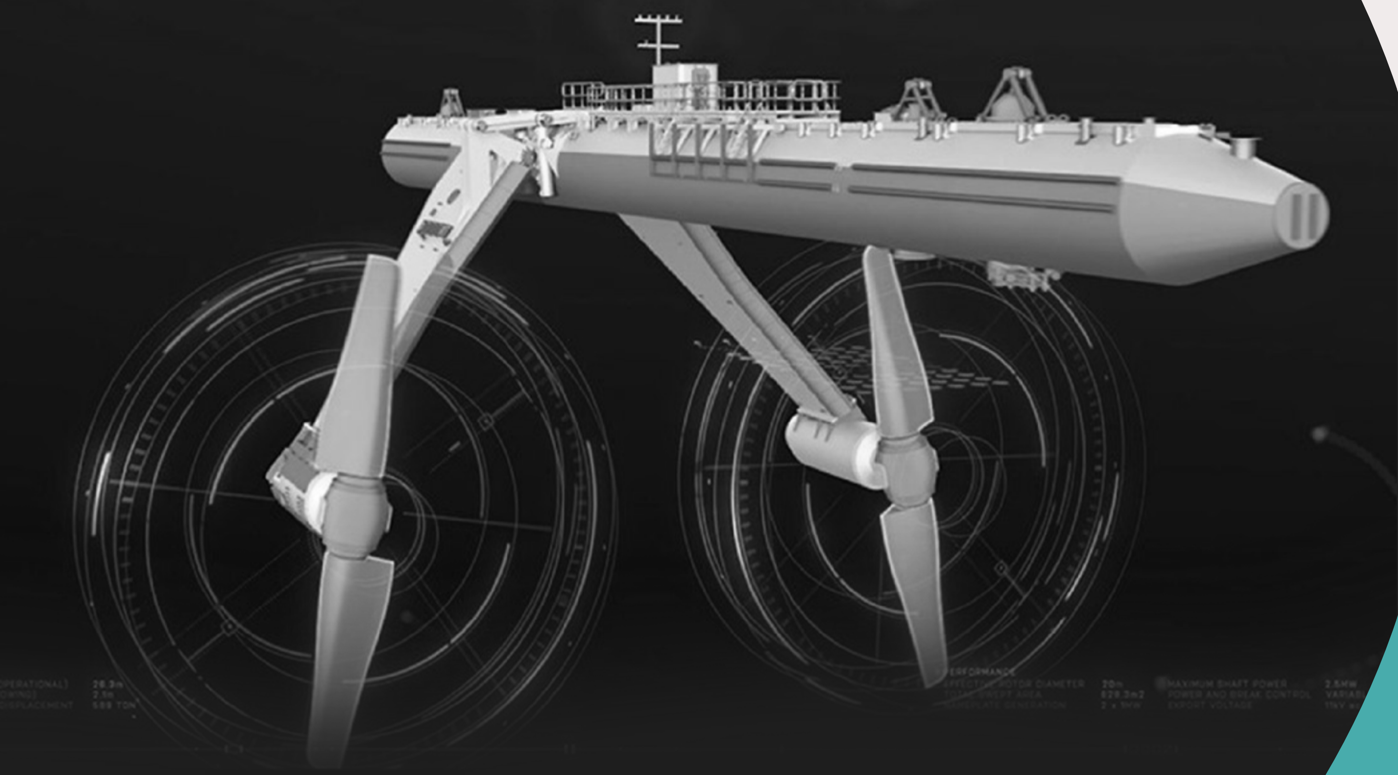
Benefits of Tidal Power and Electrolysis



Supporting Island and Remote Coastal Communities to Achieve Net Zero at Optimum Cost

November 2022

About Us

Energy Systems Catapult

Energy Systems Catapult was set up to accelerate the transformation of the UK's energy system and ensure UK businesses and consumers capture the opportunities of clean growth. The Catapult is an independent, not-for-profit centre of excellence that bridges the gap between industry, government, academia, and research. We take a whole systems view of the energy sector, helping us to identify and address innovation priorities and market barriers, in order to decarbonise the energy system at the lowest cost.

