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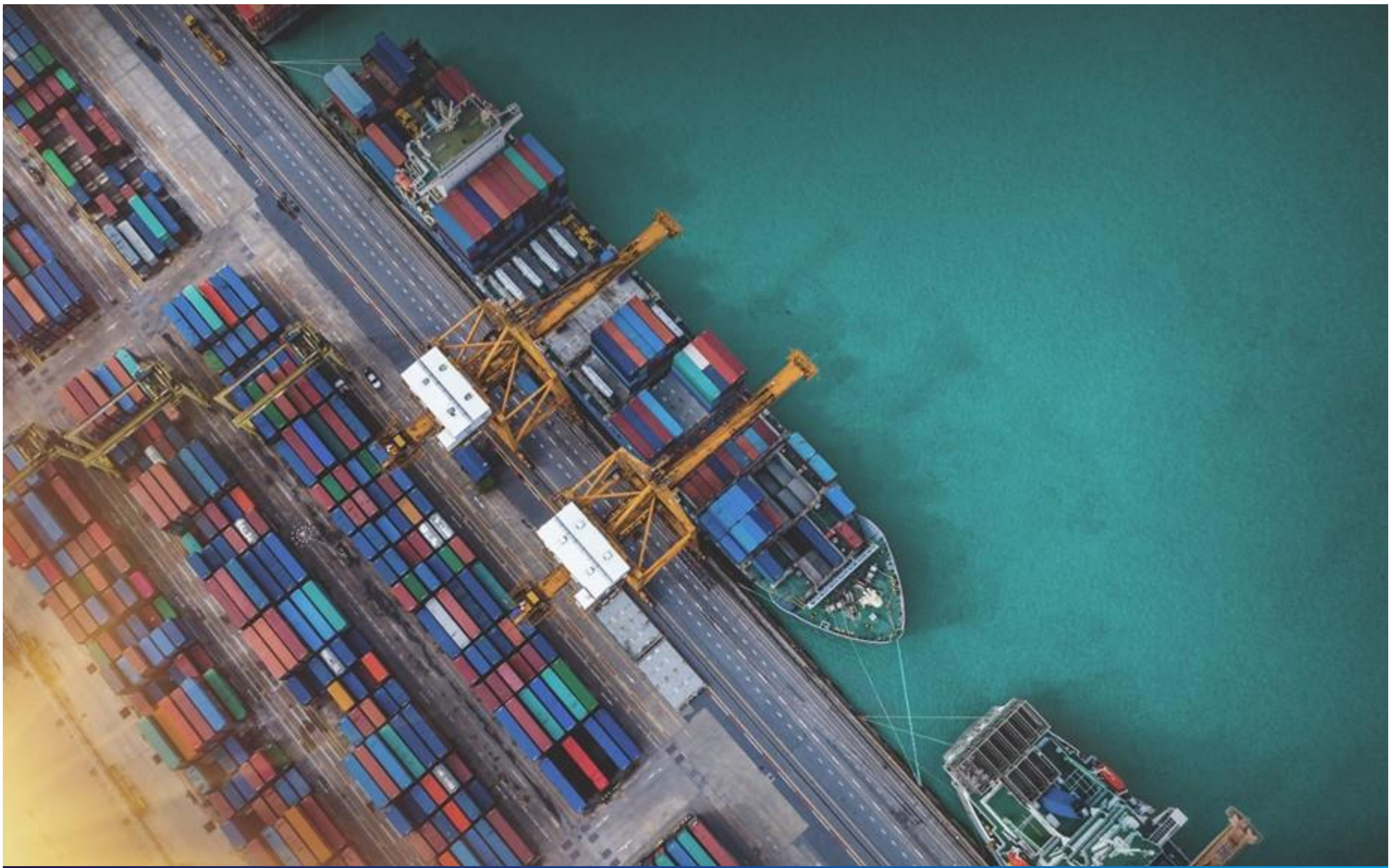

STUDY ON THE READINESS AND AVAILABILITY OF LOW- AND ZERO-CARBON TECHNOLOGY AND MARINE FUELS

Technical Proposal

For: International Maritime Organization

Ref. RFP 2022-08

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ED17328

Date:
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1. INTRODUCTION

IMO has requested proposals from qualified contractors to undertake a '*study on the readiness and availability of low- and zero-carbon technology and marine fuels*', reference RFP 2022-08.

The objective of this study is to evaluate the availability and feasibility of relevant fuels and technologies in three decarbonisation scenarios for shipping. The three decarbonisation scenarios will be compared to a business-as-usual scenario under current policies. The work feeds into the IMO's revision of the Initial GHG Strategy.

This Technical Proposal is submitted by Ricardo-AEA Ltd (Ricardo) and DNV AS (DNV). Ricardo is proposed as the contract lead for the IMO, with DNV as subcontractor to Ricardo. The organisations and key / main personnel are listed in Table 1-1.

Table 1-1: Team partners and key personnel.

Organisation	Country	Key / main personnel
Ricardo	UK	Tim Scarbrough, Michael Campbell, Graeme MacLean, Nick Powell
DNV	Norway	Tore Longva, Øyvind Endresen, Henrik Helgesen, Kristian Hammer

1.1 WHY THE RICARDO AND DNV TEAM IS WELL SUITED TO THIS PROJECT

Ricardo and DNV are well placed to deliver this work effectively and efficiently for the IMO for the following reasons:

- **Both Ricardo and DNV have extensive experience with all relevant topics for the study**, with access to state-of-the-art abatement databases covering technical and operational measures, alternative fuels, as well as onboard CCS. They have also been involved in a large number of decarbonisation pathway studies, applying their recognised abatement databases to explore in detail possible future energy and technology transitions.
- **We offer a team of more than one organisation to help meet the tight delivery schedule through parallel working**. We can do this through the clear allocation of roles and responsibilities between tasks.
- **The dual work of both Ricardo and DNV allows us to quality assure each other's work.** We have thorough and rigorous quality assurance processes that we will apply in this project.
- **We have a track record of carrying out technical studies that have tracked the technological readiness of technologies and fuels**, through studies such as for the IMO, OGCI & Concawe, the International Chamber of Shipping, and the Norwegian Ministry of Climate. As an engineering consultancy, Ricardo plc has an exceptionally strong heritage in R&D of technology. DNV as a ship classification society has more than 150 years' experience of working with safe and environmentally friendly application of technologies and solutions in the shipping sector.
- **We have previously successfully led work for the IMO and have included staff from that team in this proposal**. Using a team previously contracted to the IMO ensures a rapid contract signature with minimum commercial negotiation.
- **We are unbiased evidence providers taking a neutral position on fuels and technologies**. We demonstrate our commitment to decarbonizing the maritime sector through Ricardo's membership of the Getting to Zero Coalition and DNV's membership of the Maritime Technologies Forum, the Global Industry Alliance and the Global Centre for Maritime Decarbonisation.

1.2 STRUCTURE OF THIS PROPOSAL

The proposed method of work is further described in section 2, with an explanation of the 5 integrated tasks. The organisation of the project and milestones are provided in section 3, including the profiles of the key team of consultants. Further information about the team and relevant project references can be found in section 4.

A complete reference for where to find in this document all the items listed in the RFP cover letter are in the table below.

Table 1-2 Requirements in the RfP for the Technical Proposal, and where to find them in this proposal

RFP requirement	Where in this document
Company profile – signed vendor Registration Form	Provided separately
Company profile - Copy of the proposer's registration document/license(s)	Provided separately
Company profile - Descriptive summary of the proposer's (company's) professional capacity and experience, including a list of services relevant to the subject of this solicitation that were provided to other clients	Section 4
Company profile - Three references (with names and contact details: addresses and telephone numbers) of clients to whom projects of similar size and scope were delivered *&* *(a) Demonstrated financial and managerial capability for executing the contract. - Company to have minimum 3 years' experience in the required services*	Section 4
Proposed Personnel: Detailed CVs of proposed key personnel and potential replacement(s). *&* *(c) Proposed key personnel*	• Biographies of key personnel - section 3.3 • CVs of key personnel - Provided separately • Potential replacements - section 3.2
List of all proposed sub-contractors with indication of their role and full company details (including completed and signed Vendor Registration Forms)-if applicable	• List of sub-contractors – Section 1 • Indication of their role – Section 2 • Full company details as signed Vendor Registration Form - Provided separately
A Project Execution Plan. Description of the approach and plans towards satisfying and complying with the Terms of Reference and supporting the requirements set out in the RFP. (Applied methodology, knowledge/level of understanding, timelines, deliverables, etc.) *&* *(b) Proposed methodology.* *(d) Detailed implementation plan demonstrating the capability to provide the required services.* *(e) Timeline*	• Description of the approach / applied methodology – Section 2 • Knowledge / level of understanding – Boxes at the start of each Task • Timeline – Section 3.5 • Deliverables – Section 3.5 and 3.6
(f) Risk management plan	• Section 3.7

2. PROPOSED METHOD

2.1 SUMMARY OF APPROACH

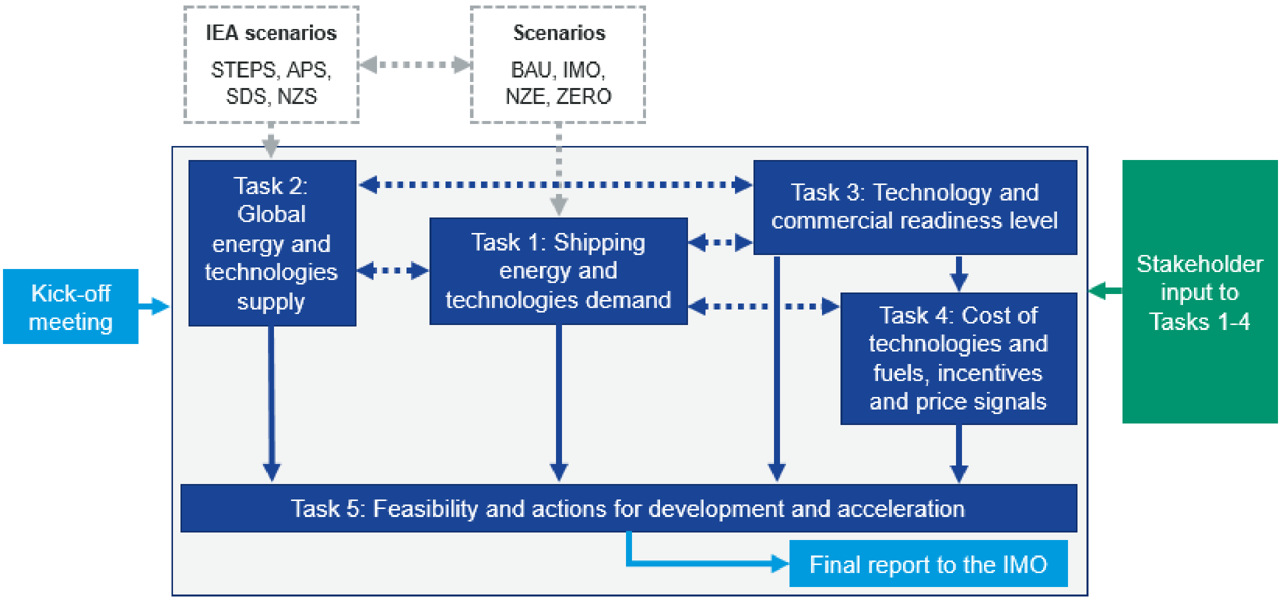
This section describes in detail the methods and data to be applied by the project team and how the items of the Request for Proposals (RfP) will be fulfilled. Note that the scope has been shifted between some of the tasks compared to the RfP.

