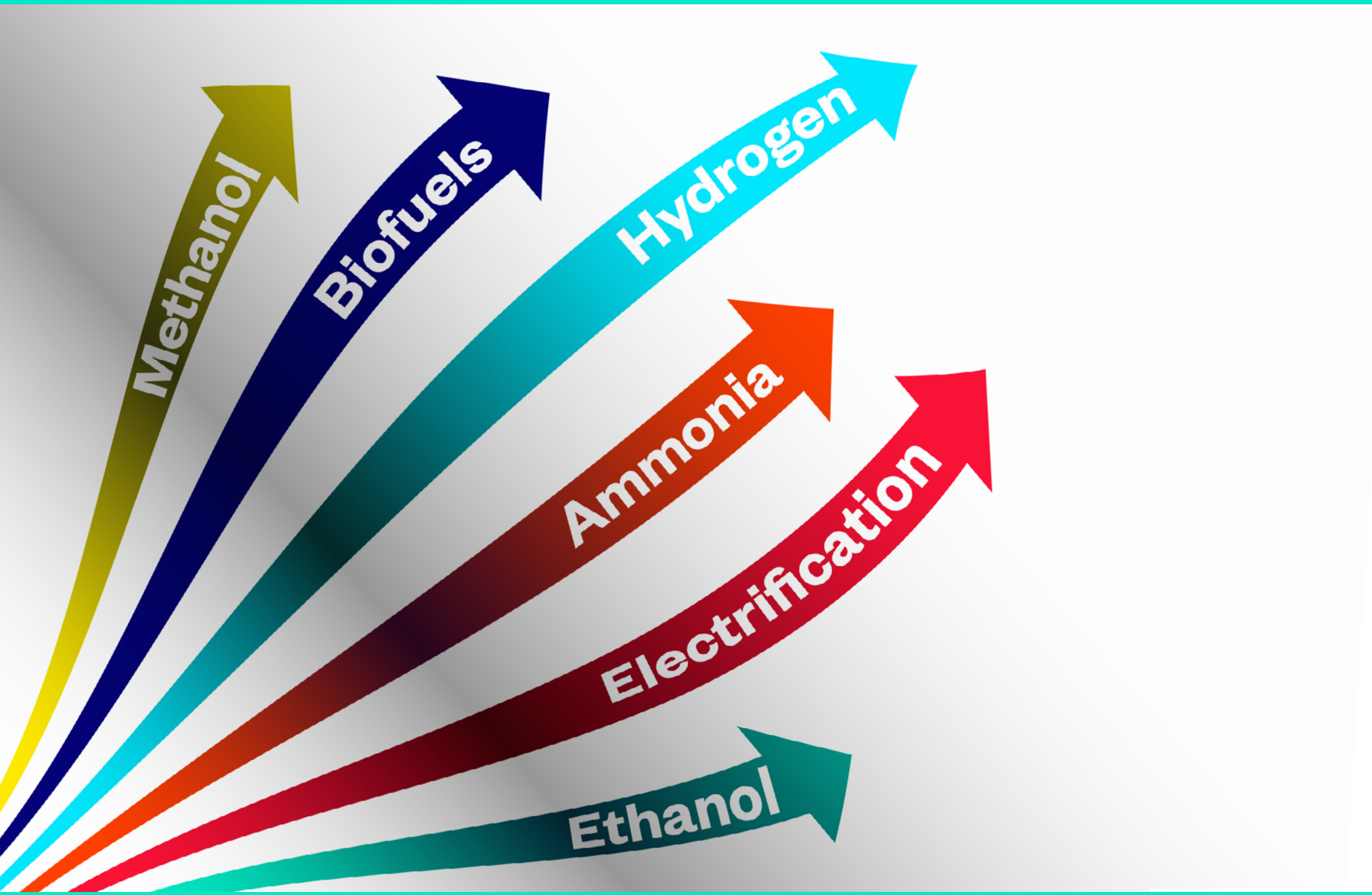
International Chamber of Shipping
Shaping the Future of Shipping

RICARDO

YEARS 100

A zero emission blueprint for shipping

In collaboration with Ricardo



November – 2021

Significant and long-term, high-risk investments will be required to trigger the step-change to advance technology readiness levels and pilot these technologies.

