LT1.2 - Business Case for Tidal Generation with Electrolysis

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Document History

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Executive Summary

Tidal stream energy is a unique and promising form of low carbon generating whose characteristics benefit from specific consideration around its use in the context of the emerging market and opportunities for hydrogen production.

With its power output coupled to the orbits of the moon and sun, it has a highly predictable generating profile. It is energetically very dense, with large regions of tidal resource situated across NW Europe, particularly in France and the UK (and Channel Islands), but also off the coasts of the Netherlands, Norway and the Faroes. It is typically situated within 10 km of the shoreline, has a low visual impact and high societal acceptance.

Globally, there is predicted to be a market of the order of 100 GW[1]. The sector is making good progress in cost reduction and towards reaching commercial maturity and scale-out.

Green hydrogen production is similarly at an emerging stage, with a range of demonstrator projects underway to scale the size of plant and reduce costs and also understand its application in areas such as commercial heating processes, transport and gas networks, as well as supplying existing users currently supplied from grey/black hydrogen, e.g. fossil fuels, which are large CO2 emitters and shouldn't be overlooked in the development of new market opportunities.

This report assesses, with reference to supporting ITEG studies and wider market initiatives, the potential opportunities that exist for tidal stream hydrogen production. With reference to Orkney as a case study, businesses cases are discussed around the co-location of tidal projects and hydrogen production in a coastal context to supply shipping, port facilities and related local uses. The potential to supply rural commercial heating processes, such as distilling are appraised.

In the wider national context, opportunities to supply tidal generated hydrogen to national and local gas networks are identified.

Across these scenarios, the potential for hydrogen export to act as an alternative energy export vector for tidal stream energy is considered, where electricity grid connection costs, delays and charges can be avoided or mitigated. This is becoming an increasing challenge for new renewable projects.

Finally, more novel businesses cases around providing grid ancillary services or combining predictable tidal stream generation with hydrogen production through grid sleeve Power purchase agreements are also explored in the context of emerging standards around green hydrogen production.

[1] https://www.lse.ac.uk/granthaminstitute/wp-content/uploads/2023/06/Sustainable-Growth-Opportunities-from-Tidal-Stream-Energy-in-the-UK-.pdf

1 Tidal Stream Energy

1.1 Tidal stream energy is building momentum.

Tidal stream energy is a virtually unharnessed renewable energy resource that involves extracting energy from fast flow tidal stream currents. With water being 800x the density of air and speeds in excess of $3ms^{-1}$ in many regions, tidal stream presents an exceptionally dense form of kinetic renewable energy.

The resource is well distributed globally with strong resource potential in the regions within and adjacent to the Interreg NWE area. Resource estimates vary from between 3 GW – 5 GW in France, c. 10 GW in the UK with a further 2 GW of potential around the Channel Islands[2]. Smaller resource areas also exist in Norway, Faroes and the Netherlands.

It is significant and advantageous that strong potential exists in the national waters of advanced economies in north-west Europe that have proven leaders in addressing policy, industrial and revenue support requirements for developing other low carbon technologies, notably offshore wind. Their experience in developing policy mechanisms and initiatives to support the deployment of these technologies can and is being readily applied to the development of tidal stream energy.

There are already several hundred MWs of tidal stream capacity leased and under development[3], an emerging, experienced supply chain and industrial base and established consenting and regulatory frameworks to enable large scale projects.

Globally, countries strong in tidal resource include Canada, USA, Chile, Indonesia, Japan and Indonesia. Forecasts predicted a long-term capacity potential of 100 GW globally[4].

[222] https://ore.catapult.org.uk/wp-content/uploads/2022/10/Tidal-stream-cost-reduction-report-T3.4.1-v1.0-for-ICOE.pdf

[3] https://www.ocean-energy-systems.org/publications/oes-annual-reports/document/oes-annual-report-2022/

[4] https://www.lse.ac.uk/granthaminstitute/wp-content/uploads/2023/06/Sustainable-Growth-Opportunities-from-Tidal-Stream-Energy-in-the-UK-.pdf

Figure 1 Key tidal resource regions (courtesy or Orbital Marine Power)

Tidal stream energy is making strong progress towards cost reduction. In 2018 ORE Catapult estimated the levelized cost of energy (LCOE) at £300/MWh. In the UK in 2022, four projects were awarded 15-year contract for difference contracts (CfDs) at £178/MWh (in 2012 prices) to commence operation from around 2025. By 2030, it is predicted that the LCOE will fall to a central case of £105 / MWh and to £80/MWh by 2035, approaching cost convergence with other forms of renewables and below the price of nuclear. These cost estimates include grid connection costs and use of system charges and as such projects directly supply hydrogen plant could deliver lower generating costs.

The sector enjoys strong levels of policy support in key jurisdictions and an EU level. There has been consistent support through the Horizon2020, Horizon Europe programmes, Interreg programmes and from regional and national development agencies for projects advancing technology and market uptake initiatives. Incentives including revenue support and capital grants have been established notably in the UK, France and Canada to support pilot projects.

The sector in Europe possesses a dedicated trade body, Ocean Energy Europe, which successfully leads advocacy with EU policy makers on behalf of its members They are also a range of initiatives and networks established to address environmental uncertainties, supply chain capacity, insurance and finance requirements to accelerate the deployment of the sector.

The EU has set deployment milestones for wave and tidal energy: 100 MW by 2025, 3 GW by 2030 and 40 GW by 2050, with the majority of this being tidal in the near term as it is generally accepted to be a more mature technology at this time. Ocean Energy Europe predicts that deployment could be between 1,324 MW – 2,388 MW[5] of tidal stream capacity by 2030 with the appropriate market support and incentives.

[5] https://www.oceanenergy-europe.eu/wp-content/uploads/2020/10/OEE_2030_Ocean_Energy_Vision.pdf

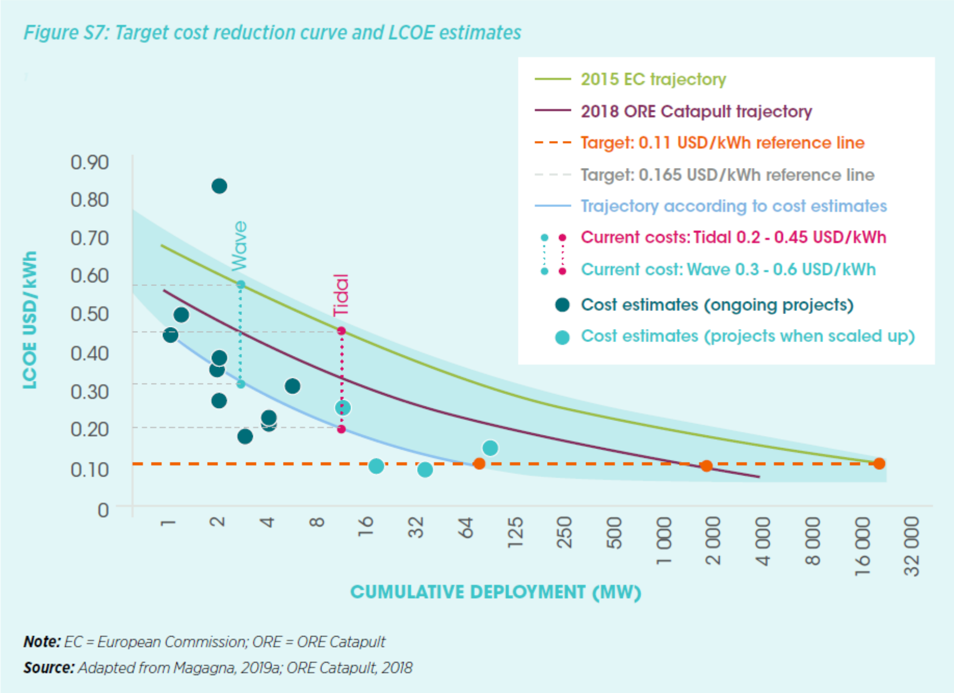

Figure 2 Tidal Energy cost trajectory predictions (courtesy of ORE Catapult)

