MILFORD HAVEN: ENERGY KINGDOM

# Technical Summary Report

## Techno-economic appraisal of investable propositions

March 2022

ARUP

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# Purpose of this report

This report summarise the whole energy system modelling delivered by Arup in support of establishing the Strategic Outline Case for a smart local energy system for MH:EK, it particularly feeds into the Economic case of the Strategic Outline case report [28].

This feasibility study has focused on three shortlisted 'propositions' to assess their viability as a SLES and set out recommended 'no regrets' opportunities as well as the required project, sector and system level changes.

A 'proposition' in this report is defined as a project or development opportunity to make an intervention to the existing energy system of the local area that results in a linked multi-vector (power, heat, and transport) system where there is (potential for) smart connectivity between assets or component parts resulting in better balancing of local energy supply and demand, towards decarbonisation by 2050.

# Disclaimer

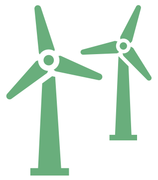
# Navigating this report

Throughout the report we will refer to the following terms:

- MH:EK: The project, Milford Haven Energy Kingdom
- Smart local energy system (SLES): a decentralised approach to set up a resilient multi-vector future energy system
- Proposition: a project or development opportunity to make an intervention to the existing energy system of the local area that results in a linked multi-vector system
    - Proposition 1: The Milford Haven Marina SLES
    - Proposition 2: The Pembrokeshire Food Park SLES
    - Proposition 3: The Pembroke Schools, Leisure Centre and Dock SLES
- Scenario: world views of what the future energy system could look like based on industry guidance. In the techno-modelling we have looked at '2020' and '2050' scenarios. The output from this techno-economic modelling suggests 'no regret' technologies or steps that could be invested in the short-term (by 2025) as the first steps towards net zero by 2050.
- No regrets: opportunities or technologies that will play a key role in the decarbonisation journey in any scenario and where investment should be prioritised to kickstart the journey to decarbonisation.
- Time horizons:
    - Short-term: now to 2025
    - Mid-term: 2025 to 2035
    - Long-term: 2035 to 2050
- Multi-vector: power, heat, and transport energy vectors forming part of the energy system
- Key objective: Primary requirements for project success
- Critical success factor (CSF): key criteria used to assess the longlist of propositions against the project objectives and enable the shortlisting process using a strategic approach.
- Multi criteria assessment (MCA): approach to enable explicit evaluation of the propositions against multiple criteria that may have conflicting or differing levels of priority or weighting.
- Whole system energy modelling (WSEM): Arup's suite of tools including a Python based linear optimisation tool, to optimise the energy supply and storage capacities based on the cost and carbon emissions.
- Levelised cost of energy (LCOE): Levelised cost of producing energy (electricity, heat and hydrogen) in £/kWh.
- Strategic outline case: Development of a strategic outline case prior to business case for scoping and planning proposals and support evidence-based decision making, following the Government's Green Book Five Case Model:
    - Strategic case: the case for change and to demonstrate how it provides strategic fit
    - Economic case: demonstrate the techno-economic viability of the propositions
    - Commercial case: demonstrate the commercial viability and models
    - Financial case: affordability and funding the propositions
    - Management case: demonstrate how the propositions are delivered.
- Actors: Parties or stakeholders involved in the development of the SLES propositions
- Anchor: Driving organisation for the proposition, project, organisational/owner or technology champion. Also referred to as 'Leading entity' in the commercial context.
- Polyvalent heat pump or simultaneous heat pump: Heat pumps that can operate simultaneously in heating and cooling mode.
- Wobbe – The Wobbe number or index is an indicator of the interchangeability of fuel gases and directly relates to their heating values. To blend hydrogen in the gas system, hydrogen must be mixed with other gases (such as propane) to meet the Wobbe number requirements of the Gas Safety (Management) Regulations

A full list of the terminology used in this report can be found in the Glossary.

The following iconography is used throughout the report for navigation:



***Milford Haven Marina SLES***

***Pembrokeshire Food Park SLES***

***Pembroke Schools, Leisure Centre and Dock SLES***

# Glossary

| | |
|---|---|
| ASHP | Air Source Heat Pump |
| BECCS | Bioenergy with Carbon Capture and Storage |
| BEIS | Department for Business, Energy, and Industrial Strategy |
| BEV | Battery Electric Vehicles |
| BGW | Blue Gem Wind |
| BM | Balancing Mechanism |
| BSC | Balancing and Settlement Code |
| BSUoS | Balancing Services Use of System |
| CAPEX | Capital Expenditure |
| CDM | Construction Design and Management Regulations |
| CCC | Climate Change Committee |
| CCGT | Combined Cycle Gas Turbines |
| CCHP | Cold Climate Heat Pump |
| CCUS | Carbon Capture, Use and Storage |
| CIBSE | Chartered Institution of Building Services Engineers |
| CO2 | Carbon Dioxide |
| CSF | Critical Success Factor |
| CUSC | Connection and Use of System Code |
| DACC | Direct Air Carbon Capture |
| DCODE | Distribution Code |
| DCUSA | Distribution Connection and Use of System Agreement |
| DER | Distributed Energy Resource |
| DNO | Power Distribution Network Operator |
| DSO | Distribution System Operator |
| ESC | Energy Systems Catapult |
| ESCo | Energy Supply Company |
| ESO | Electricity System Operator |

| | |
|---|---|
| EV | Electric Vehicle |
| FES | Future Energy Scenarios |
| GDN | Gas Distribution Network Operator |
| GO | Guarantee of Origin |
| GS(M)R | Gas Safety (management) Regulations |
| GW | Gigawatt |
| H2 | Hydrogen |
| HGV | Heavy Goods Vehicles |
| HSE | Health & Safety Executive |
| ICP | Independent Connection Providers |
| IDNO | Independent Distribution Network Operator |
| IPCC | Intergovernmental Panel on Climate Change |
| ISCF | Industrial Strategy Challenge Fund |
| IUK | Innovate UK |
| kWh | Kilowatt hour |
| LCoE | Levelised Cost of Energy |
| LCT | Low Carbon Technology |
| LNG | Liquefied natural gas |
| LW | Leading the Way |
| MCA | Multi Criteria Assessment |
| MEDA | National modernising energy data access programme |
| MH:EK | Milford Haven Energy Kingdom |
| MRA | Master Registration Agreement |
| MW | Megawatt |
| MWh | Megawatt hour |
| NG | National grid |
| NTS | National Transmission System |

| | |
|---|---|
| OB | Optimism Bias |
| OPEX | Operational Expenditure |
| OREC | Offshore Renewable Energy Catapult |
| PCC | Pembrokeshire County Council |
| PfER | Prospering from the Energy Revolution |
| PNZC | Pembroke Net Zero Centre |
| PoMH | Port of Milford Haven |
| PPA | Power Purchase Agreement |
| PW | Private Wire |
| SEC | Smart Energy Code |
| SLES | Smart Local Energy System |
| SoLR | Supplier of Last Resort |
| SP | Scottish Power Transmission plc |
| SPAA | Supply Point Administration Agreement |
| SPV | Special Purpose Vehicle |
| SSEN | Scottish and Southern Electricity Networks |
| SWIC | South Wales Industrial Cluster |
| tCO2e | Tonnes carbon dioxide equivalent |
| TCE | The Crown Estate |
| TCR | Targeted Code Review (Ofgem) |
| TGR | Transmission Generation Residual |
| TSO | Transmission System Operator |
| UNC | Uniform Network Code |
| V2G | Vehicle to Grid |
| VPP | Virtual Power Plant |

# Executive summary

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# 1. Executive summary

### Introduction to the Milford Haven: Energy Kingdom project

The Milford Haven: Energy Kingdom (MH:EK) project is a "Detailed Design" project within the Prospering from the Energy Revolution (PfER) programme funded by Innovate UK (IUK) as part of their Industrial Strategy Challenge Fund (ISCF).

MH:EK has been established to review the current energy landscape in the local area, and to investigate options for a future Smart Local Energy System (SLES) by identifying propositions that are investible in the short-term and could provide the initial smaller steps towards larger scale decarbonisation and realisation of a SLES.

The project team consists of ORE Catapult, Port of Milford Haven, Wales & West Utilities, Riversimple, Energy Systems Catapult, Arup; led by Pembrokeshire County Council.

### Purpose of this report

This report summarises the detailed techno-economic review of identified investible propositions, and the recommendations for next steps to take the preferred options forward. This report supports the Economic Case of the 'MH:EK strategic outline case for a smart local energy system' report *[28]*, which also includes the Strategic, Commercial, Financial and Management Cases which should be considered in parallel to the findings of this report.

This feasibility study has focused on three shortlisted 'propositions' to assess their viability as a SLES and set out recommended 'no regrets' opportunities that should be priorities and will kickstart the journey to decarbonisation.

A 'proposition' in this report is defined as a project or development opportunity to make an intervention to the existing energy system of the local area that results in a linked multi-vector (power, heat, and transport) system where there is (potential for) smart connectivity between assets or component parts resulting in better balancing of local energy supply and demand, towards decarbonisation by 2050.

The three shortlisted propositions were taken forward from a longlist that was reviewed using a combined approach of multi-criteria assessment (MCA) and a SLES decision tree framework.

Figure 1: MH:EK project partners and the Milford Haven waterway

# 1. Executive summary

### Proposition 1 – The Milford Haven Marina SLES

Proposition 1 focuses on the assets owned by the Port of Milford Haven (PoMH). The proposition considers the existing Liddeston Ridge Solar farm as a key supply asset alongside prospective PV and wind extensions, as well as the potential for rooftop PV on the PoMH buildings. The demand assets considered heat, power and transport vectors across the existing and proposed buildings and the commercial vehicle fleet owned by PoMH.

The analysis shows that further expansion of renewable assets and closer integration between those assets and the demand at the waterfront would be beneficial. The preferred option for expansion is a 2.5MW wind turbine with a 3.5MW solar PV expansion as second preference. Either a power purchase agreement (PPA) or a private wire connection to the waterfront demand is also recommended.

| 2020 CAPEX with 66% Optimism Bias (£million) | 2050 $CO_2$ emissions (kg/kWh) | 2020 LCOE (£/kWh) | MCA Score |
|---|---|---|---|
| 16.4 | 0.002* | 0.081 | 3.4 |


Figure 2: Map overview of the Milford Haven Marina and Liddeston Ridge site with the proposition boundary.

*$CO_2$ emissions are shown adjusted to a 2050 view and excluding gas heating emissions in order to compare like-for-like with proposition 2 and 3

### Proposition 2 – The Pembrokeshire Food Park SLES

Proposition 2 is centred around the Pembrokeshire Food Park, a planned development for a food distribution centre in Haverfordwest, alongside the planned 10MW Haverfordwest airfield solar PV, and PCC transport hub plans in Haverfordwest. There is strong interplay between the demand energy vectors (heating, cooling, electricity and hydrogen) and a significant opportunity to utilise local waste products to fulfil this demand.

As a new-build proposal, the food park could be designed to take advantage of no regret technologies, particularly anaerobic digestion, biogas CCHP and polyvalent heat pumps. These can be integrated via heating and cooling distribution networks.

Utilising excess PV generation to electrolyse hydrogen locally would be a cost-effective method of meeting some transport demand. If local hydrogen transport demand grows this proposition could form a local hydrogen transport hub.

| 2050 CAPEX with 66% Optimism Bias (£million) | 2050 $CO_2$ emissions (kg/kWh) | 2050 LCOE (£/kWh) | 2050 MCA Score |
|---|---|---|---|
| 24.1 | 0.003 | 0.074 | 3.9 |

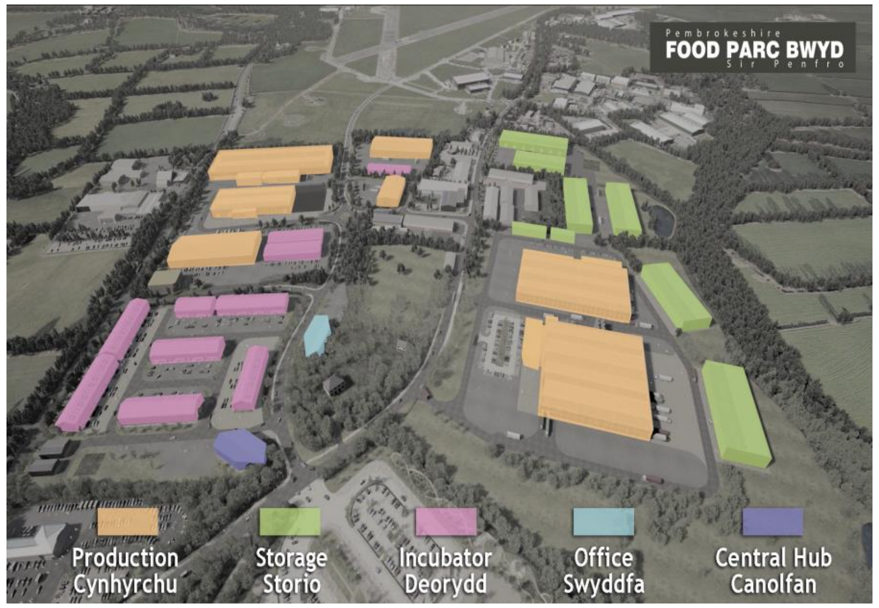


Figure 3: Visualisation of the proposed Pembrokeshire food park (©hacerdevelopments.com/)

### Proposition 3 – The Pembroke Schools, Leisure Centre and Dock SLES

Proposition 3 is located in Pembroke and is geographically closer to the industries on the Haven waterway. As such, this proposition promotes a geographical spread with prospects on stepping up to a wider SLES in the long term as the industrial partners on the Milford Haven waterway seek to decarbonise.