The study will evaluate the readiness and availability of relevant fuels and technologies to decarbonise shipping to 2050 according to three scenarios and compared to a business-as-usual (BAU) scenario under current policies. Figure 2-1 shows a conceptual outline of the tasks in the project and how they connect. The BAU scenario and three decarbonisation scenarios are each linked to a similar IEA World Energy Outlook scenario providing framing and projections of relevant technologies and energy supply.

Task 1 will describe shipping scenarios and develop a GHG pathway for each scenario. The energy and technology demand per year required to achieve the pathway will be modelled to 2050. Task 2 will provide projections on energy supply and related fuel production technologies development outside the shipping sector according to IEA scenarios and compared to other relevant projections. The task will also assess port and refuelling infrastructure projects and ship-yard capacity. Task 3 will assess the current and projected Technology Readiness Level (TRL) and Commercial Readiness level (CRL) for each shipping technology and fuel. Included will be shipping technology and fuel in TRL/CRL, such as mature, large prototype, demonstration, early adaptation. The projections on energy and technology availability and supply on ship and on land will provide the basis for assessing the potential shipping energy mix and the gaps between demand and supply of energy efficiency and fuel technologies in each scenario – i.e. there are links between Tasks 1, 2 and 3 in this way. Task 4 explores the costs and other barriers to deployment of those technologies and fuels and then identifies the scale of incentive required to make the future fuels competitive and drive adoption.

Task 5 will integrate and synthesise the findings from Tasks 1 to 4 through assessing the gaps between what is needed (demand) and what is projected (supply) of energy efficiency technologies and fuel technologies and fuels in each scenario, and evaluating potential actions to further remove barriers and accelerate development and uptake. Task 5 will therefore also summarise the findings of the study.

Figure 2-1: Conceptual outline of tasks.



Sections 2.3 to 2.7 describe the tasks in more detail with methods and data sources.

2.2 ALLOCATION OF ROLES BETWEEN RICARDO AND DNV AMONG TASKS

Table 2-1 contains the breakdown of the subtasks and how they are allocated between Ricardo and DNV to lead. Additionally, Ricardo will lead on project management and will lead the meetings, and both Ricardo and DNV will carry out quality assurance in this study.

Table 2-1: Task list and allocation of roles

Subtask	Description	Output	Lead
Task 1 Shipping energy and technologies demand			
1.1	Define shipping scenarios	Description of four scenarios with characteristics, and seaborne trade growth	DNV
1.2	Model shipping energy and technology demand	Table with key indicators per segment and scenario	DNV
1.3	Project GHG emissions associated with shipping's energy demand	Well-to-tank GHG emissions per scenario	DNV
Task 2 Global energy and technologies supply			
2.1	Assess carbon-neutral fuels production capacity	Estimated future fuel production globally for each GHG emission reduction scenario	DNV
2.2	Identify port and bunkering infrastructure projects	List of ports and bunkering infrastructure development projects	DNV
2.3	Investigate shipyard capacity	Estimation of shipyard capacity	DNV
Task 3 Technology and commercial readiness			
3.1	Define scope of assessment	*(Feeds in to next subtask)*	Ricardo
3.2	Gather and compile information from literature on current and expected TRLs and CRLs	Draft report write up with tables and graphs of TRLs/CRLs for technologies and fuels	Ricardo
3.3	Consult stakeholders on the draft current and expected TRLs/CRLs	*(Feeds in to next subtask)*	Ricardo
3.4	Finalise outputs on current, expected and future scenario TRLs/CRLs	Report write up with tables and graphs of TRLs/CRLs for technologies and fuels	Ricardo
Task 4: Costs of technologies and fuels, incentives and price signals			
4.1	Gather projections of the current costs of future fuels and technologies	Tables/graphs of costs and report write up	Ricardo
4.2	Describe the barriers to uptake of future fuels and technologies	Report chapter write up	Ricardo
4.3	Identify the possible incentives to accelerate commercialisation of new fuels and technologies	Report chapter write up	Ricardo
Task 5: Feasibility assessment and actions for development and acceleration			
5.1	Conduct gap and feasibility assessment	List of technologies and fuel/fuel input gaps per decade and scenario	Ricardo
5.2	Identify possible mitigating actions and pathways and summarise findings	Summary of feasibility assessment. Mitigating actions Discussion of realistic and achievable mitigation pathways to 2050	Ricardo

2.3 TASK 1: SHIPPING ENERGY AND TECHNOLOGIES DEMAND

Box 1 Understanding of Task 1

This task will establish three GHG emission pathway scenarios and model the energy and technology demand to achieve each pathway. A business-as-usual scenario will also be modelled including currently adopted regulations. The task is divided into three sub-tasks. The first will define the scenarios in dialogue with the IMO Secretariat; the second will model the scenarios and establish the fuel and technology demand and other relevant fleet indicators needed to evaluate the feasibility of the scenarios, which is part of Task 5; while the third sub-task will project well-to-tank GHG emissions based on a likely energy mix for each scenario.

Task 1 has the following milestones (the dates of the milestones assume a contract start of 1 December 2022):

- 15 December: Scenario storylines and seaborne trade growth scenarios concluded
- 1 February: Shipping energy and technology demand modelling completed
- 15 February: Well-to-tank emission projections completed

2.3.1 Sub-task 1.1: Define shipping scenarios

This task will define the storylines and other assumption for the four shipping scenarios to be modelled and used to determine the demand for energy and technologies to achieve a certain GHG emission pathway.

Table 2-2 shows the proposed shipping scenarios with characteristics and GHG emission target for 2050. Each scenario is mapped to a corresponding IEA World Energy Outlook scenario. The GHG target for the Net Zero Emission (NZE) scenario will be set based on IEA's corresponding NZE scenario estimate for shipping in 2050 adjusted to include only international shipping, while the target for the current IMO GHG Strategy ambition of 50% total GHG emission reduction will be set based on the estimated GHG emissions for 2008 in the 4th IMO GHG Study. The Zero by 2050 (ZERO) scenario will peak emissions as soon as possible, following IPCC's emission pathway that limits the temperature increase to 1.5°C modelling targeting a 45% emission reduction in 2030 relative to 2010 and then achieving zero emissions in 2050.[1]

Table 2-2: Proposed shipping scenarios, corresponding IEA scenarios and indicated GHG emission targets.

Shipping scenario	Characteristics	Corresponding IEA scenario	2050 GHG emission target
Business as usual (**BAU**)	Currently adopted IMO regulations (EEDI, EEXI, CII and SEEMP)	Stated policies	No target
Initial IMO Strategy (**IMO**)	50% GHG emission reduction in 2050 compared to 2008	Sustainable development	~450 Mt
Net Zero Emission (**NZE**)	Based on the IEA net zero emissions scenario stipulating 120 MT GHG emission from shipping in 2050	Net zero	~120 Mt
Zero by 2050 (**ZERO**)	Peak emissions as soon as possible, reaching 45% reduction in 2030, relative to 2010, and zero GHG emission in 2050, in line with a 1.5° pathway	Net zero	0 Mt

[1] See https://www.ipcc.ch/sr15/chapter/spm/

All GHG emission targets in the scenarios assume that fossil fuels are replaced with carbon-neutral fuels having zero or near-zero net emissions by 2050[2], although higher well-to-tank emissions can be expected in the short term, or fossil fuels with onboard carbon capture and storage (CCS).

The scenarios will either follow the same seaborne growth scenario using one of the scenarios provided in the 4th IMO GHG study, alternatively different scenarios can be chosen aligning the RCP (Representative Concentration Pathway) and SSE (Shared Socio-Economic) pathways. The actual growth scenario(s) will be selected in dialogue with the IMO. The proposal will be further refined as part of this sub-task, taking into account the other reputable sources and in dialogue with the IMO Secretariat.

Each scenario will also be compared to shipping scenarios in peer-reviewed literature and other relevant studies, such as 4th IMO GHG Study, DNV Maritime Forecast, Ricardo studies, the Maersk McKinley Møller Center, and UMAS/LR.

2.3.2 Sub-task 1.2: Model shipping energy and technology demand

The energy and technology demand in each of the four scenarios defined in subtask 1.1 will be modelled using DNV's GHG Pathway Model, a cost-based modelling tool for developing scenarios for decarbonisation of shipping.[3] The Pathway Model is used for projecting a future fleet based on a seaborne trade demand per segment. The model consists of a fleet development module and an abatement evaluation module. The fleet development module simulates scrapping and ship newbuilding year-by-year to 2050 with the objective that each segment can fulfil a given transport demand projection. The abatement evaluation module projects the uptake of energy efficiency measures, speed reduction and fuels based on net present value (NPV) calculations and reduction policies.

The modelling will provide the most cost-effective and appropriate balance of abatement measures that fulfils the GHG emission trajectory in each scenario. The output provides projection of both CO_2 and the main non-CO_2 GHG emissions (CH_4 and N_2O) using the emission factors provided in the 4th IMO GHG study, and from other estimates of future emission factors. The individual emissions will be summed to CO_2-equivalents using GWP100.