Executive Summary

International shipping is key to the global economy, transporting about 90% of global trade volumes with a value of $14 trillion, using 4 million barrels of oil a day – 4% of global oil production. Fossil-based fuels make up more than 98% of total current fuel requirement, therefore the shipping sector will need to innovate and develop new technologies to deliver the zero-emissions propulsion systems required to meet climate goals. This report, based on the findings of industry research led by the global engineering consultancy Ricardo, identifies the innovation pathways and the investment needed to support an industry transformation.

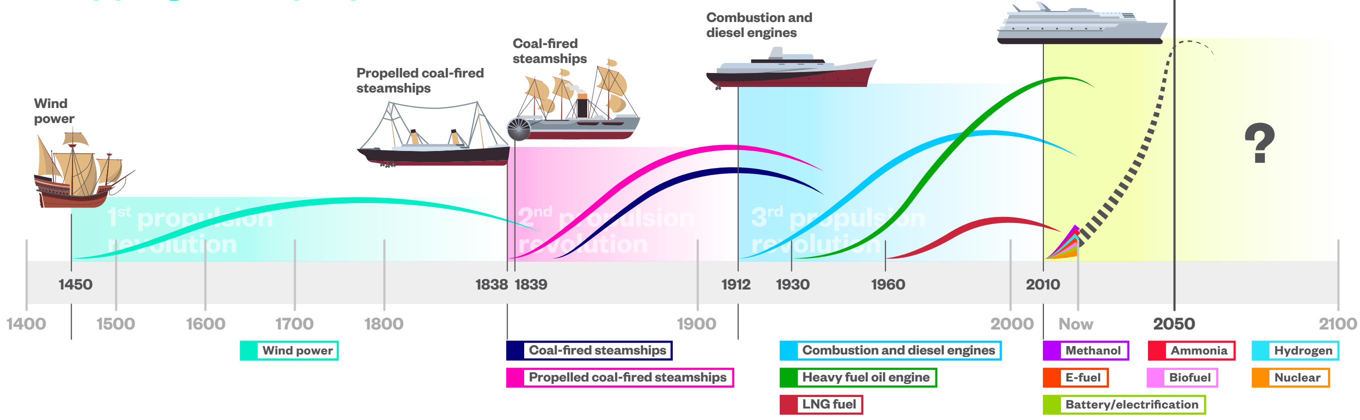
According to the International Energy Agency (IEA) just 0.1% of energy consumed in shipping comes from low-carbon fuels. Under their current policy framework scenarios low and zero-carbon fuels will only make up less than 3% of shipping's total energy consumption by 2030 and roughly one third by 2050, significantly short of the net-zero target. Despite some promising announcements and plans there continues to be a lack of investment in zero-emission technologies, with the IEA highlighting that the total amount of corporate R&D investment for maritime decreased, from $2.7 billion in 2017 to $1.6 billion in 2019.

To accelerate the shift to zero-carbon fuels, multiple nascent technologies need to be developed to reach large scale deployment. Shifting to alternative fuels such as hydrogen, ammonia, biofuels and electrification from renewable sources could cut 80% of emissions from maritime transport. The current pipeline of solutions and projects while welcome are not enough to deliver the paradigm shift in the technologies needed and at the scale required to decarbonise shipping.

