carburant. Optimisation du boil-off. Reduction de la consommation.
Qualification de la performance énergétique	EEDI, EEXI et CII applicables	Comparer les performances énergétiques Possibilité de faire des projections en fonction des objectifs règlementaires

GT Navires transporteurs de gaz
Propos liminaires navires transports de GPL

Etat de la flotte française	4 navires GPL - 3‰ de la flotte en numéraire et 5‰ en capacité. (255k m3) Age moyen < 4 ans	Projections : 2030 - 5 navires de 40k à 90k : 1x MGC, 2 x LGC & 2 x VLGC. 2050 – pas de projections
Particularités du segment de flotte	**Capacité de transport de 35k à 90k m3** **Système de propulsion :** Moteur lent 2t 6 cylindres, une seule ligne d'arbre, hélice à 4 pales et à pas fixe. • Hyundai Man B&W - 6G60 ME-C10.5 HL (dual fuel LPG) • Hyundai Man B&W - 6G50ME-C9.6-LGIP-HPSCR (dual fuel LPG) • Hyundai Man B&W - 6S50ME-B8.2 Types de navire : réfrigéré. **Fonction unique** : transport de gaz liquéfiés Utilisation de la cargaison (GPL) comme carburant.	**Emission : de réduire les émissions** Décarbonation étroitement liée à la cargaison. Enjeux de la réduction des émissions de méthane imbrulé (methane slip) et émissions fugitives
Qualification de la performance énergétique	EEDI, EEXI et CII applicables	Comparer les performances énergétiques Possibilité de faire des projections en fonction des objectifs réglementaires

Caractéristiques de la flotte

	Methaniers	GPL	Bunkering Tanker
			
Type de navire (longueur, puissance, UMS)	92 800 T, 174 000 m3, Puissance propulsive : 22 900MW "Dual-fuel" two-stroke engine	2T Dual Fuel 54000 T - 90 000m3 - Long. hors tout 173-180m 26000 T – 35 000m3 Long. hors tout 173-180m	9400 T, 18 000m3 Propulsion principale : 1750 MW
Répartition sur la façade	N/A	N/A	Méditerranée
Moyenne d'âge	3 ans	4 ans	3 ans
% de Construction française	0%	0%	0%
Consommation par type de combustible en 2022 (m^3)	252 700 MWh / navire / an Dont : 87% LNG 13% LSFO & MGO	Totalité flotte : 302 800 MWH Dont 25% GPL 75% Fuel	8700MWh Dont 25% Fuel 75% LNG
Consommation par façade 2022 (m^3 et port)	N/A	N/A	100% Méditerranée

Levier Efficacité énergétique
Evaluation des leviers

Au cours de 8 ateliers, le GT a étudié les leviers énergétiques suivants:

LEVIERS	
Carburants Alternatifs	Fuell Cell PEM
	Fuel cell SOFC
	Bio carburants
	Ammonia
	Méthanol
Propulsion Vélique	
Capture CO2	
Mesures Opérationnelles	Routage
	Trim optimisation
	Trim ballast optimisation
	Digital twins
	Voyage Opimisation
	Réduction de Vitesse
	Maintenance : anti fouling
	Predictive maintenance
	Engine Optimization
Mesures Design	Optimisation des formes
	Lubrification par air
	Révetements
	Alternateurs attelés
	Reliquefaction
	système de propulsion DFDE+PAC
	Réuction du méthane slip

Les leviers suivant n'ont pas été étudiés:

- **Branchement électrique à quai:** n'est pas exigé pour les navires transports de gaz liquefié à court terme ou moyen terme.
- **Batteries:** traité par les autres GT
- **Bio methane/e-methane:** il faudrait que ces produits soient transportés à bord des navires, qui utilisent evaporation naturelle de leur cargaison comme carburant. Ce marché n'est pas à ce jour considéré par les acteurs comme suffisamment significatif.

Levier Efficacité énergétique
Evaluation des leviers

Une évaluation a été réalisée en fonction des critères ci-dessous auquel est associé un barême (1 à 4)

Barême	Technique	Réglementaire	Opérationnel	Environnement	Financier
1	TRL <5	Pas de réglementation IMO ou classification	Incompatibilité avec l'opération du navire	pas de réduction des émissions	Capex et OPEX élevés
2	TRL < 5 Contraintes fortes pour implémentations à bord	Réglementation en cours de développement	Contraintes opérationnelles fortes	réduction des émissions < 10%	Capex élevés mais OPEX raisonables
3	TRL > 5 Contraintes fortes pour implémentations à bord	Réglemantation (guidelines) mais peuevnt encore évoluer	Contraintes opérationnelles limitées	réduction des émissions < 30%	CAPEX et OPEX raisonnables
4	TRL > 5 Pas ou peu de contraintes	Réglementation existante et applicable	Pas contraintes opérationnelles	réduction des émissions jusqu'à 90%	Capex et OPEX faibles

Levier Efficacité énergétique
Evaluation des leviers

Le résultat de cette évaluation est résumé par la matrice suivante:

LEVIERS		Scores					
		Techniques	Réglementaires	Opérationnels	Environnementaux	Financier	Total
Carburants Alternatifs	Fuell Cell PEM	3	3	2	4	2	**14**
	Fuel cell SOFC	3	3	2	4	2	**14**
	Bio carburants	2	2	2	4	1	**11**
	Ammonia	1	3	2	4	1	**11**
	Méthanol	4	3	2	2	3	**14**
Propulsion Vélique		3	3	2	4	2	**14**
Capture CO2		1	2	2	4	1	**10**
Mesures Opérationnelles	Routage Trim optimisation Trim ballast optimisation Digital twins Voyage Opimisation	4	4	4	2	3	**17**
	Réduction de Vitesse	2	4	4	2	1	**13**
	Maintenance : anti fouling Predictive maintenance Engine Optimization	4	4	4	2	3	**17**
Mesures Design	Optimisation des formes	4	3	4	2	3	**16**
	Lubrification par air	4	4	4	2	2	**16**
	Revêtements	4	4	4	2	3	**17**
	Alternateurs attelés	4	4	3	3	3	**17**
	Reliquefaction	4	4	3	3	2	**16**
	système de propulsion DFDE+PAC	3	3	2	2	2	**12**
	Réuction du méthane slip	2	4	4	4	3	**17**

Levier Efficacité énergétique
Evaluation des leviers

Deux categories emergent:

- Les leviers **mesures opérationnelles** et **mesures de design** qui peuvent être implémentés plus facilement, mais pour lequel les gains sur les émissions restent a priori limités,
- Les leviers **Propulsion Vélique, Capture de CO2 et carburants alternatifs**, qui nécessitent soit de gagner en maturité technologique, d'être disponibles sur le marché, un environnement réglementaire plus stabilisé, et une implémenatiion à bord qui entraine moins de contraintes techniques ou opérationnelles. Leur CAPEX et/ou les OPEX doit être aussi optimisés. En revanche ces leviers sont plus efficaces en terme de reduction des émissions.

Levier Efficacité énergétique
Carburants Alternatifs PAC

Levier	Description	Critères	Bénéfices	Difficultés	Potentiel estimé de réduction de GES	Construction Navires	Retrofit	Type de navire	Commentaires
Carburant alternatifs	Fuel cell PEM	Technologie	TRL 2024: 7 TRL 2030: 8 - Bon rendement	- Stockage hydrogène : Volume de stockage important	20%		Stockage de l'hydrogène à bord	[illegible]	Fuel Cell PEM en remplacement d'un DG ou plusieurs DGs. Réduction potentielle des émissions estimées à 20% maximum.
		Réglementaire		- Réglementation maritime non stabilisée					
		Opérationnel	opération à basse température -Démarrage rapide (et bon suivi des changements de charge)	[illegible]					
		Environnement	- Pas d'émissions (CO2, NOx, SOx, PM)						
		Financier	-OPEX ?	OPEX élevé					
Carburant alternatifs	Fuel cell SOFC	Technologie	TRL 2024: 6 TRL 2030: 9 -Consomme le BOG du navire - Rendement [illegible]	- Emprise au sol importante	20%			LNG	Fuel Cell SOFC en remplacement d'un DG ou plusieurs DGs. Réduction potentielle des émissions estimées à 20% maximum. Consomme le Boil Off
		Réglementaire		- Réglementation maritime non stabilisée					
		Opérationnel		- Temps de démarrage [illegible] Mauvaise réaction aux changements de charges					
		Environnement	- Réduction des émissions de [illegible] par rapport au auxiliaires Diesel - Pas de NOx/SOx						
		Financier	-OPEX faibles car pas de maintenance pendant [illegible] ans	CAPEX important ([illegible] vs une propulsion diesel conventionnelle)					