The project considers potential incorporation of existing solar generation assets into the SLES and identifies opportunities for additional renewable generation.

The outcome of Proposition 3 suggests that it is not a strong SLES candidate. The modelling outcomes mainly consisted of a large capacity of solar PV that predominantly exported its generation to the national grid for income. There is little to no district-level integration between the buildings' heating systems and very limited interaction between energy vectors.

| 2050 CAPEX with 66% Optimism Bias (£million) | 2050 $CO_2$ emissions (kg/kWh) | 2050 LCOE (£/kWh) | 2050 MCA Score |
|---|---|---|---|
| 22.2 | 0.001 | 0.030 | 2.1 |


Figure 4: Pembroke Ysgol Harri Tudur School (© https://www.ysgolharritudur.cymru/)

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# Key messages

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# 2. Key messages

### i. High-level conclusions

Our work demonstrates the value of interconnected systems, such as a SLES and the potential for hydrogen to be part of a 2050 decarbonised MH:EK energy system. Annualised cost and carbon emissions are lower in all scenarios against the counterfactuals, and further decreases from 2020 to 2050, with additional low carbon technologies selected where modelled as an option. 'Do Something' is preferable to 'Do Nothing'; and the earlier the action, the faster carbon emissions reductions will be achieved.

Looking back at the project objectives and the questions the MH:EK project is trying to answer (section 4):

What are the short-term actions within the Milford Haven project boundary to deliver net zero by 2050?

Across all the propositions, scenarios and sensitivity testing, the hierarchy of the energy supply-demand relationship has been:

1. Use locally generated electricity locally where possible, first for power and then to satisfy heating (where there is opportunity for new technologies to be installed) and EV transport.
2. If excess electricity is generated beyond the power and heat demand baseload, this is often used to support local electrolysis and green hydrogen production, in preference to exporting excess electricity to the national grid.
3. Any remaining excess electricity (or where an electrolyser is not sized to the maximum seasonal excess such that it is not underutilised) is exported to the national grid.
4. Imported electricity is used to support balancing of fluctuations for both power and electric-heating, where new technologies have been installed.
5. Where existing buildings are connected to the gas network (2020 scenarios), these remain until gas boilers are phased out. In 2050 scenarios, where natural gas is no longer an option electric heating systems dominate with hydrogen boilers featuring to a lesser extent and dependent on the scenario. Hybrid heating systems can provide resilience to future system but the timescales of system level transfer from natural gas to Hydrogen (including 20% hydrogen blend to 100% transition over time) are unknown.
6. Locally produced hydrogen is not favoured for heating demand. New hydrogen boilers are generally a much lower proportion of the overall heating mix due to their lower efficiencies, even once gas is phased out, in the current market context.
7. If electricity export prices decrease, a greater proportion of locally generated electricity may be used to produce hydrogen to satisfy a greater proportion of any hydrogen transport demand (though generally not heating).
8. Where there is a significant proportion of hydrogen transport demand, this is only partially met locally with hydrogen imports. This presents an opportunity for greater local hydrogen production if hydrogen transport demand does develop in the region.
9. Batteries feature in all scenarios, but are not a strong 'no regrets' option, we suggest they are kept in review. Based on the battery price assumptions taken in the model across 2020 (higher cost) and 2050 (lower cost), batteries are at a price tipping point and are expected to feature more predominantly and be a more favourable balancing solution soon.

Additional low carbon generation is adopted in most scenarios, with the cost-benefit and pay-back demonstrated as part of a whole systems view. The revenue, and benefits, to potential investors looking to solely develop renewable generation and sell into local systems would need further financial assessment and consideration of electricity network connection costs (which could be high due to the current constraints), and curtailment risks.

Where is the tipping point in hydrogen, carbon, electricity pricing within a multi-vector system?

Electric solutions outperformed hydrogen solutions in terms of cost due to high electricity exports and high hydrogen import costs, in the current market context.

Heat was largely electrified across the scenarios with air-source heat pumps as the dominant technology because they are more efficient than other electric heating types. Hydrogen boilers did appear in all scenarios but met less than 10% of the heat demand. Their efficiency (x0.84) is also significantly lower than air-source heat pumps (x2.21). This suggests that electrification of heat would be preferable to hydrogen boilers if natural gas was removed from the system, based on the current external market context.

Until a tipping point in the price of hydrogen is reached, which could come due to economies of scale or import of cheaper hydrogen on an international market, the electrification of the heat and transport demand is expected to be a lower cost and lower carbon approach.

Additionally, the cost of batteries is expected to continue to decrease which may result in batteries being preferable as a balancing or storage option compared to electrolysis.

This external context is expected to change over time to 2050, and sensitivity testing of hydrogen pricing indicates that current hydrogen prices of 0.135 to 0.18 £/kWh (£4.5 to £6 /kg) are close to a tipping point in making local electrolysis viable to satisfy a local hydrogen transport demand.

# 2. Key messages

### i. High-level conclusions (continued)

How 'best' to integrate hydrogen into the energy system to decarbonise energy supply?

Our modelling shows that utilising excess renewable generation to electrolyse hydrogen locally would be a cost-effective method of meeting some of the hydrogen transport demand although the majority would still be imported. If the local hydrogen transport demand materialises and regular, consistent, consumers are identified, there will be a stronger opportunity to form the core of a local hydrogen transport hub.

In the short-term, hydrogen would still be predominantly used in specific applications where it is more suitable e.g. industrial and heavier transport applications, however if a tipping point in the price of hydrogen is reached, there will be a stronger case for hydrogen for transport, and potentially heat. The role of hydrogen to decarbonise the energy supply is more significant when looking at the longer-term energy pathways for Milford Haven and considering the large-scale industrial activity in the region. This is further discussed in the 'MH:EK strategic outline case for a smart local energy system' *[28]*.

What does a 2050 decarbonised MH:EK energy system look like and the short-term investments to achieve this, on the route to net-zero by 2050?

Smart local energy systems are shown to have significant benefits in terms of costs and carbon emissions, where there is strong interplay between the demand energy vectors (heating, cooling, electricity and hydrogen) supporting system balancing and greater flexibility of supply.

The key facets of PfER SLESs are electricity, heating and mobility interaction and being mutually supportive of one another towards net-zero goals. Our work demonstrates the value of interconnected SLESs and the potential for hydrogen production as an alternative vector where electricity networks are currently constrained.

SLESs and heat networks are not always the preferred solution, this is dependent on the mix and scale of demand energy vectors. Where a SLES is not appropriate, adoption of low carbon technologies would be encouraged on an individual basis for example, rooftop PV, retrofit of air source heat pumps (ASHP) in schools, and further development of renewable generation projects.

The value of an interconnected system may not always be demonstrated where there are fewer component parts, and the supply-demand is not balanced. For instance, if a proposition solely consisted of hydrogen derived from grid or local electricity, and the local electricity generation is not used to satisfy the local electricity demand, the proposition would not be considered a SLES.

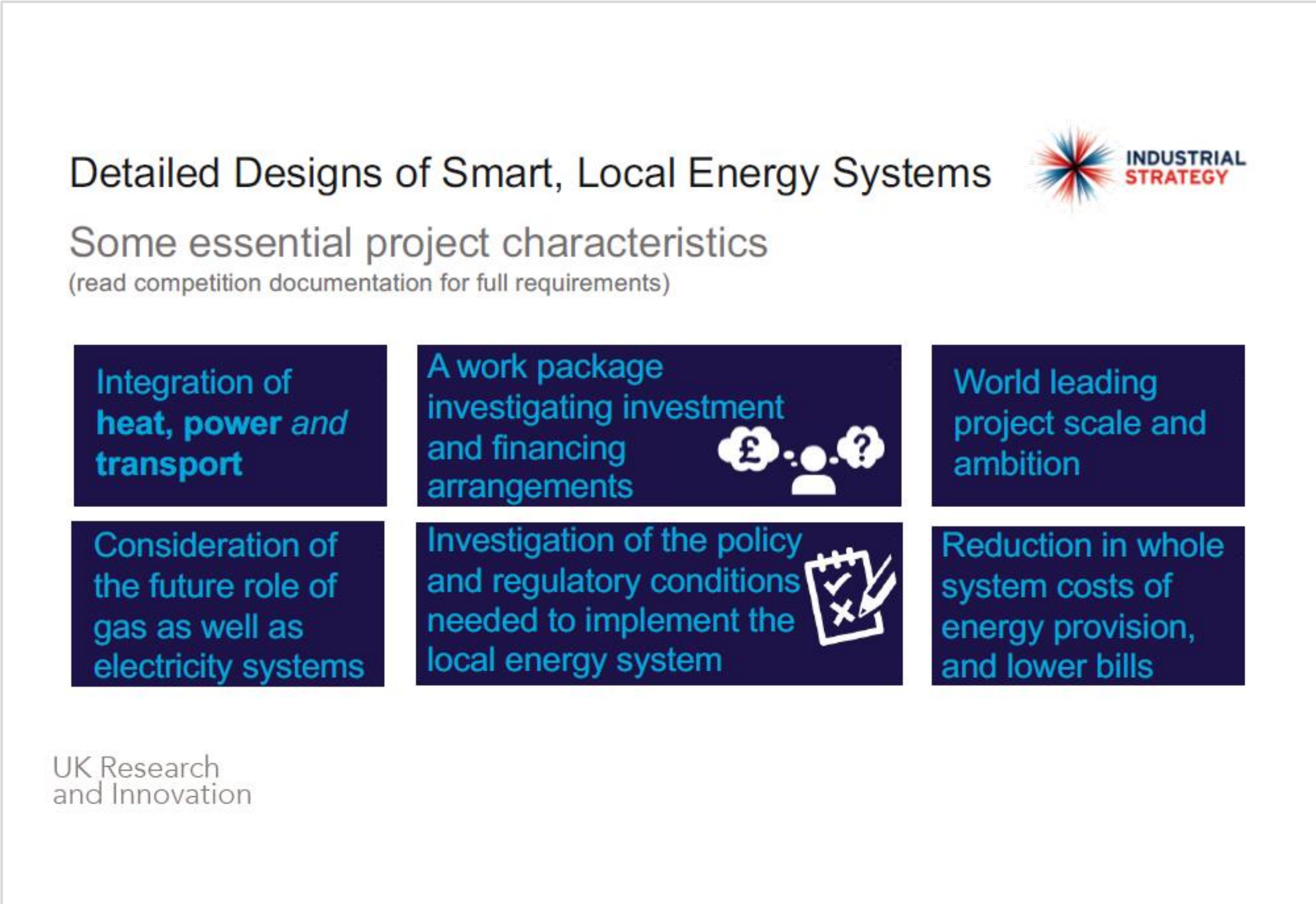


Figure 5: Key PfER facets for SLESs.

# 2. Key messages

### iv. Recommendations

MH:EK SLES project recommendations

- It is recommended that the MH:EK project pursues both Proposition 1 and Proposition 2 as SLESs.
- Further work and more detailed analysis of both propositions is required, as these propositions progress along their development journeys.
- Both present real opportunities for a catalytic stepping-stone SLES that could result in a longer term larger SLES for the Pembrokeshire region, through expansion over time to include a broader boundary of residential and industrial demands.
- These two propositions present differences in 'flavour' with Proposition 1 being more focused around local community demand and Proposition 2 encompassing more commercial / light industrial use.

Proposition 1 recommendations

The analysis shows that further expansion of renewable assets and closer integration between those assets and the demand at the waterfront would be beneficial. The preferred option for expansion is a 2.5MW wind turbine with a 3.5MW solar PV expansion as second preference.

The preferred method of integrating waterfront demand with Liddeston Ridge supply is via a private wire. However, a private wire would cost an estimated £4.4m (without optimism bias) which accounts for most of the CAPEX in all private wire scenarios. This would pay for itself over the 40-year lifetime, but the initial investment could be challenging.

If the commercial, legal and managerial challenges associated with a private wire prove insurmountable, the virtual PPA option could be preferrable to the business-as-usual operation, if it can be achieved at the 33kV scale.

Proposition 2 recommendations

This proposition represents a viable opportunity for a SLES. There is strong interplay between the demand energy vectors (heating, cooling, electricity and hydrogen) and a significant opportunity to utilise local waste products to fulfil this demand.