The shipping sector will experience a new technological revolution – as previous from wind to coal and then from coal and steam to fossil fuel combustion – that will need to meet maturity in less than three decades. This necessitates a complete transformation of the current dominant technology and a major scaling up of finance for technology development in addition to regulatory policies and effective public-private alliances. Only then can we deliver the thousands of zero-emission ships required to be in the water by 2030 and to meet our 2050 net zero ambitions. Significant and long-term, high-risk investments will be required to trigger the step-change to advance technology readiness levels and pilot these technologies.

- **The report identifies 265 projects that address key technical and systemic challenges that need to be overcome to kick-start and accelerate the transition to zero-carbon emissions.**
- **It highlights the 20 high-priority example projects requiring immediate investment.**
- **$5 billion is needed to advance alternative technologies towards pre-commercial deployment stage.**
- **Projects identified may take between 1–6 years to mature, so action is required if we are to deliver significant numbers of zero-emission ships by 2030.**

Shipping's four propulsion revolutions



Scaling up

Since the technologies needed to achieve net zero-carbon goals have not yet been commercialised, it is vital that the pace of research and development of maritime fuels and technologies is accelerated. Vessels have a lifespan of 20–25 years so the first commercial zero-carbon ships must start to be deployed in the next decade to meet 2050 targets.

The industry's global trade associations have jointly commissioned a major report, from the engineering consultants Ricardo, called Research and Development Requirements for Zero-Carbon Shipping[1]. The report identifies key systemic and technological challenges and provides a comprehensive analysis of the type of projects to accelerate technology readiness levels for the maritime sector to progress towards zero-carbon ships and fuels by 2050.

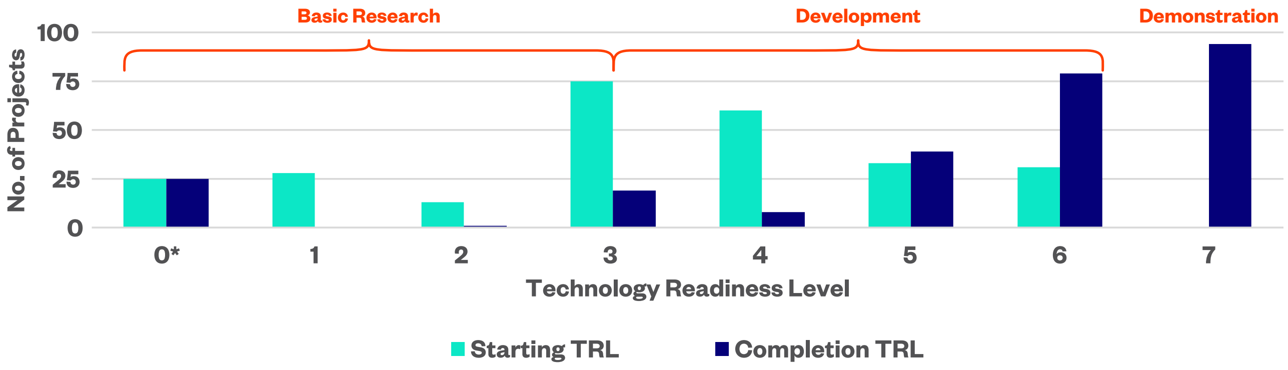
The report focuses on:

- The needs of transoceanic shipping (container, bulk carrier and tanker);
- Zero-carbon fuels and storage (ammonia, hydrogen, battery/electrification, on-vessel carbon capture and storage technology (CCS)); and
- On board vessel power systems and fuel storage systems.

The report provides a blueprint that can serve as a guide for governments and the private sector to be able to identify the most urgent and impactful zero-carbon projects. Working together to fund and develop demonstration activities will hasten cost reductions and accelerate the uptake of alternative fuels and technologies at the scale required to meet net zero-carbon goals.

It identifies 265 projects that are necessary to remove key roadblocks to high-potential technologies and solutions, including hydrogen, ammonia, and electrification. An estimated cost of ~$4.4BN would be necessary to fund these projects, **which would allow technology readiness levels (TRLs) to increase from early stages of research and development (TRL 1–6) to piloting and demonstration (TRL 7).** Increasing the TRL within six years will ultimately reduce costs so that these technologies can be ready for scale-up investment and later become affordable and widely taken up by the global shipping industry. Increasing TRL from basic research to demonstration is the first step to move faster towards decarbonisation.

