Pathways to Propulsion Decarbonisation for the Recreational Marine Industry

Synopsis Report

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Foreword

Since 1966, the International Council of Marine Industry Associations (ICOMIA) has helped move the boating community forward, advancing cutting-edge innovations and mobilising the industry to create a better boating experience. Our love for boating is fundamentally reliant on a healthy and sustainable marine environment, and we must take care of it to ensure the experiences boating provides can be enjoyed for generations to come.

ICOMIA commissioned the Pathways to Propulsion Decarbonisation for the Recreational Marine Industry report, a first-of-its-kind primary research study with Ricardo plc, a leading global engineering consulting firm, to uncover how the global recreational marine industry can further reduce carbon emissions. The study is the most comprehensive lifecycle assessment ever conducted and investigates propulsion technologies across nine common recreational watercraft to compare the impact of lifetime greenhouse gas (GHG) emissions, financial costs, usability, range, performance and infrastructure implications.

The findings illustrate that the diversity of the recreational marine industry means environmental sustainability and decarbonisation initiatives cannot take a one-size-fits all approach related to propulsion technologies. Sustainable liquid marine fuels provide the strongest path to reduce carbon emissions; with approximately 30 million recreational boats in use around the world, encouraging the use of sustainable liquid marine fuels is a data-driven, sensible transition plan to reduce emissions today. Electric, hydrogen and hybrid solutions have a promising future in select use cases, and our industry will continue innovating and investing in new technologies that push the boundaries of what's possible.

This new research paves the way for the recreational marine industry to begin educating global governments and boating industry stakeholders on the technologies and policies needed to further reduce carbon emissions. As we look to the future, acceleration of the development and distribution of sustainable liquid marine fuels, establishment of marine electric technology standards and consumer safety protocols and continued evaluation of existing and emerging technologies are needed to help protect our waters and ecosystems.

Darren Vaux,
ICOMIA President

Version History & Disclaimer

Reference Number	Issued Date	Revision
RD23-000335-1	5 May 2023	First issue – Draft Summary Report
RD23-000335-2	13 July 2023	Second issue – Final Synopsis Report
RD23-000335-3	8 September 2023	Third issue – Revised Synopsis Report including the following changes: • Clarification in "Aim and approach" section that study investigated craft below 24 m in hull length
RD23-000335-4	7 November 2023	Fourth issue – Revised Synopsis Report including the following changes: • Editorial changes to Figure 5 & 6

Ricardo - Icomia - Greenhouse Gas Reductions in Marine Leisure Propulsion – Synopsis Report

1 Introduction

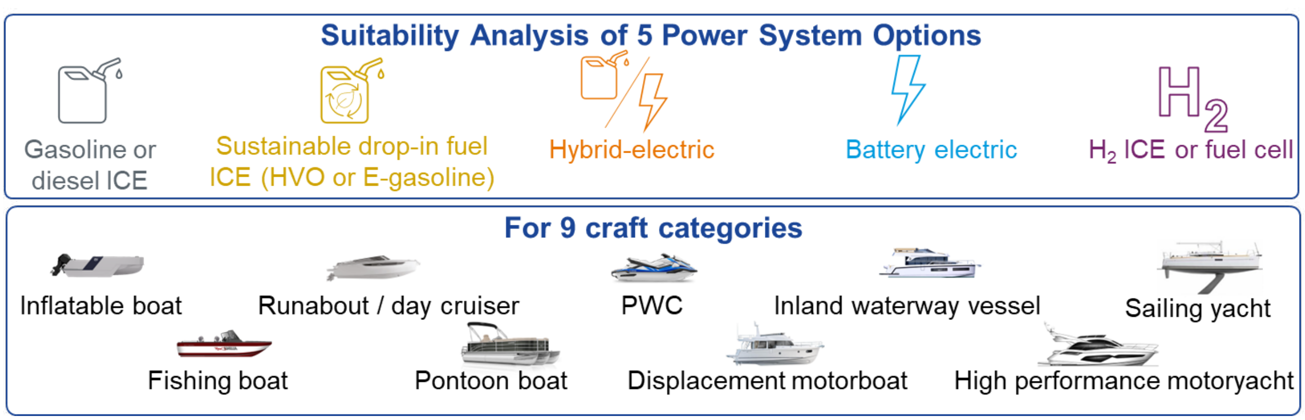
As climate change receives political and societal attention, the recreational marine industry is encouraged to present ways to address reduced carbon emissions for the sector. Despite being a small contributor to greenhouse gas (GHG) emissions relative to other sectors, accounting for only 0.4% and 0.7% of carbon dioxide (CO_2) emissions emitted by the transport sector in the EU and USA respectively [1,2], the marine leisure sector has actively investigated options to reduce its GHG emissions. The International Council of Marine Industry Associations (ICOMIA) and its decarbonisation steering committee commissioned Ricardo PLC to conduct independent scientific research and third-party reviewed life cycle assessment (LCA) to identify and independently verify suitable propulsion technologies for decarbonising recreational craft.