1.2 Tidal stream Commercialisation Status

Tidal stream energy has been under significant research, prototyping and commercial demonstrator testing for the past 20 years. The vast majority of designs have featured horizontal axis rotors, with some exceptions. This has the advantage in that there has been knowledge transfer from wind, power-take-off and conversion components are similar and power performance is recognisable albeit with the significant additional benefits that come with tidal stream energies' predictability.

Of these designs, the main delineation in approach has been in the platform that supports the drivetrain, i.e., between 'seabed mounted' and 'floating' units. Orbital Marine Power, the tidal technology partner in ITEG was founded in 2002 and for the past 20 years has pioneered the floating approach with a focus on enabling low cost and low risk installation, maintenance and decommissioning of its technology to minimise whole lifecycle generating costs.

The technology has been under continual development over this time. A 250 kW unit, the SR250 was tested from 2011 – 2013, the first floating unit to connect to the UK grid network. This was followed by a fully grid connected 2MW prototype, the SR2000, from 2016 – 2018, which produced over 3,000 MWh of electricity.

The O2 2MW delivered under ITEG and complementary research programmes was launched in 2021 and is being demonstrated at EMEC as part of a 15-year project. Importantly from a commercially perspective, the O2 tidal turbine was re-financed in 2022, with £8 million of commercial debt from the Scottish National Investment Bank and individuals via the Abundance peer-to-peer investment platform, demonstrating that the technology and sector is reducing risk towards securing non-recourse debt finance.

The company has invested over £70m to date in developing its technology.

1.2.1 Technology Advantages

The Orbital technology features a towable floating platform which is moored via anchors which positions its drivetrains and rotors in the most powerful part of the water column to maximise energy yield.

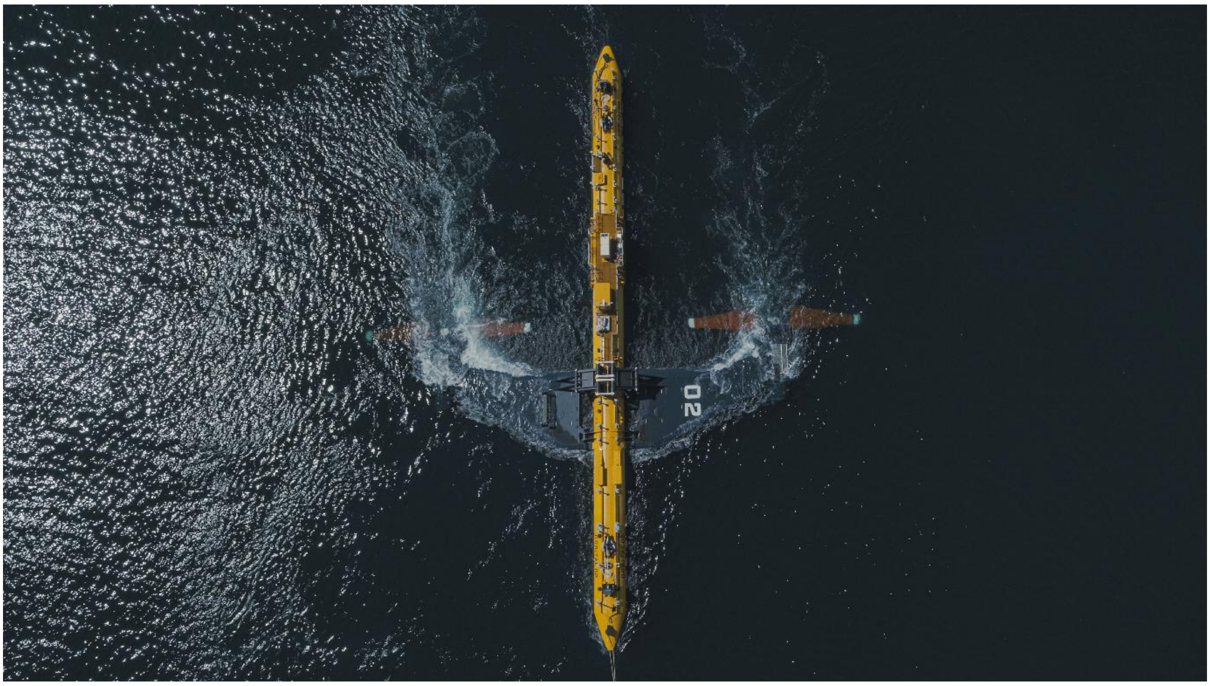

Figure 3 Orbital O2 tidal turbine, EMEC, Orkney

The entire generating unit is accessible onsite either via the floating platform or via retractable legs that bring the rotors and drivetrain to the sea-surface if required. This means that most maintenance interventions can be made onsite with personnel using fast vessels across a wide range of weather and sea conditions to access the turbine. This minimises generator down-turbine.

The majority of construction and commissioning is completed offshore in safe controlled conditions, with the powertrain, power converters, platform and all other systems integrated prior to launch. Offshore construction is limited to mooring and cable installations prior to installation. This minimises construction costs and risk.

The technology has been developed to large scale units, 2MW+. This is important to optimise extraction from the available resource. Scaling turbines where water depth permits, benefits construction economics and a reduction of failure rates on a capacity basis.

The next step in the Orbital technology, is the O2-X. This will feature 8 further innovations to reduce generating costs. Funded under the Horizon 2020 FORWARD-2030 project, these innovations will reduce CAPEX, reduce OPEX and increase yield[6].

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[6] https://forward2030.tech/

The O2-X is the platform envisaged to be used in commercial tidal projects. Combined with the powerful cost reduction dynamics realisable from moving to volume manufacturing of multi-unit tidal arrays at scale and the commercial benefits that result from reduced risk profiles as further performance data is collected, there is strong potential for further and rapid cost reduction as deployed capacity grows.

It should be recognised that there are a number of other technology developers developing tidal stream designs, with approximately six developers currently active that have developed their technology to 1MW scale or above. Regardless of the ultimate convergent generating solution, it is clear that the sector is highly active and that committed technology developers, academic, supply chain and research partners, supported by government and EU innovation agencies, are delivering strong progress towards commercialisation.

1.3 Supporting a just transition with high societal acceptance and low environmental impact

Tidal energy converters typically take the form of generating platforms either subsea or floating with relatively slow rotating blades. Beyond placing these rotors in the water column, most environmental impact pathways and impacts on other sea-users can be understood already with a high degree of confidence by drawing upon analogous marine sectors. As the sector develops and further units are deployed, potential environmental impact pathways more specific to the technology and key resource regions are being assessed and validated[7]. No significant showstoppers to the extraction of a large percentage of the global theoretical tidal resource have been identified.