A core aspect essential to each scenario is a solar farm located at Haverfordwest airfield connected to the food park via private wire. The renewable energy is beneficial to minimise the amount of electricity purchased via the national grid. However, it does account for a significant proportion of the CAPEX (£9.5m-£10.5m) for every scenario.

Given that Proposition 2 represents a new-build proposal, the food park could be designed from the beginning to take advantage of no regret technologies, particularly anaerobic digestion, biogas CCHP and polyvalent heat pumps. These can be integrated via heating and cooling distribution networks with no disruption to existing services or replacement of legacy assets unlike Proposition 1 and 3.

Utilising excess PV generation to electrolyse hydrogen locally would be a cost-effective method of meeting some of the hydrogen transport demand although the majority would still be imported.

If local hydrogen transport demand becomes a reality and regular, consistent, consumers are identified, this proposition could begin to form the core of a local hydrogen transport hub. Further work on the Hydrogen refueller costs and business case would be required.

When a clearer understanding of end user demands is available, further analysis is required to understand the feasibility of the proposed solution and adjust efficiencies if necessary. We would also recommend to undertake a more detailed level of modelling to model different system configurations (as with Proposition 1).

Proposition 3 recommendations

The outcome of Proposition 3 suggests that it is not a strong SLES candidate. Proposition 3 was shortlisted on the basis of identifying interconnected demand but was not realised during more detailed assessment. So, the proposition became less attractive under detailed scrutiny.

The optimised outcome of each scenario mainly consisted of a large capacity of solar PV that mainly exports its generation to the national grid for income. There is little to no district-level integration between the buildings heating systems and very limited interaction between the energy vectors.

It does however demonstrate the opportunity to increase local renewables but there is a need to understand the wider system constraints and connection cost implications for any specific site under consideration for new renewables development.

MILFORD HAVEN: ENERGY KINGDOM

# What is Milford Haven: Energy Kingdom?

## Introduction to the project

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# 3. Project introduction

**Our vision** is to create a whole energy system which shines a light on the potential of hydrogen as a renewable energy source as part of an integrated SLES and the future potential and net zero transition pathway for the predominantly hydrocarbon reliant Haven.

**The ambition** of the project is to have a positive impact on local communities and ultimately help the UK achieve net zero greenhouse gas emissions by 2050.

**Our mission** is to explore how hydrogen can help us decarbonise across multiple vectors.

### i. Project introduction

The objective of Milford Haven: Energy Kingdom (MH:EK) is to establish seed markets for use of hydrogen around the Milford Haven waterway, by integrating a wide range of major energy facilities, renewable energy generators and energy consumers in the community, using a systems architecture that can be implemented with commercial-ready solutions and which focuses on underlying fundamentals and is therefore robust in the face of regulatory change.

The £4.5m project is one of the chosen “Detailed Design” projects within the Prospering from the Energy Revolution (PfER) programme of works funded by Innovate UK (IUK) as part of their Industrial Strategy Challenge Fund (ISCF). The project team consists of ORE Catapult, Port of Milford Haven, Wales & West Utilities, Riversimple, Energy Systems Catapult, Arup; led by Pembrokeshire County Council.

Over a period of two years, the project team has explored what a decarbonised smart local energy system could look like for Milford Haven, Pembroke and Pembroke Dock. The team has also explored the potential of hydrogen as part of a multi-vector approach to decarbonisation. Our aim is to gather detailed insight into the whole energy system around Milford Haven, to identify and design a future smart local energy system (SLES) based on a truly multi-vector approach and comprehensive energy systems architecture.

Central to the project, and to achieving net-zero, is a commitment to engage with the community and local industry, providing insight and opportunities for growth.

### ii. Project boundary

The project has considered a smart local energy system concept design for the Milford Haven, Pembroke and Pembroke Dock areas, focused on the Milford Haven waterway. The project area has been considered within the context of a wider South Wales regional picture as well as drawing on national and European future plans as appropriate.

The Milford Haven waterway is an ideal location for this project which is at the forefront of energy innovation. It is located at the centre of nationally important energy infrastructure, with major energy-related investment targeting efficiency and decarbonisation, underway. Milford Haven, Pembroke and Pembroke Dock have a population of around 30,000 people, providing a range of diverse and representative energy supply and demand centres connected to the local gas and electricity networks.

To develop a detailed concept design of a SLES for MH:EK that is investable in the short-term (2030) and is in transition towards Milford Haven being fully decarbonised by 2050, we adopted a bottom-up approach of identifying a longlist of opportunities for SLESs within Milford Haven, Pembroke and Pembroke Dock.

In order to set the limits of the study and data gathering for existing supply and demand energy assets and opportunities, the first step was to define the project boundary.

Figure 6 shows the project boundary for MH:EK. This boundary is designed to be sufficiently large to allow the study to identify key opportunities while also remaining focused on the local area.

# 3. Project introduction

### ii. Project boundary (continued)

To identify a suitable boundary for the project, we analysed both supply and demand opportunities for renewables and hydrogen. This was primarily through analysis of the Renewable Energy Planning Database, published by the Department for Business, Energy and Industrial Strategy (BEIS) on a quarterly basis.

The proposed boundary follows the outline of Lower Layer Super Output Areas (LSOAs) for ease of analysis. The boundary includes major generation assets along with areas that have potential for renewable generation in the future.

The boundary was extended to include Haverfordwest to the north of Milford Haven as it was anticipated that the town and associated airfield may provide opportunities for future hydrogen use and generation, which could act as a seed market for the broader area.

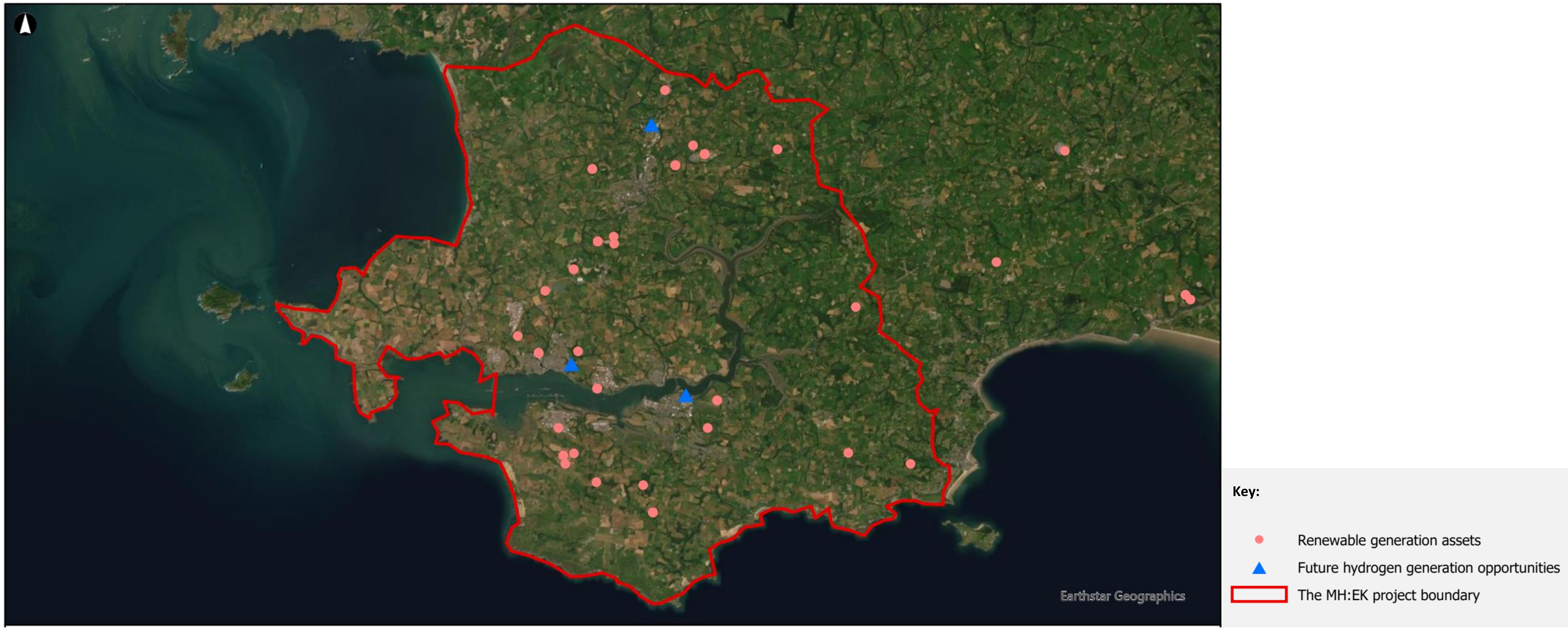


Figure 6: The MH:EK project boundary

# Approach

## Overview of the techno-economic modelling

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# 4. Approach

### i. Project objectives

The primary objective of MH:EK is **to develop a conceptual proposal for what a 2050 decarbonised Milford Haven: Energy Kingdom energy system could look like and the short-term investments to achieve this, on the route to net-zero by 2050.**

To build up the economic case, the project aims to develop a detailed concept design of a preferred Smart Local Energy System (SLES) for Milford Haven in 2030 that is in transition towards being fully decarbonised by 2050.

A series of questions set the frame for the project, under an overarching question of **how 'best' to integrate hydrogen into the energy system to decarbonise energy supply?**

**The reason for the focus on hydrogen within this project is threefold:**

1. The MH:EK boundary is uniquely located around the Port of Milford Haven, the UK's largest energy port, with an associated highly skilled workforce of people working in the fossil fuel industries – people who understand about dealing with hydrocarbons, the processes involved, and safe working practices. We need to harness their skills for hydrogen. It is critical that we develop new skills and transition communities, in parallel with the changes to the physical components of our energy systems.
2. The MH:EK boundary includes other significant national energy assets, which will continue to retain a supporting role in the transitioning energy sector such as the Pembroke Power Station which is central to RWE's proposed Pembroke Net Zero Centre. Similarly, Pembrokeshire is considered to have a key role in new renewables developments both onshore and with offshore wind in the Celtic Sea, as well as being the site of the nationally significant Greenlink connector which will support balancing of the GB energy system with Ireland. This national role, and significant generation potential, will likely require incorporation of hydrogen production as a storage vector to enable local and national balancing and trading of a broader mix of energy vectors.
3. Hydrogen can be created using excess electricity generated by renewable technologies, acting similarly to a battery, storing energy until it's needed and supporting electricity grid balancing which will be increasingly important as the energy sector decarbonises and electricity demand increases. This project explores how to make hydrogen financially viable within the different energy vectors of heat, power and transport, and doing so both at scale and at a local level; whether it's putting in a hydrogen-fuelled heating system, running a hydrogen vehicle, or building a hydrogen manufacturing facility.

To help answer the overarching question, the project aims to answer the following associated questions:

- What does a "best" scenario look like for the Milford Haven project boundary by 2030 & 2050?
    - E.g. across different future UK energy scenarios what are the 'no regrets' options that can be adopted now?
- What carbon price is needed to make hydrogen a viable energy vector?
    - E.g. where is the tipping point in hydrogen, carbon, electricity pricing within a multi-vector system that supports a sustainable hydrogen economy?

The study output follows the Government's 5-case or 'Green Book' business case model.

To understand the economic case for a decarbonised multi-vector energy system, we have undertaken whole systems energy modelling considering technical, economic, and carbon emission factors.

This "Technical Summary Report" provides detail on the whole energy system modelling, which itself provides the supporting evidence for the Economic Case chapter of the "MH:EK strategic outline case for a smart local energy system" report *[28]*.

# 4. Approach

### ii. Getting to a preferred option

The process to develop a preferred option for a conceptual decarbonised SLES for MH:EK included investigating the economic case for short-term investments that are in transition to a decarbonised system by 2050, supported by review of commercial models, trading mechanisms and the system architecture required to deliver this. Figure 8 shows the process to get to a preferred option for a scalable, replicable and investable SLES for MH:EK.

To build up the economic case, we gathered data to gain a detailed insight of the physical energy system within the Milford Haven project boundary through stakeholder mapping, planning and engagement.

Recognising that SLESs have an important role to play in setting stepping-stones to deliver system level change and energy transition, the study looked at identifying opportunities for investable, replicable and scalable SLESs based on the project objectives and critical success factors – referred to throughout this report as Investable Propositions or propositions.

A longlist of 16 propositions was identified through spatial analysis of the existing and planned physical assets, high-level energy demand and supply balance estimation and a RAG (Red, Amber, Green) triage against the project critical success factors.

We evaluated the agreed longlist of propositions using a multi-criteria assessment (MCA). The definition of a successful SLES is ambiguous due to differing levels of complexity across technical, commercial, market mechanisms etc. To address this ambiguity and support the shortlisting of the propositions, we developed a SLES Decision Tree that provides a framework to shortlist a proposition based on system level need, local support, technology readiness, finance and multi-vector nature of the proposition.

Taking the results of the MCA supplemented by the SLES Decision Tree, expert review and stakeholder engagement, we shortlisted three propositions to be progressed to detailed techno-economic modelling.

The three shortlisted propositions were:

- Proposition 1: The Milford Haven Marina SLES;
- Proposition 2: The Pembrokeshire Food Park SLES; and
- Proposition 3: The Pembroke Schools, Leisure Centre and Dock SLES

The longlist to shortlist appraisal is discussed in more details in section 5.