The output will be a set of indicators indicatively structured as follows:

- Years: 2022, 2030, 2040, 2050
- Fleet segments: Short sea – bulk/tank, deep sea – bulk/tank, short sea – container/unitised, deep sea – container/unitised, other
- Indicators: Tank-to-wake GHG (CO_2, CH_4 and N_2O) emissions, number of ships, age profile, energy use, share of carbon-neutral fuel, energy efficiency

The modelling needs to make assumptions of energy efficiency potential, costs and fuel prices in order to develop consistent fleet, technology and energy projections. **These will be calibrated with the maturity and cost data in Tasks 3 and 4.** However, results will only be provided at a high level in order to evaluate the demand for energy from fossil fuels, energy from carbon-neutral fuels and energy efficiency technologies. The results will not provide the uptake of each individual technology. Although IEA provides estimates for the energy use in shipping, we will use our modelling results for the required energy and compared with IEA and other sources. This demand will be matched with the energy supply and technology TRL and CRL in tasks 2 and 3 and assessed as part of Task 5. The age profile will also be provided which can be used to determine when a certain technology needs to be introduced for all new builds in order to have a certain uptake in the target year. It will also be evaluated against the yard capacity.

2.3.3 Sub-task 1.3: Project GHG emissions associated with shipping's energy demand

The GHG emissions associated with international shipping's forecasted energy demand, or well-to-tank emission, will depend on the energy mix and the global GHG intensity of producing the various fuels. In this

[2] Carbon-neutral fuels refer to a variety of energy fuels or energy systems that have no net GHG emissions. See Intergovernmental Panel on Climate Change (IPCC) definition of carbon-neutral at https://www.ipcc.ch/sr15/chapter/glossary
[3] See https://eto.dnv.com. The GHG Pathway Model does not form part of the deliverables.

task we will project the well-to-tank emission from the demand for energy in sub-task 1.2 and assuming a likely energy mix based on the supply from sub-task 2.1. The emission intensity of key input factors (cultivation and extraction), processing/transportation (e.g. electricity, carbon capture), and other emission (e.g. methane slip) will be estimated based on projections consistent with the scenario storylines by IEA, IPCC, DNV's Energy Transition Outlook, Ricardo's Technological, Operational and Energy Pathways for Maritime Transport to Reduce Emissions Towards 2050 (concawe.eu) and other relevant sources.

The output will be a well-to-tank GHG emission projection per scenario and pre-defined segments from 2022 to 2050.

2.4 TASK 2: GLOBAL ENERGY AND TECHNOLOGIES SUPPLY

Box 2 Understanding of Task 2

The transition towards carbon-neutral shipping requires large investments; it will lead to a massive shift in the energy mix and onboard technologies. Under the three emission reduction scenarios, task 2 will consider the developments in capacity of providing carbon-neutral fuels and required associated production technologies worldwide up to 2050. Sub-task 2.1 will map the developments on fuel supply and identify the availability of feedstocks globally and for the shipping sector. In sub-task 2.2 we will map the availability of carbon-neutral fuel supply in terms of projects and development trends related to port and bunkering infrastructure for such fuels (technology maturity is included in Task 3). In addition, in sub-task 2.3 the shipyards' historical delivery capacities, and planned deliveries of new vessels will be used to estimate shipyards capacities in supporting the accelerated uptake of technologies and fuels.

Task 2 has the following milestones (the dates assume a contract start of 1 December 2022):

- 1 February: Map capacity of providing carbon-neutral fuels and required associated production technologies
- 15 February: List of port and bunkering infrastructure projects
- 15 February: Shipyards' technical capacity

2.4.1 Sub-task 2.1: Assess carbon-neutral fuels production capacity

Under the three GHG emission reduction scenarios established in Task 1, this subtask will undertake a comprehensive consideration of energy and technology capacity and supply developments toward 2050.

We will first identify the potential carbon-neutral fuel pathways, their feedstocks, fuel production, including the specific production technology and the final fuel types/energy carrier. The technologies related to production will be evaluated in Task 3 for TRL/CRL, while this task focuses on the energy supply. The future fuel mix is highly dependent on the availability of sustainable energy sources and what feedstocks are available for production. The different fuels will be categorised in "fuel families" based on primary energy source:

- **Biofuels** from sustainable biomass sources to produce carbon-based fuels
- **Electrofuels** from renewable or low GHG electricity, to produce zero-carbon fuels (hydrogen, ammonia and electricity), or combined with captured non-fossil sustainable carbon to produce carbon-based fuels
- **'Blue' fuels** from reformed natural gas with Carbon Capture and Storage (CCS) to produce low-carbon fuels (hydrogen and ammonia).

Nuclear fuel, and fossil fuel with onboard CCS are also potential solutions to reduce GHG emissions. The supply of these fuels is not covered in this task, but the technologies will be assessed in Task 3 and 4 and included in the feasibility assessment in Task 5.

Figure 2-2 shows a decision tree from DNV's Maritime Forecast to 2050, explaining how the future fuel mix will be determined, depending on which resources and technologies are available. We will use this decision tree in Task 5 to determine a feasible energy mix. To provide the input we will, in this task, do a mapping of the four key indicators for selected years (2030, 2040 and 2050):

- Sustainable biofuel (EJ)
- Hydrogen (from renewable electricity) (EJ)
- Hydrogen (from reformed methane and CCS) (EJ)
- Sustainable carbon (Gt)

The mapping will be based on a literature review, mainly using the IEA World Energy Outlook, but supplemented by peer-reviewed literature and other references such as the IPCC, IRENA, DNV Energy Transition Outlook, Shell Sky scenario, and other global energy scenarios. The availability will be assessed both globally and for the shipping sectors. The literature review will be supplemented with input from fuel suppliers, bunker suppliers, research institutes and other experts both externally and internally in DNV and Ricardo. A sample table is shown in Table 2-3 indicates the output with a low to high estimate and IEA estimate in parenthesis.

Figure 2-2: Availability levels will determine which carbon-neutral fuels will be available for large-scale maritime use (Maritime Forecast to 2050, DNV 2022)

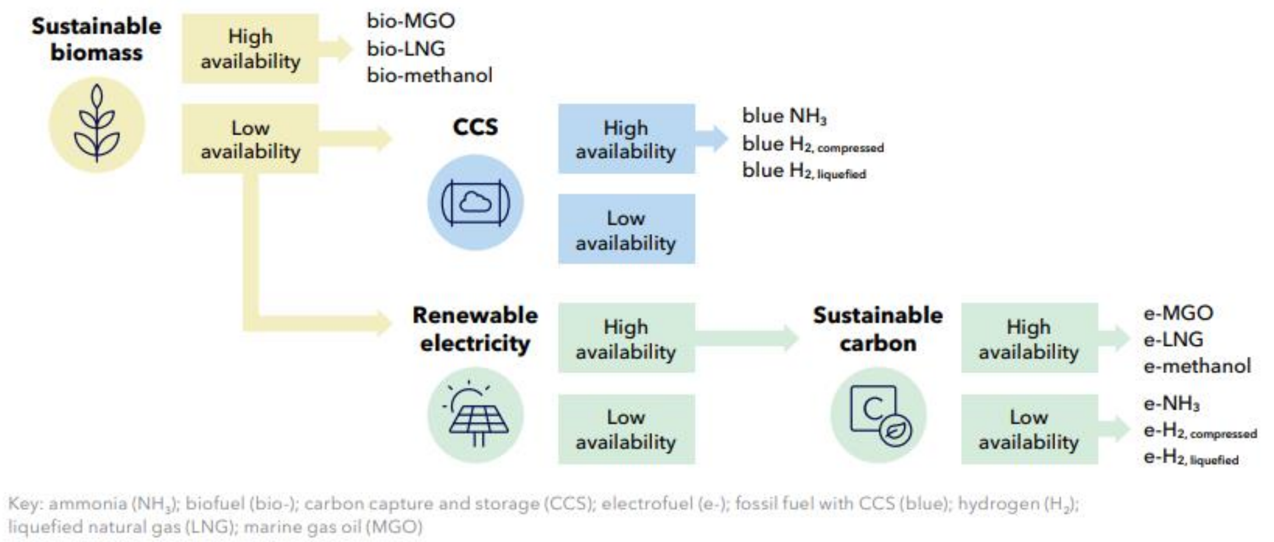


Table 2-3 Indicative table for the mapping of energy supply. IEA's estimate in parenthesis

Scenario	Indicator	2030	2040	2050
IMO	Sustainable biofuel (EJ)	10-24 (13) EJ	30-50 (45) EJ	50-80 (70) EJ
	…			

2.4.2 Sub-task 2.2: Identify port and bunkering infrastructure projects

Ports will play a key role in the green maritime transition by serving as energy hubs providing both shore-side electricity and infrastructure for storing and fuelling ships with future fuels. Most refuelling operations for deep-sea shipping take place today at the major refuelling hubs, which are located strategically along the major international trade lanes. The task will map global refuelling volumes/capacities and major bunkering hubs, as well as address the bunkering availability of different carbon-neutral fuels, anticipating that vessels may refuel more regularly with less energy dense fuels thus may not just refuel at today's major hubs.

The sub-task will deliver a list of port and bunkering infrastructure projects, with location, bunkering volumes and relevant fuel type (see *indicative structure,* Table 2-4). The task will use input from experts, port authorities, bunker suppliers, and other relevant stakeholders in the shipping value chain. The main sources will be DNV's Alternative Fuels Insight (AFI) portal, the World Ports Climate Action Program, and input from DNVs Nordic Roadmap project[4].