Levier Efficacité énergétique

Carburants Alternatifs Bio Carburants

Levier	Description	Critères	Bénéfices	Difficultés	Potentiel estimé de réduction de GES	Construction Neuves	Retrofit	Type de navire	Commentaires
Carburant alternatifs	**Bio Carburants** (FAME (fatty acid methyl ester), BTL biomass to liquid fuels, HVO (huile végétale hydrotraitée) ou HDRD (diesel renouvelable dérivé de l'hydrogénation)	**Technologie**	TRL 2024: 7 TRL 2030: 9 - les résultats ont montré que les performances du moteur étaient comparables à celles du diesel conventionnel (sur des applications terrestres).	Caractéristiques physiques et chimiques: ✓ Croissance microbienne ✓ Dégradation de l'oxygène ✓ Stockage pour une durée limitée ✓ Performance des moteurs sensible à la qualité des carburants et des réglages de certains paramètres	5%			LNG/LPG/LBV	Reduction des émissions GES estimée à 5% car le bio carburant remplacera le fuel pilot, qui représente une très faible contribution des émissions pour ce segment de flotte.
		Réglementaire		- Contraintes réglementaires pour l'utilisation comme carburant marin (MARPOL ne considère que les combustibles fossiles) (les moteurs doivent être re certifiés, en usine avec mesures de Sox et Nox, (ou éventuellement à bord mais cela reste difficile). La certification reste donc compliquée à obtenir -Il n'existe pas actuellement de charte partie existante pour ce type de carburant					
		Opérationnel		- Disponibilité : actuellement pas de disponibilité sur les points de soutages utilisés sur les routes maritimes. N'est pas adapté pour des navires au tramping ; éventuellement pour des navires sur des lignes fixes, avec point de soutage identifiés.					
		Environnement	- énergie respectueuse de l'environnement, non toxique et possèdent des propriétés similaires au carburant diesel - les émissions des moteurs biodiesel indiquent de meilleurs résultats par rapport aux carburants fossiles. (à confirmer pour les applications marines)						
		Financier		CAPEX: OPEX: Coût du carburant (3 fois supérieur au MDO)					

Levier Efficacité énergétique

Carburants Alternatifs Ammoniaque

Levier	Description	Critères	Bénéfices	Difficultés	Potentiel estimé de réduction de GES	Construction Neuves	Retrofit	Type de navire	Commentaires
Carburant alternatifs	Ammoniaque	Technologie	TRL 2022: 4 TRL 2030: 7 Le faible rapport air - carburant, stoechiométrique compense le PCI de l'ammoniac qui est inférieur à celui de la plupart des autres carburants standards ; le contenu énergétique est alors comparable dans le cylindre	vitesse de flamme faible par rapport aux autres carburants courants). Cela conduit à un processus de combustion plus lent, ce qui peut impacter le rendement. son énergie minimale d'inflammation d'environ 14 mJ est relativement élevée pour un gaz, ce rend difficile l'inflammation du mélange ammoniac/air. Il est nécessaire d'utiliser un préchauffage avec un système d'allumage (pilot fuel).	90%			LNG/LPG/LBV	Réduction des émissions estimée à 90% si remplacement du fuel [illegible] par l'ammoniaque comme carburant.
		Réglementaire							
		Opérationnel	Le stockage et la distribution du carburant sont similaires à celles du gaz de pétrole liquéfié (GPL).	Forte toxicité (aigüe), qui entraîne des conséquences sur la conception des systèmes de stockage, d'alimentation des moteurs et de post traitement. Gestion des fuites. Nécessité d'un personnel qualifié pour la manipulation du carburant et d'EPI adaptés.					
		Environnement	Pas d'émissions de CO2, Sox. Un rejet d'ammoniac dans l'environnement, même en grande quantité, n'entraîne aucun effet significatif à long terme, il est facilement dilué et désintégré dans l'environnement. (à confirmer)	Possibilité de production de N2O et d'ammoniac imbrûlé					
		Financier		CAPEX: OPEX: Coût du carburant (3 fois supérieur au MDO)					

Levier Efficacité énergétique
Carburants Alternatifs Méthanol

Levier	Description	Critères	Bénéfices	Difficultés	Potentiel estimé de réduction de GES	Construction Neuves	Retrofit	Type de navire	Commentaires
Carburant alternatifs	Méthanol	Technologie	TRL 2024: 7 TRL 2030: 8 Densité énergétique comme l'[illegible]	La position du mât de dégazage doit être définie en fonction de l'assiette et de la gîte. Le méthanol est plus lourd que l'air et retombe donc sur le pont. Il existe des solutions innovantes de d'évent sous la [illegible]	15%			LNG/LPG/LBV	Peu d'intérêt si ce n'est pas du méthanol vert car carburant secondaire nécessitant du fuel pilote.
		Réglementaire		Étude de dispersion : zones de gaz plus importantes ([illegible]) ; les études doivent être réalisées [illegible]					
		Opérationnel	Stockage à T ambiante Moins de volume utilisé que les GNL Retour d'expérience sur le transport	Gaz toxique Le méthanol est à l'état liquide jusqu'à 64°C et se vaporise au-delà. Disponibilité/Soutage					
		Environnement		10% de CO2 de moins si c'est du méthanol pas green (GNL 20%)					
		Financier		Coût élevé					

Levier Efficacité énergétique
Propulsion Vélique

Levier	Description	Critères	Bénéfices	Difficultés	Potentiel estimé de réduction de GES	Construction Neuves	Retrofit	Type de navire	Commentaires
Propulsion Vélique	Aile, voile, etc	Technologie	TRL 2024: 5 TRL 2030: 7 Diminue le besoin d'énergie donc possibilité d'utiliser du bio fuel peu disponible.	Équipement ATEX	25%			LNG/LPG/LBV	Estimation des réductions de GES autour de 25%, cela varie entre 5%-30% selon les technologies d'assistance vélique choisies.
		Réglementaire		Réglementation aérienne à respecter dans certains cas.					
		Opérationnel	Bonne image Plus grande autonomie Moins de soute donc plus de cargaison	Il faut routage météo associé pour en tirer un avantage. [illegible] Dynamique : Pas exploitable sur toute les lignes : privilégier transat et trans pacifique... Routage météo adapté nécessaire Conditions d'utilisation : Chenalage/ zone à fort trafic... Maintenance : Déséquipement de la voile compliqué Problème de gestion du [illegible]					
		Environnement	Énergie renouvelable et inépuisable, non fossile GES [illegible]						
		Financier							

Levier Efficacité énergétique
Capture CO2

Levier	Description	Critères	Bénéfices	Difficultés	Potentiel estimé de réduction de	Construction Neuves	Retrofit	Type de navire	Commentaires
Capture CO2	Absorption par solvant	Technologie	TRL 2024: 6 TRL 2030: 8	Stockage à bord du CO2	90%			[illegible]	Réduction des émissions estimée à 90% mais non démontrée à ce jour.
		Réglementaire							
		Opérationnel	-Utilisable pour la propulsion et production électrique -Utilisable avec tous les types de fuel	-Logistique du débarquement -Gestion du Solvant, y compris son débarquement					
		Environnement	Jusqu'à 90% du CO2 produit peut être capté						
		Financier		OPEX CAPEX important					

Levier Efficacité énergétique
Mesures Opérationnelles

Levier	Description	Critères	Bénéfices	Difficultés	Potentiel estimé de réduction de GES	Construction Neuves	Retrofit	Type de navire	Commentaires
Mesures Opérationnelles	Routage Trim optimisation Trim ballast optimisation Digital twins Voyage Optimisation	Technologie	TRL 2024: 9 TRL 2030: 10 Possibilité de mise en œuvre à court terme ces technologies peuvent être testées avant d'être déployées sur la flotte	Faisabilité: Qualité des données et manque de numérisation Efficacité sur routes régulières	15%			[illegible]	Réduction des émissions est estimée jusqu'à 30 % en combinant les leviers opérationnels. Gestion difficile des interactions entre les différents leviers.
		Réglementaire	[illegible] / SEEMP Plan de gestion de l'efficacité énergétique des navires						
		Opérationnel		Formation, requalification					
		Environnement	Réduction des émissions et de la consommation Gains estimés 15%						
		Financier							

Levier Efficacité énergétique
Mesures Opérationnelles

Levier	Description	Critères	Bénéfices	Difficultés	Potentiel estimé de réduction de GES	Construction Neuves	Retrofit	Type de navire	Commentaires
Mesures Opérationnelles	Réduction de vitesse	Technologie	TRL 2024: 5 TRL 2030: 5 Possibilité de mise en œuvre à court terme	Adaptation du navire (design, moteurs, etc.) au profil de vitesse sélectionné pour obtenir une réduction des émissions	15%			LNG/LPG	Mesure peu efficace car Augmentation du nombre de navires est nécessaire pour transporter la même quantité de marchandise. Réduction des émissions est estimée jusqu'à 10 % en combinant les leviers opérationnels.
		Réglementaire	Conformité à SEEMP Plan de gestion de l'efficacité énergétique des navires						
		Opérationnel							
		Environnement	Réduction des émissions et de la consommation Gains estimés jusqu'à 10 % en combinant les leviers opérationnels						
		Financier		Augmentation du nombre de navires pour transporter la même quantité de marchandises.					