This document is a summary of selected findings from the whole energy system studies carried out by Energy Systems Catapult under the Integrating Tidal energy into the European Grid (ITEG) project

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For more detailed information, including full reports, click here es.catapult.org.uk/report/ITEG/

Interreg North-West Europe ITEG

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Introduction

The Integrating Tidal energy into the European Grid (ITEG) project has developed and demonstrated a state-of-the-art energy solution combining a tidal stream turbine with an electrolyser and hydrogen storage, supplying green hydrogen to a number of local end uses.

Energy Systems Catapult developed a detailed whole-system model of the Orkney Islands energy system, and used it to study the potential impacts and benefits which this combination of technologies could provide when deployed at scale – in particular to island and remote coastal communities seeking to achieve net zero at optimum cost.

One of the key objectives was to understand how best to overcome network constraints which are typical in such communities with large renewable resource potential but relatively weak electricity networks.

This detailed case study of Orkney was then used to inform an assessment of the potential wider roll-out of the ITEG technologies across North West Europe.

Several scenarios were modelled, each building on the previous. Results from three of these are compared in this summary:

- **ITEG Technologies:**
  A single demonstration unit of project technologies (tidal turbine and electrolyser plus hydrogen storage).
- **Scaled up ITEG Technologies:**
  Installation of multiple units, including roll-out of scaled up, co-located tidal arrays and electrolysis plants.
- **Connected Hydrogen:**
  Uncoupling of technologies (generally resulting in location of electrolysis plants close to hydrogen demand rather than co-located with tidal generation), addition of fuel cells and other sources of hydrogen demand such as hydrogen ferries, and access to a hydrogen export market providing additional demand options.

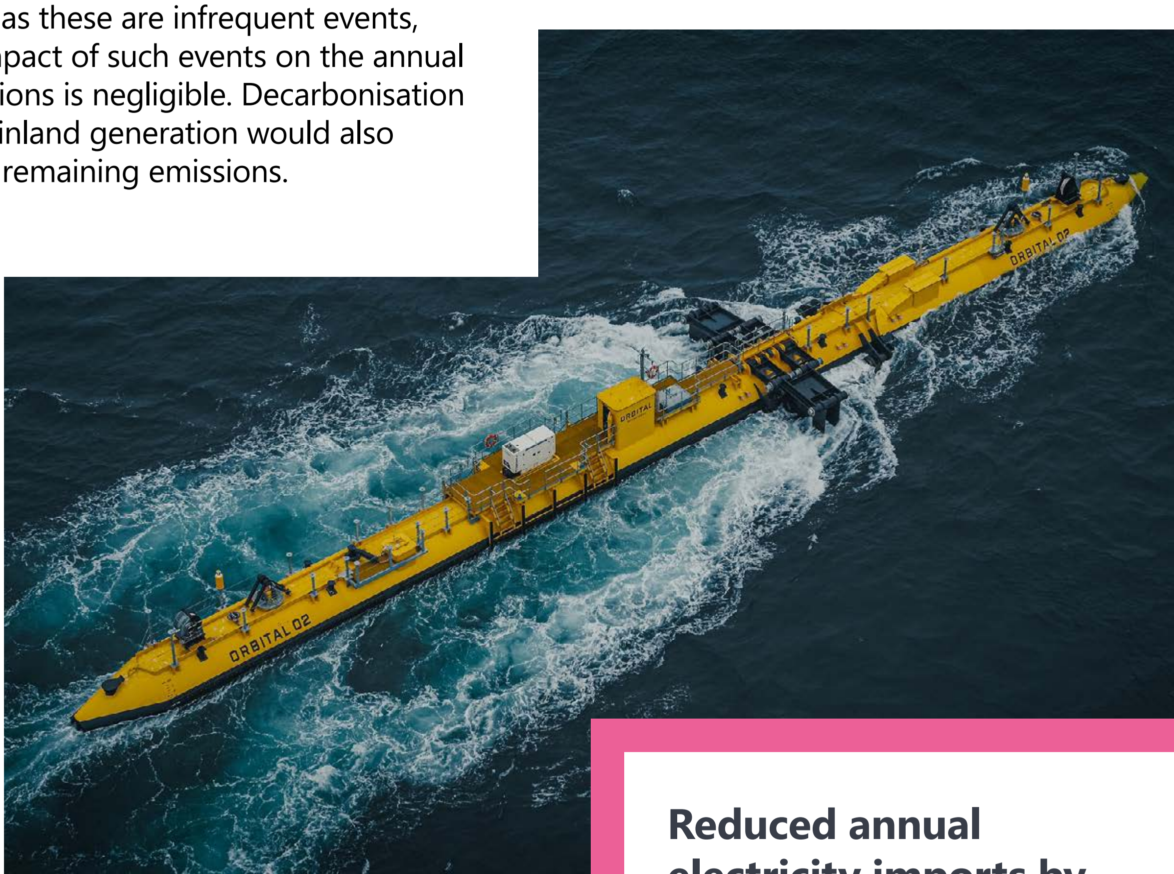
The Orkney energy system has significant electricity network constraints resulting from deployment of low carbon, renewable generation without corresponding network upgrades, with considerable additional resource still available to harness. Exploring the role that tidal generation and electrolysis can play in this context, and particularly the influence of these technologies within the wider energy system, enables informed choices to be made regarding cost effective routes to low carbon energy systems..