Table 2-4 Indicative structure for a list of port and bunkering infrastructure projects for carbon-neutral fuels

Project name	Project owner	Partners	Relevant fuel type	Location (Port, Country/Region)	Description of project (port/bunkering/infrastructure)	Bunkering capacity	Readiness level
…							

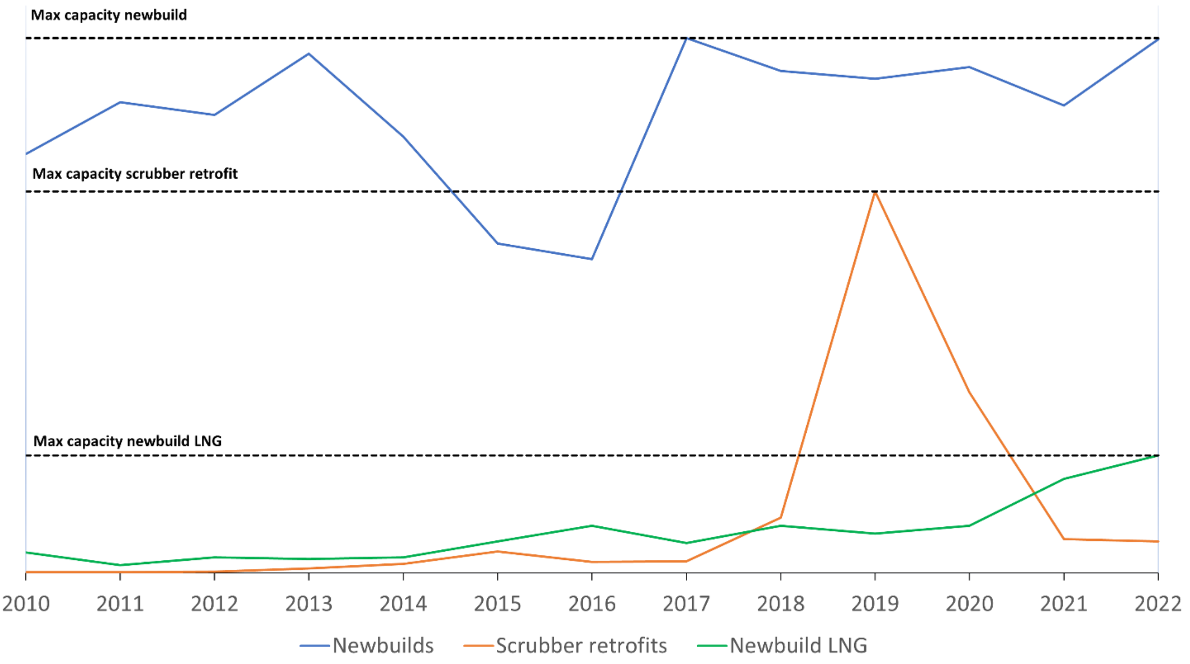
2.4.3 Sub-task 2.3: Investigate shipyard capacity

The potential capacity of manufacturers and shipyards to produce and install equipment and build and retrofit ships is essential to estimate how fast a technology can be taken up by the shipping sector. This subtask will investigate shipyards' technical capacity and their track record. The investigation will be used to estimate the future capacity for shipyards to build and retrofit carbon-neutral vessels and to assess whether a certain uptake is feasible in 2030, 2040 or 2050 as part of Task 5.

The estimation will be based on deliverables of vessels, annual updates, and shipyard monitors from the last 10 years. This will include a description of the shipbuilding market and world fleet renewal and historical assessments of retrofitting, such as for scrubbers and ballast water treatment. An indicative example is shown in Figure 2-3 with the annual new build deliveries, scrubber retrofits and LNG fuelled newbuilds and the maximum achieved output the last 10 years.

The main sources will be Clarkson's Research: World Shipyard Monitor and Shipping Intelligence Networks, and other references. The estimation will be used in Task 5 to highlight gaps in the shipyard capacity and evaluate if the required rate of uptake of technologies is feasible with regards to yard capacity, either as retrofits or as new builds.

Figure 2-3: Indicative example of output from shipyard capacity – the stapled lines show the maximum capacity achieved the last 10 years for selected indicators.



[4] About the project: https://futurefuelsnordic.com/about-us/

2.5 TASK 3: TECHNOLOGY AND COMMERCIAL READINESS

Box 3 Understanding of Task 3

This task is to assess the readiness of technologies and fuels and their pathways out to 2050. The aim is to establish an understanding of what the technology readiness level (TRL) and commercial readiness level (CRL) is of each of the technologies and fuel pathways now, under a business-as-usual projection, and the required developments under the various scenarios set out in Task 1 in Section 2.3.

TRLs have been a widely used concept for several decades, originating from NASA using a numerical scale of 1 to 9. Acknowledging the connectedness of the concepts of TRL and CRL, we propose to adopt the IEA's approach[5] to conceptualizing CRLs through combining them with TRL in an extended scale, as shown in the Figure below:

Figure 2-4: TRL and CRLs combined into extended sequence

Basic research	TRL	1	Basic principles of scientific research observed and reported
	TRL	2	Invention and research of practical application
	TRL	3	Proof of concept with analytical and experimental studies to validate the critical principles of individual elements of the technology
Development	TRL	4	Development and validation of component in a laboratory
	TRL	5	Pilot scale testing of components in a simulated environment to demonstrate specific aspects of the design
	TRL	6	Prototype system built and tested in a simulated environment
Demonstration	TRL	7	Prototype system built and validated in a marine operational environment
	TRL	8	Active commissioning where the actual system is proven to work in its final form under expected marine operating conditions
Deployment: early adoption	TRL/CRL	9	Operational application of system on a commercial basis
	TRL/CRL	10	Integration needed at scale: solution is commercial and competitive but needs further integration efforts
Mature	CRL	11	Proof of stability reached, with predictable growth

In this way, we have, for this proposal, combined the tasks set out in the RfP on gathering information on TRLs and CRLs. This is because we believe the process for gathering the information on each will be the same and will be consulting with in many instances the same literature sources and stakeholder groups. Thus, we propose to integrate the two tasks together for efficiency reasons.

Given this task outputs will need to work in conjunction with that of the earlier tasks, the TRL and CRLs sought in this task will need to be differentiated by year and by scenario. The baseline of current and projected future TRLs/CRLs on the basis of business of usual will need to be differentiated from what additional acceleration of TRLs/CRLs could be possible if additional commitments were made, putting the technologies/fuels on a pathway for more rapid deployment in more ambitious scenarios.

Some procedural aspects of this task (literature reviews, stakeholder consultation) will also integrate research needed from Task 4.

The scope of the task includes:

- On-vessel **technologies**: propulsion devices, energy efficiency measures and onboard CCS
- Alternative **fuels**: fuel production pathways as well as the supply to the vessels and use onboard

[5] IEA (2020) Energy Technologies Perspectives 2020. https://iea.blob.core.windows.net/assets/7f8aed40-89af-4348-be19-c8a67df0b9ea/Energy_Technology_Perspectives_2020_PDF.pdf

Our proposed approach for this task is split into eight steps (i to viii) across four subtasks as follows:

Sub-task 3.1: Define scope of assessment	• Step i: agree/define list of technologies and fuels to be assessed
Sub-task 3.2: Gather and compile information from literature on current and expected TRLs and CRLs	• Step ii: gather existing internal information • Step iii: assemble in to a tabular format • Step iv: external literature search • Step v: compile information into draft output
Sub-task 3.3: Consult stakeholders on the draft current and expected TRLs/CRLs	• Step vi: consultation, comprising: • email exchange • workshop • bilateral interviews
Sub-task 3.4: Finalise outputs on current, expected and future scenario TRLs/CRLs	• Step vii: integrate information from consultation • Step vii: fill remaining gaps on scenarios

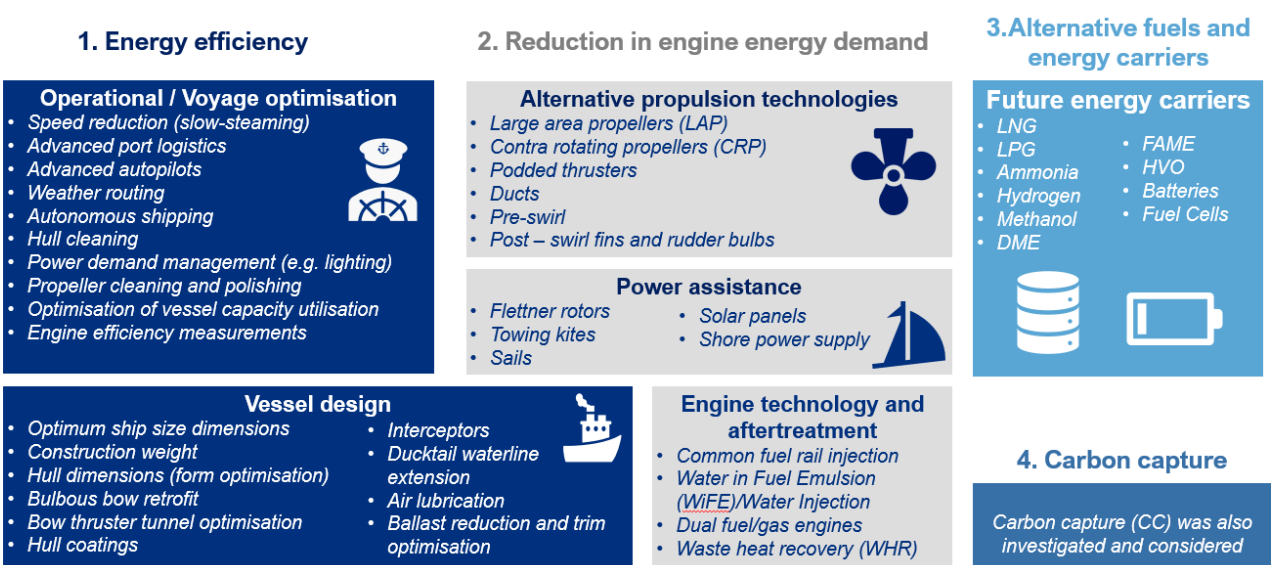
The key milestones of this task are (assuming a contract start of 1 December 2022):

- 13 January 2023 Step v: **interim report** on TRLs and CRLs, prior to stakeholder consultation
- 28 February 2023 Step viii: report on TRLs and CRLs, within project **draft final report**

2.5.1 Sub-task 3.1: Define scope of assessment

Step i of Task 3 is to define and agree on the list of technologies and fuels to be assessed. In our work for OGCI and Concawe (Ricardo, 2022), we categorised the options to decarbonise shipping into the following categories and sub-categories as shown in Figure 2-5.

Figure 2-5: Categories, sub-categories and individual techniques considered in Ricardo (2022)



Source: https://ogci2018.wpenginepowered.com/wp-content/uploads/2022/02/OGCI_Concawe_Maritime_Decarbonisation_Final_Report_Issue_6C.pdf

We propose to draw on existing work done with the industry to use the categorisations above to help the scope of this Task, and additionally discuss with the IMO on the inclusion of nuclear in scope. In this way, the scope of this assessment is (referring to the categories in Figure 2-5):

<table>
<tr><td rowspan="5">Technologies:</td><td colspan="2">Energy efficiency measures – vessel design</td></tr>
<tr><td rowspan="3">Reduction in engine energy demand</td><td>Alternative propulsion technologies</td></tr>
<tr><td>Power assistance</td></tr>
<tr><td>Engine technology and aftertreatment</td></tr>
<tr><td colspan="2">Carbon capture onboard</td></tr>
<tr><td>Fuels:</td><td colspan="2">Future energy carriers (and their fuel value chain and on-board technology needs)</td></tr>
</table>

For the assessment of TRLs/CRLs, there are a multitude of pathways, for example with distinctions for a single fuel between different on-board implementation (e.g., for hydrogen, via ICE or fuel cell), and hence each permutation needs to be considered separately.