Large amounts of energy can be extracted from relatively small development areas minimising potential impact including disruption to other sea-users. Tidal stream resource regions are also typically impractical for fishing owing to the strong tides.

While tidal barrage and impounded hydroelectricity can also offer predictable renewable energy, tidal stream has the benefit of requiring no impoundment of water and the large structures associated with this.

Tidal stream energy (and marine energy) in general enjoys high levels of societal acceptance, with up to date studies to assess this carried out within the ITEG project. This is likely to be in part due to the fact that it has minimal onshore infrastructure requirements and visual impact.

Owing to its predictability, it is recognised by the public to offer benefits for efficient electricity network balancing and reinforcement. This is in contrast to wind, which fairly or unfairly, is sometimes associated with negative perceptions around curtailments and compensation payments associated with grid congestion.

In many western countries, there have been recent challenges around competitiveness in global shipbuilding, initially with competition from South Korea and China and more recently from

[7] https://tethys.pnnl.gov/publications/state-of-the-science-2020

Vietnam, the Philippines and Brazil in particular.[8] From a dominant position, the UK's decline in shipbuilding long pre-dates this and its orderbook makes up a very small fraction of those of other European countries such and Germany and Italy. Tidal stream energy, particularly floating tidal, offers the socio-economic benefit and potential to build 'vessels' in western countries for installation in national tidal stream projects. This industrial diversification (and in the UK's case) renewal opportunity is well received publicly and politically and also aligns with security of supply policies at a national and EU level, which are increasingly relevant and being legislated for.

The potential for high local and national supply chain content, to rejuvenate historical shipbuilding regions and in the context of Interreg NWE, the potential to provide a diversification opportunity for the North Sea oil and gas sector businesses, both at supplier and operator level, all supports a just transition away from fossil fuels with high societal acceptance.

1.4 Tidal energy sustainability

With significantly increased activity in hydrogen development, there is an increased scrutiny and standards being introduced to define what the definition of 'green hydrogen' is. This has implications for the eligibility of the produced hydrogen for various services and use in certain sectors.

The whole lifecycle carbon footprint of hydrogen production will depend on both the lifecycle carbon emissions associated with the hydrogen plant itself, but particular the emissions associated with the electricity being supplied.

Orbital Marine Power has already committed significant resources to auditing the carbon footprint associated with its technology. In 2019, an independent carbon audit was carried out supported by funding from ZeroWaste Scotland. The study concluded that the whole lifecycle carbon footprint of the O2 tidal turbine was already in line with many mature renewable technologies and typically lower than solar PV arrays. The company aims to reduce the technology carbon footprint by a further 33% in the next two years and for these improvements to be incorporated into the O2-X core product.

This means that hydrogen plant sourcing electricity from Orbital's tidal technology can be assured they are sourcing energy from an extremely low carbon source.

[8] https://ec.europa.eu/docsroom/documents/10506/attachments/1/translations/en/renditions/native

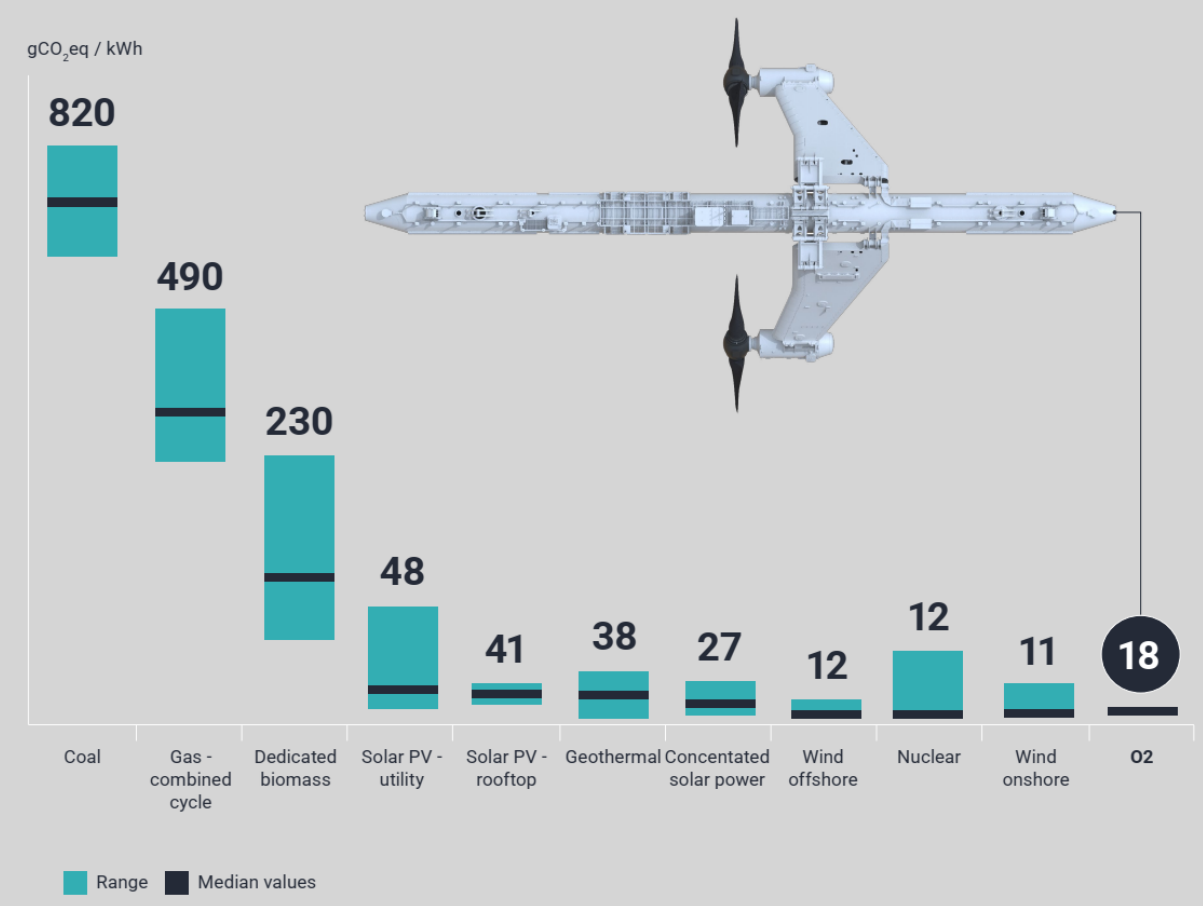

Figure 4 Orbital O2 whole lifecycle (gCO2eq/kWh) against other generating sectors

1.5 Tidal energy electrical characteristics

Tidal stream energy is a highly predictable form of energy. The generating characteristic in unlikely that of any other renewable energy technology.

For the O2-X, which will become the Orbital core product, generation begins at tidal current speeds of c. 0.5 m/s, reaching rated power at 2.5m/s. With active pitch control, the technology consistently generates at rated power at a typical site for around 3 hours until the tidal current reduces in speed and changes direction. The following illustrates the power output profile from the O2 tidal turbine over a period of 5 days at the EMEC tidal test site.