Tidal stream turbines, electrolysers and batteries can play significant roles within a low carbon energy system.

A whole system analysis found deployment of the ITEG technologies helped reduce energy-related carbon emissions on Orkney.

Within the scaled up ITEG scenario five packages were deployed across Orkney, each consisting of 20MWp of tidal generation and 5MW electrolyser capacity. These reduced annual electricity imports by approximately 300MWh.

These technologies have the potential to play a significant part in the decarbonisation of the Orkney energy system. Some residual emissions are likely to remain due to electricity imports from the UK mainland during periods of peak demand, but as these are infrequent events, the overall impact of such events on the annual carbon emissions is negligible. Decarbonisation of the UK mainland generation would also reduce these remaining emissions.



Reduced annual electricity imports by approximately 300MWh

from deployment of 100MW tidal capacity with 25MW of electrolysis

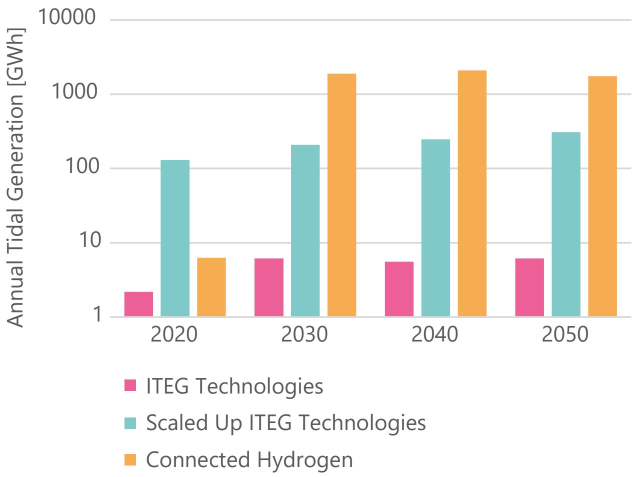
Tidal generation is a cost-efficient choice in a low carbon system.

In order to meet carbon emission targets, all scenarios saw increasing tidal generation as part of a cost optimal low carbon energy system – alongside wind and solar generation.

Tidal generation is valuable due to predictability, diversity, complementary generation profiles, increased resilience and security of supply.

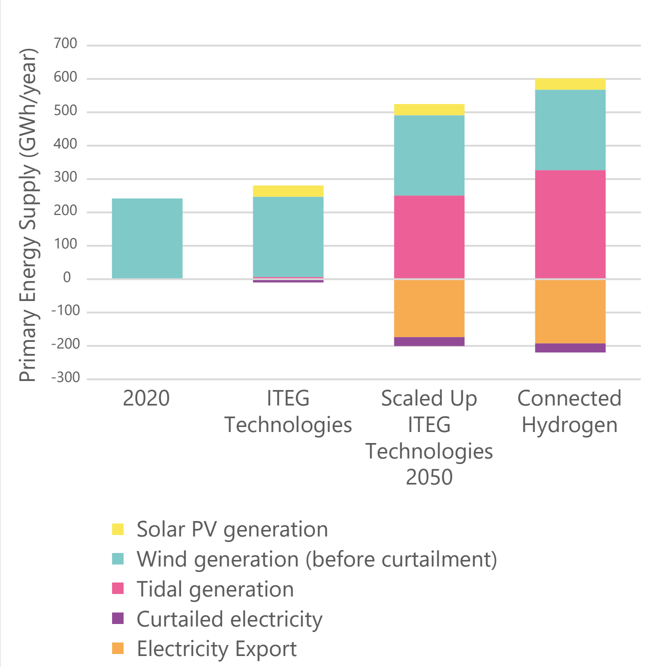
Carbon associated with power imported from the UK mainland added to locally produced emissions. With higher costs assigned to these emissions, the model deployed additional tidal generation, allowing imports of power to the Orkney energy system to be virtually eliminated.