For the fuels, the associated production stages (value chains) that are considered in scope are shown in the table below. We will discuss these proposals with the IMO and the project steering group at project inception.

Production & use stage to be analysed	Inputs	Output
Electrolysis	Water Electricity	Hydrogen (Electrolytic)
Natural gas extraction	Gas energy	Methane (natural gas)
Biogas production	Farm waste	Biogas
Biogas upgrading	Biogas	Methane (bio) CO_2
Steam methane reforming	Methane water	Syngas
Syngas pressure swing adsorption	Syngas	Hydrogen (blue or bio) CO_2
Nitrogen separation (PSA or cryo)	Air	Nitrogen Oxygen (& other traces)
Haber Bosch process	Nitrogen Hydrogen Heat energy	Ammonia
Ammonia liquefaction	Ammonia (gas)	Ammonia (liquid)
Carbon capture (industrial)	Flue gas	CO_2
Carbon capture (air)	Electricity Air	CO_2
Sabatier process	CO_2 Hydrogen	Methane (synthetic) Oxygen
Methane liquefaction	Methane (nat gas, bio, eCH_4) Electricity	LCH_4
Hydrogen liquefaction	Hydrogen Electricity	LH_2
Ammonia liquefaction	Ammonia Electricity	LNH_3
Liquid bio-fuels	Wastes, oils, crops	HVO, FAME, etc.
Methanol synthesis	Hydrogen CO_2	Methanol (synthetic)
Fischer Tropsch (inc WGSR)	Hydrogen CO_2	Blue crude -> e-diesel
Hydrogen ICE	Hydrogen	Water (+ NOx)
Hydrogen FC	Hydrogen	Water
Methane ICE	Methane (+ diesel)	CO_2 +NOx+CH_4
Methanol ICE	Methanol (+ diesel)	CO_2 +NOx
Ammonia ICE	Ammonia + diesel	CO_2+NOx+NH_4+N_2O
Diesel ICE	Diesel	CO_2+NOx

2.5.2 Sub-task 3.2: Gather and compile information from literature on current and expected TRLs and CRLs

Step ii: we will gather existing available information on TRLs and CRLs from work already carried out by Ricardo and DNV from internal and published studies. Given that existing estimates of technologies readiness can become out of date as R&D projects continue, this information gathering will record the dates that the work was carried out and/or published. Examples of the work that we will draw upon for this include:

- Ricardo (2021) A zero emission blueprint for shipping. Study for International Chamber of Shipping summary published online based on research in summer 2021. TRL progression associated **with specific R&D projects** was estimated. A full (not published) report details all the R&D options.
- Ricardo (2021) Technological, Operational and Energy Pathways for Maritime Transport to Reduce Emissions Towards 2050. Study for OGCI and Concawe published online early 2022 based on research conducted 2020 and 2021. Includes TRL estimates for fuels and on-ship propulsion and energy efficiency technologies. Full details from stakeholder consultation in its Appendices.
- DNV (2019, 2020), Maritime Forecast to 2050, 2019 & 2020 editions. Introducing the “Alternative Fuel Barrier Dashboard”, which maps key barriers to implementation, and key stakeholders.
- DNV (2022), Maritime Forecast to 2050, 2022 edition, published in September, includes TRL projections for hydrogen, ammonia, methanol converters and onboard CCS, indicating projected dates for maturity to TRL 9. Safety regulation maturity for fuel use is indicated.
- DNV GL (2020), Zero emissions in 2026 for ships in the world heritage fjords, rep. no. 2019-1250, Rev. 0. DNV GL provided TRL assessment of selected fuels and technologies considered relevant in connection with the requirement for zero emissions in the world heritage fjords in 2026 (or earlier).
- DNV (2022), State of play – status on regulatory development for zero-carbon fuels. DNV report (not published), Nordic Roadmap publication no.1-B/1/2022.
- DNV (2022), Fuel properties and their consequences for safety and operability. DNV report, (not published), Nordic Roadmap publication no.1-B/2/2022.
- DNV (2020), Potential for reduced costs for carbon capture, transport and storage value chains (CCS). Report No.: 2019-1092, Rev. 2. Feb. 2020.
- DNV (2021), Carbon Capture Utilization and Storage – Screening of Technology and Market from a Maritime Point of View, Report No.: 2021-0214, Rev. 01.

It is important to acknowledge that the technology readiness of an individual fuel pathway will depend overall on the least ready stage or process in that pathway. For example, for the use of green ammonia as a fuel, there are technology readiness considerations of the production of the renewable electricity, the production of the ammonia, the storage and refuelling infrastructure, as well as the considerations on board the vessel. Safety aspects will be taken into account in each of the stages as relevent. Consequently we propose to break down the TRL assessment into stages of the production pathway as follows:

Stage	Technologies	Fuels
Resource generation	Not assessed	Assessed
Fuel production	Not assessed	Assessed
Supply / refuelling / manufacturing	Assessed (shipyard capacity from Task 2)	Assessed
On-board storage	Not assessed	Assessed – separately for new and existing vessels
Propulsion	Assessed – separately for new and existing vessels	Assessed – separately for new and existing vessels

Step iii: To enable consistent analysis of literature for the TRL and CRL status we will set out a system for formalising assesment. This is expected to use a tabular fomat to help easily structure the information gathered in step 2 methodically through standardised fields. We expect the information that we gather to reflect the current (or recent) year in terms of the status of development. The tabular structure will however be much broader than this in order to relfect the data points needed as an output of this task, which will cover the expected TRL/CRL developments at each stage in the near term and out to 2050 for BAU and each of the three scenarios. The system will also record the information source(s) used for each data point. This will be important due to the need for transparency and providing a full set of references in the later stages of the Task. If there are any discrepancies among information sources, we will use our expert judgement to assess which source is the most reliable for this stage in the project (noting that consultation of stakeholders is yet to occur).

We expect that, after completing this step, coverage of TRL/CRL status for the different technology and fuel pathways will have gaps where limited information is found, particularly regarding future timescales.

Step iv: After using our internal resources (step ii) and compiling this information (step iii) we will conduct a literature search to identify planned and current R&D projects which are/will be targeting the development of a specific part of a technology value or safety chain. Such projects may not make explicit statements on the objective of the work in terms of resulting TRL / CRL levels. Therefore, we will draw on our in-team expertise of technology specialists to map reports of technology development into the TRL / CRL grading system that we have adopted. I.e. we will provide internal guidance in the project team on how to interpret and classify according to the scale adopted, and how to translate from other scales (e.g. from the different CRL scale used in the JEC study). We will also include any developments of relevant guidelines on safety use of fuels/technologies; this will draw on expertise within DNV. The research projects targeted will include those funded publicly (e.g. EU research projects funded under HORIZON) as well as R&D projects announced by individual private-sector organisations, such as engine suppliers.

The literature review will then be widened to include scientific and grey literature for further information on the TRL / CRL levels of the technologies and fuels in scope. In this review, we will identify if any of the information sources make projections for technology readiness on the assumption of a particular emissions reduction pathway, and if so, we will identify which of the scenarios (BAU, IMO, NZE, ZERO) it is most closely aligned with. Relevant sources we will include in this step are:

- The dashboard produced by Lloyd's Register[6]
- The NavigaTE model of the Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping. The Total Cost of Ownership component of this model is available upon request according to their website.
- Getting to Zero Coalition, e.g. Global Maritime Forum (2022), Mapping of Zero Emission Pilots and Demonstration Projects[7]
- The Zero Emission Shipping Mission
- The IMO's 4th GHG study
- The JEC WTW study – although for road fuels, several of the upstream production pathway assessments include pathways relevant for maritime fuels, with TRL and CRLs
- IEA (2020), Energy Technology Perspectives 2020. Time to materiality for selected technologies in the Sustainable Development Scenario. Timescales in taking technologies from laboratory to market.
- World Bank (2021) The Potential of Zero-Carbon Bunker Fuels in Developing Countries[8]
- Scientific literature, such as Prussi et al (2021)[9]

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[6] https://www.lr.org/en/marine-shipping/maritime-decarbonisation-hub/zcfm/dashboard

[7] https://safety4sea.com/wp-content/uploads/2022/03/Getting-to-Zero-Coalition-Mapping-of-zero-emission-pilots-and-demonstration-projects_third-edition-2022_03.pdf

[8] https://openknowledge.worldbank.org/handle/10986/35435

[9] Prussi M, Scarlat N, Acciaro M, Kosmas V. (2021), Potential and limiting factors in the use of alternative fuels in the European maritime sector. Journal of Cleaner Production. 2021 Apr; https://europepmc.org/article/med/33814732#free-full-text

Step v is the compilation of information gathered from wider literature in step iv and updating and expanding the assessments produced in step iii. We anticipate this step will need internal conferral and agreements on the values assembled from literature, as these could differ/conflict among information sources. For this, we will draw on the deep technical knowledge of fuel pathways and ship energy efficiency technologies in the team.

With this step, we will generate a short report compiling the information gathered which will:

- Facilitate the quality assurance process of checking and agreeing on the information gathered.
- Provide an input for the consultation with stakeholders in the next subtask
- Serve as an interim report for the IMO.

We expect that, because there will be a large amount of data, and because the TRLs and CRLs are time-based, **one of the best ways to present the information will be graphically, showing how the TRL/CRL increase over time, marking at what point the technology/fuel is technologically ready, and at what point commercially ready, and how (if available) this could differ under each scenario**. We will make clear any assumptions of the projections scenarios as relevant to the TRL/CRL projections (and e.g. show uncertainty in the graphic as widening lines). We expect that, at this stage, there will also be information gaps.

2.5.3 Sub-task 3.3: Consult stakeholders on the draft current and expected TRLs/CRLs

Step vi: Following on from the compilation of information from literature on technology and commercial readiness, we will consult with external stakeholders on our draft findings. Three methods are envisaged for this: (1) email exchange, (2) an online workshop inviting many stakeholders together at once, and (3) bilateral discussions after the workshop.