Technology readiness level distribution



*'0' TRL projects are those that aren't specifically related to development of a technology, e.g. safe engine room standards for ammonia

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[1] See https://www.ics-shipping.org/wp-content/uploads/2021/08/MEPC-77-7-1-Comprehensive-analysis-of-RD-projects-to-be-supported-by-the-IMRB-to-rapidlyincrease-Tech...-ICS-BIMCO-INTERTANKO-C...-1-002.pdf

High-level challenges and solutions for maritime decarbonisation

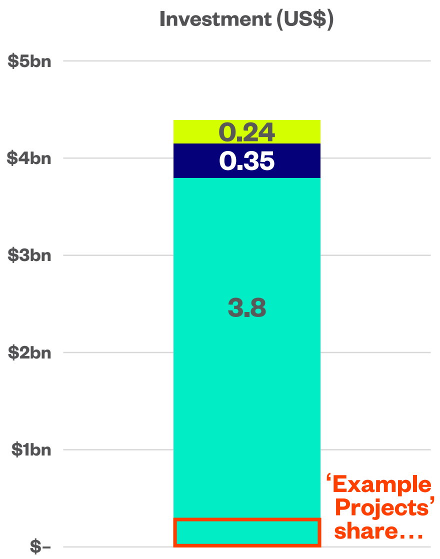
The Research and Development Requirements for Zero-Carbon Shipping report by Ricardo identifies both systemic and technological challenges to reach decarbonisation in the maritime sector. There are high-level challenges as the majority of vessels in operation will need to be zero carbon by 2050. Furthermore, fundamental vessel reconfigurations may be required, limiting future retrofit opportunities.

The report has identified 120 high-level challenges related to operation, safety, scope of current and future greenhouse gas emissions and several other aspects for each of the technologies covered.

Summary of challenges and projects

Number of projects

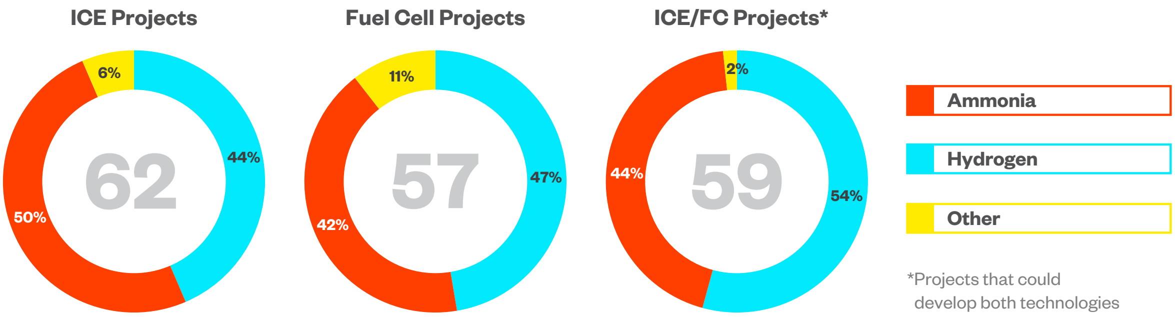
Required investment



	Nominal Cost*		No. Projects
🟨	$5m	x	48
🟦	$12.5m**	x	28
🟩	$20m	x	190

*Based on high-level estimate
**Average of $5–20m

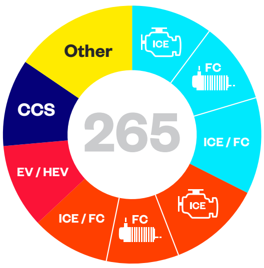
Internal combustion engine and fuel cell projects