2 Aim and Approach

Aim The aim of the study is to provide objective data which can be used to guide strategic decisions and technology choices on future propulsions solutions to achieve greenhouse gas reductions in marine leisure propulsion.

Approach The study compared the suitability of five different propulsion technologies including baseline fossil fuel ICE (gasoline & diesel), hybrid electric, hydrogen ICE or fuel cell, ICE with drop-in sustainable marine fuels including HVO and e-gasoline, and battery electric for nine representative recreational craft to help decarbonise the marine leisure industry through to 2035. The craft selected in this study include a range of small recreational craft below 24m in hull length, representing the global market. Consideration was given to the sales volume of craft as well as the typical engine power and usage profiles to provide the most representative and meaningful overview.

To achieve this, an analysis has been undertaken to investigate greenhouse gas (GHG) life cycle emissions, costs, usability, range, and performance, along with future technology and fuel availability, as illustrated in Figure 1. The resulting analysis was used to determine overall suitability of different energy options for each craft category through to 2035.



Task 1 — **Decarbonisation Options**
Overview of each propulsion system type including systems required, impact on craft, infrastructure required and fuel supply options

Task 2 — **Greenhouse Gas Life Cycle Assessment (LCA)**
Lifecycle assessment to ISO 14044 and 14067 including manufacture, use phase and end of life for energy converters and energy carriers

Task 3 — **Total Cost Of Ownership**
Purchase cost and operational costs including energy and maintenance for energy converters, energy carriers and new infrastructure

Task 4 — **Boat Power Systems Implications**
Analysis of life expectancy, maintenance requirements, performance, safety and commercial availability

Task 5 — **Infrastructure Implications**
Analysis of life expectancy, safety, expected availability of fuels or energy

Task 6 — **Suitability And Ranking**
Overall suitability of different options for each craft type and usage case

Figure 1 – Summary of study objectives and approach

3 Key Conclusions

Key conclusions are described related to practicality and performance, life cycle assessment, total cost of ownership and overall suitability of decarbonisation options, as well as policy recommendations.

Practicality and Performance Conclusions

- Recreational craft are very different than automotive (on-road vehicles) in terms of their suitability for specific decarbonisation technologies. There are no one-size-fits-all technology solutions for the unique and diverse types of recreational boats investigated in this study.

- Hybrid systems and sustainable fuel internal combustion engines (ICEs) can maintain the same range and power as current baseline ICEs with minimal to no impact to the vessel displacement and on-board space.

- Pure battery electric and hydrogen propulsion craft will require a significant reduction in range and potentially also power to mitigate impacts on vessel mass, on-board volume and purchase price. It is impractical to match the range and performance of baseline fossil fuels when sizing a hydrogen or battery-electric propulsion system as the H2 tanks or batteries take up too much space within the craft or are simply too heavy to be practical as indicated in Figure 2. Therefore, these alternative propulsion systems were optimized by reducing the overall size of the hydrogen storage tank or battery pack.

- Because of the necessary reduction in hydrogen tank storage or battery pack size due to weight, impact on vessel space, and cost, in the case of pure battery electric, the runabout/day cruiser's range was reduced by 80% relative to the baseline fuel. The fishing boat's range was reduced by 76%, and the displacement motorboat's range was reduced by 90%. These optimised alternative propulsion systems were then subsequently subjected to comprehensive life-cycle assessment investigations.