Although tidal generation and electrolysis appear to be complementary in cost effective low carbon energy system transitions, the specific capacities of each should be considered independently (rather than in a fixed ratio), due to interactions with other elements of the system.



An optimal mix of electrolysers and tidal generators allows more electricity to be exported.

Where there is demand for hydrogen, electrolysers provide an effective means of managing peaks in both electricity supply and demand, reducing the extent of curtailment of renewable generation. There is significant value in using electrolysers to deliver demand-side response to electricity networks even with upgraded interconnector capacity.



The importance of system flexibility is further demonstrated with the use of electricity storage, although battery technologies were not a focus of the modelling. A 1.76MWh battery (installed at EMEC's Caldale site on Eday) was utilised in all scenarios, and all further battery capacity available to the model in later scenarios was selected and utilised.

During periods where generation exceeds local demand, electricity exported to the UK mainland generates income which results in a lower system cost. Electrolysers, batteries and export capacity provide outlets for peak generation, increasing the cost-effectiveness of tidal generation. This in turn increases the quantity of renewables which can be installed in a cost-optimised system.

Hydrogen offers a solution to sectors that are hard to decarbonise.

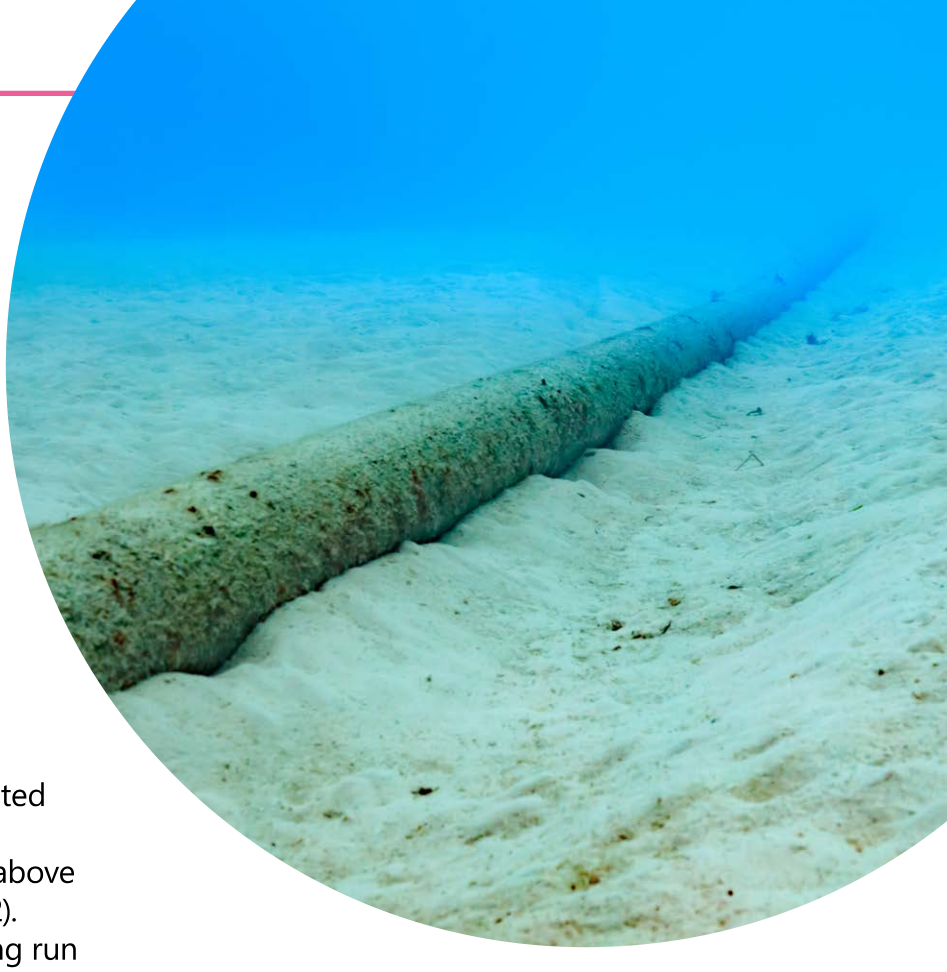
Deployment of electrolysers and attendant hydrogen infrastructure should allow nearly all residual carbon emissions to be eliminated. Hydrogen can provide low-carbon fuel for elements of transport such as ferries, and for industrial and commercial buildings that are otherwise hard to decarbonise due to a requirement for higher temperature heat that is difficult to provide with heat pumps.