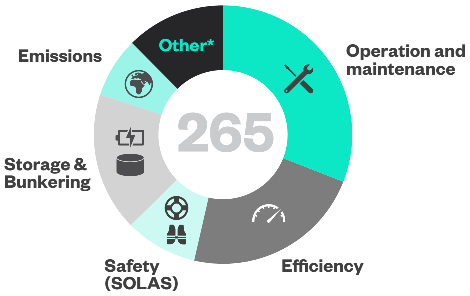
*Projects that could develop both technologies

Demonstrator projects and projects by category

No. of projects by 'Demonstrator'



No. of projects by 'Category'



*Includes end-of-life, economic, political, regulative and legislative factors among others.

Steps following identification of challenges

Once all major challenges were identified for every system, these were grouped into common themes to focus on the underlying issues and help identify suitable **project categories.**

Project titles were subsequently drafted to address a specific *challenge* or topical issue – based on one of the aforementioned categories.

Operational Efficiency

Ensuring new solutions offer **comparable operational efficiency** compared to "conventional solutions".

Longevity of Solution

Ensuring **new solutions** survive the test of time; **are robust to withstand increasingly stringent environmental measures** and afford sufficient GHG benefit over time to achieve IMO ambition.

Safety

Ensuring new solutions are **safe, or risk managed** – without compromise to the health of human or aquatic life

Cost Effective Technologies

Ensuring new **technologies** are **economically viable** – does not necessarily demand immediate price parity with diesel ICE.

Minimal Disruption

Ensuring the implementation of new solutions affords **minimal disruption to trade & transport.** Also, champion solutions that drive long-term market growth.

Sustainable Resources

Ensuring **sustainability of key component resources for alt. propulsion vessels** e.g. batteries (along with the challenge of procuring sustainable alt. fuels supplies).

Retrofit Potential

Ensuring an adequate number of the **new decarbonisation options can be retrofitted** to existing vessels. Also, managing the risk of stranded assets with new vessel technologies.

Global Acceptance

Ensuring new solutions meet critical levels of **international acceptance,** ensuring viability – particularly pertinent for transoceanic vessels.

Bunkering Infrastructure

Ensuring new fuels are available at major ports which requires **updated bunkering infrastructure.**

The report identifies which fuels and technologies have the largest number of potential projects. There is a larger number of projects for hydrogen (89) and ammonia (82), than generic (66) and electric (28). The report provides the types of projects required, but is not an exhaustive list of projects. Overall, there is a focus on transoceanic shipping based on two key research lines for development:

1. Zero-carbon fuels such as ammonia and hydrogen; and
2. On board vessel power, fuel and energy storage systems, including carbon capture and storage technology.

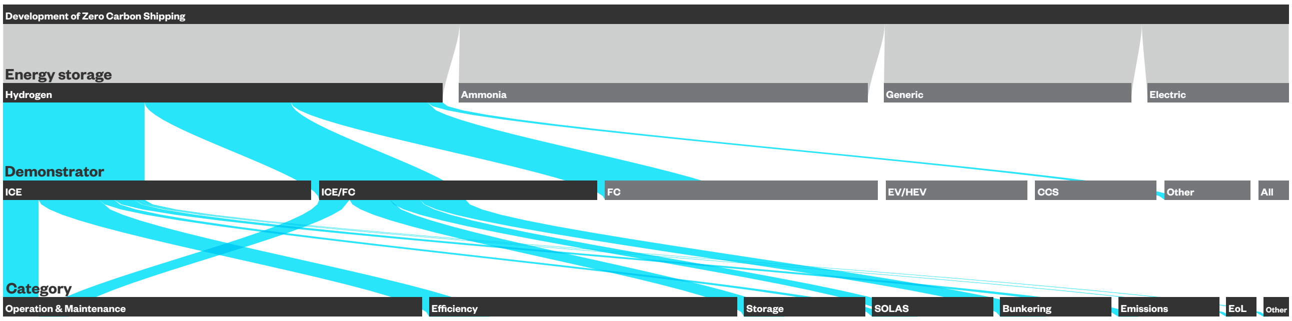
The report includes projects that address solutions to the challenges of decarbonisation for internal combustion engines, fuel cells or projects that could develop both technologies as well as other demonstrators. In addition, it provides a visual representation of how each project covers a specific challenge area or category.