We undertook detailed techno-economic modelling of the three propositions considering a variety of future energy scenarios to produce an optimised system for each proposition and cost-benefit model with associated carbon emissions.

***Milford Haven Marina SLES***

***Pembrokeshire Food Park SLES***

***Pembroke Schools, Leisure Centre and Dock SLES***

# 4. Approach

### ii. Getting to a preferred option (continued)

Techno-economic modelling overview

The modelling process started with a literature review considering potential influencing factors from a national to a local level and across topics including policy, regulation, commercial models, future energy scenarios, low carbon technologies and hydrogen. A full list of reviewed publications is provided section 5, with specific references provided throughout this document.

Where previous studies have been undertaken relevant to the proposition boundary, these were also reviewed such as the Cardiff University Low Carbon Zone study *[5],* which assessed the feasibility of low carbon technologies in locations across the longlisted propositions.

We reviewed industry publications on the future of energy systems such as the National grid Future Energy Scenarios (FES) 2020 *[19]* and regional plans such as the Regen Net Zero South Wales 2050 *[20].*

Using the data gathered from key data holders and stakeholders, demand profiling was carried out to set out heat and electricity loads for buildings and transport demand time series within the proposition boundaries. This process is summarised in section 7.

We reviewed the existing assets, and land availability within the proposition boundary for new technologies such as onshore wind turbines, solar farms and ground source heat pumps.

We developed a longlist of technologies that could form part of a SLES for each proposition and carried out a first screening to qualitatively assess each technology against key performance indicators (KPIs) such as cost and carbon emissions. Technologies that did not meet the requirements of this first screening were discounted. We undertook high level resource availability calculations on the remaining technologies to estimate how much heat and electricity can be generated from each technology within each proposition and the associated site constraints and opportunities. This provided direct input into the modelling but also enabled discounting technologies with low resource availability. This is further discussed in section 8.

To define the future energy scenarios for modelling, we reviewed industry publications such as the National Grid Future Energy Scenarios 2020. The scenarios considered in the modelling consisted of two counterfactual systems (business as usual) and three decentralised systems ranging from the high electric to high hydrogen spectrum. These scenarios were modelled across two-time horizons – 2020 and 2050. The energy scenarios considered are further explained in section 8.

Shortlisted technologies were categorised across the scenarios, defining where they could be implemented.

We then developed a data catalogue and database for the collected data including the demand profiles, energy supply and generation assets, technology capital cost and technical data, yearly operational costs, network infrastructure costs and carbon emissions as well as geospatial information. The database was specifically developed to be a single source of truth that was integrated into the modelling workflow for each scenario within each proposition.

Using Arup's suite of whole system energy modelling (WSEM) tools, which includes a Python based linear optimisation tool, we optimised the energy supply and storage capacities based on the Levelised Cost of Energy (LCOE) and carbon emissions for each scenario.

This enabled us to review and draw out conclusions from across the range of scenarios to inform the most economically viable design of the propositions to reach net-zero by 2050, setting out the assets and technologies that are 'no regrets' or are 'to monitor'. The results of the techno-economic modelling are presented in section 9.

The detailed techno-economic review and the recommendations will inform commercial modelling, trading platform specification, market mechanism assessment and finance and investment review to recommend the preferred SLES option(s) for MH:EK to pursue.


Figure 7: Methodology overview of the techno-economic modelling of the shortlisted propositions.

# 4. Approach

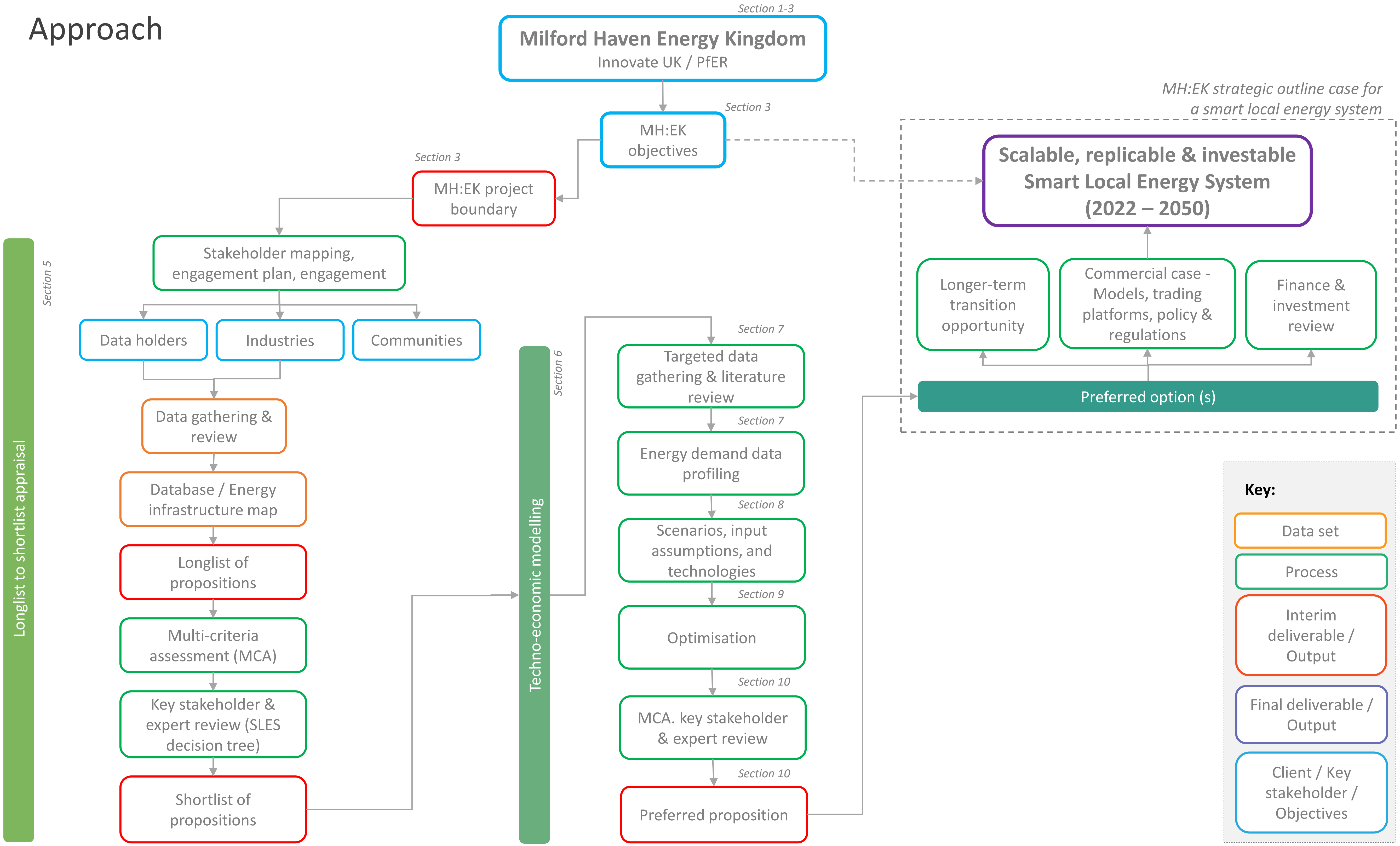



Figure 8: Workflow to get to a preferred SLES option for MH:EK

MILFORD HAVEN: ENERGY KINGDOM

# Longlist to shortlist appraisal

## Establishing three shortlisted propositions for detailed assessment

ENERGY KINGDOM
DEYRNAS YNNI

# 5. Longlist to shortlist appraisal

## i. Introduction

To develop a detailed concept design of a SLES for MH:EK that is investable in the short-term (2030) and in transition towards Milford Haven being fully decarbonised by 2050, we adopted a bottom-up approach of identifying a longlist of opportunities for SLESs within Milford Haven, Pembroke and Pembroke Dock based on the project objectives and critical success factors. This was then refined to a shortlist through a multi-criteria assessment, expert & stakeholder review for further techno-economic modelling.

## ii. Data gathering and review

### The project boundary and data gathering (Phase 1)

The project boundary for MH:EK is designed to be sufficiently large to allow the study to identify key opportunities while also remaining focused on the local area. The boundary includes major generation assets along with areas that have potential for renewable generation in the future.

To build up a picture of the physical energy supply and demand assets and the existing energy distribution network within the MH:EK project boundary, we undertook an extensive first phase of data gathering, to enable us to build a deep understanding of the local energy infrastructure and system.

We gathered demand data for key energy demand centres and buildings owned by Pembrokeshire Country Council and the Port of Milford Haven as well as data and insight on planned developments and opportunities by engaging directly with asset owners and undertaking literature review of various studies around future developments and opportunities within the project boundary.

We consulted publicly available databases such as BEIS Renewable Energy Planning Database *[21]* to gather data on existing and planned renewables generation and supply assets.

We engaged with the local gas network operator Wales & West Utilities (WWU) and electricity network operator, Western Power Distribution (WPD) to gather data on the network infrastructure, constraints and management.

We have further engaged with the MH:EK project team to identify any critical energy demand or supply asset and opportunities for renewables and hydrogen generation.

Note that the propositions include planned developments with high level planning and masterplanning details; the propositions are based on the details of the proposed phases of developments available at the time of shortlisting and modelling, assuming the whole schemes go ahead. However, each build / phase will be subject to review and may or may not proceed.

### Stakeholder Engagement

Due to the breadth of data required and the range of stakeholders involved, a structured and considered approach to data collection and stakeholder engagement is fundamental in the efficient delivery of techno-economic modelling and meeting the project objectives.

Our stakeholder engagement process is as follows:

I. Identify stakeholders
II. Stakeholder mapping
III. Stakeholder engagement
IV. Document engagement activity and data received
V. Measure effectiveness and review

### Summary of key stakeholder engagement activities

We primarily engaged with Pembrokeshire County Council (PCC) and the Port of Milford Haven (PoMH) as key data holders to build a comprehensive picture of the energy demand and supply assets, existing and planned, within the MH:EK project boundary. Examples of key data gathered from PCC and PoMH include:

- List of properties owned by PCC and PoMH and associated electricity and heat demands
- PCC and PoMH vehicle and freight fleet information to inform the transport demand
- NHS vehicle fleet information (through PCC)
- PoMH owned renewable asset information including installed capacity, generation, curtailment information
- PoMH land ownership information
- List of planned developments or prospective energy generation projects within the MH:EK boundary

We engaged with the gas and electricity network operators – WWU and WPD respectively to gather data on existing energy infrastructure. Information requested included data on the gas pipelines and grid and substation capacities. We also held further discussions with WWU and WPD to gather insight on the constraints and pressures on their system and the barriers to increasing capacity, which is summarised in section 5/ii.

### Energy Revolution Integration Service (ERIS) – LEAR study

We collaborated with the ERIS team to make use of their Local Area Energy System Representation (LEAR) tool to extract residential demand loads for our project boundary.

However, due to data confidentiality, the data from LEAR could only be provided in an aggregated form with a granularity that therefore was insufficiently informative as an input to the MH:EK modelling process and analysis.

# 5. Longlist to shortlist appraisal

## ii. Data gathering and review (continued)

### The Milford Haven energy network infrastructure

A key use case of hydrogen as a vector is to act as a storage mechanism for excess electricity that may otherwise be curtailed or lost if the electricity network has no available capacity to carry all the locally generated supply.

It is important to understand the constraints on the electricity network and how new applications to connect to the electricity network are managed in the Milford Haven and Pembroke area.

To understand the local picture, we engaged with WPD at various points in the project. We gathered data on the substations and their capacities within the project boundary. The Milford Haven area is in an active network management (ANM) zone.

> *WPD uses the ANM system to continually monitor the limits on the local network capacity and allocates available capacity based on the date of their grid connection application. New renewable projects risk being constrained with a requirement to wait for capacity to be available to progress their projects and without compensation. This represents an undesirable situation when compared with non-ANM areas where they would be compensated for the networks inability to accommodate electricity export. Alternatively, there is the option to pay for reinforcement of the network, but this is likely to be prohibitively costly for individual developments.*

The implication of ANM within the MH:EK boundary is that new renewable energy generation projects are currently stalled which doesn't align with, and could be a hindrance to, the need to increase renewable energy generation to reach net-zero by 2050. This context highlights the case for development of a SLES or decentralised clusters that are less dependent on the regional and national electricity network and support balancing to bring greater resilience and energy security.

The gas network infrastructure in the region is generally considered to be hydrogen "ready". The Energy Networks Association (ENA) *[22]* announced that the British gas grid is set to be ready to deliver gas blended with 20% hydrogen by 2023. So, if large scale hydrogen heating or blended hydrogen, with either future or existing boilers is shown to be commercially viable then the network itself should not present a blocker.

There are still many other considerations around the integration of hydrogen into the existing gas network that would need to be considered before wide scale adoption, for example injected gas quality. To enter the gas network, gas must meet certain criteria including achieving a Wobbe number in a specific range for the Gas Safety (Management) Regulations. Hydrogen has a very low Wobbe number and often needs to be mixed with propane to reach the required specification. This proved too expensive on a previous PoMH project.