Adopting hydrogen for heating, particularly in non-domestic buildings, achieves a reduction in both emissions from the burning of fossil fuels and carbon associated with electricity imports. If future electricity market prices are higher nationally, then locally-produced green hydrogen could avoid these costs and would be likely to play a bigger role and displace more electric heating as the cost-effective choice. A need to further reduce direct emissions could be driven by higher carbon abatement costs, disincentivising electricity imports, and enhancing the role of hydrogen in the energy system.

Adopting hydrogen for heating, particularly in non-domestic buildings, achieves a reduction in both emissions from the burning of fossil fuels and carbon associated with electricity imports.

The most cost-effective choice in the systems modelled here included electrolysis close to both electricity generation and hydrogen demand sources. In scenarios featuring larger export volumes, most hydrogen production is sited near export facilities, with relatively small amounts of local distribution from there.

Many applications benefit from locating electrolysers near to hydrogen demand, rather than near the source of power as this exploits existing electricity networks and avoids the costs of developing hydrogen distribution infrastructure. This is made possible, despite local electricity network constraints, as more generated electricity is consumed locally (e.g. with electrification of heat using heat pumps), instead of being distributed between islands or exported from the archipelago, thus allowing network capacity to be released and used to transmit power for hydrogen production elsewhere.



Increased tidal and electrolysis plant capacity is possible under the right market conditions.

With a high enough hydrogen export market price, a greater capacity of both tidal and electrolysis technologies is likely to be economic. Renewable generation and electrolysis plant should then be optimally located close to the export hub.

A step change in the quantity of exported hydrogen occurred as the modelled hydrogen market price was increased above £125/MWh (approximately £4.15/kg H2). This suggests the model places the long run marginal cost of hydrogen production to the Orkney system above this level. As this was not a focus of this project, costs should be taken as indicative of qualitative behaviour, with more detailed analysis of specific technologies and potential future hydrogen market prices required for an estimate to inform investment.

Some renewable generation curtailment is expected in a cost optimized system.

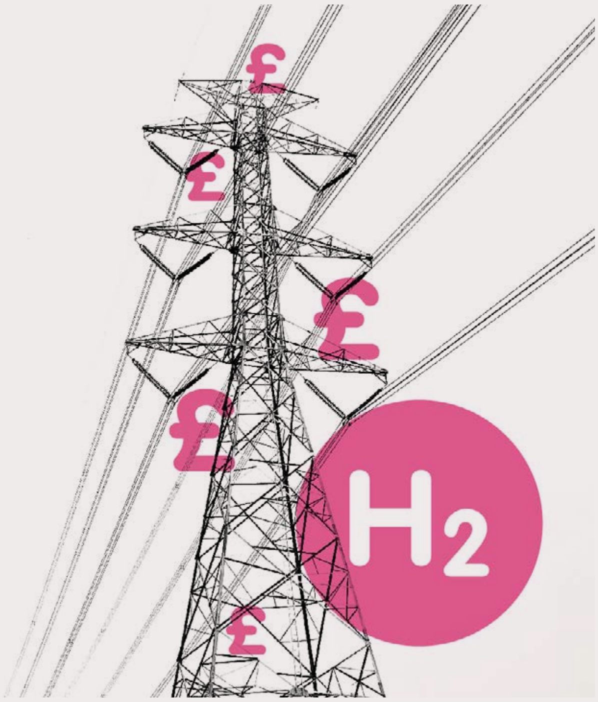
Although the current interconnector to the UK mainland facilitates significant amounts of uncurtailed generation on Orkney in the scenarios modelled, all scenarios see some curtailment of renewable generation. It is financially preferable to install generation such that peak generation exceeds peak demand even after introduction of hydrogen electrolysis and accept some curtailment, rather than invest in a system able to support infrequent very high generation conditions. This is based on creating the lowest cost whole energy system solution which may differ from operations preferred by individual actors looking to maximise their own revenue.