The Sankey visual is comprised of **three levels** – each of which describe a different project attribute for each of the fuel technologies:

1. **Energy Storage:** Is the mechanism by which energy is stored, either as; hydrogen, ammonia, electricity or another (generic)[2] energy storage mechanism.
2. **Demonstrator:** Is the vessel power/propulsion system under which the project falls, e.g. internal combustion engine (ICE), fuel cell (FC), electric/hybrid-electric vessel (EV/HEV), carbon capture and storage (CCS), or ‘other’ types of demonstrator.[3]
3. **Category:** Defines the challenge area under which the project falls, e.g. operation and maintenance (O&M), efficiency, storage, safety of life at sea (SOLAS), bunkering, emissions, end of life (EoL) or ‘other’.

Hydrogen – 89 projects

Project Distribution by; Energy Storage Type, Vessel Demonstrator and Project Category



* The width of each band is proportional to the number of projects.

Ammonia – 82 projects

Project Distribution by; Energy Storage Type, Vessel Demonstrator and Project Category

* The width of each band is proportional to the number of projects.

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[2] Including, for example, fossil fuels.

[3] Some projects have ramifications which apply to all the aforementioned demonstrators, hence the ‘All’ category.

Electric – 28 projects

Project Distribution by; Energy Storage Type, Vessel Demonstrator and Project Category

* The width of each band is proportional to the number of projects.

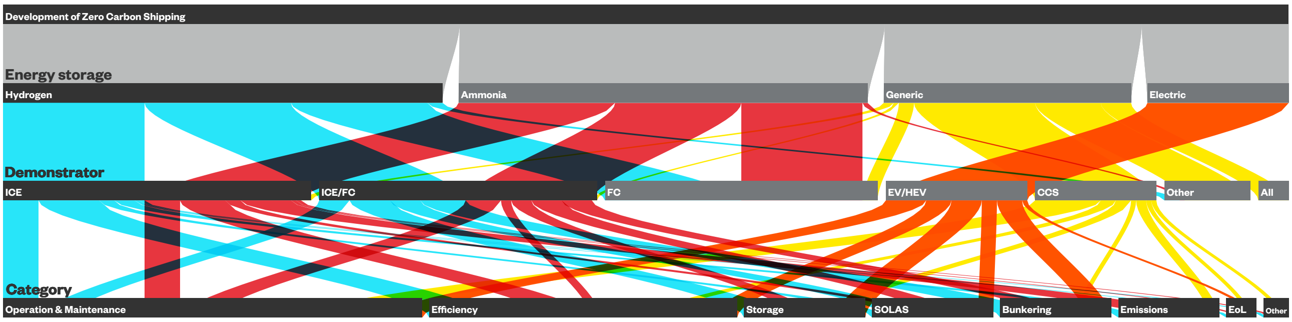
Generic – 66 projects

Project Distribution by; Energy Storage Type, Vessel Demonstrator and Project Category

*The width of each band is proportional to the number of projects.

The graph below incorporates the projects for all technologies analysed in the Ricardo report and demonstrates the magnitude and complexity of the challenge for decarbonising shipping. The Ricardo study shows that multiple R&D projects will need to be undertaken in order to achieve zero carbon shipping by 2050. Many of these projects are closely related creating an intricate web of complex projects.