### Literature review

Several previous studies were undertaken on potential opportunities within the project boundary. These were reviewed to inform the longlisting process.

To identify future opportunities and understand the feasibility of the developments and constraints, and to gather information on potential demand and timescales, we reviewed multiple local studies as well as key regional policy documents.

The final longlist was established through combination of data gathering and review, stakeholder engagement, and literature review which supported identification of focal areas and clusters of potential SLES development.

To build up a better understanding of the longer-term plans and developments in the area including larger scale national energy assets that could integrate into the local energy system, we considered future opportunities such as the Greenlink interconnector, the ERM Dolphyn offshore hydrogen production project and the Celtic Sea offshore wind project pipeline and engaged with other groups such as SWIC (South-West Industrial Cluster). The longer-term energy transition opportunities are further explained in the 'MH:EK strategic outline case for a smart local energy system' report *[28]*.

### Future energy scenarios

The future direction of the energy system, the energy mix and energy supply is uncertain. Any SLES identified through this project should therefore perform well when placed in the external context of a range of future energy system environments. Several industry studies explore the various driving factors and possible pathways. We reviewed these scenarios to inform the scenarios taken for analysis in this study. The scenarios are further discussed in section 8.

A list of the key documents we reviewed to inform the techno-economic modelling and other references are provided in the References section. A summary of the key documents reviewed and the implication on the MH:EK project is given in Appendix A.

# 5. Longlist to shortlist appraisal

### iii. The physical energy infrastructure map

The data gathered, and insights drawn from stakeholder engagement and literature reviews were recorded in a database alongside metadata where available. The database acts as a single source of truth and to visualise this data, we developed a digital, dynamic and interactive energy infrastructure map.

The GIS based geospatial map enables users to view the existing energy supply and demand assets, alongside additional asset information such as capacity, asset ownership, status, commissioned year, technology type, planning details etc. We also mapped the energy distribution network and local information such as energy capacity, gas pipe pressures or electric line voltages and substations. We used the map to identify constraints and opportunities for future potential energy generation and used the tool to connect assets and networks to form clusters that could be opportunities for a SLES and so formed a longlist of propositions.

The map has provided a dynamic and live picture of the MH:EK energy system and kept evolving as we progressed through the data gathering, literature review and techno-economic modelling.

The methodology, process and tools used to develop the energy infrastructure map is a key step in the development of SLES opportunities that can be replicated and scaled elsewhere.

The map and the inbuilt data is accessible and interactive, supporting the move to open data and a modern digitalised energy future with the opportunity to continue to evolve beyond this first phase of MH:EK.

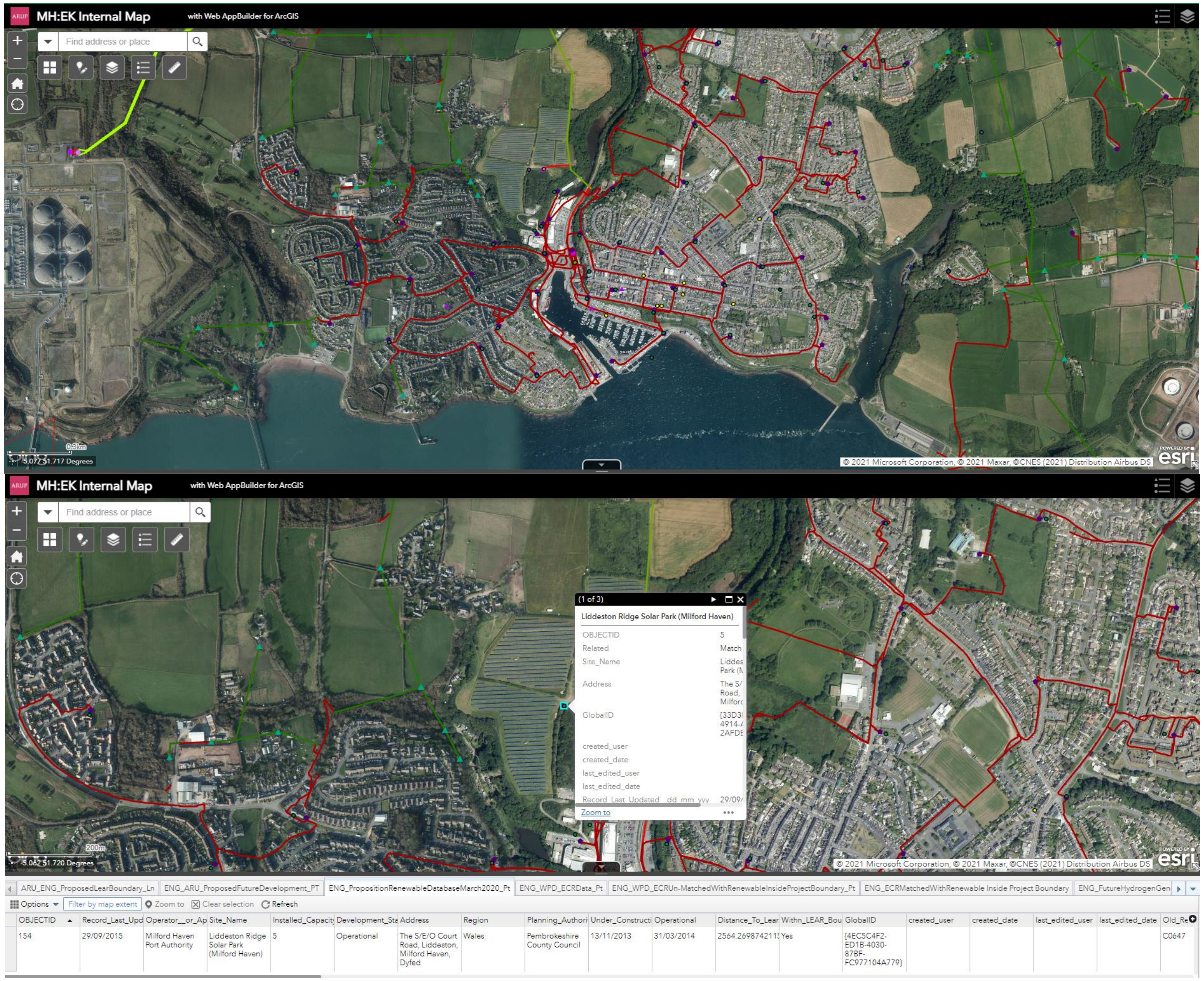



Figure 9: Top - extract of the energy infrastructure map for energy asset and network mapping. Bottom - Energy asset metadata information is accessible through a 'pop-up' or full attribute table at the bottom by clicking on the asset icon.

# 5. Longlist to shortlist appraisal

### iv. What makes a successful SLES?

To define the success criteria that will enable the identification of a longlist of opportunities for a SLES, the MH:EK project team reflected collectively on **What makes a successful SLES?**

> *A smart local energy system is an emerging concept that currently does not have a single definition. A SLES is a decentralized approach to setting up a system whereby energy demand is met by local supply and generation but is supported by conversion technologies to balance for intermittence in energy supply, seasonality and surplus electricity to promote a secure and resilient energy system. The smart aspect can take different levels from automation, communication and flexible transfer and trading. As defined by Ofgem [29], a SLES uses grid flexibility to manage network constraints and provides routes to market and investment models for local generation.*

The team collectively derived four key components of a SLES that is required for success within the MH:EK context:

- Reaching net-zero – the overarching aim and drive for SLESs is to accelerate the transition to net-zero carbon emissions by 2050 (from action at the local level).
- The role of hydrogen – hydrogen could be a significant component of SLESs and play an important role in the transition to net-zero. But its viability is highly dependent on scale and the regulatory frameworks (local and national).
- Regulatory model – the existing energy system is extremely complex and introducing new concepts such as SLESs will face several barriers and will require changes to the energy regulatory models.
- SLESs, how to realise them? – what is the best approach to realise SLESs within the MH:EK context and looking ahead to ensure they are replicable, scalable and investable?

| Reflection points | |
|---|---|
| **Reaching Net-Zero** | **The role of hydrogen** |
| • Significant (increase in) renewable electricity generation and hydrogen required to reach net zero.<br>• Scenarios with differing mix of electricity and hydrogen, from 'low hydrogen, high electric' to 'high hydrogen, low electric' needed to assess SLES in broader national context.<br>• Net zero requires BECCS, as some industries cannot completely decarbonise.<br>• By 2050, blue hydrogen needs to be deployed carefully - like gas, blue hydrogen becomes a transition fuel. | • Pros: storage vector, greater ability to respond to seasonal demands when at scale, considered a good alternative for transport particularly heavy goods vehicles.<br>• Cons: efficiency low compared to air source heat pumps (ASHP) for example, not currently commercially viable, requires deployment at scale.<br>• Threat: Hydrogen should not be incorporated in SLESs if shown not to be technically or commercially viable at a local scale, as this runs the risk of being damaging to the broader net-zero picture. |
| **Regulatory Model** | **SLESs – How to realise them?** |
| • Currently not fit for reaching net zero, as network investment cannot be made proactively and in ANM areas there is a blocker to new renewable development as developers could incur significant costs associated with network upgrade. The value of alleviating these network constraints is also not monetised within the current set-up meaning that the potential value that SLES could bring in balancing local constraints is not able to be considered as part of a commercial viability assessment.<br>• Most likely to achieve net zero - "**Devolution Revolution**, Data Decides, Government Decisions". *[23]* | • SLESs have a role to play in setting stepping stones to realise system level change & hydrogen at scale - but who pays?<br>• SLESs could be more efficient than centralised solutions. More commercially viable SLES propositions likely to be majority electric in the transition to net-zero.<br>• Hydrogen & ULEV likely for future transport.<br>• A tipping point of commercial viability and technological system level change is expected as technology is further developed. |
| **What is required for success?** | |
| **Reaching net-zero** | **The role of hydrogen** |
| • Lowest carbon and cost solution and/or enabling a future system.<br>• Understanding the tipping point that a SLES becomes more beneficial than centralised system?<br>• Understanding the influence / impact of carbon pricing.<br>• Explore the role of SLESs as an approach and part of the journey to net-zero. | • Explore the role of Hydrogen in small / local scale SLESs – technically and commercially to realise seed markets for hydrogen but be critical of it's viability.<br>• Scale and vector – is it viable at smaller scale for transport only and how to get to larger scale system viability? |
| **Regulatory Model** | **SLESs – How to realise them?** |
| • Does it need to be the lowest carbon / cost solution now or just enabling a future system? [Going LOCO]<br>• What's the tipping point that a SLES becomes more beneficial than centralised?<br>• What influence / impact does carbon pricing have?<br>• Are we trying to aggregate lots of SLES's into a centralised system? Is the SLES approach part of a journey? | • SLES have a role to play in setting stepping stones to realise system level change and hydrogen at scale - but who pays & what mechanism?<br>• Consider 3 shortlisted propositions that bring out differences and tipping points through modelling at various timescales:<br>  ◦ Immediate local change - existing assets<br>  ◦ Immediate-mid-term local change - bringing new assets online<br>  ◦ Longer term and larger scale (inc. industrial and system level change; unlocking renewables; ensuring a just workforce, community and industry transition). |

Table 1: MH:EK reflection points and factors for success of smart local energy systems

# 5. Longlist to shortlist appraisal

### v. The critical success factors

The critical success factors (CSFs) are key criteria that are used to assess the longlist of propositions against the project objectives and enable the shortlisting process using a strategic approach.

The list of CSFs are grouped in three main categories:

- the MH:EK project objectives

  These CSFs directly address the MH:EK objectives and the benefits of developing SLESs including benefits in accelerating the transition to net-zero, the associated social and community benefits.

- the technical, commercial and economic viability

  These CSFs ensure that the solution contributes to ensuring energy security & resilience, is technically, economically and commercially viable and addresses other development risks such as the broader need, investment, policy & regulatory considerations, planning and other development risks.