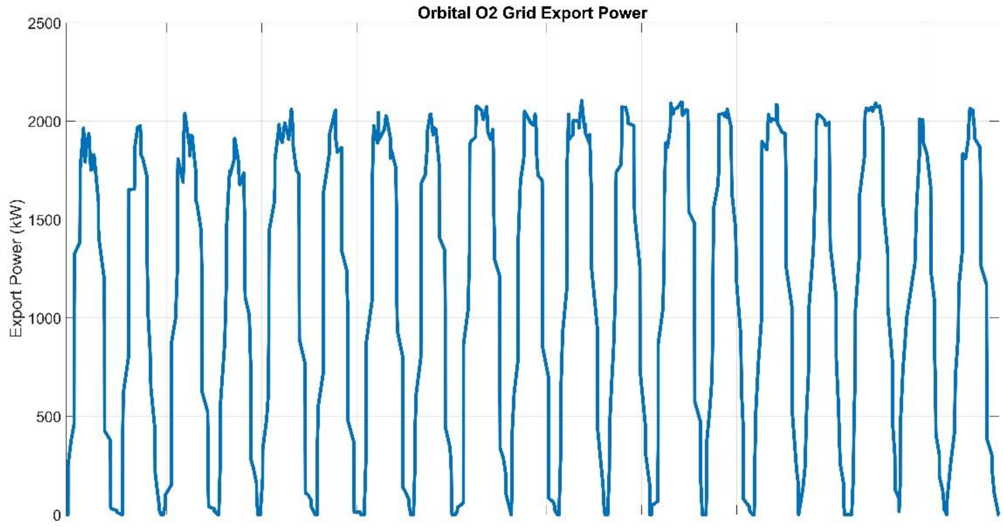

Figure 5 O2 generation profile of 5 days

Depending on the site, capacity factors of up to 50% are achievable.

Resource and energy yield assessment methodologies and modelling for tidal stream energy are relatively mature and once assessments are made, export power can be predicted with c. 10-minute granularity if required for the entire project lifetime. As such, as costs reduce and the sector reaches maturity, it will offer a predictable electricity source, with fixed generating costs, that for large percentages of the tidal cycle provides a constant power output. This aspect can be further enhanced through the introducing of battery storage.

Project sites are likely to range from c. 10 MW – 200 MW in capacity. Modelling by Orbital suggests that this aggregation of power from multiple units will be beneficial towards helping to smooth high frequency power variation from 'tidal gusts' etc.

2 Tidal stream, Hydrogen and the blue economy.

Hydrogen use today is dominated by industrial applications. The predominant uses are oil refining, ammonia production, methanol production and steel production, with the hydrogen almost entirely produced from fossil fuels. In these use cases, there is likely to be a shift from fossil fuel to green hydrogen production, considering that there are total annual CO_2 emissions of 830 million tonnes associated with these existing uses, equivalent to the CO_2 emissions of the UK and Indonesia combined[9].

[9] https://www.iea.org/reports/the-future-of-hydrogen

However, it is in the energy sector where the vast majority of growth is predicted with hydrogen identified to be a key energy vector in all main national and international net zero energy scenarios.

Transport, building and power sectors all have potential to use hydrogen if costs can become competitive versus other low carbon approaches such as direct electrification and these opportunities have been studied in detail in ITEG, with Orkney as a case study.

It should be noted that unlike the status quo where almost the entire world's transport fleet is powered via internal combustion engines (ICE), that the energy transition may result in a diversity of long-term fuel solutions rather than convergence on a single technology. For instance, in the case of terrestrial transport, locations with a lack of electrical grid infrastructure may find that hydrogen powered transport is a lower cost option when all systems costs are considered. In areas with strong electricity networks, electrical vehicles may provide the overall lower cost solution. These sorts of dynamics should be considered when identifying potential businesses opportunities.

The ultimate use case and market trajectory will be governed by innovations in the hydrogen technology and cost of the renewable energy feedstock, competing decarbonisation approaches, regulatory, policy and market support and a range of practical and technical considerations, but the following present an indication of where these markets and business cases for supply from tidal stream energy are likely to emerge:

- Shipping and aviation have limited low-carbon fuel options and there are several pilot projects already underway to address technical and regulatory requirements around the use of hydrogen, including in Orkney. The first hydrogen powered ferries are starting to be constructed. This could also be in form of hydrogen-based fuels (synthetic jet fuel) and for shipping as ammonia.
- Hydrogen powered boilers have the potential to replace heating oil / diesel powered heating systems for industrial processes. This could present a more straightforward. retrofit opportunity in many cases over heating electrification. In weak grid networks, e.g. rural areas this would avoid the need for new grid capacity.
- Hydrogen fuel cells have already been trialled, including in Orkney, in road transport. This could hold advantages for heavy duty options with long distance range and shorter refuelling times.
- There is an opportunity to blend hydrogen with existing gas networks. Blending as opposed to the use of pure hydrogen mitigates challenges around leaks and compatibility with existing boiler systems.
- Hydrogen could provide ancillary services for grid balancing and studies have shown it has a demand response that is compatible with some frequency services. Related to grid balancing, it can also be used for seasonal power storage.

The European Commission has identified the importance of renewable hydrogen to help decarbonise transport and industrial processes, to provide long-term and large-scale energy storage and improve the flexibility of energy systems by balancing out supply and demand.

REPowerEU sets out key actions to increase the uptake of renewable hydrogen and an overall ambition to produce 10 million tonnes of renewable hydrogen in the EU by 2030.

The **EU Hydrogen Strategy** sets an objective of 40 GW of renewables-linked electrolysis capacity in the EU by 2030.

The **UK Hydrogen Strategy** projects a 5GW production ambition by 2030 and expects hydrogen to help meet the Sixth Carbon Budget and net zero commitments. Scotland has an even more ambitious action plan with a strategic approach to the development of the hydrogen economy and a clear ambition of 5GW installed hydrogen production capacity by 2030 and 25GW by 2045.

In parallel with these timescales and trajectories for tidal stream energy cost reduction, the costs of green hydrogen production are also predicted to become competitive, and despite uncertainty on the exact end user cases, rapidly increased deployment is highly likely.

Positively, no dramatic breakthroughs are envisaged to be required, but incremental progress is expected as the technology continues to evolve and become more efficient. Cost reductions will be achieved through a combination of increases in electrolyser module size and innovation, economies of scale associated with larger plant size, increased electrolyser efficiencies and plant lifetime and reductions in the cost of finance within increased operational data. Also the cost of the renewable energy feedstock will be key and ultimately will make up the majority of generating costs.

The purpose of new projects is now to scale up production from MW to 100MW+ scale, to improve the supply chain and to integrate hydrogen within the whole energy system.