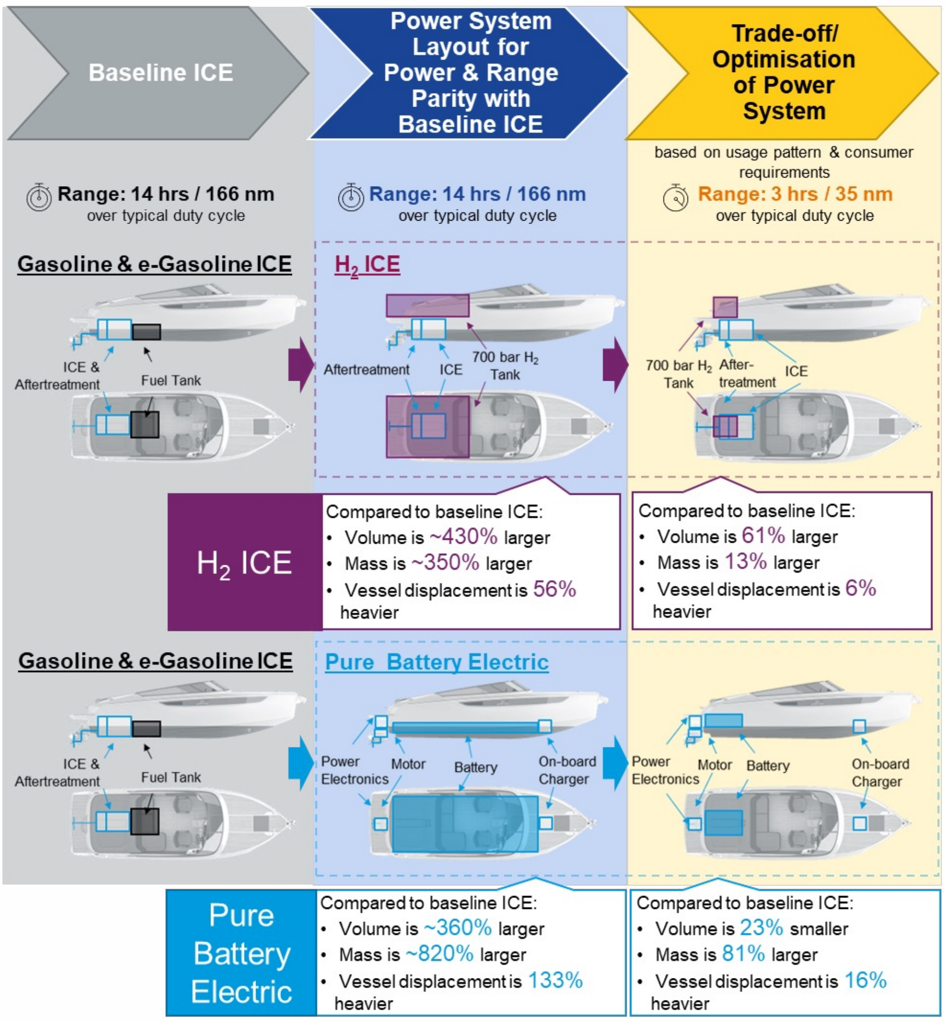
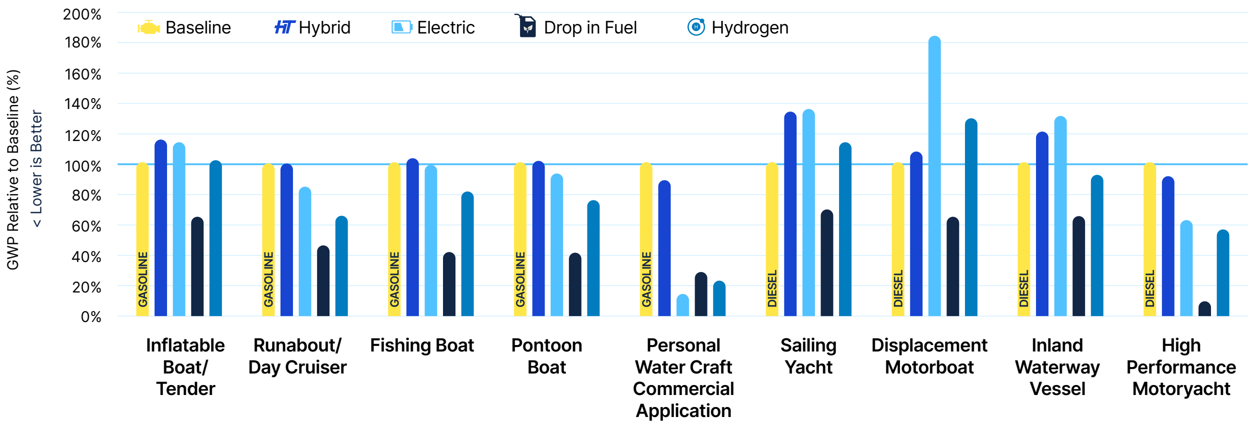