Upgrading electrical links with the UK mainland unlocks further tidal and wind generation.

With the construction of the proposed 220MW link between Orkney and the UK mainland, an additional 400MW of tidal and 140MW of wind generation could become cost-beneficial to the system. This mix of tidal and wind generation supports the view that a diversified portfolio of plant is of value to the system.

Upgrading the UK mainland connection would allow more tidal generation to be optimally deployed on Orkney, supplying the wider Scottish or UK energy system with low carbon electricity. The predictability of tidal resource provides benefits over other variable renewable generation methods when managing electricity networks. The cost-effective deployed capacity of tidal generation increases when there is less curtailment, bringing Orkney close to self-sufficiency in a decarbonised future, with only occasional imports needed through the year.

Investment is needed in electrical networks and hydrogen transport infrastructure.



In all future low-carbon Orkney energy systems, development of electrical networks and investment in hydrogen infrastructure will be required. This will allow additional generation capacity and meet increased demand associated with the electrification of heat.

In some parts of the system, additional renewable generation has the potential to reduce distribution costs as power could be consumed locally. This supports the electrification of space heating without additional network upgrades costs. Elsewhere, surplus generation could increase network capacity requirements and associated system cost. In most cases, the transport of electricity was found to be more economic than transporting hydrogen, in part due to the cost of either hydrogen pipeline construction or transport of hydrogen by road and ferry. Under scenarios incorporating high-volume hydrogen production, the need for both hydrogen and electricity infrastructure investment increases.

Deployment of tidal stream turbines and electrolysers can help decarbonise energy systems beyond Orkney.

This analysis of the Orkney energy system demonstrates the role which ITEG technologies can play in reducing carbon emissions in an area with nearby tidal stream resource, constrained networks, and potential hydrogen demand. By identifying other sites which share some of these characteristics, several areas of North-West Europe were identified which would provide maximum advantage from roll-out of these technologies at scale. These high-value sweet-spots, comprising approximately 6GW of tidal stream capacity, represent potential early-adoption targets for this combination of technologies.

High-value locations were identified at Orkney, Islay, the Mull of Galloway, the Isle of Wight, the Faroe Islands, the Pentland Firth, Brittany and the Netherlands.

Sweet-spots for maximum benefit from tidal & hydrogen roll-out across North West Europe (with likely hydrogen demand and grid constraints)

The full size of the markets for separate deployment of tidal generation and hydrogen are each considerably larger than the sweet-spots identified here for the combination of technologies.

Conclusions

1

There is abundant tidal energy resource in the coastal waters around the UK and North-West Europe. Tidal generation is a cost-effective and highly valuable contribution to energy systems, alongside wind and solar generation, providing both zero-carbon energy and increased system security, independence and lower overall system costs.

2

Tidal generation and hydrogen – both separately and together – offer specific additional benefits to island and remote communities. As well as increasing resilience and independence, lowering costs and enabling greater decarbonisation, they also enable reduced energy imports, with the potential for both electricity and hydrogen exports. These benefits are increased with further network investment.

3

Rather than being seen as a problem for network operators, these technologies together can help to alleviate electricity network capacity constraints which are common in island and remote coastal communities. Counterintuitively, this is often best achieved by adopting a whole-system solution, locating the electrolysis close to the hydrogen demand (using the hydrogen in particular for high-temperature heat loads which are hard to decarbonise by any other means), and electrifying other demand close to the tidal generation substations.