- wider benefits in line with the Welsh Future Generations Act (WFGA) *[24]* and wider sustainability objectives

  These CSFs consider how MH:EK should contribute to wider regional and global sustainability goals. The WFGA seven wellbeing goals stem from the United Nations Sustainable Development Goals and have been translated into the Welsh context to ensure public bodies and projects think about the long-term impact of their decisions, to work better with people, communities and each other, and to prevent persistent problems such as poverty, health inequalities and climate change.

| Critical success factors | Icon |
|---|---|
| **Key objective:** Achieves emissions reductions, significant contribution to net-zero 2050 pathway | |
| **Key objective:** Catalyst / First of a kind & supports future expansion<br>*Potential to develop seed markets for hydrogen in the fields of heat, transport, gas & power.* | |
| **Key objective:** Jobs & Prosperity<br>*Stimulate growth in local community,*<br>*Potential for job creation/upskilling,*<br>*Decarbonises heating or transport for local community,*<br>*Contribute to the alleviation of fuel poverty* | |
| **Key objective:** Optimises social value (social, economic and environmental), in terms of the potential costs, benefits and risks | |
| **Key objective:** Stakeholder / Community Acceptability & Awareness raising | |
| **Viability:** Technical: Balance of supply & demand | |
| **Viability:** Technical: Technology maturity<br>*Existing vs novel technologies*<br>*Supply chain - availability / investment required* | |
| **Viability:** Contributes to Energy Resilience | |
| **Viability:** Immediate Need / Opportunity Readiness | |
| **Viability:** Commercial Opportunity | |
| **Viability:** Commercial: Capex investment required | |
| **Viability:** Investor Interest / Funding Streams | |
| **Viability:** Complexity / Asset ownership / Number of parties | |
| **Viability:** Policy & Regulatory Considerations | |
| **Viability:** Development Risks & Scheme Constraints | |
| **Wider benefits:** WFGA Goals<br>*Prosperous / Resilient / Healthier / More equal / Cohesive communities / Vibrant culture / Globally responsible* | |
| **Wider benefits:** WFGA Ways of Working<br>*Long term / Prevention / Integration / Collaboration / Involvement* | |
| **Wider benefits:** Waste Reduction / Circular Economy | |

Table 2: The critical success factors of MH:EK

# 5. Longlist to shortlist appraisal

### vi. The longlist of propositions

We used the energy infrastructure map to identify the critical or central energy assets, to form the longlist of investable propositions. These are either demand or supply assets that have a stronger opportunity to be part of a SLES. For example, it could be a significant building (school, library, leisure centre) with the opportunity to transition its heating or electricity demand to a net-zero technology within a SLES, or a renewable energy asset that has the opportunity of feeding the generated energy to a SLES rather than fully exporting to the grid.

We clustered a broader mix of assets around a central or critical asset (as defined above) considering feasible geographical links to form propositions that are broadly in line with the CSFs and key success criteria.

We undertook a high-level demand and supply assessment using the gathered data to determine the overall scale of the proposition. This supported a first pass assessment of technical viability. We carried out a qualitative 'triage' of the longlist against the CSFs using a RAG assessment to further consolidate the longlist, and either group or remove weaker propositions from the longlist.

An example of a proposition card is shown in Figure 10 which gives a summary of the proposition and shows how each component (defined within a hexagon) can be clustered to form a proposition.

The card provides information about each proposition including title and description; the value of the proposition; the scale of the energy supply-demand; the demand, supply and conversion components of the proposition; the timeframe considered; the energy vectors represented; the network distribution systems; asset ownership and a qualitative triage RAG assessment against the CSFs.

Proposition summary cards for each longlisted proposition are provided in Appendix B.

An initial longlist of 13 propositions was developed in line with the CSFs (Table 2) and SLES success criteria (Table 1). These were identified geographically across the project boundary as well a temporally from short-, mid-, and longer-term time horizon propositions.

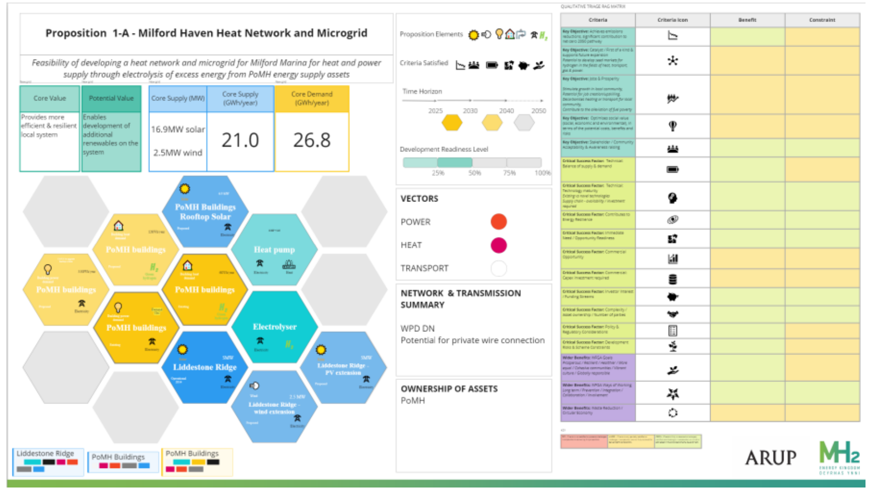



Figure 10: Example of a proposition card

A longlist review workshop was held with the MH:EK project team to identify gaps such as assets or proposed projects / opportunities that may have been missed and to confirm that the initial longlist were in line with the project objectives. In the workshop, an additional three critical assets were identified:

- The PCC recycling centre
- The Haverfordwest Riverside shopping centre
- The Pembrokeshire food park

We formed three new propositions around these critical assets and reviewed these using the high-level supply-demand assessment and qualitative triage against the CSFs, as per the other longlisted propositions.

This assessment concluded that they were strong propositions and were included in the longlist to form a final longlist of 16 propositions. The full longlist and a description is provided in Table 3 and shown in Figure 11.

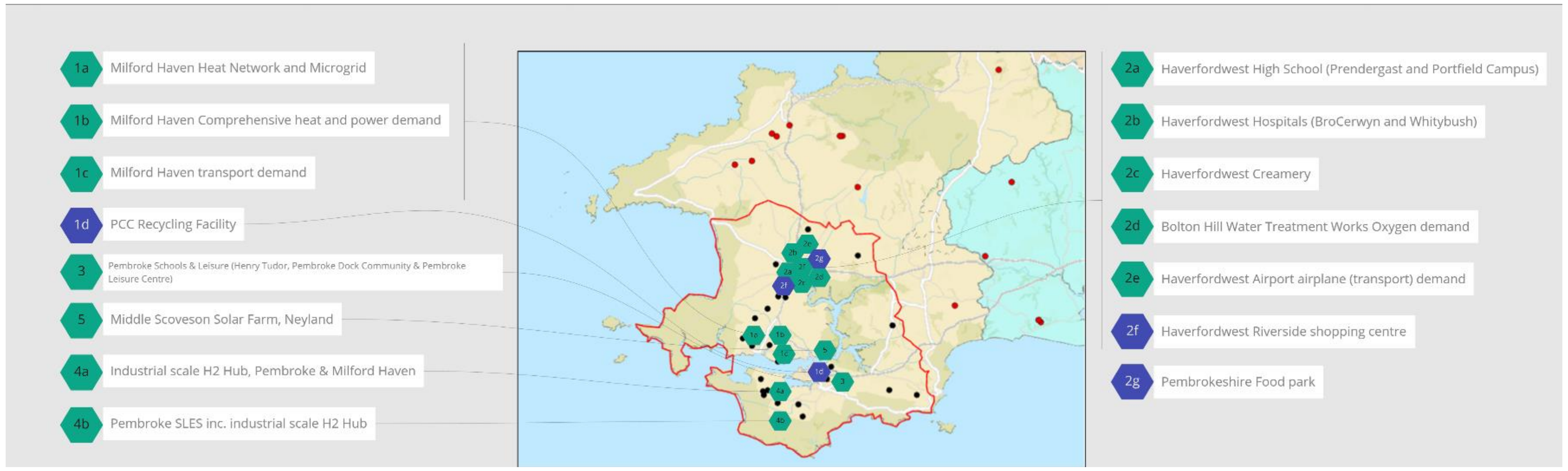



Figure 11: Overview of the longlist proposition within the MH:EK project boundary

# 5. Longlist to shortlist appraisal

### vi. The longlist of propositions (continued)

| Proposition Number | Proposition Name | Proposition Description |
|---|---|---|
| 1a | Milford Haven Heat Network and Microgrid | Feasibility of developing a heat network and microgrid for Milford Marina for heat and power supply through electrolysis of excess energy from PoMH energy supply assets. |
| 1b | Milford Haven Comprehensive heat and power demand | Feasibility of meeting the existing and future heat and power demand of the Milford Haven Comprehensive school by Hydrogen through electrolysis of excess energy from PCC and PoMH owned assets. |
| 1c | Milford Haven transport demand | Feasibility of meeting the existing and future PCC and PoMH transport demand from Hydrogen through electrolysis of excess electricity from PCC and PoMH owned assets. |
| 1d | PCC Recycling Facility | This proposition integrates a proposed recycling centre at the current Milford Haven Puma Energy site with existing local renewable energy supplies. |
| 2a | Haverfordwest High School (Prendergast and Portfield Campus) | Meeting power demand of Haverfordwest High School campuses from nearby renewable energy assets and heat demand through the electrolysis of excess renewable energy. |
| 2b | Haverfordwest Hospitals (BroCerwyn and Whitybush) | Providing Hydrogen for heat and transport demand as well as potential oxygen demand for Haverfordwest hospitals through the electrolysis of excess renewable energy from nearby assets. |
| 2c | Haverfordwest Creamery | Meeting heating/cooling demand of Haverfordwest creamery using hydrogen from biomass conversion of sewage sludge and power demand from nearby renewable energy assets. |
| 2d | Bolton Hill Water Treatment Works Oxygen demand | Proposition to supply oxygen to the Bolton Hill sewage water treatment works through the electrolysis of excess energy from nearby renewable assets. |
| 2e | Haverfordwest Airport airplane (transport) demand | Longer term proposition to supply blue hydrogen for airplane refuelling at Haverfordwest airfield and general heat demand within the MH boundary through reformation of natural gas. |
| 2f | Riverside Shopping Centre | Proposition to provide heat and power to Riverside Shopping Centre in Haverfordwest. This will most likely be via a microgrid due to current electric heating infrastructure. |
| 2g | Pembrokeshire Food Park | Electricity from potential new ground PV farm at Haverfordwest airfield used to meet future heating/cooling and power demand of the planned food park and to create hydrogen to supply freight/HGV transport demand from Pembrokeshire Food Park hub. |
| 3 | Pembroke Schools & Leisure (Ysgol Harri Tudor, Pembroke Dock Community & Pembroke Leisure Centre) | Feasibility of meeting the existing and future heat and power demand of existing PCC school and leisure assets from renewable assets and by Hydrogen through electrolysis of excess energy. |
| 5 | Middle Scoveson Solar Farm, Neyland | Heat demand of Neyland Health centre through the electrolysis of excess energy from existing and proposed renewable energy assets. |
| 4a | Industrial scale H2 Hub, Pembroke & Milford Haven | Transition of the Haven waterway industrial energy sector towards being a major UK H and $CO_2$ hub. Includes H production, storage, import/export and $CO_2$ storage and export in the longer term. |
| 4b | Pembroke SLES inc. industrial scale H2 Hub | Transition of the Pembroke area to a smart interconnected local system balancing electric or hydrogen supply based on availability & seasonality. Import of green H for UK transmission. |

Table 3: The longlist of the propositions

# 5. Longlist to shortlist appraisal

### vii. Multi-criteria assessment (MCA)

To evaluate the longlist of propositions against the project CSFs in a consistent manner, we adopted a multi-criteria assessment approach. This approach enables explicit evaluation of the propositions against multiple criteria that may have conflicting or differing levels of priority or weighting.

We developed an MCA tool specific to the review of SLES, the assessment is carried out as per the following process:

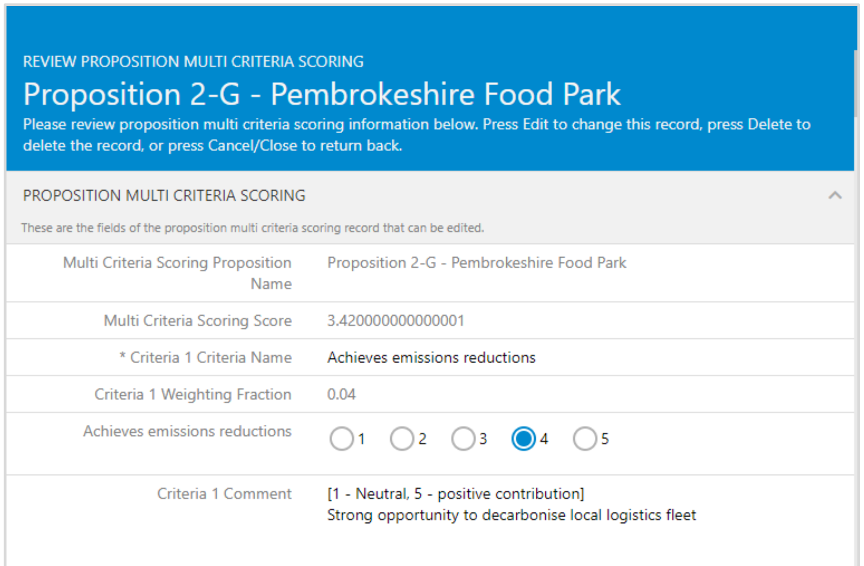
1. Criteria definition
2. Relative criteria importance defined by a weighting factor
3. Scoring of the propositions against each criterion
4. Weighting factor applied to each proposition criterion score
5. Proposition ranking based on the final sum of the weighted scores

**Criteria definition:** A list of 35 criteria was used to evaluate the propositions built from the CSFs and provide greater granularity through specific criteria to enable a robust assessment. The criteria were split into nine categories: key objectives; technical viability; environmental impact; financial viability; funding streams; deliverability; resilience; wider wellbeing & future generations and sustainability goals. Health, safety and welfare as a topic is not considered as a criterion on the basis that it should not be assessed on relative importance; health, safety and welfare should be considered through all aspects of the project.