1. The email exchange is an initial rapid response option, allowing stakeholders the ability to provide input in their own time. The email providing material for commenting will also advertise the workshop.
2. The online workshop, within which will be breakout groups for smaller working sessions, allows for getting a larger number of stakeholders together at one time. Considering this will be an event where we are seeking to gain time from stakeholders for limited benefit for them, it will need to be billed as an opportunity to feed in to work for the IMO.
3. We expect bilateral discussions to be needed in addition for several reasons:
    - Some stakeholders will be unable to make the workshop
    - Some workshop participants may be reluctant to share information in a workshop
    - Some active workshop participants may have further information to contribute beyond what they offer in a workshop

For the **email exchange**, we will first identify the list of stakeholders that we are seeking information from. This process will seek to ensure that we have a sufficiently representative contact list covering all the required stakeholder categories of manufacturers, naval architects/ship designers, ship builders/yards, ports, research institutes, other classification societies, fuel supply companies including oil and gas companies. Ricardo will use its extensive global contacts across marine power systems and supply chain, major ports, marine engineering, project finance and regulatory bodies. We have conducted previous similar consultative exercises in other studies, successfully securing interview time and stakeholder input from multiple stakeholder categories. The document output from step v will be sent as an attachment to the email. In our experience of eliciting feedback from stakeholders, it is important to make it as easy as possible for them to reply. To make it easier for stakeholders to provide a reply, we will: (a) provide the option for stakeholders to provide their input by email reply directly; (b) provide the document output in an editable format to allow responses directly in comments or track changes; and (c) include optional questions in a mini questionnaire, with open text responses possible. We will request stakeholders provide evidence to support their inputs in all cases.

The delivery of the **workshop** will follow a high-level event planning process (see Figure 2-6). At the project outset, and as part of the Gantt chart, we will include indicative dates for when each of these stages will be implemented. The document output from step v will be used to prompt for feedback, with an initial plenary session of the workshop describing the work carried out and the draft findings, before using breakout sessions focusing on individual technologies and fuels to gather feedback in smaller more targeted groups.

Figure 2-6: Our workshop design and management process

To maximise attendance at the workshop, we will promote the workshop at least four to six weeks in advance of the delivery date via the email communication. As part of this process, we will ask interested stakeholders to register for the event in advance to enable us to gauge the spread of interested stakeholders.

We propose the workshop is a 90 minute session, to avoid the time burden appearing overly high. A longer event would require a break, which can often be a cue for losing participation at online events.

From our experience, both Microsoft Teams and Zoom offer effective tools for hosting such events. Ricardo has extensive experience in the delivery of webinars to industry and policy audiences, including the use of effective breakout sessions using either Microsoft Teams or Zoom, to allow for more in-depth discussions amongst smaller groups of attendees. As well as the use of breakout groups, we will make use to polls to increase audience participation. We propose to use Mentimeter to do this due to its ease of integration into presentations.

Ricardo has delivered a series of successful live workshops and webinars for clients across the globe. Through these, we have developed a breadth of experience in the management and delivery of live webinars and Ricardo has an in-house Communications team available to provide technical support, where needed.

For the **bilateral discussions**, we will hold up to 10 interviews with individuals.

2.5.4 Sub-task 3.4: Finalise outputs on current, expected and future scenario TRLs/CRLs

In **Step vii**, as with step v, we will compile the information gathered from the consultation in step vi and update and expand the entries in the tables from step v. Again, this step will likely need internal conferral and agreements on the values provided during consultation, as these could differ/conflict among stakeholders. For this, we will draw on the deep technical knowledge of fuel pathways and ship energy efficiency technologies in the team.

The output of step vii is an updated draft report on the TRLs/CRLs. This will be internally reviewed for checking consistency.

Step viii is a final gap-filling step. The project overall needs projections of TRLs/CRLs not only under BAU, but under additional more accelerated scenarios too. We anticipate that this may be possible to gain for the IMO scenario, but the NZE and ZERO scenarios may leave some gaps. We will use our expertise in the team to fill the gaps. We have purposefully not included this step earlier in the process due to the short timescale of the project and to avoid the risk of having to wait for external feedback on a potentially very large document.

The completed report with the assessments of TRLs/CRLs per the system set out in step iii and step v will be fully referenced, providing transparency on the origin of TRLs/CRLs.

2.6 TASK 4: COSTS OF TECHNOLOGIES AND FUELS, INCENTIVES AND PRICE SIGNALS

Box 4 Understanding of Task 4

Whilst Task 3 will generate estimates of the technological and commercial readiness of the technologies and fuels under the different scenarios considered in the study, Task 4 aims to understand the barriers to deployment of those technologies and fuels, and assess the cost projections of these measures. The aim here is to establish how much the cost – which is a function of commercial readiness – is a barrier between technology/fuel options. It is likely that all future fuel options will be more expensive than the incumbent fuels. Therefore, this cost assessment will identify the scale of intervention or incentive required to make the future fuels competitive and drive adoption.

Existing literature sources have well documented how it is technologically feasible, though challenging, to decarbonise the global shipping sector to the ambition level of the IMO or beyond. However, the low current trajectories of deployment and uptake of alternative fuels suggest that barriers to decarbonising the shipping sector remain. The barriers are not just on price. Barriers include the scale-up of the production and supply of alternative fuels, current inadequate infrastructure, need for propulsion system technology scale up, uncertainty leading to investment impasse, the lack of standards for the sustainability of alternative fuels production and the lack of regulation to drive the transition to alternative fuels (Ricardo, 2022).

The key milestone of this task is (assuming a contract start of 1 December 2022):

- 28 February 2023 Report from all subtasks within project **draft final report**

2.6.1 Sub-task 4.1: Gather projections of the current costs of future fuels and technologies

The costs of future fuels and technologies are a key part of the commercial readiness. A fuel or technology may be commercially available, but if it costs several times the conventional alternative, without an additional interventions or incentives it is unlikely there will be uptake of the fuel or technology. This is a key distinction between CRL 9 and CRL 11.

This subtask will gather and assemble from literature the current costs and projections of costs of future fuels and technologies under a BAU scenario. This will be set against the projected development of the TRL and CRL (Task 3). Sources of information we will use for the subtask include:

- The 4th IMO GHG study – marginal abatement cost curves
- Ricardo (2021) Technological, Operational and Energy Pathways for Maritime Transport to Reduce Emissions Towards 2050. Study for OGCI and Concawe published online early 2022 based on research conducted 2020 and 2021. This report includes cost assumptions for fuels and for on-ship propulsion and energy efficiency technologies, specifically for trans-oceanic vessels.
- DNV (2022) Maritime Forecast to 2050, published in September, includes cost assumptions.
- The NavigaTE model of the Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping – in particular the Total Cost of Ownership component of this model which is available upon request.
- The IEA's Energy Technology Perspectives reports
- IRENA (2021), A pathway to Decarbonise the shipping sector by 2050[10]
- The Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping - Industry Transition Strategy from October 2021

We will also ensure consistency between information sources about whether learning effects are taken into account in projected cost reductions.

[10] https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2021/Oct/IRENA_Decarbonising_Shipping_2021.pdf

For many of the fuels, a large proportion of their costs are from upstream fuel pathway components of resource generation: e.g. the costs of renewable electricity via electrolysis. In several cases, these upstream cost trajectories will be independent of the shipping trajectory and will be driven by the global scenario. Therefore, for this assessment it will be important to break down the costs into component costs to understand the drivers. This will be performed in a similar manner to that proposed in subtask 3.2.

2.6.2 Sub-task 4.2: Describe the barriers to uptake of future fuels and technologies

In this subtask, we will provide qualitative outputs describing the barriers facing each of the technologies and fuels considered in the study from reaching the top TRL/CRLs. This will be drawn from:

- Existing literature available, both internally within Ricardo and DNV, as well as externally. The literature searches on barriers will be integrated with the searches on TRLs/CRLs of Task 3.
- Stakeholder views gathered by email, in the workshop or in 1:1 interviews conducted in Task 3.
- Our previous experience.

We expect to need to categorise the barriers. Our initial thinking is to categorise by the following topics:

Uncertainty in GHG reduction potential e.g. accounting rules	Price differential	Infrastructure needed	Production increases required and in different locations	Split incentives	Resource availability	Sustainability (un)certainty

Where possible, we will also provide quantitative outputs of the cost/price barrier of particular technologies and fuels, where information has been available from subtask 4.1. For example, the cost projections in subtask 4.1 when set against their associated CRL (9, 10 or 11) will show the cost premium.

2.6.3 Sub-task 4.3: Identify the possible incentives to accelerate commercialisation of the most appropriate new fuels and technologies

In the majority of cases, it is unlikely that the new fuels will achieve full technology or commercial readiness (and thus significant market penetration) without some form of incentive or penalty to transition to the top TRL/CRLs. Even when legislation is applied to improve energy efficiency/address decarbonisation (such as CII or EEDI), it is possible that there may be unintended consequences, such as a temporarily cheaper fuel gaining early prevalence and delaying or preventing the uptake of the fuel(s) with the most promising zero-GHG credentials at scale further in the future.

We will perform a high-level review of the potential options to move technologies and fuels to the top TRL/CRLs, including for example carbon taxes, grants for technology funding and demonstrators, and loans for infrastructure development, without making recommendations. We will identify where such interventions may be beneficial and any significant risk factors. We will base this research on our own previous experience of identifying actions to accelerate technology development and deployment, as well as reviewing proposals for decarbonisation within shipping and other industries.

2.7 TASK 5: FEASIBILITY ASSESSMENT AND ACTIONS FOR DEVELOPMENT AND ACCELERATION

Box 5 Understanding of Task 5

This task will assess the feasibility of the three GHG emission pathway scenarios, and the gap between business as usual and achieving the “more ambitious” scenarios. We will compare the demand for fuels and technologies from Task 1 with the availability and supply of energy and technologies (Task 2) and the technological and commercial readiness levels of shipboard and fuel production technologies (Task 3). Task 4 considered the projections of cost, other barriers and possible actions to accelerate the maturing and the uptake of technologies and fuels close the gap to price incentives identified in Task 4. This task will bring all these components together as a synthesis of the feasibility assessment, setting the actions in the context of the scenarios. This task will summarise the findings and lead to the final report.