Project Distribution by; Energy Storage Type, Vessel Demonstrator and Project Category



Priority projects

To support policy makers and the R&D community, the report also includes detailed case studies for 20 key example projects which are considered to be vital priorities to gain knowledge and experience for the other 200+ projects identified. These case studies identify the research tasks, indicative budgets and required timings. Key projects were selected based on their: high impact, need and/or urgency for shipping decarbonisation. The projects were given an urgency ranking.

Detail Example Projects

20

20 projects are picked from the 265 and described in greater detail

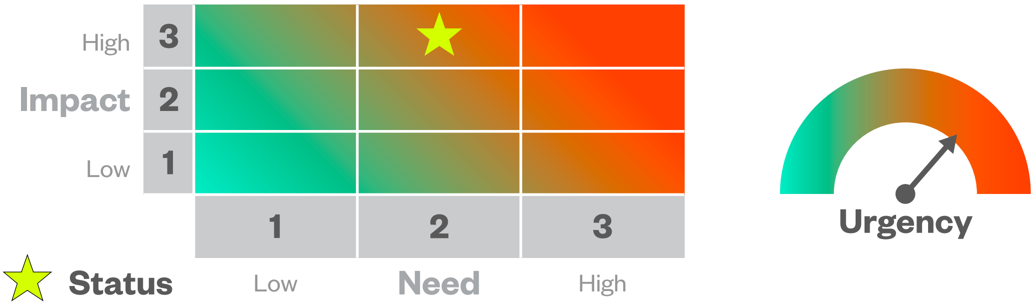
Examples of the detailed projects include... (see more in table on p10)

Case Study 2 '**Ammonia cracking to hydrogen for reducing on-board hydrogen storage requirement**'.

Case Study 3 '**Ammonia fuel cell durability testing to estimate lifetime at sea**'.

Case Study 18 '**Novel battery technology development for marine applications**'.

The example projects were given a ranking from 1 to 3 in terms of impact and need in order to identify their urgency status.



Project Summary – Detail is provided for 20 projects

Case studies have been produced for the following projects:

Ammonia

No.	Title (TRL Progression)	Cost (US$ m)	Duration (yrs)	Impact**	Need**	Urgency**
1	**Ammonia fuel cell (primary power) transoceanic demonstrator vessel (TRL 5 → 7)**	100	3–4	3	3	2
2	**Ammonia cracking to hydrogen for reducing on-board H2 storage requirement (TRL 4 → 7)**	20	2–3	3	2	3
3	**Ammonia fuel cell durability testing to estimate lifetime at sea (TRL 5 → 6)**	10	1–2	3	3	3
4	**Bunker barge development for ammonia-fuelled vessels (TRL 4 → 7)**	40	2–3	3	2	2
5	**Improving ammonia powered solid-oxide fuel cells (SOFCs) warm-up phase (TRL 3 → 6)**	5	1–2	2	3	2
6	**Decommissioning of ammonia ICE vessels (TRL 2 → 7)**	1	1	2	3	2
7	**Control of unburnt NH3 in combustion, impact on; ICE, human & aquatic health (TRL 4 → 7)**	20	3–5	3	2	3
8	**Safe engine room concepts for ammonia (TRL 4 → 6)**	2	1–2	2	3	3

Hydrogen

No.	Title (TRL Progression)	Cost (US$ m)	Duration (yrs)	Impact**	Need**	Urgency**
9	**Crankcase explosion risk in hydrogen combustion engines (TRL 4 → 5)**	20	2	3	3	3
10	**Increasing hydrogen storage energy density (TRL 1 → 5)**	10	3–4	3	3	3
11	**Ignition technologies for extreme durability & knock avoidance in a H2 ICE (TRL 3 → 6)**	10	2	2	3	3
12	**H2 ICE retrofit to existing vessel, practical approach & economic assessment (TRL 5 → 7)**	20	1–2	3	3	3
13	**Concept development of a H2 fuel cell auxiliary power system for large vessels (TRL 3 → 4)**	1	1	3	2	3