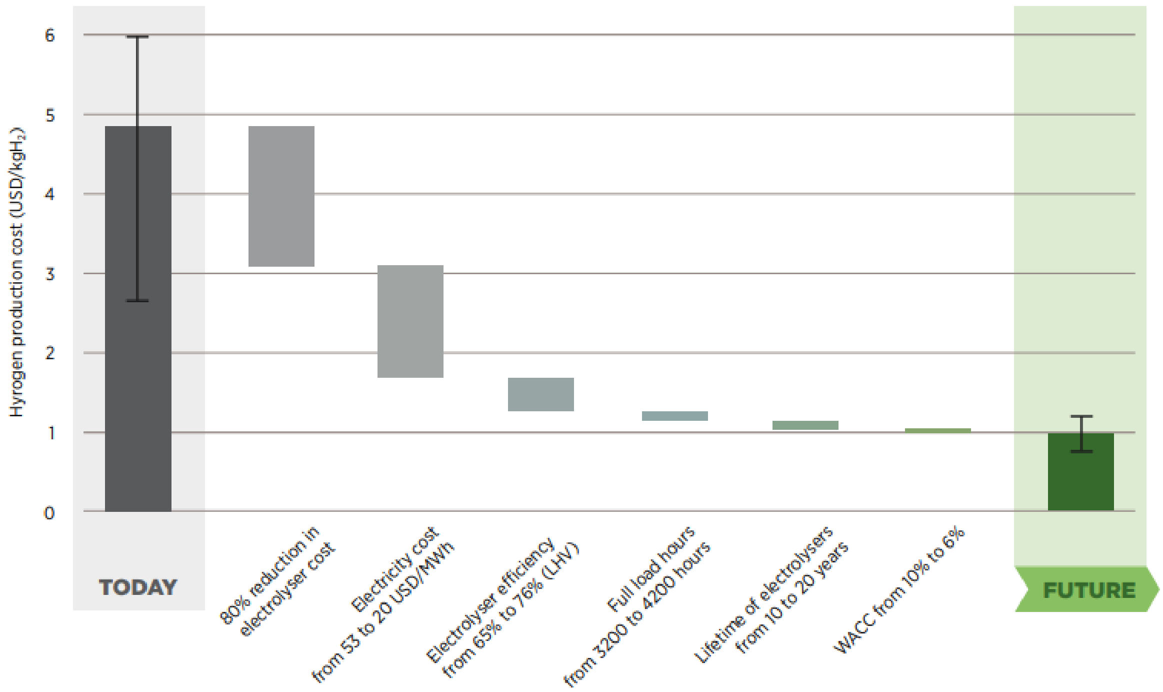

Figure 6 Potential pathway for 80% reduction in hydrogen production cost [IRENA][10]

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[10] https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Nov/IRENA_Green_Hydrogen_breakthrough_2021.pdf?la=en&hash=40FA5B8AD7AB1666EECBDE30EF458C45EE5A0AA6

2.1 Tidal and hydrogen

Over the past four years, the ITEG project has progressed technical and commercial de-risking and development through a range of workstreams to understand the potential synergies between the emerging tidal stream and hydrogen sector.

As a practical level, Orbital Marine Power's O2 2MW tidal stream turbine has been integrated with the EMEC Fall of Warness Tidal Test Centre and it's 500 kW hydrogen electrolyser. The facility also features inputs from a 900 kW wind turbine, that experiences curtailment at times owing to grid congestion. The site also features a Vanadium Flow call battery to help manage power flows between the tidal turbine, wind turbine and hydrogen electrolyser, to support its efficient functioning.

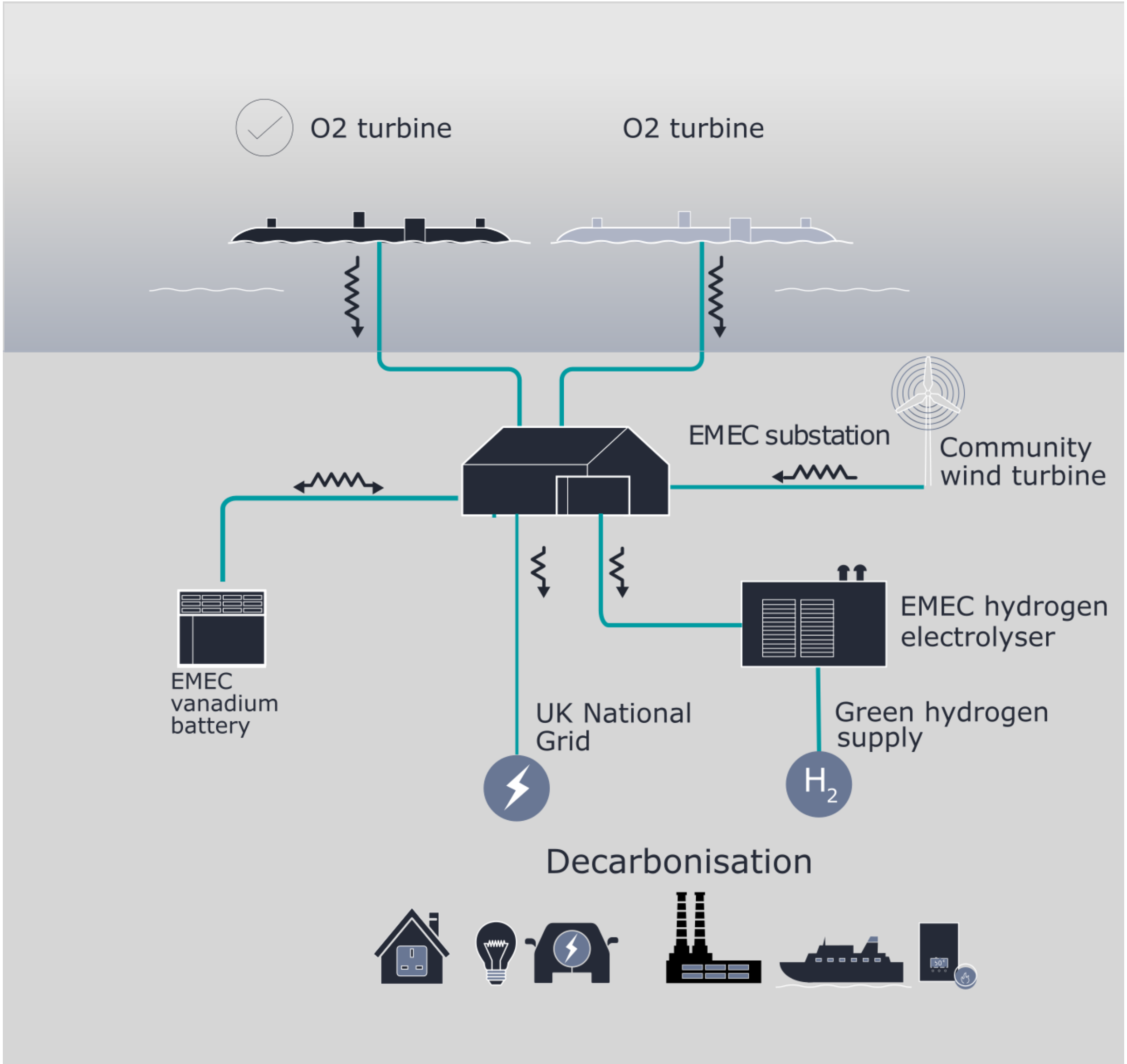

Figure 7 ITEG electrical arrangement with additional O2 turbine planned for 2025.

The project has developed strategies for the efficient control and management of the "all – in – one" system, with a view to wide scale replication across North-West Europe. At least one further generating unit will be installed into this system in 2025, another two c. 2026. There will also be incorporating of a 1 MW/MWh Lithium Ion BESS around 2025, and continued refinements to the associated EMS (Energy Management System) and trialling of various test cases with wider scale potential.