Figure 2 - Pure battery electric and H2 ICE volume, mass and range trade-off demonstrating power & range parity with fossil fuel ICE on the left, and optimised power system based on usage pattern & consumer requirements on the right

Life Cycle Assessment Conclusions

- The most suitable propulsion system from a global warming potential (GWP) perspective does vary on a craft-by-craft basis. A one size fits all approach is not appropriate for the wide range of craft types assessed in the life cycle analysis (LCA)
- Recreational craft engines are operated on average between 35 and 48 hours [3] per year which makes it more difficult to achieve sufficient emission reductions in the use phase to outweigh the higher production and maintenance impacts of electric only, hybrid and hydrogen systems. These embodied impacts are especially associated with the battery and hydrogen (H2) storage components and are magnified if these components must be replaced in the lifetime of the craft.
- Internal combustion engines (ICEs) powered by renewable liquid fuels are suitable candidates to decarbonise privately owned marine leisure craft. These power systems can provide significant GHG savings, especially for craft with low utilisation and long lifetimes which are highly susceptible to manufacturing and maintenance impacts.
- LCA results indicate that, out of the options considered, e-gasoline ICEs offer the greatest potential to reduce GHG emissions of privately owned gasoline craft but only if low carbon electricity is used in fuel production.
- Renewable diesel fuel, specifically hydrotreated vegetable oil (HVO) ICEs can provide the largest global warming potential (GWP) reductions for diesel craft provided the fuel is produced using waste feedstocks.
- The pure battery electric propulsion system has a notably higher contribution from raw materials and manufacturing than other propulsion systems. Consequently, craft types with lower utilisation (which increases the relative importance of raw material and manufacturing impacts) are unlikely to find that the battery electric system results in a reduction in GWP compared to the baseline ICE. It is important to note that this study considers battery lifetime in years rather than recharging cycles as battery performance is expected to degrade over time due to calendar aging despite low utilisation. This could further impact a craft with a long lifetime but little utilisation as it will be assumed to require numerous battery replacements throughout the craft lifetime.
- In terms of the greatest potential for greenhouse gas reductions (GHG), if the production of drop-in fuels and hydrogen is optimised, i.e., bio-fuels from waste feedstocks and hydrogen produced via electrolysis with zero fossil fuel electricity, then the propulsion systems powered by these fuels represent the greatest potential to reduce GHG emissions under the study’s assumptions as indicated in Figure 3.



	Inflatable Boat/ Tender	Runabout/ Day Cruiser	Fishing Boat	Pontoon Boat	Personal Water Craft Commercial Application	Sailing Yacht	Displacement Motorboat	Inland Waterway Vessel	High Performance Motoryacht
Annual utilisation (h)	35	43	35	35	156	24	48	48	130
Lifetime (y)	10	30	38	38	12.5	45	45	50	50

Figure 3 - Lowest global warming potential (GWP) for each propulsion system relative to the baseline ICE of each craft in 2035* (kgCO2eq/vh). Lower values result in lower CO2 emissions over the lifetime of the craft
*Production of hydrotreated vegetable oil (HVO) for diesel powered boats assumed to be produced from waste feedstocks such as used cooking oil. All sources of electricity are zero fossil fuel.

NOTE: Typical annual usage of PWC in a recreational application is 35 hours per year.

Total Cost of Ownership Conclusions

- From an economic perspective, sustainable drop-in fuel ICEs and parallel hybrid power systems are the most suitable decarbonisation options for privately owned recreational craft – Craft destined for the rental market may be more suited to adopt hybrid or battery electric propulsion systems due to the larger number of annual operating hours.
- For large marinas wishing to fully decarbonise their fleets, hydrogen and sustainable fuel refuelling infrastructure provide better total cost of ownership (TCO) than electric charging stations, mainly due to high refuelling speed.
- The total cost of ownership, including purchase price and operational costs increased with all propulsion technologies relative to the baseline systems. Even in 2035, battery-electric will yield cost increases of between 40% and 250%, hydrogen systems between 85% to 200%, hybrid systems between 25% and 115% and sustainable drop-in marine fuels between 5% and 45%. These costs should be reduced over time as alternatives achieve market scale.