Levier Efficacité énergétique
Mesures Opérationnelles

Levier	Description	Critères	Bénéfices	Difficultés	Potentiel estimé de réduction de GES	Construction Neuves	Retrofit	Type de navire	Commentaires
Mesures Opérationnelles	Maintenance / anti fouling Predictive maintenance Engine Optimization	Technologie	TRL 2024: 8 TRL 2030: 10 Possibilité de mise en œuvre à court terme		15%			LNG/LPG/LBV	Réduction des émissions est estimée jusqu'à 10 % en combinant les leviers opérationnels.
		Réglementaire	Conformité à SEEMP Plan de gestion de l'efficacité énergétique des navires						
		Opérationnel							
		Environnement	Réduction des émissions et de la consommation Gains estimés jusqu'à 10 % en combinant les leviers opérationnels						
		Financier							

Levier Efficacité énergétique
Mesures de Design

Levier	Description	Critères	Bénéfices	Difficultés	Potentiel estimé de réduction de GES	Construction Neuves	Retrofit	Type de navire	Commentaires
Mesures de Design	Optimisation des formes	Technologie	TRL 2024: 7 TRL 2030: 8 Les designs sont généralement adaptés à un profil, un tirant d'eau et une vitesse.		15%			LNG, LPG, LBV	N/A en retrofit Réduction des émissions estimée de 5% jusqu'à 15%.
		Réglementaire		La réglementation EEDI actuelle ne tient pas compte de la réalité d'exploitation des navires.					
		Opérationnel							
		Environnement							
		Financier							

Levier Efficacité énergétique
Mesures de design

Levier	Description	Critères	Bénéfices	Difficultés	Potentiel estimé de réduction de GES	Construction Neuves	Retrofit	Type de navire	Commentaires
Mesures de Design	Lubrification par air	Technologie	TRL 2024: 6 TRL 2030: 8 Adaptés aux gaziers car tirant d'eau pas important et la forme de la carène permet une bonne injection d'air.		8%			LNG/LPG	Pratique courante aujourd'hui. Solution adaptée aux gaziers car tirant d'eau pas important et la forme de la carène permet une bonne injection d'air
		Réglementaire							
		Opérationnel							
		Environnement		consommation électrique importante (utilisation d'un groupe en plus qui produit du méthane slip) adapté avec un alternateur attelé					
		Financier		consommation électrique importante (utilisation d'un groupe en plus qui produit du méthane slip) adapté avec un alternateur attelé					

Levier Efficacité énergétique
Mesures de design

Levier	Description	Critères	Bénéfices	Difficultés	Potentiel estimé de réduction de GES	Construction Neuves	Retrofit	Type de navire	Commentaires
Mesures de Design	Revêtements	Technologie	TRL 2024: 8 TRL 2030: 9 Anti-Fouling selection: type and thickness specifications (TPL, IIP, Speed)		5%			LNG/LPG	
		Réglementaire							
		Opérationnel							
		Environnemental							
		Financier							
Mesures de Design	Alternateurs attelés	Technologie	TRL 2024: 8 TRL 2030: 9		10%			LNG/LPG	Réduction estimée à 10% car diminution des émissions liées à la consommation des groupes électrogènes en mer.
		Réglementaire							
		Opérationnel		Étudier la puissance : De façon que l'hôtel load en mer puisse être alimenté par les alternateurs attelés, sans avoir à démarrer un groupe. Adapter le couple et la MCR lors du design du navire si il est équipé d'un alternateur attelé.					
		Environnemental	Diminuer le methane slip car le methane slip, qui est plus produit par moteurs 2t que par les 4 t.						
		Financier							

Levier Efficacité énergétique
Mesures de design

Levier	Description	Critères	Bénéfices	Difficultés	Potentiel estimé de réduction de GES	Construction Neuves	Retrofit	Type de navire	Commentaires
Mesures de Design	Reliquéfaction	Technologie	TRL 2024: 8 TRL 2030: 9		5%			LNG/LPG/LBV	Réduction estimée à 5% car cela permet de limiter l'utilisation du GCU.
		Réglementaire							
		Opérationnel	Unité standard sur les méthaniers qui permet de limiter l'usage du GCU						
		Environnemental							
		Financier							
Mesures de Design	Système de propulsion DFDE+PAC	Technologie	TRL 2024: 6 TRL 2030: 7	Le stockage de l'hydrogène à bord	20%			LNG/LPG/LBV	Aujourd'hui la majorité des navires méthaniers sont équipés d'une propulsion avec un moteur fonctionnant au gaz. Une propulsion DFDE permettrait d'offrir plus de flexibilité et permettrait de pouvoir transformer un groupe en pile à combustible, même en retrofit. Réduction estimée à 20% car remplacement d'un ou plusieurs DGs.
		Réglementaire							
		Opérationnel		Le stockage de l'hydrogène à bord					
		Environnemental							
		Financier							
Mesures de Design	Réduction du méthane slip	Technologie	TRL 2024: 6 TRL 2030: 7		30%			LNG/LPG/LBV	Parmi tous les leviers la réduction du méthane slip est le plus efficace pour la décarbonation. Il est estimé à 3% pour les moteurs 2T et 30% pour les moteurs 4T. Il sera intégré dans l'ETS en 2026
		Réglementaire							
		Opérationnel							
		Environnemental							
		Financier							

Thématiques particulières à travailler

(infrastructure, réglementation, formation, financement…)

Fuel Cell PEM	Poursuivre les développements pour confirmer la faisabilité de l'utilisation des fuel Cell à bord des navires gaziers. Développer les solutions de stockage hydrogène et de soutage d'un point de vue technique et réglementaire. Assurer la formation des équipages et des autorités portuaires à l'utilisation de l'hydrogène. Faciliter le suramortissement due à l'implémentation de cette technologie à bord. Soutenir la filière française hydrogène.
Propulsion vélique	Déployer des démonstrateurs à bord des gaziers pour confirmer la faisabilité et l' efficacité de l'assistance vélique. Assurer la formation des équipages à l'utilisation de ces technologies. Associer une solution de routage efficace à la solution vélique. Faciliter le suramortissement due à l'implémentation de cette technologie à bord. Soutenir la filière française.
Carbone Capture	Déployer des démonstrateurs à bord des gaziers pour confirmer la faisabilité de la technologie. Développer les solutions de stockage à bord et les infrastructures pour le déchargement du CO2. Assurer la formation des équipages à l'utilisation de ces technologies. Faciliter le suramortissement due à l'implémentation de cette technologie à bord.
Carburants alternatifs	Poursuivre les développements techniques des moteurs pour s'adapter aux carburants alternatifs. Assurer la disponibilité des carburants à un cout compétitif. Développer la chaine d'approvisionnement et de soutage des carburants. Amender la règlementation pour faciliter l'utilisation des carburant à bord des navires en toute sécurité. Assurer la formation des équipages et des autorités portuaires à l'utilisation des carburants alternatifs.

Démonstrateurs à déployer

Démonstrateur 1	*Carbone capture*	
Démonstrateur2	**Propulsion vélique**	

Thématiques particulières à travailler

(infrastructure, réglementation, formation, financement…)

Reduction du Méthane Slip	Poursuivre les développements techniques des moteurs pour diminuer le méthane slip.