Task 5 has the following milestones:

- 15 February: Gap and feasibility assessment
- 28 February: Mitigation actions
- 28 February: Draft executive summary and report
- 31 March: Final executive summary and report

2.7.1 Sub-task 5.1: Conduct gap and feasibility assessment

The feasibility will be assessed for each scenario in 2030, and 2040 and 2050 divided into two topics

- The supply and demand of carbon-neutral fuels, in relation to readiness of associated land and ship-board technologies; port and bunkering infrastructure projects and shipyard capacity
- The demand of energy efficiency technologies in relation to readiness of such technologies

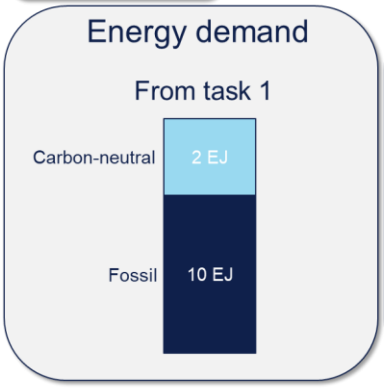
Figure 2-7 shows a conceptual infographic of the feasibility assessment for a scenario and specific year. It starts with the demand for carbon-neutral energy. This is compared to the supply of energy in task 2 to give a % of the energy supply needed for shipping. Together with the TRL of the fuel production technologies in task 3 we can then assess the availability of the various fuel resources.

In the next step we include the assessment of the various onboard fuel technologies from Task 3. The potential uptake is derived from the shipyard capacity evaluation in Task 2, and it is the maximum uptake that can be achieved in the fleet from the time the fuel technology reaches TRL 11. The current TRL for refuelling, onboard storage and propulsion are also included.

Based on this a feasible energy mix can be estimated according to the decision tree for the fuel supply and the TRL of the fuel technologies. For the near-term assessment, the list of port and bunkering infrastructure projects will also be taken into account. A similar assessment of the energy efficiency technology will also be provided.

Figure 2-7: Feasibility assessment – illustrative assessment of energy and technology supply and an estimated feasible energy mix combining inputs from other tasks.

Scenario: IMO
Year: 2030



Energy supply

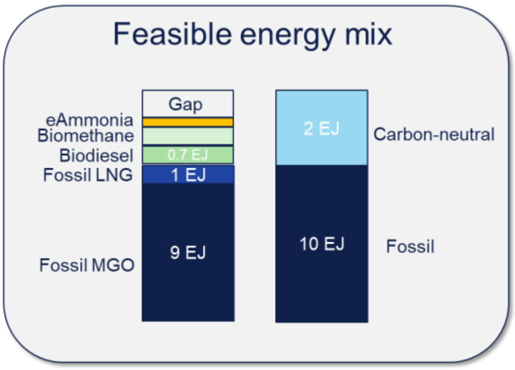
From task 2 / From task 3

Resource	Supply	% needed to supply shipping	TRL Resource generation	TRL Fuel production	Availability assessment
Biofuel	10-20 EJ	10%	6	6	High
Hydrogen (electrolysis)	20-35 EJ	70%	5	5	Med
Hydrogen (reformed methane with CCS)	10-15 EJ	40%	8	3	Low
Sustainable carbon	50-65 GT	20%	5	5	Low

Onboard fuel technology supply

From task 2 / From task 3

Fuel type	% of fleet potential	TRL refuelling	TRL onboard storage	TRL Propulsion
Diesel ICE	100%	11	11	11
Methane ICE	70%	11	11	11
Methanol ICE	20%	9	7	7
Hydrogen ICE	3%	5	5	5
Hydrogen FC	0%	9	7	7
Ammonia ICE	2%	5	5	5
Ammonia FC	0%	9	7	7
Onboard CCS	1%	5	5	5
Nuclear	0 %	2	2	2



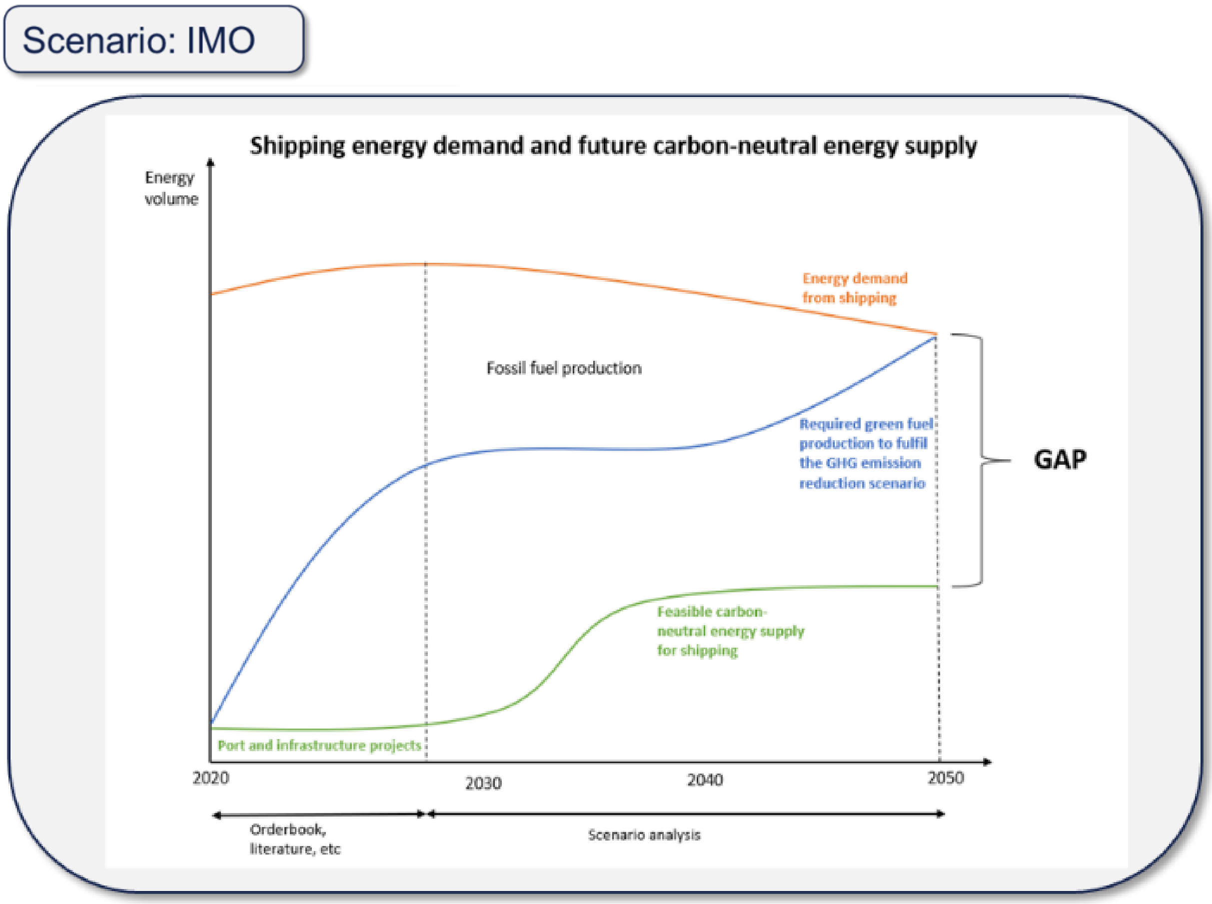
Energy efficiency technology

From task 1 / From task 3

Generation (package)	% of fleet	TRL Manufacturing	TRL Onboard use	Feasibility assessment
1 generation (-2015)	30%	11	11	High
2 generation (-2020)	30%	11	11	High
3 generation (-2025)	40%	9	7	Med
4 generation (2025-)	0%	5	5	Low

The feasible energy mixes for 2030, 2040 and 2050 provide a blueprint for the transition for carbon-neutral fuels, including any gaps in the energy supply or technology maturity that needs to be closed for them to be realistic. This is illustrated in Figure 2-8.

Figure 2-8: Illustration of shipping energy demand compared to a feasible supply



2.7.2 Sub-task 5.2: Identify possible mitigating actions and pathways and summarise findings

This subtask will summarise the feasibility assessment and propose mitigating actions to close gaps and accelerate the development and uptake of fuels and technologies needed to realistically achieve the GHG emission pathways in the three shipping scenarios. The cost projections, barriers and possible price incentives identified in task 4 will be considered as well as findings from the feasibility assessment. In light of this, realistic and achievable mitigation pathways toward 2050 will be discussed.

TRL/CRL development resulting from actions, compared to BAU scenario

Action / incentive	Fuel/ tech affected	TRL/CRL development resulting	Required for scenario
Example 1	Hydrogen	8 → 11	IMO
Example 2	Ammonia	9 → 10	NZE
Example 3	Methanol	9 → 11	ZERO
Example 4	CCS	5 → 9	ZERO

This task will also summarise the findings from all tasks and provide conclusions. A draft report will be provided by 28 February. In dialogue with the IMO we will decide on external stakeholders to review the report and findings. Following the review, a final report will be delivered on 31 March.

3. ORGANISATION OF THE PROJECT

This section sets out:

- Our proposed team structure in section 3.1
- A description of the staff roles in section 3.2
- Biographies of the main/key personnel in section 3.3
- How we will manage this study in section 3.4
- The proposed schedule of work and the milestones in section 3.5
- A suggested structure of the final report in section 3.6
- A risk register in section 3.7.

3.1 PROPOSED TEAM STRUCTURE

Removed from this issue

3.2 SUMMARY OF STAFF ROLES

Removed from this issue

3.3 BIOGRAPHIES OF KEY TEAM MEMBERS

Removed from this issue

3.4 OUR APPROACH TO MANAGING THIS PROJECT

Ricardo's Project Management Process, policies and systems fully meet the requirements of ISO9001 and ISO14001, many of the principles of PRINCE2 and meet standard UK Government project management QA methodology requirements. All quality systems are subject to regular checks by management and biannual audit by the accreditation body. In addition, to further ensure the quality, consistency and currency of key management documents such as risk assessments and customer success plans, Ricardo's management team conducts scheduled, formal reviews of all standard project deliverables.

Quality of deliverables in this project is assured through the role of the Project Director Tim Scarbrough whose functions include to be the Technical Reviewer of all deliverables issued to the IMO. For this study, Ricardo and DNV have agreed to quality assure each other's work. Tore Longva and Øyvind Endresen of DNV will reciprocally quality assure Ricardo outputs.

Effective customer communication is key to successful project delivery and achieving exceptional customer satisfaction. This includes the agreed formal meeting schedule as set out above, and starts with the kick-off meeting at project inception, which is an opportunity to review the detail of the proposed project methodology as well as to introduce the team. The Project Manager will maintain regular contact regarding the progress of the project with the Marine Environment Division (MED) of the IMO Secretariat, in particular the 'Future fuels and technology for low- and zero-carbon shipping' project team. We suggest scheduled fortnightly telephone meetings, supported by emailed progress updates and additional phone calls as agreed appropriate. The progress updates will summarise progress against each task, literature assessed, data identified and barriers to progress. The Project Director and Project Manager can be contacted for questions or updates as required.