Overall Technology Suitability Summary

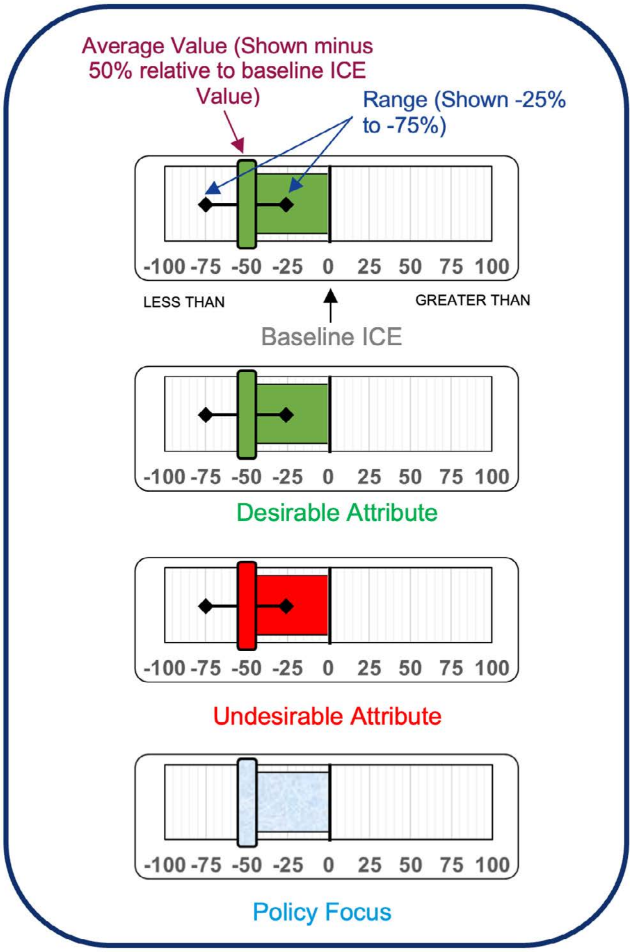


Figure 4 - Interpreting results: Overall Technology Suitability Attributes. Green is a desirable attribute, red is an undesirable attribute, and blue is a policy focus attribute. All Charts are Relative to Baseline Internal Combustion Engine