3. "Large service vessels" working group

GT grands navires de service
Caractéristiques des flottes

	Les Abeilles	Genavir - Ifremer	Orange marine	GPM Nantes-St Nazaire	LDA - ASN
Type de navire	4 remorqueurs de sauvetage et d'assistance 1 navire lutte pollution 1 remorqueur de manutention d'ancre	4 navires océanographiques (571, 2803, 3559 et 7854 UMS)	6 câbliers (2 installation, 3 maintenance, 1 polyvalente), 1 navire de survey	Drague aspiratrice en marche	10 câbliers 3 SOV 1 cargo/océano (M.D.)
Répartition sur la façade	Boulogne sur Mer, Cherbourg, Brest, Toulon AHTS : marché du spot faç. atlant et med	Atlant. Nord/équatorial, Caraïbes, Pacifique, Nouvelle Calédonie	Worldwide, mais bases marine de Brest et de la Seyne-sur-mer + dépôt Catane (Sicile)	50% Nantes St Nazaire 50% Rouen / Le Havre	SOV: auj. Europe nord (hors France) Câbliers: worldwide (usine Calais)
Moyenne d'âge	17 ans	26 ans	10,6 ans	22 ans	20 ans
Construction française	0%	100% sauf futur NHS (Espagne) et Michel Rocard (UE)	0% sur les navires RIF 14% sur l'ens de la flotte	0%	0%
Consommation totale 2022	7001 m3	5 849 900 L	18155 m3 de MDO	MGO : 1200m3 GNL : 380 m3	66 963 mt
Consommation par façade 2022	Façade manche/atlant : 4089 m3 Façade médit : 2912 m3	30% Brest, 30% Toulon, 40% worldwide	Brest : 2250 m3 MDO Seyne : 2000 m3 MDO	50%/50%	10 % Calais, 30 % Europe, 60 % Worldwide (hors Marion Dufresne: 5000t à La Réunion)

Levier Efficacité énergétique
Réduction de la trainée

		Les Abeilles	Genavir - Ifremer	Orange marine	LDA-ASN
RETROFIT	Revêtement des carènes	Période importante à quai, difficile d'aller dans cette direction Etudes en cours sur la prévention du fooling par ultrason.	Pas très impactant	Nettoyage de la carène : passage de 5ans d'inter-carénage à 2.5ans Nettoyage de la carène à flot	Peintures antifouling incompatibles avec les faibles vitesses d'opération (câblier 4nds, SOV 6 nds) A suivre
	Modification du bulbe	NA	Pas compatible avec les navires océano		Nécessité propulseurs d'étrave => pas de bulbe effilé. Intérêt qu'en transit
	Modification de l'étrave	NA	A expertiser. Attention portée au bullage des équipements acoustiques sous coque		Bullage possible pour transit câbliers + M. Dufresnes Remplacement carénage hélices princ. Remplacement hélices/tuyères par profils + techn. améliorés par simulation num.
CONSTRUCTION NEUVE	Optimisation des formes	Chaque navire a une coque unique adaptée à l'exploitation Affinement des formes d'hélices Possibilité ajout de volets sur les propulseurs transverses d'étraves	Optimisation en bassin de carène	Essais en bassin de maquettes avec itération pendant le design du navire	Revêtement de la carène : idem Optimisation maximale de la résistance du navire (travail des formes navire/largeur). Affinement des formes et rendement d'hélices/tuyères. Bullage sous coque : idem

Levier Efficacité énergétique
Optimisation du rendement propulsif

	Les Abeilles	Genavir - Ifremer	Orange marine	GPM Nantes St Nazaire	LDA - ASN
RETROFIT	Propulseurs innovants : NA	Propulseurs innovants	Remplacement des propulseurs à pales variables par des propulseurs à pales fixes/vitesses variables (cas applicable au Descartes)	Propulseurs innovants	Possibilité de réduction de la puissance réactive sur les navires conçus dans les années 2000 (remplacement des convertisseurs). Remplacement des propulseurs principaux sur les diesel-électriques des années 1990.
CONSTRUCTION NEUVE	Difficile pour remorqueurs de sauvetage car besoin de beaucoup de traction, possible sur les autres navires	Propulsion électrique – DA électriques sur tous les navires.	Hybridation de la propulsion pour avoir une redondance GE/Batteries à la place de GE/GE Hybridation de la propulsion pour faire du Peak Shaving		Propulseurs innovants à meilleur rendement (propulsion diesel-électrique) comme les propulseurs trochoïdaux.

Armateurs de France

Levier Efficacité énergétique
Optimisation de la consommation d'énergie à bord

	Les Abeilles	Genavir - Ifremer	Orange marine	LDA - ASN
RETROFIT	Dès que possible passage éclairage en LED	Branchement à quai: en cours, mais ports peu équipés pour les puissances	Installer une connexion au courant quai sur tous nos navires	Recalibrage des besoins chaudière. Retrofit des batteries de climatisation par des solution HVAC plus efficaces (ex. : pompes à chaleur). Optimisation par installation d'équipements moins énergivores et moins puissants ou permettant d'ajuster la charge au juste besoin. Réutilisation chaleur fatale : ex. : ORC, TEG (Thermal Electric Generator) à effet Peltier-Seebeck. Eclairage : intégralement LED Gros moteurs électriques : utilisation de varia-teurs de fréquence Mise en place de VPMS (vessel performance monitoring system) pour un suivi factuel à haute fréquence de la génération et consommation d'énergie. Logiciel ESG (gestion de l'énergie) déjà à bord des navires en gestion LDA
CONSTRUCTION NEUVE	Optimisation des équipements , parc de batterie pour absorber les peaks de tension	Remplacement de l'hydraulique par de l'électrique (treuils de travail). Optimisation consommation climatisation/ventilation/éclairage. Batteries de puissance : peak sheaving et back-up opérationnel (évite le démarrage systématique d'un DA supplémentaire).	Avoir 1 étagement pertinent des puissances disponibles par GE suivant l'utilisation du Navire Avoir une connexion au courant quai universelle 50/60Hz	Remplacement de l'hydraulique par de l'électrique (treuils de travail). Optimisation consommation climatisation / ventilation / éclairage. Amélioration de l'isolation (choix des matériaux et application). Réutilisation chaleur fatale : idem Eclairage : idem Gros moteurs électriques : idem Mise en place de VPMS : idem Système de stockage d'énergie (ESS – energy storage system : batteries de puissance, volants d'inertie, supercondensateurs) : peak shaving et back-up opérationnel (évite le démarrage systématique d'un DG supplémentaire). Devenu un standard de l'industrie sur quasiment tous les navires de service à positionnement dynamique.

Levier Exploitation
Excellence opérationnelle et sobriété

RETROFIT & CONSTRUCTION NEUVE	Les Abeilles	Genavir - Ifremer	Orange marine	LDA - ASN
EXCELLENCE OPERATIONNELLE	optimisation vitesse/conso : propulsion hybride, routage météo	Routing météo : sur les transits longs identifiés.	Avoir les performances nécessaires pour travailler dans toutes les conditions acceptables pour réduire les downtimes météos	Routage météo : sur les transits longs identifiés. Routage d'autant plus efficace qu'il prend en compte les vents et les courants (peu de sociétés proposent aujourd'hui les deux).
SOBRIETE & REDUCTION DE LA VITESSE	Réduction de la vitesse sur transit ou patrouille	Travail sur le SEEMP et la notion de vitesse optimale.	Faire accepter aux clients : transit à P constante et non à V constante. Maintenir bollard pull 60T pr éviter de surconsommer même si demande client évolue vers BP 80T pr amélioration performance ensouillage cables.	Utilisation de solution d'aide à la décision pour un ajustement optimal de l'assiette et tirant d'eau.

Levier Exploitation
Nettoyage de coque et des hélices

RETROFIT & CONSTRUCTION NEUVE	LDA - ASN
NETTOYAGE DE COQUE	Evaluation du niveau de salissure des coques très régulier. Possibilité de développement de nouveaux services. Nettoyage très régulier de la coque par plongeurs ou robot sous-marin : préférable avec peinture antifouling adaptée (matrice dure) Problématique de la gestion des déchets.
NETTOYAGE DES HECILES	Polissage des hélices à flot très régulièrement.

Levier Energies et Infrastructures

Energies fossiles moins carbonées et transitoires GNL

GNC non envisageable

	Genavir - Ifremer	LDA - ASN
RETROFIT		Retrofit très (trop) couteux.
CONSTRUCTION NEUVE	GNL: Difficultés sur le volume nécessaire pour une autonomie similaire. Point à regarder pour les nouveaux navires suivant façades concernées. Moteur dual fuel: Piste intéressante pour les zones protégées, mais non existants sur le marché pour les petites puissances.	Difficultés sur le volume nécessaire pour une autonomie similaire. Point à regarder pour les nouveaux navires suivant façades concernées. Plutôt piste en moteur dual fuel (Diesel / GNL).