**Relative criteria importance:** To assess the relative importance of different criteria against one another, we used a tool to capture the perspective of each project partner and combined to give an overall weighting. Whilst it is recognised that the relationship between criterion is in most cases not linear and easy to distinguish relative importance, the tool captures the views of a project team based on project knowledge and the local context. Overall, the 'catalyst' criterion resulted as the most important followed closely by 'achieving carbon emissions' , 'stakeholder acceptability', 'water bodies' and 'WFGA Goals'.

The full list of the criteria, their categorisation and description and the resulting weighting factor is provided in Table 5 overleaf, with the top 5 criteria highlighted in **bold.**

**Proposition scoring:** Using the MCA tool, we scored each proposition against the criteria using a scale of 1 to 5: a score of 1 being a negative or no contribution and 5 being a positive contribution to the criterion. Rationale of the scoring against each criteria is also recorded in the tool.


REVIEW PROPOSITION MULTI CRITERIA SCORING

Proposition 2-G - Pembrokeshire Food Park

Please review proposition multi criteria scoring information below. Press Edit to change this record, press Delete to delete the record, or press Cancel/Close to return back.

PROPOSITION MULTI CRITERIA SCORING

These are the fields of the proposition multi criteria scoring record that can be edited.

| | |
|---|---|
| Multi Criteria Scoring Proposition Name | Proposition 2-G - Pembrokeshire Food Park |
| Multi Criteria Scoring Score | 3.420000000000001 |
| * Criteria 1 Criteria Name | Achieves emissions reductions |
| Criteria 1 Weighting Fraction | 0.04 |
| Achieves emissions reductions | 1 2 3 4 5 |
| Criteria 1 Comment | [1 - Neutral, 5 - positive contribution]<br>Strong opportunity to decarbonise local logistics fleet |

Figure 12 shows an example of the scoring for a proposition against criterion 1: Achieves carbon emissions reduction.

**Proposition ranking:** Once the scoring of each proposition against each criterion is completed, the tool applies the weighting factor to the score to give an overall score out of 5 for every proposition. The propositions were then ranked from the highest to lowest score to show how best they contribute to the project CSFs.

### The emerging shortlist

The MCA process provides a robust and consistent approach to aid decision making, but has some limitations linked to the subjective nature of the scoring. Output is always recommended to be reviewed by technical experts familiar with the local context.

We conducted an expert peer review of the top 10 propositions from the MCA to support the shortlisting process. This review identified emerging focal points and clusters that were recommended to be taken forwards to shortlisting:

A. The Milford Haven cluster
B. The Haverfordwest cluster
C. The Pembroke & Pembroke Dock cluster
D. Longer term industry transition
E. Longer term whole system energy transition.

The project team and expert review confirmed the top 10 propositions as shown in Table 4.

| Rank | Proposition Name | Score | Cluster |
|---|---|---|---|
| 1 | Proposition 4-B Pembroke SLES inc. industrial scale H2 Hub | 3.62 | D |
| 2 | Proposition 1-A - Milford Haven Heat Network and Microgrid | 3.54 | A |
| 3 | Proposition 2-G - Pembrokeshire Food Park | 3.43 | B |
| 4 | Proposition 2-F - Riverside Shopping Centre | 3.43 | B |
| 5 | Proposition 3 - Pembroke Schools & Leisure (Ysgol Harri Tudor, Pembroke Dock Community & Pembroke Leisure | 3.41 | C |
| 6 | Proposition 4-A - Industrial scale H2 Hub, Pembroke & Milford Haven | 3.34 | E |
| 7 | Proposition 2-D - Bolton Hill Water Treatment Works Oxygen demand | 3.32 | B |
| 8 | Proposition 1-C - Milford Haven transport demand | 3.27 | A |
| 9 | Proposition 1-D - PCC Recycling Facility | 3.18 | A |
| 10 | Proposition 1-B: Milford Haven Comprehensive heat and power demand | 3.14 | A |

Table 4: The top 10 propositions after the MCA.

# 5. Longlist to shortlist appraisal

| Number | Criteria Category | Criteria Name | Notes | Weighting |
|---|---|---|---|---|
| **Criteria 1** | **Key Objectives** | **Achieves emissions reductions** | **Achieves emissions reductions, significant contribution to net-zero 2050 pathway** | 0.04 |
| **Criteria 2** | **Key Objectives** | **Catalyst** | **Catalyst / First of a kind & supports future expansion Potential to develop seed markets for hydrogen in the fields of heat, transport, gas & power.** | 0.05 |
| Criteria 3 | Key Objectives | Jobs & Prosperity | Jobs & Prosperity Stimulate growth in local community, Potential for job creation/upskilling, Decarbonises heating or transport for local community, Contribute to the alleviation of fuel poverty b) enabling the development of a mixed, zero carbon energy system for the city region c) providing clean, reliable and competitively priced energy for current and future local businesses and communities | 0.03 |
| Criteria 4 | Key Objectives | Social Value | Optimises social value (social, economic and environmental), in terms of the potential costs, benefits and risks | 0.03 |
| **Criteria 5** | **Key Objectives** | **Stakeholder acceptability** | **Stakeholder / Community Acceptability & Awareness raising** | 0.04 |
| Criteria 6 | Technical | Design | Design – known technology & approaches, appropriateness and balance of supply & demand | 0.02 |
| Criteria 7 | Technical | Construction | Construction – known methods, supply chain skills & technical capability, local supply of materials and construction support facilities, installation programme & weather downtime vulnerability, construction of environmental mitigations | 0.02 |
| Criteria 8 | Technical | Operation | In-use phase – operation & maintenance requirements, schedule, access & safety considerations, supply chain availability and material supply for significant maintenance events | 0.01 |
| Criteria 9 | Technical | Decommissioning | Decommissioning - known technology & approaches, timeframe & likely changes to supply chain and technologies, design life & potential extension, environmental mitigation, safeguarding of other benefits. How robust is the scheme to external scenarios. | 0.02 |
| Criteria 10 | Environmental | Impact | The scheme will be capable of avoiding, reducing the effects to and/or compensating for the loss of European designated sites. | 0.02 |
| Criteria 11 | Environmental | Mitigation | The scheme will be capable of mitigating its environmental effects to acceptable levels. | 0.02 |
| **Criteria 12** | **Environmental** | **Water Bodies** | **The scheme will be capable of either maintaining the ecological status of a water body or capable of supporting a case for derogation under the Water Framework Directive.** | **0.04** |
| Criteria 13 | Environmental | Biodiversity | The scheme will be capable of achieving a net biodiversity gain. | 0.02 |
| Criteria 14 | Financial Viability | Commercial Opportunity | The scale of the commercial opportunity the scheme presents | 0.03 |
| Criteria 15 | Financial Viability | Capital Cost (CAPEX) | The upfront cost of the solution to the point of installation or commissioning | 0.03 |
| Criteria 16 | Financial Viability | Maintenance Cost (OPEX) | The annual costs of operating and maintaining the proposed scheme | 0.02 |
| Criteria 17 | Financial Viability | Price Resilience | The resilience of the scheme to energy price volatility | 0.03 |
| Criteria 18 | Financial Viability | Levelised Cost of Energy (LCOE) | The anticipated LCOE | 0.03 |
| Criteria 19 | Financial Viability | Supply chain | The opportunity for investment in the supply chain to realise the delivery of the scheme, if any. And if so, the scale of investment. | 0.03 |
| Criteria 20 | Funding Streams | Investor Interest / Funding Streams | The scheme will be capable of unlocking funding streams where possible. This should also consider to what degree it relies on these streams to be economically viable. | 0.03 |
| Criteria 21 | Proposition Deliverability | Immediate Need / Opportunity Readiness | Is there an identified immediate need or opportunity associated with the proposition? E.g. planned (re)development. | 0.02 |
| Criteria 22 | Proposition Deliverability | Complexity of asset ownership | Number of parties or direct stakeholders involved | 0.03 |
| Criteria 23 | Proposition Deliverability | Policy & Regulatory Considerations | Critical barriers or obstacles presented by current policy & regulation to the scheme | 0.03 |
| Criteria 24 | Proposition Deliverability | Development Risk | The risk associated with the proposition from planning through to installation and commissioning | 0.03 |
| Criteria 25 | Proposition Deliverability | Scheme Constraints | The number of significant constraints associated with the scheme | 0.03 |
| Criteria 26 | Proposition Deliverability | Future Expansion | The scheme will be capable of connecting to additional loads, and bring benefits to the wider area. The scheme will be capable of supporting future expansion of energy capacity / be adaptable to future new technologies. | 0.03 |
| Criteria 27 | Proposition Deliverability | Visual Impact | The visual impact of the scheme in the landscape and the possibility of raising objections. | 0.03 |
| Criteria 28 | Proposition Deliverability | Low-Carbon Technologies | The scheme will allow for low-carbon technologies to be on display | 0.03 |
| Criteria 29 | Resilience | Energy Resilience | The scheme will provide a secure supply of energy | 0.03 |
| Criteria 30 | Resilience | Innovation | The scheme will demonstrate innovation in the energy sector | 0.03 |
| **Criteria 31** | **Wellbeing & Future Generations Act** | **WFGA Goals** | **The scheme will promote wider benefits to wellbeing goals in terms of: Prosperous / Resilient / Healthier / More equal / Cohesive communities / Vibrant culture / Globally responsible** | **0.04** |
| Criteria 32 | Wellbeing & Future Generations Act | WFGA Ways of Working | The scheme will promote wider benefits to ways of working in terms of: Long term / Prevention / Integration / Collaboration / Involvement | 0.03 |
| Criteria 33 | Sustainability | Waste Reduction / Circular Economy | The scheme will include efficiencies or waste reduction within or across sectors E.g. Energy + Water | 0.03 |
| Criteria 34 | Sustainability | Air Quality | The impact of the chosen technology solution on local air quality | 0.03 |
| Criteria 35 | Sustainability | Education | The scheme will support education about energy and the environment | 0.02 |

Table 5: Complete list of criteria. The top five most important criteria to the project team are highlighted in bold.

# 5. Longlist to shortlist appraisal

### viii. SLES decision tree

To establish the final shortlist of propositions to be taken forward for detailed techno-economic modelling, a second-level review in the form of a SLES decision tree was developed to support assessment of potentially viable propositions, alongside the MCA.

The SLES decision tree shown in Figure 13 captures the key requirements for a successful SLES and walks through key decision points from the highest-level societal need for a change down to the fundamental SLES requirement of being multi-vector.

Given the stage of development of the project, we identified the absolute key requirements that the propositions must satisfy prior to being shortlisted, as follows:

1. Need:
    a. Societal / National Contribution towards Net-Zero
    b. System Level Need
    c. Project or Local Level Need
2. Anchor - someone to drive the proposition: Project, organisational/owner or technology champion. Not all are necessarily required but having an anchor across all three will likely prove more successful.
3. Technology - 'ready to roll' or novel: This influences the ability to deliver (design & construct) as well as the confidence of investors.
4. Finance: Are potential investors identified or on-board?
5. Multi-vector - incorporates transport, heat & power in a truly "smart" way.

The SLES Decision Tree provides a framework to test each propositions against the five absolute key requirements above. The complete MCA output, the decision tree framework and completed SLES decision trees for the emerging top five propositions are provided in Appendix C.