Battery

No.	Title (TRL Progression)	Cost (US$ m)	Duration (yrs)	Impact**	Need**	Urgency**
14	**Maintenance requirements for marine based battery systems (TRL 6-7)**	10	2–3	2	3	3
15	**Battery pack and cell degradation over time (TRL 3 → 5)**	5	1–2	3	2	3
16	**Hyper-charging systems for multi-MWh marine batteries (TRL 3 → 6)**	20	3	3	2	2
17	**Vessel safety standards & protocols for emerging high voltage components (TRL n/a)**	10	1–2	3	3	3
18	**Novel battery technology development for marine applications (TRL 1 → 5)**	40	5–6	3	3	3

Carbon capture/offloading

No.	Title (TRL Progression)	Cost (US$ m)	Duration (yrs)	Impact**	Need**	Urgency**
19	**Development of carbon off-loading technology (TRL 6 → 7)**	5	1–2	3	2	2
20	**Achieving marine engine post-combustion CCS system efficiencies of >99% (TRL 3 → 6)**	20	2–3	2	3	3
	TOTAL Investment (million US$)* =	369				

* Does not include costs for remaining 245 identified projects – which equates to a total cost of c. US$4.1BN.

** See definitions for these indicators provided in the full Ricardo report (2021), along with TRL definitions etc.

Conclusion

The Research and Development Requirements for Zero-Carbon Shipping report presented at the Shaping the Future of Shipping conference at COP26 is intended to complement information and reports for policy-makers to advance on innovation programmes that can accelerate the shipping decarbonisation pathway.

Shipping is serious in its ambition to reach net zero-carbon emissions by 2050 but also recognises the scale of challenges and opportunities that lay before it. To meet emissions targets, thousands of zero-carbon vessels will need to be operating in the water by 2030 and most vessels will need to be zero-carbon by 2050. Yet, more than 60% of the emissions reductions required in 2050 will come from technologies that are not commercially available today. The latter represents a major transformation for the industry.

There are clear pathways laid out in this report to achieve this goal, with projects in hydrogen and ammonia, as well as battery power among the most vital to start work on.

R&D of alternative powertrains and fuels is urgently needed to reduce costs and improve performance, as well as measures to develop the associated infrastructure. It is down to governments and industry to work together to push forward and ensure that the policies, funding and incentives are in place for shipping to decarbonise at the pace and scale targetted. Shipping will need to enter a rapid transformation in its whole innovation ecosystem for the sector to generate the paradigm-shift required in its fourth propulsion revolution. Innovation will play a key role for the maritime sector to unlock its current path dependency and deliver zero-carbon ships in the scale and timeframe required by 2050.

The $5BN Shipping R&D Fund

The Research and Development Requirements for Zero-Carbon Shipping report, and its comprehensive analysis of urgently needed R&D projects, supports a proposed $5BN IMO Maritime Research Fund (IMRF). The IMRF, to be established by the UN International Maritime Organization (IMO) is urgently required to rapidly accelerate R&D of zero-carbon technologies for application to large oceangoing ships, and make a net zero target plausible for international shipping.

Latest figures from the IEA on Private Sector R&D in maritime reveals R&D spending has fallen to $1.6BN[4] in 2019. The IMRF could triple the current level of R&D spending for technological development and deployment of zero-carbon shipping technologies without using governments' money. There is also an opportunity to increase public-private collaboration in supporting R&D projects by funding them through the IMRF.

The IMRF concept has been developed over the past four years with the full backing of the entire global shipping industry and is now supported by a wide range of governments, with the US$5BN to be raised from 2023 via mandatory R&D contributions from shipping companies.

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[4] www.iea.org/reports/international-shipping

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Established in 1921, ICS is concerned with all aspects of maritime affairs particularly maritime safety, environmental protection, maritime law and employment affairs.

ICS enjoys consultative status with the UN International Maritime Organization (IMO) and International Labour Organization (ILO).

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