Armateurs de France

Levier Energies et Infrastructures

Biocarburants

	Genavir - Ifremer	Orange marine	LDA - ASN
RETROFIT	Diesel supérieur à B7 : Essais en cours sur encrassement des filtres et régulation. Problème de distribution et de coût.	Intéressé mais pour l'instant difficile à apprivisionner	Tests réalisés sur certains moteurs avec du B100. Niveaux d'encrassement corrects mais problématiques à long terme. Test réalisés sur l'île de Bréhat avec du B30. RAS.
CONSTRUCTION NEUVE	Diesel supérieur à B30 : Etude en cours sur encrassement des filtres et régulation. Problème de distribution, de coût.		Sélectionner des moteurs pouvant consommer plusieurs types de biocarburants à 100 % (B100)

Armateurs de France

Levier Energies et Infrastructures
E-carburants: Méthanol & ammoniac

	Les Abeilles	Genavir - Ifremer	Orange marine	LDA - ASN
RETROFIT	Adaptation au E-Méthanol envisagé			E-méthanol: Retrofit très (trop) couteux, voire techniquement impossible.
CONSTRUCTION NEUVE	Propulsion par E-Methanol ou Ammoniac selon degré de maturité technologique et disponibilité carburant	Méthanol/Bio-Methanol : Problème de distribution et de coût. Point éclair assez bas à 12°C. Manque de réglementation. Moins complexe à intégrer que le GNL pour des petits volumes. Intérêt moteur dual fuel Ammoniac: Gaz très dangereux et très toxique avec un très fort impact carbone en cas de fuite. L'encombrement des soutes a carburant est une contrainte majeure compte-tenu de la faible densité énergétique de l'ammoniac. Intérêt moteur dual fuel	Intéressé mais pour l'instant difficile à approvisionner	Méthanol / Bio-Méthanol : Problème de disponibilité, de distribution (à développer avec les autorités portuaires) et de coût. Point éclair assez bas à 12°C. oins complexe à intégrer que le GNL pour des petits volumes, possible pour les SOV mais probablement trop encombrant pour les câbliers Gaz très dangereux et très toxique avec un très fort impact sur l'effet de serre en cas de fuite. Rendement des moteurs médiocre ; possibilité lointaine d'utiliser des PAC à haute température. La réglementation n'est pas encore mature, donc difficile de se lancer dans de tels projets à ce stade. Meilleur encombrement que l'H2

Levier Energies et Infrastructures
Electrification - hybridation

	Les Abeilles	Genavir - Ifremer	Orange marine	LDA -ASN
RETROFIT	**Branchement:** Passage sur courant de quai de l'ensemble de la flotte	**Branchement quai:** en cours, mais les ports peu équipés avec nos puissances. **Habrydation:** Déjà une architecture électrique à la prop pour améliorer le bruit rayonné et la manoeuvrabilité.		**Branchement à quai :** - Projet en cours pour le terminal de chargement d'ASN à Calais sans le concours du port de Calais. A l'étape de la définition du besoin et d'identification de la solution technique. - Projet de dépôt de maintenance à Dunkerque. **Hybridation:** La majorité des navires de service avec DP est construit avec une architecture électrique pour la propulsion afin d'améliorer le bruit rayonné et la manœuvrabilité (souplesse et réactivité aux états de la mer).
CONSTRUCTION NEUVE	Courant de quai, propulsion hybride, parc de batterie pour absorber les peak de tension	Batteries pour assurer la redondance du DG au lieu d'un second DG. Architecture électrique en bus DC haute tension (bus continu) pour faciliter l'alimentation des gros consommateurs électriques (treuils…) et la régénération électrique en freinage.	**L'hybridation** Gasoil/Electrique est réellement efficace pour des câbliers neufs.	ESS pour assurer la redondance au lieu d'un second DG à faible charge (cf. Optimisation de la consommation d'énergie à bord ci-dessus). Architecture électrique en bus DC (bus continu) pour faciliter l'intégration de l'ESS, réduire la puissance réactive, l'alimentation des gros consommateurs électriques (moteurs de propulsion, treuils…) et la régénération électrique en freinage. Pour les SOV : ESS dimensionné pour opérations dans les champs éoliens intégralement électriques avec recharge en mer.

Levier Energies et Infrastructures
Propulsion par le vent

	Les Abeilles	Genavir - Ifremer	Orange marine	LDA-ASN
RETROFIT	Participation au développement de la propulsion par aile de Kite avec la société Beyond The Sea			Peu de possibilité en rétrofit, navires très compacts sans beaucoup de place pour installer les piedestauxis nécessaires. Assistance vélique par kite : à évaluer sur câbliers pendant les transits, si un système est validé (tous sont en cours de développement).
CONSTRUCTION NEUVE	Propulsion par Kite	Études en cours, difficulté pour trouver le bon compromis système/opérabilité du navire (lieux très variés, peu de transits longs, fardage induit compliqué et espace de travail à conserver). Difficultés à avoir de la part des fournisseurs de valeurs fiables de gain. Appoint lors des transits. De ce fait, les gains sont minimes sur nos navires. Néanmoins, GT de navire océano-vélique en cours pour affiner les conclusions sur ce point.	A évaluer	Études en cours, difficulté pour trouver le bon compromis système/opérabilité du navire (lieux très variés, peu de transits longs, fardage induit compliqué et espace de travail à conserver). Utile uniquement en transit. De ce fait, les gains sont réduits. Assistance vélique par kite : idem

Levier Energies et Infrastructures
Hydrogène

<table>
<tr><th></th><th>Les Abeilles</th><th>Genavir - Ifremer</th><th>Orange marine</th><th colspan="2">LDA - ASN</th></tr>
<tr><td>RETROFIT</td><td></td><td>Possibilité de PACK pile à combustibles à H2 pour production courant quai dans les ports non équipés.</td><td></td><td>Possibilité de branchement à quai sur des PAC H2 pour production courant quai dans les ports non équipés de courant quai.
Retrofit H2 : peut être envisagé sur le pont pour un SOV (comme source limitée d'énergie).</td><td rowspan="2">Etude complète réalisée pour un client de navire SOV démontrant la faisabilité de la solution H2 pour une autonomie de 2 jours, l'hydrogène étant produit et souté directement au sein du champ éolien offshore. Solution non développée encore du fait de l'absence d'installation d'hydrolyseurs dans les champs offshore existants. Une autre solution avec soutage à quai est aussi à l'étude.</td></tr>
<tr><td>CONSTRUCTION NEUVE</td><td>Via e-méthanol</td><td>Hydrogène : participation au projet REDII Bretagne.
Difficultés du stockage à bord incluant l'aspect sécuritaire fort sur ce gaz, le volume plus important (mini x4 hors pile) et donc une autonomie plus faible. Problème d'approvisionnement (pas de possibilité de créer la chaine d'approvisionnement) et coût.
Peut-être possible sur des navires de façade, mission courte et soutage à un port fixe.</td><td>A évaluer</td><td>Possibilité de branchement à quai sur des PAC H2 : idem
Difficultés du stockage à bord incluant l'aspect sécuritaire fort sur ce gaz, le volume plus important (mini x4 hors pile) et donc une autonomie plus faible. Problème d'approvisionnement (pas de possibilité de créer la chaine d'approvisionnement) et coût.
Peut-être possible sur des navires de façade, mission courte et soutage à un port fixe, type SOV sur champ éolien européen.</td></tr>
</table>

Levier Energies et Infrastructures
Nucléaire

	LDA - ASN
RETROFIT	**Retrofit impossible.**
CONSTRUCTION NEUVE	**A moyen/long terme (10-15 ans), on peut espérer que l'un des développements en cours (typiquement réacteur à sel fondu – molten salt) sera approuvé. Cela pourrait constituerait une très bonne solution pour les câbliers de pose et le successeur du Marion Dufresne. Néanmoins restera le sujet de l'acceptabilité sociale de cette solution, et surtout l'adaptation nécessaire du corpus réglementaire mondial en la matière (conventions portant sur le transit et les escales de navires à propulsion nucléaire).**

Armateurs de France

Scenarios d'évolution de la flotte
Les Abeilles

Branchement sur courant de quai de la totalité de nos navires (déjà 3 navires connectés), devrait permettre une économie de consommation gasoil d'au moins 30% (sur les navires pas encore branchés) :

L'Abeille Normandie basée à Boulogne sur mer passe environ 70% de son temps à quai, soit 35% de sa consommation annuelle de gasoil.
=> Besoin de disponibilité de courant de quai idéalement en 690V ou 440V, 60 Hz mais nous pouvons convertir la fréquence et la tension (car à priori le courant fourni sera en 380V / 50 Hz). La puissance minimum à fournir est de 300 KW
Le besoin en financement pour pouvoir connecter le navire par couplage sur courant de quai est d'environ 300 k€

L'Abeille Bourbon basé à Brest passe environ 85% de son temps à quai.
=> Besoin de disponibilité de courant de quai en 380V, 50 Hz, avec un ampérage de 500A, et une puissance moyenne de 160 KW.
Le besoin en financement pour pouvoir connecter le navire par couplage sur courant de quai est estimé entre 150 et 200 k€

Partenariat de développement en cours avec la société Beyond the Sea pour le déploiement de Kite. Le système va être installé à bord au printemps et durant l'été. Premiers essais à l'automne avec une aile de 50 m2, puis augmentation de la taille de l'aile sur les années suivantes pour arriver à 400 m2.