Using the Orkney Islands as a case study, detailed research and modelling has been carried out within ITEG, to understand the most beneficial configurations of tidal stream energy and hydrogen production with respect to the wider grid network and evolving energy vectors such as hydrogen transport and fuels.

Fundamentally it is self-evident that if tidal stream costs and hydrogen production costs fall steeply, at a simplistic level, there will be benefits to hydrogen production using tidal stream energy as a feedstock. However, ITEG considers the unique electrical generating characteristics of tidal stream energy, technical and practical factors for both technologies and the potential for local and international markets that might naturally emerge in coastal locations where tidal stream energy is present to developing a more sophisticated view of what the business case for synergistic projects might be.

2.1.1 Co-location of tidal stream and hydrogen electrolyser

Within the ITEG project, trials have ben carried out of the co-location of Orbital's tidal technology and hydrogen electrolyser. This has included the additional of an Invinity flow battery (1.8 MWh) that can smooth the power flow into the electrolyser when the tidal is changing direction to maintenance a consistent power flow for efficient operation. This co-location arrangement has significant replicability potential. It offers the benefit for reliable, predictable generating feedstock, with no reliance on fluctuating electricity market prices, where a 'behind the meter' PPA can be agreed.

For the tidal project operator grid connection charges and grid use of system charges are avoided. In the Orkney Case and UK as a whole, there is wide locational variance in use of system charges and so these can present a barrier to the deployment of renewable energy, particularly in North Scotland. It also means that projects are less reliant on grid capacity constraints and timescales, which are an increasing challenge for new distributed generation. Less reliance on these wider timescales for grid connection, could simplify and de-risk business models.

Depending on the end use, there is the potential to decouple the tidal generating plant and hydrogen production location with subsea electrical cabling to link the two. For instance, in the Orkney case, there are prime tidal resource areas within the Westray Firth while is it conceivable that a hydrogen supply hub could develop around the Kirkwall harbour areas. These locations are around 15 km apart, which could represent a relatively small investment if hydrogen demand grew to sufficient levels. This could still operate as a 'behind the meter' arrangement.

Figure 8 Hydrogen refuelling at Kirkwall Pier

2.1.2 Local use cases - Maritime

The decarbonisation of shipping is at an early stage globally. Orkney has been at the forefront of research and demonstrator projects, with a particular focus on hydrogen, recognising its strong potential for use within local fleets and international cruise ships and other shipping that visits the islands. Indeed, around 25% of hydrogen research and demonstrator programmes completed or underway in Scotland have primarily been located in Orkney, increasing the prospects that a commercial hydrogen production hub develops there. Some of the most relevant projects are as follows:

- **BIT HIT** production of hydrogen on the islands of Eday and Shapinsay using wind and tidal energy. In Kirkwall a 75 kW hydrogen fuel cell supplies heat and power for several harbour buildings, a marina and 3 ferries (when docked) in Kirkwall. The project also features a hydrogen refuelling station for 5 Symbio hydrogen fuel cell road vehicles for Orkney Islands Council.
- **HyDIME** (Hydrogen Diesel Injection in a Marine Environment) – design and physical integration of a hydrogen injection system on a commercial passenger and vehicle ferries.
- **Hyseas III** demonstrator that fuel cells may be successfully integrated with a proven marine hybrid electric drive system (electric propulsion, control gear, batteries, etc), along with the associated hydrogen storage and bunkering arrangements.
- **DUAL Ports -** designing world's first hydrogen bunking system and identifying how it will be implemented within Orkney.
- **HiMET** focussing on ferry services and cruise terminal operations. Activities to build the evidence base required to support the development of future-ready health and safety procedures, policies, and regulatory standards that will keep hydrogen-fuelled maritime activities as safe as possible.

In terms of potential demand, within the archipelago, there are 10 ferries serving 13 islands with around 20,000 sailings per year. This equates to around 3 million litres of marine gas oil being used and 398 MWh of shore power.

Figure 9 Concept design for European's first hydrogen powered ferry (courtesy of HySeas III)

The Orkney Islands are also the UK's most popular cruise ship destination with over 170 cruise ships calling annually. The majority of these call at Hatston. There are tentative steps in the cruise sector to decarbonise operations. It remains to be seen if there will be convergence on a preferred solution, but in 2022 and 2023 first orders for cruise ships that will have an element of hydrogen power were made, and it is likely that hydrogen propulsion and/or fuel cells for electrical supply will find some adoption.

The potential for a significant maritime market for hydrogen presents the opportunity to realise scale in production and storage facilities. Large areas of tidal resource existing within c. 15km of main vessel ports of Kirkwall and Hatston meaning that direct to customer businesses cases could be possible.

Within the main Orkney Island (Orkney Mainland), local planning policy is not strongly in favour of new onshore wind developments and so tidal stream energy may be more straightforward to consent and offer the electricity required for hydrogen production.

While there may be competition from offshore wind generation, the nearshore locations of tidal stream projects which results in less electrical export infrastructure, and the predictability and lack of seasonality associated with the generating profile offer a number of competitive advantages for matching to maritime vessel requirements and the increase in demand over the summer period with cruise ship visits and increased inter-island sailings.

It should be noted that similar businesses cases may emerge around other large ports. For instance, Scrabster, Caithness, Scotland and Cherbourg, Normandy, France both see significant cruise ship and ferry use and are in close proximity to large tidal resource regions.

These coastal regions, often away from main population centres tend of have more available area for the onshore infrastructure associated with hydrogen production.

2.1.3 Local industry - Distilling

There are a range of small industry sectors, which involve the use of process heat, that present challenges to decarbonisation. Currently, electrification or hydrogen combustion systems offer routes for decarbonisation. However, in coastal areas including Orkney, grid infrastructure tends to be weak, inhibiting the potential for electrification of these processes.

For premium products whose brand is tied in with the production location, it is likely that production will remain or even increase in these coastal locations, rather than moving closer to centres of demand. It is increasingly important also that such brands demonstrate a low carbon footprint, without reliance on carbon offsetting schemes which are increasing seen by the public as problematic.

In Orkney, whisky distilleries make up the bulk of off-grid heating processes and have an annual energy use of around 23,000 MWh, with similar heat processes in gin distilleries, brewing, dairy and cheese making, with a total off-grid fuel for heating estimated at 34,600 MWh per annum.

19 Whiskey distilleries are located on Scottish Islands making up 9% of the total industry volume, and their heating oil emissions amount to 70,700 tCO2e per annum. More broadly, there are 39 off-gas network distilleries representing 31% of the annual carbon emissions associated with the sector.

In these situations, hydrogen combustion can offer a convenient route for fuel switching typically through the retrofitting of burners in industrial boilers though the preferred approach may be project specific and continuing development is underway to assess technical and practical challenges and potential convergence on a standard solution.

There are a range of feasibility studies and pilot projects underway in the UK, including in Orkney, to decarbonise the distilling industry. In 2021, 17 projects were awarded a total of £10 million from Phase 1 the BEIS Green Distilleries Fund to progress feasibility studies, research and development. 10 of these projects involve the use of hydrogen.