3.5 PROPOSED SCHEDULE AND MILESTONES

Table 3-1 lists the main milestones of the project including deliverables. This timeline depends on the contract being signed by 1 December 2022. If the contract is signed later than this, the project delivery schedule will need to be commensurately pushed back. The kick-off meeting will be in early December, and will need to be carefully scheduled to avoid conflicts with ISWG-GHG scheduled prior to MEPC 79. With our project manager and project director attending our London office, we offer to the IMO to hold the kick off meeting in hybrid format with our staff attending in London and others joining by video.

The project team will have a close and continuous dialogue with the IMO Secretariat throughout.

One interim report is proposed in order to provide content for the IMO to comment on earlier than the draft final report, and which can also double up as information for the IMO to include in bulletins/newsletters. The interim report is suggested to be in the middle of January when Task 3 concludes the literature review and material is presented to stakeholders for comment.

A draft executive summary and report will be delivered by 28 February 2023, and the IMO will have the opportunity to review the report and provide comments by 22 March 2023. This will be followed by another meeting and Q/A session which we also offer as a hybrid event for those of us UK-based to attend in person and others joining by video. After the review and Q/A session, the project team will finalise the report for delivery by 31 March 2023 (subject to confirmation at contract signing). The project manager and other lead authors will be available to present the study at MEPC 80 or a similar event in London.

Table 3-1: Project milestones with deliverables in bold.

Date	Milestone
1 December 2022	Contract signed
5 December 2022	Kick-off meeting (conference call, or hybrid in-person in London)
15 December 2022	Scenario storylines and seaborne trade growth scenarios concluded (Task 1)
13 January 2023	**Interim report on TRL/CRLs (draft, based on literature review) (Task 3)**
1 February 2023	Shipping energy and technology demand modelling completed (Task 1) Map capacity of providing carbon-neutral fuels and required associated production technologies (Task 2)
15 February 2023	Well-to-tank GHG emission projections (Task 1) List of port and bunkering infrastructure projects and Shipyards' technical capacity (Task 2) Draft Gap and feasibility assessment (Task 5)
28 February 2023	**Draft executive summary and report, incorporating Final output of Tasks 1-5**
27 March 2023	Review and Q/A session (conference call, or hybrid in-person in London)
31 March 2023	**Final executive summary and report (all tasks)**

Table 3-2 shows the proposed project schedule, split by subtask and the report drafting (in blue). The red diamonds show the deliverables, and meetings are shown in green.

Table 3-2: Work task schedule.

Weeks	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	05-Dec	12-Dec	19-Dec	26-Dec	02-Jan	09-Jan	16-Jan	23-Jan	30-Jan	06-Feb	13-Feb	20-Feb	27-Feb	06-Mar	13-Mar	20-Mar	27-Mar	03-Apr
Inception meeting	■																	
Task 1: Shipping energy and technologies demand																		
Subtask 1.1: Define shipping scenarios	■	■																
Subtask 1.2: Model shipping energy and technology demand			■		■	■	■	■	■									
Task 2: Global energy and technologies supply																		
Subtask 2.1: Fuel production capacity and technology maturity					■	■	■	■	■									
Subtask 2.2: Identify port and bunkering infrastructure projects								■	■	■	■							
Subtask 2.3: Estimate shipyard capacity								■	■	■	■							
Task 3: Technology and commercial readiness																		
Sub-task 3.1: Define scope of assessment	■																	
Sub-task 3.2: Gather and compile information from literature on current and expected TRLs and CRLs		■	■		■	■ ◆												
Sub-task 3.3: Consult stakeholders on the draft current and expected TRLs/CRLs						■	■	■	■	■	■							
Sub-task 3.4: Finalise outputs on current, expected and future scenario TRLs/CRLs												■	■					
Task 4: Costs of technologies and fuels, incentives and price signals																		
Subtask 4.1: Gather projections of the current costs of future fuels and technologies		■	■		■	■	■	■	■	■	■							
Subtask 4.2: Describe the barriers to uptake of future fuels and technologies					■	■	■	■	■									
Subtask 4.3: Identify the possible incentives to accelerate commercialization of new fuels and technologies										■	■	■	■					
Task 5: Feasibility assessment and actions for development and acceleration																		
Sub-task 5.1: Conduct gap and feasibility assessment										■	■	■	■					
Sub-task 5.2: Identify possible mitigating actions and pathways										■	■	■	■					
Final Report drafting												■	■ ◆	■	■	■	■ ◆	
Review and Q/A session																■		
Project management phone calls	■		■		■		■		■		■		■		■		■	

3.6 DELIVERABLE STRUCTURE

The study will be delivered as a report with attachments. The report will be in electronic format, in English. The report will have the following indicative outline:

- Executive summary
- Introduction
- General approach
- Shipping scenarios
- Global Energy and technologies supply
- Technology and commercial readiness
- Costs of technologies and fuels, price incentives
- Feasibility assessment, mitigating actions
- Discussion and conclusions
- References
- Appendices (e.g. detailed method descriptions)

3.7 RISKS AND OUR MITIGATION MEASURES

Our project manager will keep live a risk register for the project. Our preliminary thinking on the risks for the project and the mitigation measures are shown in the table below.

Risks	Mitigation measures
Deadlines not met. The start date of 5 December 2022 (based on contract signature of 1 December) is key to moving ahead with the study in time for the 31 March 2023 deliverable.	• We have included a broad team of more than one organisation – i.e. Ricardo and DNV working together – to provide depth in ability to deliver at pace, working in parallel • Our contracts team have already negotiated terms and conditions with the IMO from previous contracts delivered to the IMO, thus minimising the risk of delay of contract signature • We have confirmed availability of our proposed staff for the dates and volumes of time needed to deliver this study • We have allocated back-up staff for our main/key personnel in case of unforeseen absence
Quality of the work does not meet the IMO's needs	• Our proposed key / main personnel are recognised experts in the topics of this study • We have put in place a comprehensive quality assurance system with DNV to quality assure Ricardo's work, and for Ricardo to quality assure DNV's work • Our proposed technical reviewers have a high level of expertise in the topic
Scope of work changes. E.g. with COP27 and MEPC 79 developments between bid submission and project start	• Our proposed methodology has flexibility to adjust the scope of the scenarios – this is planned for discussion with the IMO for agreement by 15 December to account for these possible developments

4. COMPANY PROFILES

The following contains short descriptions of each partner organisation in the proposed team and our project track record which also demonstrates how we fulfill the requirement in the RFP of 'Company to have minimum 3 years' experience in the required services'.

4.1 RICARDO

Ricardo Energy & Environment (Ricardo) is a consultancy with over 40 years' experience working with clients across the globe. Employing over 700 people, including many internationally renowned technical experts and consultants, we form part of Ricardo Group plc. Ricardo plc is a global organisation with an annual revenue in excess of £350 million, employing over 3,000 engineers, scientists and consultants around the world. Ricardo plc is a public company quoted on the London Stock Exchange and a constituent of the FTSE techMark100. Several of the core activities of Ricardo plc align with the UN Sustainable Development Goals.

We are a leading provider of environmental advice to UK, European and international clients. We bring deep technical insights, capabilities and services to the full range of global environmental challenges including climate and energy, air and environmental quality, waste and resource efficiency, and sustainable transport. We work internationally across several environmental topic areas, including on climate change, air quality, resource efficiency, energy, water, chemicals. This is supported by strong cross-functional teams specialising in data science, IT solutions and economics.

Ricardo is well suited for working on this project because:

- We have a track record of carrying out technical maritime studies that have tracked the technological readiness of technologies and fuels, through studies such as for OGCI & Concawe and the International Chamber of Shipping.
- We have previously successfully led work for the IMO and have included staff from that team in this proposal.
- We have thorough and rigorous quality assurance processes that we will apply to assuring the quality of ours and DNV's work in this project.
- As an engineering consultancy, Ricardo plc has an exceptionally strong heritage in R&D of technology.
- We demonstrate our commitment to decarbonizing the maritime sector through membership of the Getting to Zero Coalition.

4.2 DNV

DNV is the world's leading ship and offshore classification society and a world-leading provider of independent assurance and expert advisory services. DNV has experience in running large advisory projects helping clients in the maritime sector to reduce their GHG footprint. Among our clients are Norwegian governmental bodies such as Ministry of Climate and Environment, Ministry of Finance, The Norwegian Public Roads Administration, The Norwegian Environment Agency, as well as international authorities like IMO, OECD and the EU Commission. Our analyses are frequently applied as decision support to policymakers in Norway's ambition to drastically reduce GHG emissions in the maritime sector. As a class society, we are involved in the development of international environmental legislation and are well familiar with the ongoing work for a continuous reduction of emissions from the maritime sector.

DNV is well suited for this project because:

- We have broad competence and modelling tools within ship traffic monitoring and calculation of GHG emissions and climate effects from shipping, as well as cost/benefit assessments of alternative fuels, energy efficiency and further emission reduction technologies. We issue annual forecasts on emissions and energy use and related technologies to 2050 for the shipping sector.

- We have large databases of ship traffic (AIS), ocean and atmospheric data, and emission abatement solutions for ship, and well-established models for effective data processing, enabling us to draw conclusions based on the whole picture.
- We have hands-on knowledge of operational details from sailing ships with emission reduction technologies implemented, through our work with ship owners, the Norwegian NOx fund and the SEEMP (Ship Energy Efficiency Management Plan).
- We are initiator and coordinator of The Green Coastal Shipping Programme (GCSP), with a vision that Norway will establish the world's most effective and environmentally friendly coastal shipping, powered wholly or partially by batteries, LNG, or other eco-friendly fuels.
- For alternative fuels DNV has developed and maintains the Alternative Fuels Insight platform[11], launched in 2018 as the industry go-to source for information on uptake of alternative fuels and technologies in shipping, and on bunkering infrastructure for alternative fuels.

The project will be carried out in our section for Environmental Advisory (around 30 employees) within Maritime Advisory division (around 150 employees). Furthermore, we will use our pool of experts within strategic research on alternative maritime fuels, green infrastructure and sustainability.

4.3 REFERENCES

As requested in the RFP, we have included references for clients to whom projects of similar size and scope have been delivered, by each of Ricardo and DNV.

References redacted from this issue to protect personal data.

[11] Alternative Fuels Insights for the shipping industry – AFI platform. Webpage: https://afi.dnv.com

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