En ce qui concerne le verdissement de sa flotte, outre **les problèmes techniques** que rencontrent tous les armateurs, LES ABEILLES est soumis aux contraintes supplémentaires suivantes :

- Pour le renouvellement ou le retrofit, les Abeilles est soumis aux critères imposés par les cahiers des charges des appels d'offres de la Marine Nationale. Sans mécanisme d'aide, elle ne peut financièrement pas soutenir des surcoûts environnementaux car sinon nous n'avons aucune chance de les remporter
- Propulsion vélique compliqué (hormis Kite) car nos navires rencontrent des conditions météos extrêmes difficilement incompatible avec la portance des mats (même sans voile)
- Programme d'exploitation aléatoire car une opération de sauvetage peut durer 1 journée comme 1 mois

Armateurs de France

Scenarios d'évolution de la flotte
Les Abeilles

Avec comme préambule ce qui a été dit ci-dessus, la stratégie de renouvellement de flotte est donc liée aux échéances contractuelles avec la Marine Nationale et si ceux-ci le permettent nos futurs navires devraient proposer les optimisations suivantes :

- Propulsion hybride (pour ajuster au mieux les différences opérationnelles entre patrouille à faible charge et puissance élevé requise pour opérations (vitesse et Bollard Pull)
- Réduction de la vitesse de patrouille, dépendant cependant des ordres du préfet Maritime.
- Amortissement des peaks électriques par rack de batterie pour limiter la taille des groupes électrogènes
- Moteurs principaux et groupes électrogènes fonctionnant au E-méthanol ou à l'ammoniac selon la maturité de production de ces combustibles
- Branchement sur courant de quai
- Routage météo

Armateurs de France

Scenarios d'évolution de la flotte
Génavir - Ifremer

La feuille de route de renouvellement des navires océanographiques est en cours de réalisation et sera disponible mi 2024.

- Nouveau navire : NSH entrée en flotte en 2025 a la capacité à mi-vie (2045) d'être jumboïsé pour changement de propulsion/d'énergie si une technologie est mature à ce moment-là.
- Navire Michel Roccard : arrivée en flotte en 2027. Ce navire devra répondre au code Polaire et aux réglementations australiennes. Un.e étude est en cours sur le système propulsif possible.
- Remplacement de l'Atalante : Probablement, 2030-2032, une réflexion est amorcée pour y inclure une propulsion la moins impactante possible et compatible avec l'activité.

Une réflexion est en cours avec les utilisateurs (la communauté scientifique) pour modifier les usages ou la répartition dans le temps des différentes campagnes récurrentes tout en conservant les objectifs scientifiques, par exemple :

- développement de la télé science (moins de personnes embarquées => navire plus petit?)
- complément des campagnes avec des USV et AUV pour obtenir des données avec un support moins impactant. Cet usage est possible sur certains type de données seulement.
- ajustement des usages avec une miniaturisation des capteurs et minimisation des prélèvements.
- développement d'un voilier pour de la science extra-légère - GT de navire océano-vélique en cours pour affiner les orientations scientifiques possibles.

Armateurs de France

Scenarios d'évolution de la flotte
Orange marine

Nouveau navire hybride Gasoil/Électrique avec capacité à utiliser les courants quais, carène optimisée et puissance étagée. Identifier si l'apport d'un système vélique rétractable est réaliste.
Étudier les solutions de financement de ce type de navire si elles existent.

Améliorer le câblier René Descartes pour avoir une connexion avec le courant terre 50/60Hz et des propulseurs transversaux à vitesse variable moins consommateurs.

Armateurs de France

Scenarios d'évolution de la flotte
GPM Nantes St Nazaire

Les scénarios d'évolution de la flotte ne sont pas définis à ce stade. Du fait des caractéristiques de notre activité et de l'âge de la drague, une construction neuve est envisagée d'ici 2032. Les leviers probables seront :

- Efficacité énergétique des navires
- Exploitation
- Biocarburant/E-carburant
- Branchement à quai

Armateurs de France

Scenarios d'évolution de la flotte
LDA - ASN

1 : facile / relativement facile (peut être cher, ex. : tourner au HVO)
2 : modérément difficile ou cher
3 : difficile et/ou très cher

Scénario 1 : retrofit complet câblier coréen
- modifications pour courant de terre à Calais - 2
- consommer du B30 - 1
- système de routage météo et courants - 1
- changement des convertisseurs de propulsion - 3
- installation de systèmes de récupération de chaleur fatale - 2
- ajout d'un kite sur la plage avant - 3
- bullage sous coque - 2
- antifouling à matrice dure - 1

Scénario 2 : retrofit SOV
- consommer du HVO (solution déjà validée par le motoriste MAN) - 1
- augmenter fortement la taille du pack batteries (passer de 400 kWh à plusieurs MWh), adapter pour s'alimenter sur un système de recharge électrique en mer (responsabilité de l'opérateur du champ) et rester autant que possible complètement sur batteries lorsque le navire est à l'intérieur du champ éolien - 3
- PAC avec H2 sur le pont (responsabilité de l'opérateur du champ qui doit alors fournir de l'H2 à partir d'hydrolyseurs installés au sein du champ éolien lui-même) - 3

Scénario 3 : construction neuve câblier : prendre plus ou moins tout ce qui est listé.

Armateurs de France

Thématiques particulières à travailler

Les Abeilles	**Besoin de disponibilité de courant de quai principalement sur Boulogne sur mer et Brest**
Génavir - Ifremer	**Infrastructures électriques: branchement** **Réglementation à adapter aux technologie: SOLAS, div 215....** **Distrib nouveaux carburants, carto distrib GNL, Méthanol, Ethanol, Biogasoil, H2 (à court et moyen terme)**
Orange marine	**Infrastructures électriques** **Distribution efficace des bio et e-carburants** **Solutions de financement**
LDA - ASN	**Infrastructures électriques : branchement à quai à traiter en priorité.** **Réglementation à adapter aux différentes technologies : SOLAS, division 215, BV etc incluant la vie à bord, sécurité d'exploitation, les contraintes d'intégration ….** **Distribution des nouveaux carburants et cartographie des distributions GNL, Méthanol, Biogasoil (B10, B30, B100…), H2 à court et moyen termes.**

Armateurs de France

4. "Large ferries" working group

GT Grands Ferries
Propos liminaires

Particularités du segment de flotte Qualification de la performance énergétique	• Lignes et horaires fixes entre 2 ports ou plus	• Vitesse relativement élevée en comparaison d'autres secteurs
Particularités du segment de flotte Qualification de la performance énergétique	• Transport de volume, plutôt que de masse	• Espace contraint à bord • Hautes superstructures, retrofit solutions éoliennes difficile
Particularités du segment de flotte Qualification de la performance énergétique	• Navires à forte valeur ajoutée, durée de vie des navires élevée • Navires historiquement designés pour une ligne spécifique	• Coût élevé des navires • Difficultés à produire des navires en série
Particularités du segment de flotte Qualification de la performance énergétique	• Transport de passagers, règles de sécurités plus contraignantes	• Calculs stabilité état intact/après avarie incitent à construire des navires plus larges, à l'inverse des règles d'efficacité énergétique (EEDI) • acceptabilité ammoniac difficile
Particularités du segment de flotte Qualification de la performance énergétique	• Navires parfois designés pour desservir des ports de petite taille, difficiles d'accès	• Navires courts, moins efficaces énergétiquement
Freins à l'excellence opérationnelle	• Pour un ferry en ligne régulière au schéma opérationnel optimisé, toute contrainte sur l'activité en escale, ou en traversée est un frein à l'excellence opérationnelle	Obstacles potentiels : • Contrôles aux frontières (EES)/douane/contrôles sanitaires • Surface quai embarquement/débarquement réduite • Restriction locale de vitesse • Déviation de la route optimale (parc éolien, accès port non direct)