With respect to ITEG, a notable project was HySpirits 2. Led by EMEC alongside research partner Napier University and industrial partners Edrington and Orkney Distilling Limited, the project assessed four different technology pathways to facilitate green hydrogen fuel-switching in the distilling sector. The study focussed on the Highland Distillers' Highland Park Whiskey Distillery and Orkney Distillery gin stills.

The project assessed the potential roll-out opportunities, the costs and quality implications associated with the final product, health and safety and generally how the transition to hydrogen could be made while minimising operational disruption.

The key challenge identified was alignment between any transition to hydrogen boilers and the availability of a reliable, hydrogen supply capacity. Mitigations options identified for this were the use of dual fuel boilers, that could burn both hydrogen and hydrocarbons.

Of the projects supported by the Green Distilleries Fund, another notable project that is likely to be the first to power a distillery with green hydrogen is the Arbikie Distillery, Montrose, which has commenced work (in 2023) on the installation of a hydrogen ready boiler. To address supply reliability it will produce hydrogen onsite via a 500 kW hydrogen electrolyser and wind turbine. The learning from this project will also be important for producing hydrogen from tidal energy, with the electrolyser sizing similar to that employed in the ITEG project.

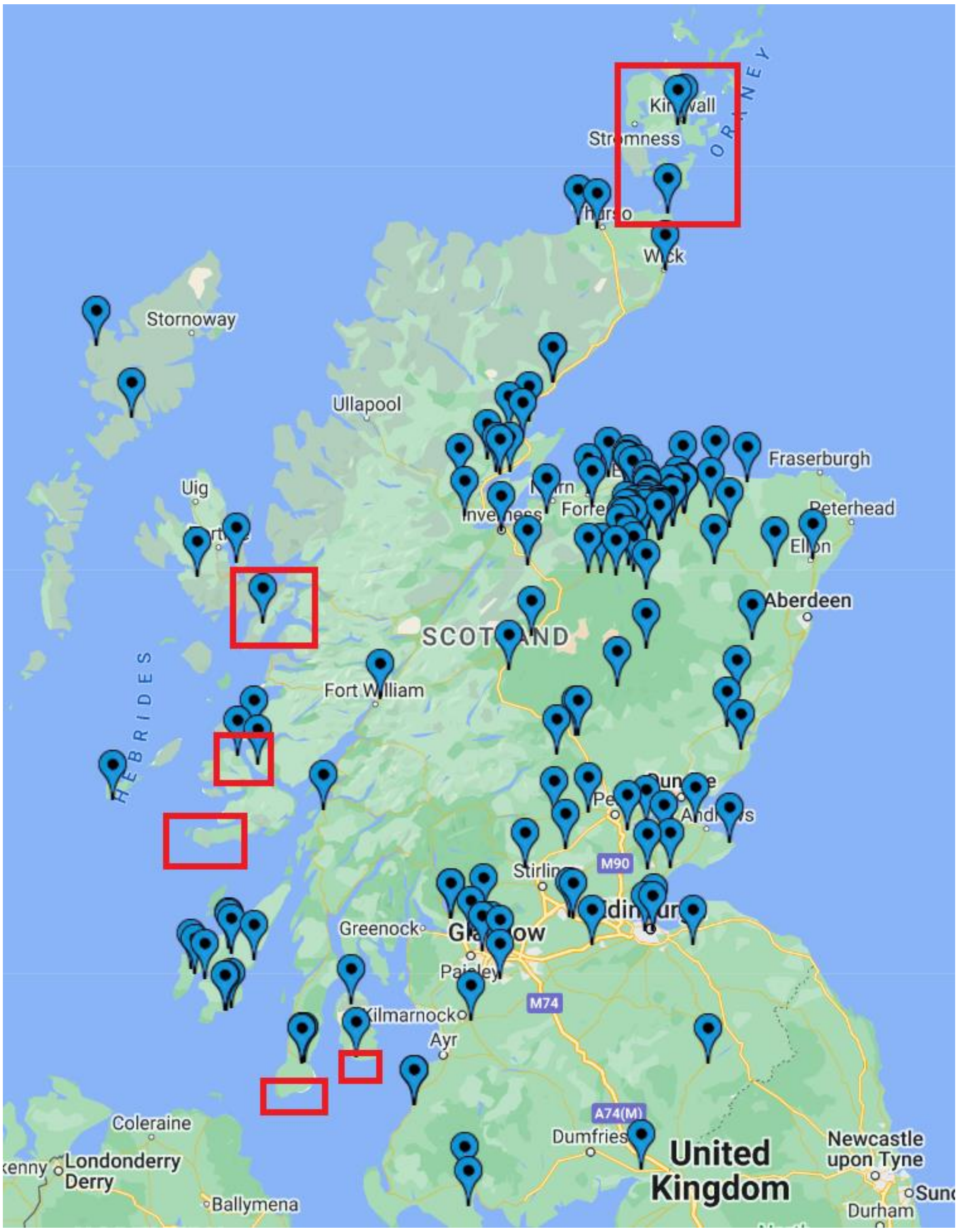

Figure 10 Currently operating Scottish whisky distilleries and areas of strong tidal resource (in red)

2.1.4 National use cases

There are tests underway to understand the potential for blending hydrogen into the existing national gas network up to the limit that can be safely used in existing appliances. As the sector matures and both tidal and hydrogen plants increase in installed capacity, there will be the potential to explore export of hydrogen via subsea pipelines to main populations centres or to the main European gas grids should hydrogen be used and blended into the wider gas networks.

There is a broad network or such pipelines and associated terminals in the north sea region coincident particularly with North Scotland and Norway with strong tidal stream resource and an emerging project pipeline.

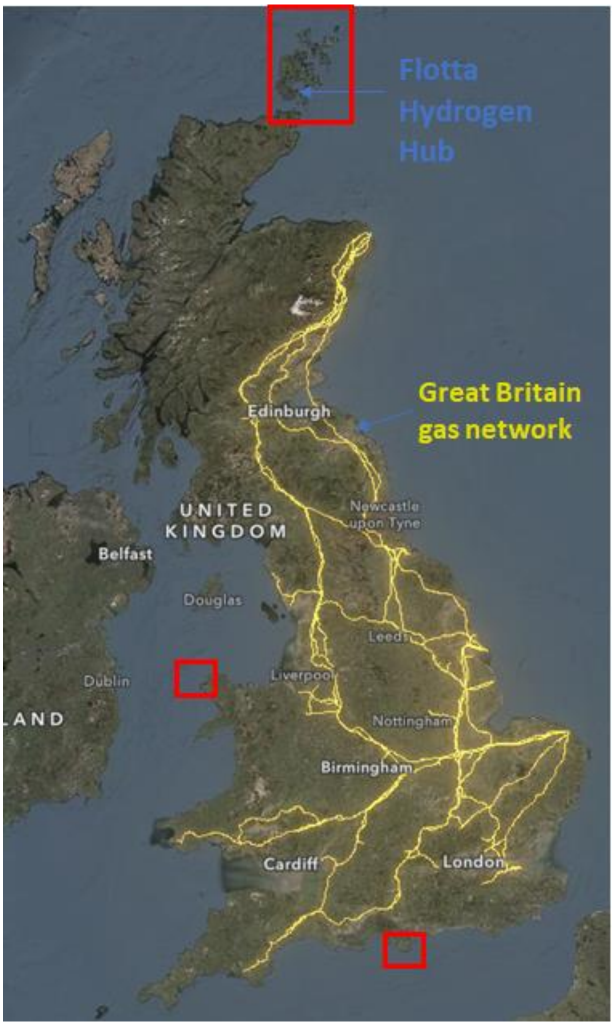

Figure 11 GB gas network and main tidal resource regions in red

In France, in the Normandy region, where the vast majority of the French tidal stream resource resides, there is good proximity to the existing gas network.