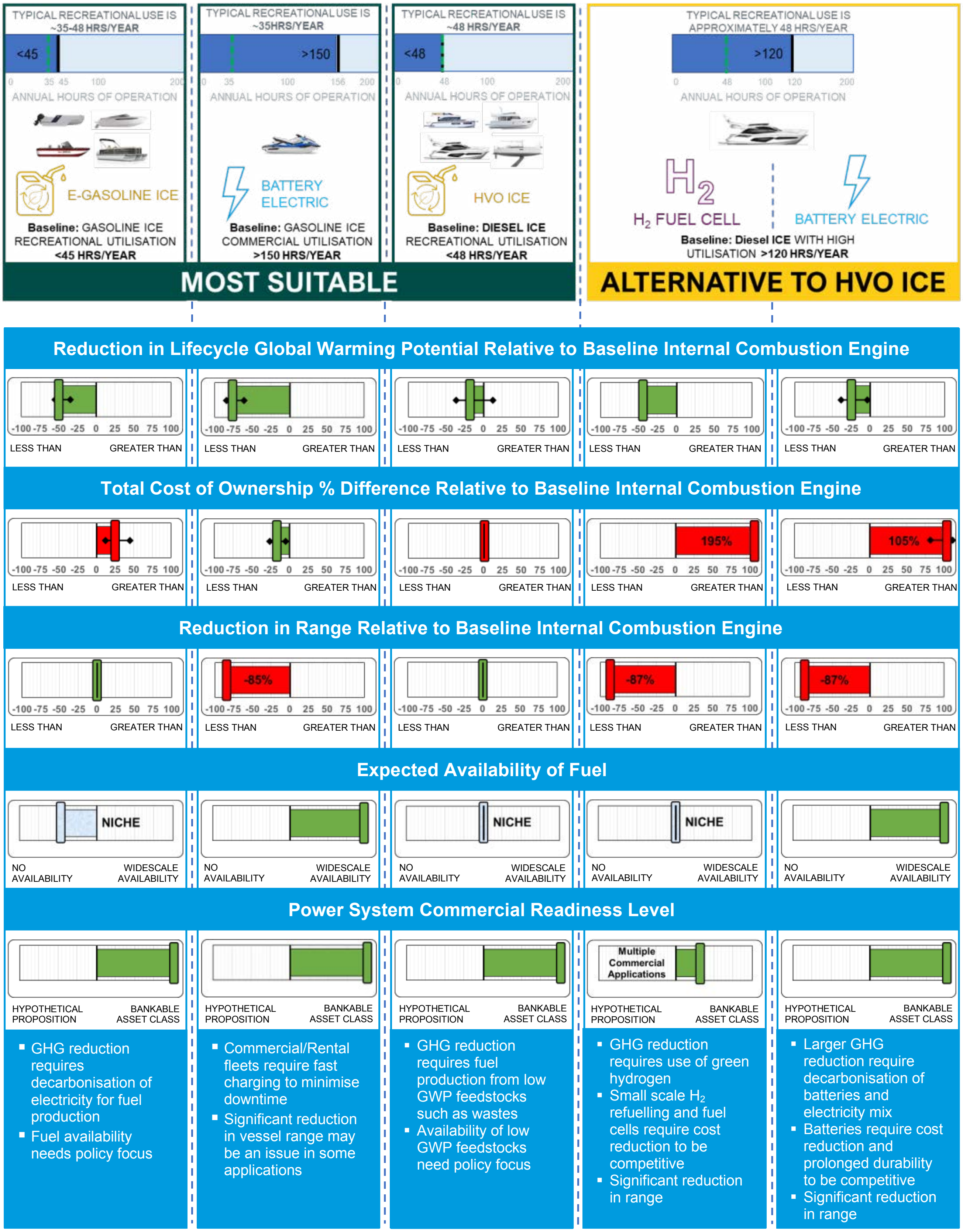


Figure 5 – Summary of most suitable decarbonisation options identified for 2035

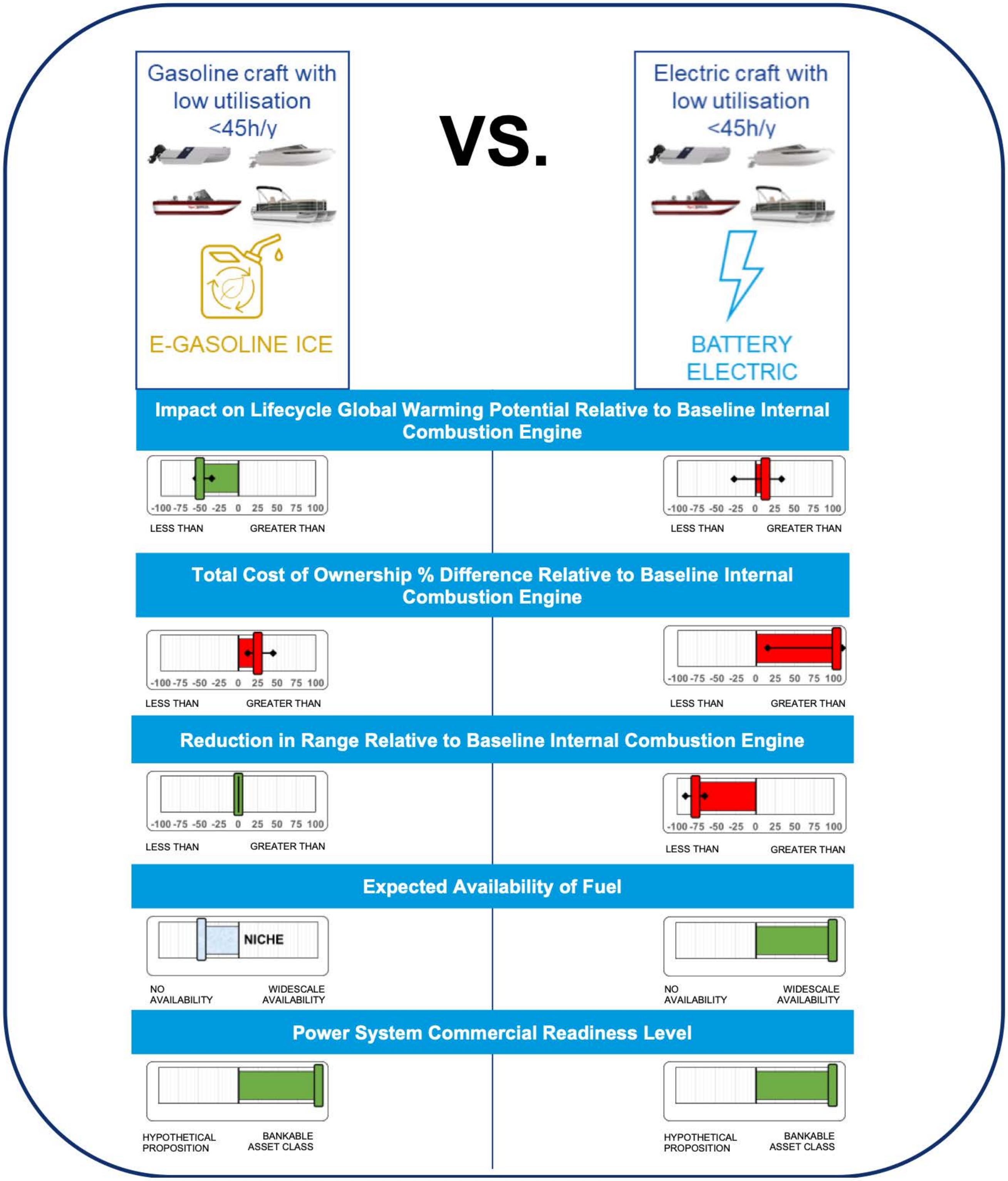


Figure 6 - Example Impact of electrification on craft with low utilisation based on key attributes for 2035

Summary

The analysis undertaken concluded that internal combustion engines (ICEs) powered by renewable liquid fuels are suitable candidates to decarbonise privately owned marine leisure craft. These power systems can provide significant global warming potential savings, especially for craft with low utilisation and long lifetimes, as they are highly susceptible to manufacturing and maintenance impacts. The adoption of renewable fuels also provides the opportunity to reduce greenhouse gas emissions from craft already in operation, as fossil fuel ICE craft and refuelling infrastructure require minimal or no modifications to use renewable alternatives to fossil fuels. Furthermore, renewable liquid fuel ICEs may also benefit from lower economic and performance impacts than other options considered, which may assist widescale adoption in the sector. Nevertheless, there is considerable uncertainty over the availability of these fuels through to 2035, and caution must be taken to guarantee that e-fuels are produced using low carbon electricity sources and biofuels are produced with low GWP feedstocks.

Craft with high utilisation, for instance used in shorter duration rental applications, are also suited to adopt pure battery or hydrogen propulsion systems. These propulsion systems can provide lower in-use greenhouse gas emissions than renewable liquid fuel ICEs provided hydrogen and electricity are generated from low carbon sources and are therefore highly suited to these usage patterns. Nonetheless, these power systems will require range and technology cost reductions to ensure competitiveness from an economic perspective.