Caractéristiques de la flotte

	Armateur 1	Armateur 2	Armateur 3	Armateur 4
	Brittany Ferries	CORSICA linea	DFDS	La Méridionale
Type de navire (longueur, puissance, UMS)	Longueur : 180 m Puissance : 24 420 (MP) + 5380 (GE) 32 500 UMS	Longueur : 180 m Puissance : 31 400 (MP) + 5630 (GE) 32 200 UMS	Longueur : 174 m Puissance : 28 240 (MP) + 4700 (GE) 29 200 UMS	Longueur : 177 m Puissance : 26 200 (MP) + 3900 (GE) 30 800 UMS
Répartition sur la façade	100% façade MANCHE/ATL	100 % MEDT – CORSE Lignes : Marseille – Corse/ Algérie / Tunisie	100 % MANCHE EST	100 % MEDT – CORSE
Moyenne d'âge	18 ans	24 ans	14 ans	25 ans
% de Construction française	10%	30%	20%	0%
Consommation par type de combustible en 2023 (m^3)	HFO : 75 806 t MGO : 42 358 t GNL : 30 717 t	HFO : 76 878 t MGO : 18 978 t GNL : 2 656 t	HFO : 47 729 t MGO : 578 t GNL -	HFO : 42 211 t MGO : 4 370 t GNL -
Consommation par façade 2022 (m^3 et port)	100% façade MANCHE/ATL	100 % façade MEDT (MRS)	100% façade MANCHE EST	100% façade MEDT (MRS)

Levier Efficacité énergétique

Réduction de la trainée

RETROFIT	Revêtement des carènes	Peut générer des gains d'efficacité allant jusqu'à 10%. En particulier, l'adoption de peintures au silicone est particulièrement adaptée pour les navires à passagers ayant des vitesses d'exploitation élevées. A noter que les contraintes liées au processus contractuel de construction neuve d'un navire font que celui-ci n'est pas nécessairement livré avec un système peinture adapté à l'exploitation du navire. Un passage en cale sèche est alors à recommander.
RETROFIT	Modification du bulbe	Le rebulbing, ou changement de bulbe, peut être couplé à un reblading. Il est toutefois plus difficile à mettre en œuvre (durée d'arrêt technique augmentée). Les gains sont de l'ordre de quelques %. Un frein à l'adoption reste le besoin d'interopérabilité des navires au sein d'une flotte, avec des vitesses d'exploitation différentes. Le design du navire doit rester suffisamment souple pour lui permettre d'opérer une ligne plus rapide. Des gains supérieurs peuvent être observés pour certains navires au design spécifique, approche au cas par cas.
RETROFIT	Modification carène	Un allongement des formes du navires (ducktail) peut réduire la trainée et apporter des gains significatifs (5/10%). Les travaux de modifications peuvent toutefois être lourd à mettre en œuvre et impacter les durées d'arrêt technique
RETROFIT	Autres	Des dispositifs type ESD (Energy Saving Device) ayant pour but une amélioration de l'écoulement en amont et/ou en aval de l'hélice ont été testés, avec un succès mitigé, les gains étant difficilement mesurables. L'utilisation de safrans profilés a donné des résultats probants, même si les gains intrinsèques sont difficilement mesurables, car souvent couplés avec d'autres mesures
CONSTRUCTION NEUVE	Optimisation des formes	Une étude hydrodynamique numérique (CFD) peut mener à des propositions simples ou complexes de modifications de design, avec des gains allant de 5 à 20%. Ces études doivent nécessairement prendre en compte le profil opérationnel envisagé pour le navire (vitesse de croisière). Elles ont donc un impact majeur sur la performance énergétique du navire.

Nécessaire Envisagea Non applicable

Levier Efficacité énergétique
Optimisation du rendement propulsif

	Armateur 1	Armateur 2	Armateur 3	Armateur 4	Armateur 5
RETROFIT	Le reblading est une pratique répandue, très efficace dès lors que le navire est opéré à une vitesse différente de sa vitesse de design. Couplé à une réduction de vitesse, les gains mesurés vont de 8% à 18% selon les navires Un frein à l'adoption reste le besoin d'interopérabilité des navires au sein d'une flotte de ferries, avec des vitesses d'exploitation différentes au sein de la même flotte. Le design du navire doit rester suffisamment souple pour lui permettre d'opérer une ligne plus rapide. De(s) propulseur(s) d'étrave sont systématiquement installés sur les grands ferries pour leur permettre de manœuvrer sans assistance de remorqueurs. La protection des tunnels de propulsion par des déflecteurs est un axe de travail pour plusieurs armateurs. Les résultats restent difficilement mesurables (de l'ordre de 1-2%)				
CONSTRUCTION NEUVE					

Nécessaire Envisageable Non applicable

Levier Efficacité énergétique
Optimisation de la consommation d'énergie à bord

	Armateur 1
ORC	Les ORC permettant de produire de l'électricité à partir de chaleur, ne sont pas répandus dans le secteur. En retrofit, le manque de place caractéristique de ce type de navire est un frein.
Usage MP/GE	L'optimisation de l'usage des moteurs de propulsion par rapport à celui des auxiliaires est un sujet d'étude largement répandu dans le secteur. Les navires ont en effet a minima 2, voire 4 MP, et souvent 3 GE. Les alternateurs attelés sont largement répandus et contribuent à l'optimisation de la consommation d'énergie à bord. L'arrivée de batteries permettant de fonctionner sur les points de fonctionnements optimaux va rendre ce point encore plus important
Eclairage	Le sujet de l'éclairage est plus important sur ce type de navire que pour d'autres secteurs (espaces passagers, garage). Le passage aux LED est déjà très répandu.
HVAC	Les ferries disposent de systèmes de ventilation pour les garages, qui peuvent être optimisés à l'aide de variateurs de vitesse. La régulation de la température des locaux est également un sujet plus important pour les ferries que pour d'autres secteurs
Chaudières récupération	Les chaudières de récupération sont généralement installées dès le neuvage, et sont quasiment la norme sur ce type de navire

Nécessaire Envisageable Non applicable

Levier Exploitation

Excellence opérationnelle et sobriété

RETROFIT & CONSTRUCTION NEUVE				
EXCELLENCE OPERATIONNELLE	L'utilisation de routage météo se fait au cas par cas, selon les zones d'opérations. Elle est privilégiée sur les navires effectuant des traversées longues.	Outils d'aide à la décision : étudiés, mais pas encore systématiquement répan Difficulté d'estimation des gains	Les ferries, en ligne régulière à horaire fixes, sont moins sujets à la problématique du « just in time » que d'autres secteurs. Des problématiques saisonnières peuvent cependant survenir (disponibilité pilotes	Des formations internes se mettent en place progressivement.
	Importance de l'optimisation des temps d'escale (voir en intro)	Monitoring performance : répandu, en adaptation constante		Un besoin de formations externes, pour toute la filière, est nécessaire, commençant par les formations académiques jusqu'aux formations continues.
SOBRIETE & REDUCTION DE LA VITESSE	Les ferries, dont l'exploitation est dimensionnée par des horaires fixes, sont très sensibles à ce point. Ce levier peut être mis en œuvre au cas par cas, mais ne devrait en aucun cas être imposé			

Nécessaire Envisageable Non applicable

Levier Exploitation

Nettoyage de coque et des hélices

Si applicable seulement

RETROFIT & CONSTRUCTION NEUVE	Tous les armateurs
NETTOYAGE DE COQUE	Les navires à passagers sous pavillon français passent plus régulièrement en cale sèche et leur coque est donc nettoyée plus régulièrement. A noter que les pointures au silicone donnent des résultats parfois surprenants, avec un besoin faible de nettoyage. Le nettoyage à flot est effectué au cas par cas et permet des gains de vitesse, et donc de consommation, immédiats.
NETTOYAGE DES HELICES	Voir ci-dessus

Nécessaire Envisageable Non applicable

Levier Energies et Infrastructures

Energies fossiles moins carbonées et transitoires GNL et/ou GNC

RETROFIT

Retrofit GNL à coût élevé car remotorisation, mais aussi cuves de stockage et réseaux de distribution