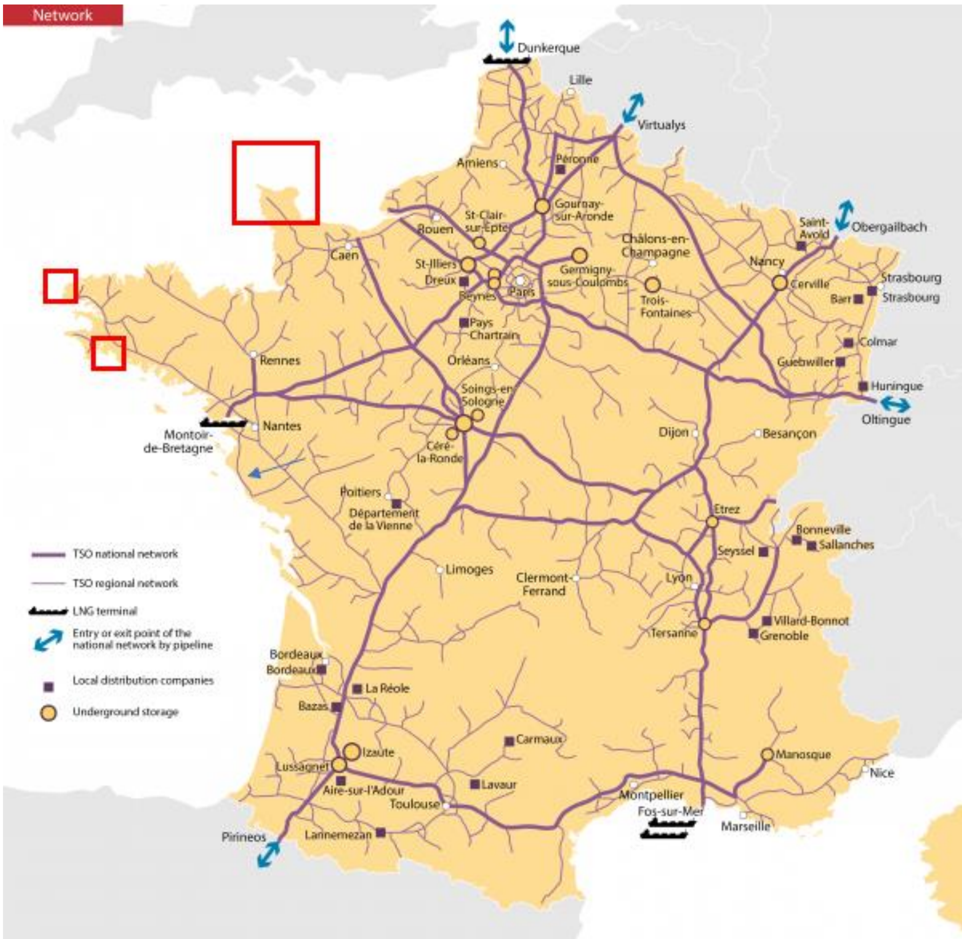

Figure 12 French gas network and main tidal resource regions in red

In Scotland, there are opportunities in the more immediate term to realise synergies with similar initiatives being pursued by the wind sector, such as the Flotta hydrogen hub, which is located close to an area of strong tidal resource.

Local gas networks

There is also potentially a role for the use of hydrogen in local gas networks. This would allow higher penetrations of hydrogen to be used.

Currently, there is a study underway with gas distribution company SGN and RWE to supply hydrogen gas to a number of locations within Scotland. The focus currently is to produce hydrogen via electrolysis from onshore wind farms. Interestingly, two of these towns, Thurso (Caithness) and Campbeltown (Argyll) are situated close to tidal resource regions.

Figure 13 RWE/SGN local hydrogen network initiative

2.1.5 Hydrogen and grid constraints.

Across NW Europe, it is predicted that there will be a requirement for a 200% increase in electricity generation to 2050[11] in response to increasing electricity requirements from transport and heating sectors in particular. It has been extremely challenging for grid system operators and the associated regulatory process, to keep up with demand for grid connections, with the result being that grid connection timescales are being significantly extended and 'non-firm' grid connection agreements being awarded.

Orkney is a prime example of this. Despite a demonstrated, strong renewable energy resource, the investment case by the energy regulator Ofgem in the UK for a 220 MW transmission connection, the first transmission connection for Orkney was only approved in July 2023 despite grid constraints first emerging c. 12 years prior to this. It is likely that this connection capacity will quickly be filled with demand from onshore wind and tidal projects.

Hydrogen offers an alternative vector for the sale of electricity from tidal power plants where there are lengthy grid connection waits. Energy Systems Catapult (ESC) in their analysis of the wider InterregNWE region identified a number of regions where there is strong tidal resource and minimal transmission electricity capacity. These include Orkney, but also the islands and headlands of SW Scotland, the Isle of Wight and Channel region. Outside the Interreg NWE region hydrogen production could be a useful option for islands such as Alderney which are small, islanded networks (with vast tidal resource) but no interconnectors to neighbouring France or the UK.

In certain circumstances, a hybrid approach could be employed to accelerate grid connection timescales and limit curtailment. Tidal stream projects could be connected to the electricity

[11] https://etipwind.eu/publications/getting-fit-for-55/

network, but in times of grid congestion, hydrogen could be produced in increased volumes to limit curtailment. This would be in line with recent proposals to allow renewable energy projects to connect but with less 'firm' grid connections. This system of 'active network management' is already in use in Orkney to allow wind and tidal assets to connect to the distribution network in reduced timelines with major costs of grid reinforcement avoided.

Figure 14 Potential areas identified by ESCAT where grid congestion could be avoided through hydrogen production

2.2 Other business models.

The predictability around the timing and volumes of tidal stream energy opens up opportunities around grid-sleeved Power purchase agreements (PPAs) between tidal plant operator and corporate off-taker. In the UK, recent legislative changes have made it possible to use grid-sleeved PPAs to achieve the Low Carbon Standard set by BEIS[12]. This may result in hydrogen production being located closer demand locations.

Over the past number of years, there has been an evolution and increase in the range of ancillary services and markets that are under development to balance the grid network. There has been some limited and promising research in the application of electrolyser and fuel cells to partake in providing such services.

[12] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1151288/uk-low-carbon-hydrogen-standard-v2-guidance.pdf

In a similar way to which Battery Energy Storage Systems (BESS) seek to generating revenue through 'stacking' ancillary service provision, hydrogen electrolysers have the potential to generate revenue in this way also. The generating characteristic of tidal stream energy if co-located with hydrogen electrolysers seek to stack revenues through ancillary services could offer interest potential.

Orbital Marine Power and research partners EMEC and Laborelec are exploring this potential under the FORWARD-2030 project, with plans for a 1 MW/1MWh lithium-ion battery to be installed at EMEC in 2025.