The sector's diversity means future decarbonisation policies cannot take a one-size-fits-all approach. If policies were to promote exclusively electric propulsion, for example, this would generate better results for craft types with higher levels of utilisation. This option might even have a negative net decarbonisation effect for craft with low levels of utilisation. This implies that a blanket "one-size-fits-all" policy approach promoting specific technologies would not be the best approach and focus could be on ensuring sufficient flexibility in the types of solutions adopted.

4 References

[1] Panteia, TNO and Emisia, "Review study on the Recreational Craft Directive 2013/53/EU", 15 September 2021, https://single-market-economy.ec.europa.eu/system/files/2021-11/Final%20Report%20Review%20Study%20on%20the%20Recreational%20Craft%20Directive%202013%2053%20EU.pdf

[2] US EPA, Greenhouse Gas Explorer CSV File Download 1990–2020, "Greenhouse gas emissions from ships and boats in the United States", 20 April 2023, https://cfpub.epa.gov/ghgdata/inventoryexplorer/#allsectors/allsectors/allgas/econsect/all

[3] US EPA, "40CFR Part 1045 Control of Emissions from Spark-Ignition Propulsion Marine Engines and Vessels", 8 October 2008, eCFR :: 40 CFR Part 1045 -- Control of Emissions from Spark-Ignition Propulsion Marine Engines and Vessels

5 Acknowledgements

Ricardo wish to thank the ICOMIA LCA Steering Group who took part in the stakeholder engagement, providing industry information and opinions for this study.

A full list of participating companies cannot be published due to confidentiality constraints.