CONSTRUCTION NEUVE

Mature techniquement, mais un investissement plus élevé, et des infrastructures/possibilités de soutage pas toujours présentes dans les ports, notamment sur les terminaux opérés par les ferries (peu de choix sur les possibilités de soutage, peu de navires de soutage adaptés)
Effet de methane slip à prendre en compte qui déprécie les effets positifs du GNL, notamment pour le type de moteurs (semi-rapides) installés sur les ferries. L'utilisation de valeurs par défaut, des émissions de méthane, non basées sur l'exploitation réelle et les niveaux de charge des moteurs, pénalise les choix qui ont été réalisés par les armateurs. Des méthodes de comptabilisation alternatives doivent pouvoir être validées dans le cadre réglementaire (par exemple, en se basant sur la moyenne des mesures réelles à bord, pondérée par la distribution de charge moteur).
Le Gaz Naturel Liquéfié est utilisé ou considéré pour 3 des 4 armateurs. A ce jour, 3 navires sont opérés (2 BAI, 1 CL), 3 sont en construction (2 BAI, 1 CL), et 2 sont à l'étude (LM).
Le GNL est apprécié pour sa maturité et sa capacité à répondre aux enjeux liés aux émissions locales, notamment pour des ferries dont les escales sont effectuées en zones urbaines et sa capacité à faire la transition vers des énergies moins carbonées : biométhane, e-CH4
On note aussi une tendance vers GNL à s'associer à l'électrique : propulsion LNG-électrique, ou hybridation

Nécessaire — Envisageable — Non applicable

Levier Energies et Infrastructures

Biocarburants liquides - gazeux

RETROFIT

Le plus simple techniquement à mettre en œuvre, pas besoin de retrofit pour du biodiesel
Cependant, le mix est limité à B25/B30 pour moteurs diesel (IAFP)
Le potentiel d'incorporation est plus élevé pour du biométhane, mais la problématique de liquéfaction/disponibilité pour le maritime et la possibilité, pour le secteur, d'avoir recours à des garanties d'origines (seul « produit » disponible en quantités) sont cruciaux pour permettre la décarbonation du GNL.
Aujourd'hui, le surcoût actuel comparé à du carburant d'origine fossile (2 à 3 fois plus cher) et sa disponibilité pour le secteur ne permettent pas d'envisager un recours accru à ce type de combustible.

Le soutage de biodiesel est utilisé ou testé par certains armateurs. La logistique spécifique (stockage dédié, soutage par camions) engendre toutefois des coûts supplémentaires qui viennent s'additionner à la différence de prix entre fuel fossile et biofuel.

Tous les armateurs reconnaissent le besoin d'intégration progressive de bio-carburants dans leur mix énergétique, à court et moyen terme.
Le soutage de bio-LNG devrait être bientôt testé. Il est important de noter sur ce point que la souplesse du dispositif de garanties d'origine aurait un rôle important à jouer pour le développement du bio-méthane pour le maritime. Il n'y a en effet que peu d'intérêt énergétique/environnemental à consommer de l'énergie pour liquéfier du bio-méthane gazeux à des fins d'utilisation sur les navires comme bio-GNL, quand sur un autre point du réseau, dans un terminal GNL, on procède à la regazéification pour injection dans le réseau.

CONSTRUCTION NEUVE

Nécessaire — Envisageable — Non applicable

Levier Energies et Infrastructures
E-carburants: Méthanol, Ammoniac, Hydrogène…

RETROFIT

Des CAPEX et adaptations techniques trop élevées pour les incertitudes évoquées ci-dessous, notamment pour des ferries.

CONSTRUCTION NEUVE

maturité faible pour e-CH3OH, e-NH3, e-CH4 et e-H2
Tous les armateurs reconnaissent que les e-carburants devront être la principale part de leur mix énergétique d'ici 2040. Il reste cependant difficile d'envisager une discussion avec un producteur d'énergie pour inciter au développement de ces carburants, pour des raisons de coûts de production qui sont encore trop élevés pour être considérés.
La mutualisation des besoins, avec un travail commun entre armateurs, est identifiée comme un moyen pouvant permettre d'accélérer le développement des e-fuels, tout en sécurisant les quantités nécessaires à la décarbonation progressive des navires de leur flotte
Ce travail reste cependant tributaire de l'identification de l'e-fuel en question : e-méthane ? e-ammoniac ? e-méthanol ? A l'heure actuelle, à l'image de la même question se posant pour le shipping mondial en général, il n'y a pas de consensus qui se dégage au sein des armateurs de ferrys français.

Nécessaire — Envisageable — Non applicable

Levier Energies et Infrastructures
Electrification – Hybridation du navire

RETROFIT

Types de projets d'électrification :
- Retrofit : Installation de dispositifs pour connecter les ferries au réseau électrique à quai, réduisant les émissions pendant l'escale, conformément aux normes environnementales.
- -Batteries pour manœuvres : Utilisation de batteries (10 MWh) pour des opérations zéro émission en escale et manœuvres. Cette solution est cependant limitée pour les longues traversées en raison du poids des batteries.
- Navires 100 % électriques : Option viable pour les courtes distances, bien que les limites d'autonomie et de poids des batteries demeurent des obstacles.

Capacité des ports :Les ports doivent fournir des puissances élevées pour alimenter les navires hybrides ou 100 % électriques, soit pour une charge simple (1-2 MW) ou une recharge de batteries (jusqu'à 20 MW), ce qui nécessite des infrastructures coûteuses.
Normes de connexion :Les standards actuels limitent la puissance à 6,5 MVA par câble, ce qui pourrait nécessiter des adaptations des installations portuaires pour atteindre des puissances jusqu'à 20 MVA, entraînant des coûts accrus.
Défis techniques :Les ferries doivent être équipés de multiples points de connexion pour s'adapter aux infrastructures, et l'automatisation des connexions est nécessaire pour optimiser les escales courtes.
Problématique de fréquence :Les différences de fréquence (les flottes de ferries représentées étant aussi bien équipés en 50 Hz qu'en 60 Hz) nécessitent des convertisseurs coûteux, augmentant les pertes énergétiques et les coûts. Les investissements dans des convertisseurs de fréquence doivent être portés par les ports et non chacun des navires.
Impact des véhicules électriques :L'électrification des véhicules transportés par les ferries impose des exigences de ventilation et de refroidissement accrues, ajoutant aux besoins énergétiques.
Enjeux économiques :Les coûts élevés d'hybridation, les subventions limitées, le prix de l'électricité, la nécessité de renouveler les batteries tous les dix ans, freinent l'adoption des technologies électriques

CONSTRUCTION NEUVE

Plutôt matures techniquement, mais des investissements conséquents à faire côté navire, avec des ROI très longs.

Nécessaire — Envisageable — Non applicable

Levier Energies et Infrastructures
Propulsion par le vent

RETROFIT	La structure même des Ro-Pax, avec des superstructures sur une partie importante de la longueur du navire, rend difficile l'installation de tels systèmes, en particulier en rétrofit
CONSTRUCTION NEUVE	faible intérêt lié à la vitesse d'exploitation des navires. Le respect des horaires étant crucial avec une clientèle passagers, le vélique n'est étudié par les armateurs Ro-Pax que pour de l'assistance à la propulsion Sur les lignes courtes (<4h), l'assistance vélique ne suscite pas d'intérêt car le temps de mise en œuvre diminue le retour sur investissement associé. Les traversées courtes empêchent également les possibilités d'aller chercher les zones ventées plus propices. Les traversées courtes sont d'autres part synonymes de trafic maritime transverse plus intense, zones où l'attention de l'équipage est dédiée en particulier à la veille anticollision. Sur les lignes longues (>4h), l'assistance vélique est ou a été à l'étude chez la majorité des armateurs. Toutefois, les vitesses d'opération de cette catégorie de navires sont un frein à l'adoption de tels systèmes, les gains envisagés étant de l'ordre de quelques pourcents. Sur des lignes opérées plus lentement, elle peut toutefois être une option intéressante.

Nécessaire Envisageable Non applicable

Thématiques particulières à travailler
(infrastructure, réglementation, formation, financement…)

Branchement électrique à quai	**Problématique de fréquence** :Les différences de fréquence (les flottes de ferries représentées étant aussi bien équipés en 50 Hz qu'en 60 Hz) nécessitent des convertisseurs coûteux, augmentant les pertes énergétiques et les coûts. Les investissements dans des convertisseurs de fréquence doivent être portés par les ports et non chacun des navires.
Besoin en financement	**- Les navires sont construits en majorité en Asie, ce qui bloque l'accès à de nombreux dispositifs de co-financements. - Concernant le courant quai, les dispositifs de financements visent en majorité les équipements portuaires. Ils devraient également inclure le retrofit des navires, coûteux sur ce segment (>1 M€ par navire)**

Démonstrateurs à déployer

Démonstrateur 1	*Ferry 100% électrique*	*Estimation du cout*
Démonstrateur2	*Solution vélique adaptée aux contraintes structurelles des ferries et à leurs opérations (retrofit / construction neuve)*	
Démonstrateur3	*Solutions décarbonées pour les infrastructures de branchement à quai des petits ports et/ou ports insulaires.*	
Démonstrateur4		
Démonstrateur5		