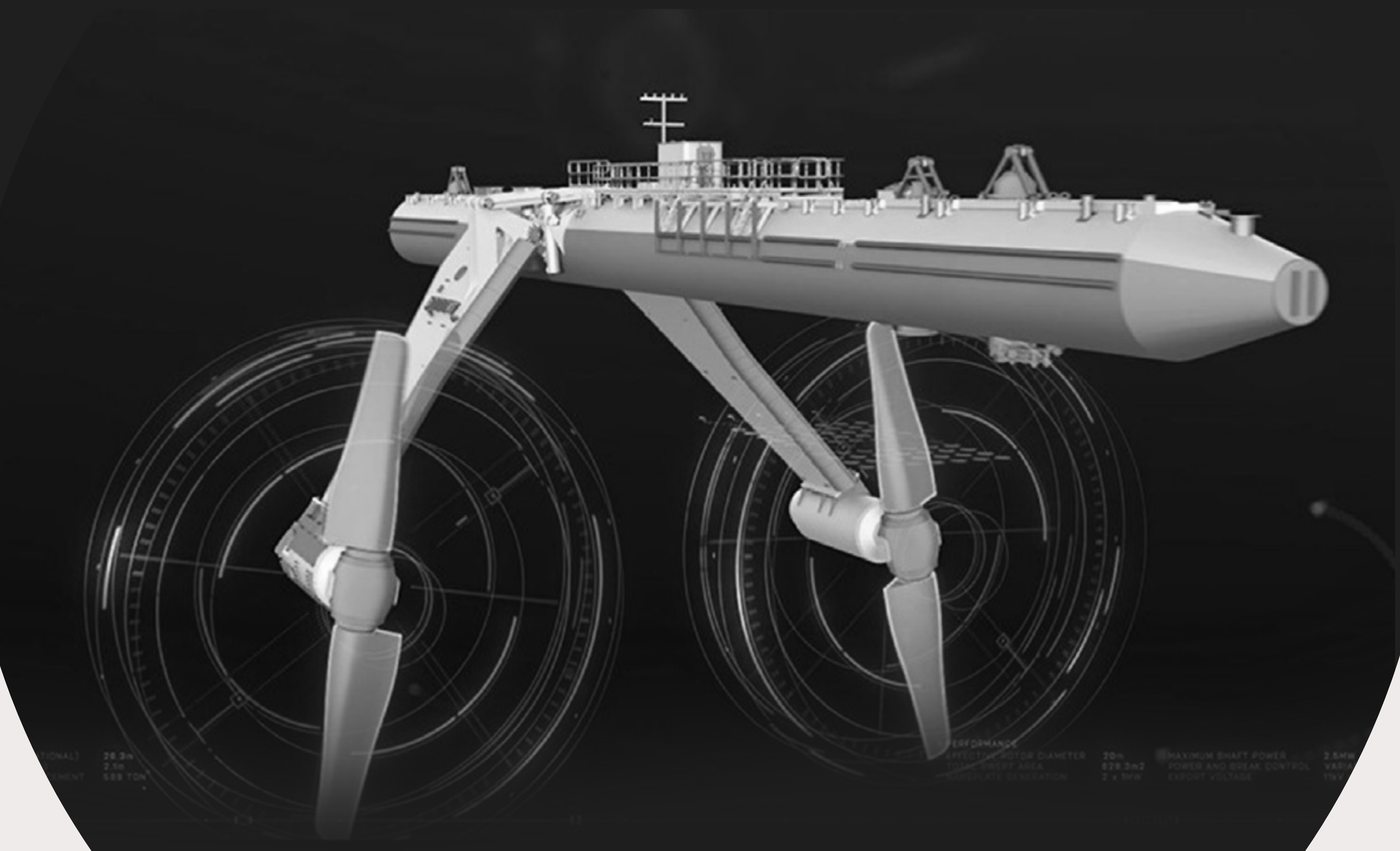
Tidal generation is a cost-effective and highly valuable contribution to energy systems

Recommendations

1. Planning for the Orkney energy system should take account of the detailed study of that system undertaken in the ITEG project, how it might optimally develop to achieve net zero, and how tidal generation and hydrogen can play key parts in the system.

2. Developers of energy assets, network operators and local authorities across Europe and worldwide should note the clear benefits of deploying the combination of tidal generation and hydrogen technologies into energy systems alongside other forms of generation. They should adopt an integrated, whole-system optimisation approach with electrolysis typically located close to the key hydrogen demands.

3. Detailed feasibility studies should be prioritised for the identified areas in which tidal resource and potential hydrogen demand are found together with network constraints, enabling the combination of tidal generation and hydrogen technologies to deliver maximum value return from initial deployments in these high value potential areas,



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