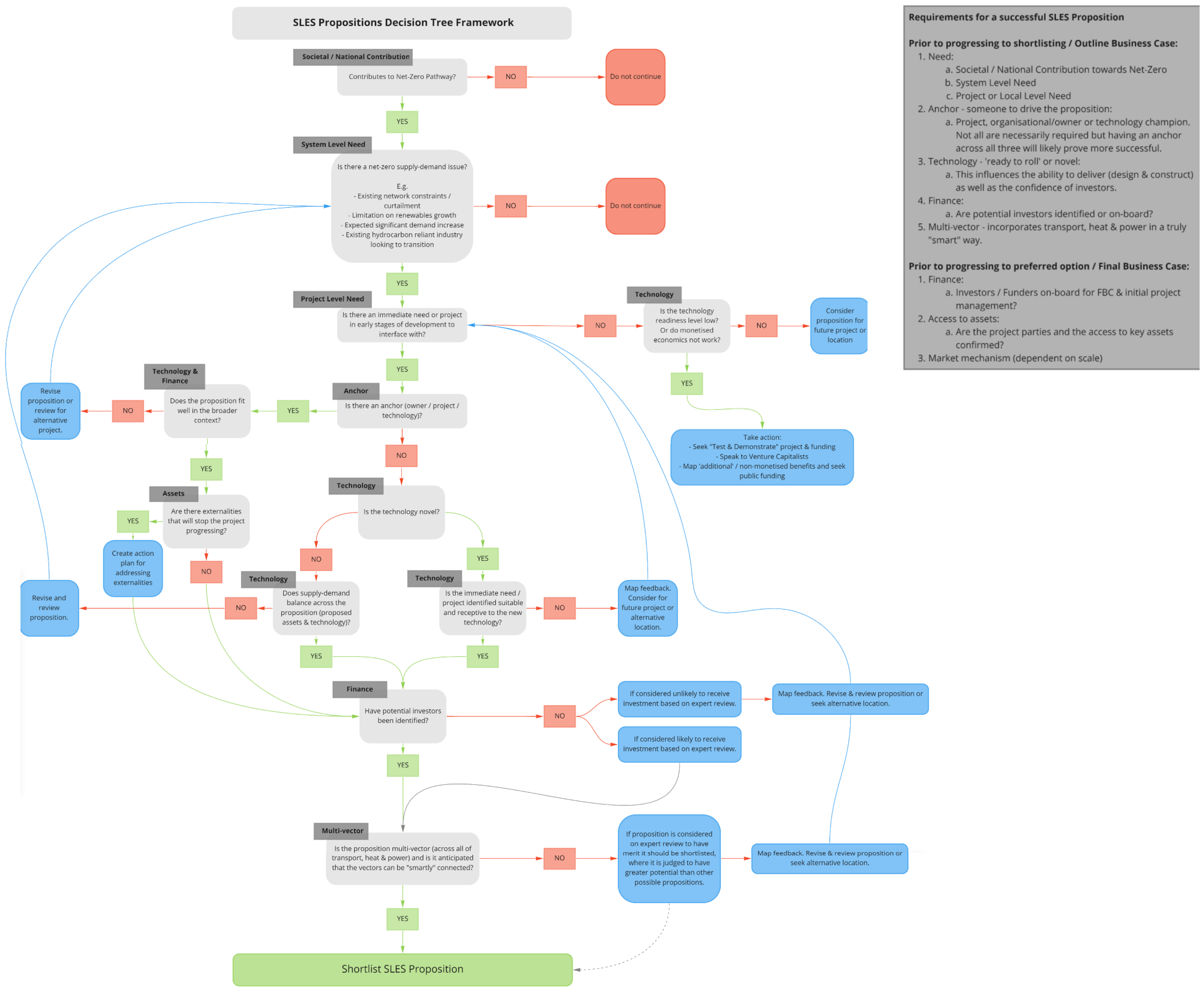



Figure 13: The SLES decision tree framework developed to assess the propositions against five absolute key SLES requirements (Appendix C)

# 5. Longlist to shortlist appraisal

### ix. The shortlist of propositions

We ran the longlist of 16 propositions through the SLES decision tree and five propositions met all the requirements and were recommended for shortlisting. The five-emerging shortlist were spread geographically within the project boundary and showed opportunities for short-, mid- and long-term projects. Figure 14 shows the top five emerging propositions.

We held a second workshop with the project team where we revisited the SLES reflection points and success criteria (Table 1) and the finalised longlist. We collectively reviewed the SLES decision tree framework and discussed the emerging shortlist.

We concluded that whilst some propositions scored highly in the MCA, they were not necessarily 'stepping –stone' opportunities, that is ready or investable in the short term, and would be better further developed as longer-term visions or pathways for MH:EK. This was the case for propositions 4a and 4b. The development of the longer-term energy pathways for MH:EK is discussed in the 'MH:EK strategic outline case for a smart local energy system'.

Using this stakeholder and expert review approach, we arrived at three propositions recommended for shortlisting and detailed techno-economic modelling as follows:

- Milford Haven Heat Network and Microgrid;
- Pembrokeshire Food Park (Haverfordwest); and
- Pembroke Schools and Leisure.

The final three shortlisted and discounted propositions (from the top 5) are summarised in Table 6. The three propositions were shortlisted for having a strong anchor to drive the project, they are multi-vector, smart and tangible investable opportunities that could be a catalytic stepping-stone project towards a decarbonised energy system. The three propositions are considered to be replicable in context and form, and present significant future scaling opportunity. The three shortlisted propositions are summarized in more detail overleaf.

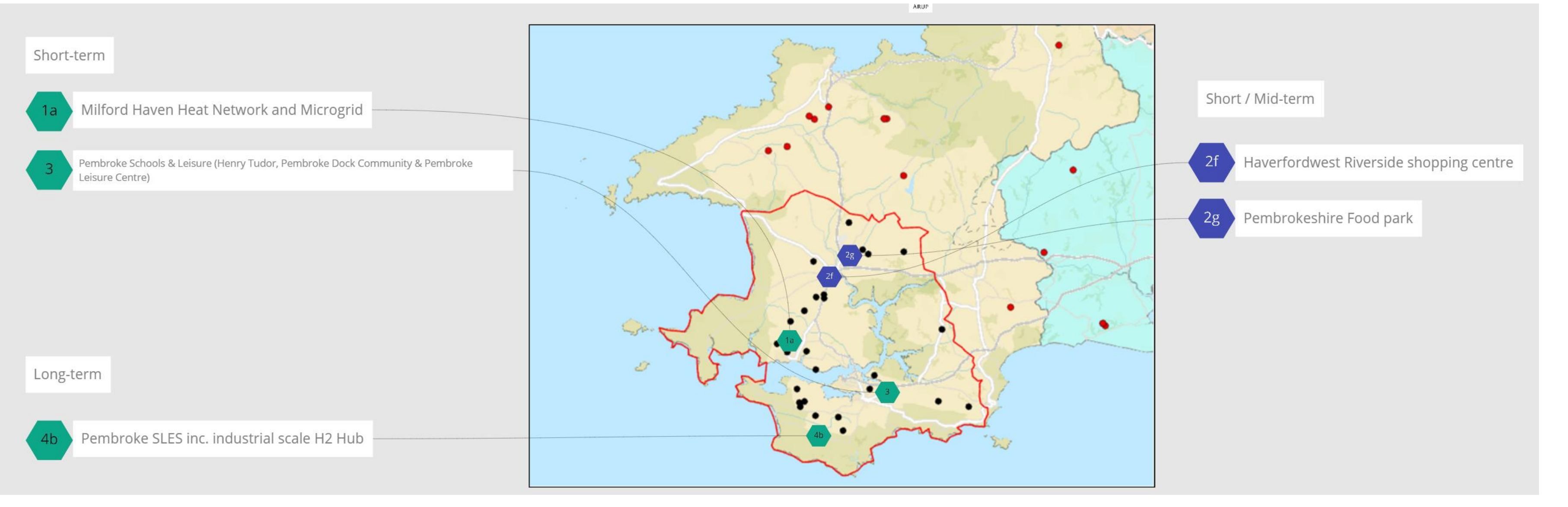



Figure 14: The five-emerging shortlist of propositions that passed through the SLES decision tree shown within the MH:EK project boundary.

| Clusters | Propositions | Recommendation for shortlist |
|---|---|---|
| Milford Haven | 1a – MH Heat Network and Microgrid (Milford Haven Marina SLES)* | Yes – greater consideration to transport vector required. |
| | 1d – PCC Recycling facility | No – limited opportunity for heat recovery from waste but can be considered as part of 1a during further stages. |
| Haverfordwest | 2g – Pembrokeshire Food Park (Pembrokeshire Food Park SLES)* | Yes – multi-vector, strong project anchor and future PV potential. |
| | 2f – Haverfordwest Riverside Shopping Centre | No – MH:EK to engage with the project regarding a HN and microgrid approach. |
| Pembroke | 3 – Pembroke Schools and Leisure. (The Pembroke Schools, Leisure Centre and Dock SLES)* | Yes – Strong project anchor, promotes a geographical spread, greater consideration of transport vector required. |

Table 6: Summary of the recommended propositions for the shortlist and the discounted propositions.

*Note the shortlisted propositions were renamed after the shortlist was agreed.

# 5. Longlist to shortlist appraisal

## ix. The shortlist of propositions (continued)


Figure 15: Map overview of the Milford Haven Marina and Liddeston Ridge site and the proposition boundary.


Figure 16: Visualisation of the proposed Pembrokeshire food park (©hacerdevelopments.com)


Figure 17: Pembroke Ysgol Harri Tudor School (© ysgolharritudur.cymru)

### Proposition 1 – The Milford Haven Marina SLES

Proposition 1 focuses on the feasibility of a SLES incorporating the assets owned by the Port of Milford Haven (PoMH).

The proposition considers the existing Liddeston Ridge Solar farm as a key supply asset and prospective PV and wind extensions as well as the potential for rooftop PV on the PoMH buildings. The demand assets considers the existing and proposed buildings and the commercial vehicle fleet owned by PoMH.

The proposition considers heat, power and transport vectors and the role of electricity, gas and hydrogen in balancing the energy demand and supply up to 2050.

This proposition has a strong anchor in the PoMH and early studies have already been undertaken as part of the Cardiff University Smart Living Demonstrator study *[5]* making it a strong short term stepping-stone opportunity for a SLES.

### Proposition 2 – The Pembrokeshire Food Park SLES

Proposition 2 is centred around the Pembrokeshire Food Park, a planned development for a food distribution centre in Haverfordwest. The food park is a multi-million-pound development looking at providing a modern distribution hub with renewable energy infrastructure and to create a practical research and educational base to ensure sustainable future growth for years to come. They also seek to make local food producers more competitive in the global market and transform the wider economy by directly creating 1000 new jobs. *[25]*

The project is at early stages of development with PCC being a key stakeholder and project anchor. It therefore presents a significant opportunity to be integrated with the planned 10MW Haverfordwest airfield solar PV and PCC transport hub plans in Haverfordwest. This proposition is truly multi-vector and presents opportunity for a short to mid term SLES and long-term prospects such as airplane refuelling.

### Proposition 3 – The Pembroke Schools, Leisure Centre and Dock SLES

Proposition 3 is located in Pembroke and is geographically closer to the industries on the Haven waterway. As such, this proposition promotes a geographical spread with prospects on stepping up to a wider SLES in the long term as the industrial partners on Haven waterway seek to decarbonise.

The project considers potential incorporation of existing solar generation assets into the SLES and also identifies opportunities for expansion and additional renewable generation.

The proposition has strong anchors in PoMH and PCC, also sharing the asset ownership.

Looking to the future, this proposition has other longer-term prospects such as a transport hub in Pembroke and potential vessel refuelling at Pembroke Dock.

MILFORD HAVEN: ENERGY KINGDOM

# Techno-economic modelling overview

## Objectives and process

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# 6. Techno-economic modelling overview

## i. Overview of the techno-economic modelling methodology

### Scope of modelling

The scope of the techno-economic modelling for multi-vector SLESs considers demand centres across the heat, electricity and transport vectors and supply assets within the proposition boundary. The techno-economic modelling optimises the system considering whole life cost and carbon emissions in order to meet the energy demand up to 2050, for different scenarios or 'world views' from high electricity to high hydrogen. The modelling provides insight on 'no regrets' options that are readily investable (2023-2025) and an optimised energy system solution for each proposition across the modelled scenarios.

It should be noted that Proposition 1: The Milford Haven Marina SLES was at a more advanced stage of development when being considered in the longlist; and due to additional funding available within the project for developing this proposition, modelling has been undertaken to a greater level of detail for Proposition 1 compared to propositions 2 and 3.

### Modelling objectives and output

The objectives of the modelling are to:

- Provide the cost-benefit ratio to enable assessment of the economic viability of each proposition.
- Understand the energy flow, costs and carbon emissions across multiple future energy scenarios up to 2050.
- Understand the tipping point at which a SLES becomes more viable than a centralised system.
- Understand the potential for the proposition to be an economically viable stepping-stone SLES to catalyse a broader system level change.
- Investigate the role of hydrogen to realise each of the propositions in the short-term time horizon (2023-2025) and in 2050.

For each proposition and the modelled scenarios, the outputs of the techno-economic modelling are:

- Capital expenditure (CAPEX) of the technologies to be installed to implement the proposition
- Operational expenditure (OPEX) of the technologies annually over the lifetime of the proposition
- Levelised Cost of Energy (LCOE in £/kWh) – blended and individually across electricity, heat and hydrogen
- Carbon emissions (kg/kWh)
- Energy capacity by technology (MW)
- Energy flow diagram (Sankey diagrams)

### Modelling input requirements

The required modelling input information is as follows:

- List of the demand and supply assets, conversion and storage technologies that form the proposition boundary.

  The list of technologies within each proposition is bound by a screening process against the project objectives, KPIs and scenarios.
- Demand and supply data covering both existing and proposed assets across heating, power and transport obtained through targeted data gathering, literature review and stakeholder engagement.
- Modelling scenarios or world views based on industry guidance on future energy systems.
- Whole life costs of technologies, commodities and distribution.
- Carbon emissions of the components of the system.

Where gaps were identified in the gathered project data, we used industry datasets and benchmarks, supported by a series of modelling assumptions. (Appendix D)

### Modelling process

We used Arup's suite of whole system energy modelling (WSEM) tools, which includes a Python based linear optimisation tool, to optimise the energy supply and storage capacities based on the cost and carbon emissions objectives. The modelling was undertaken for three different future energy scenarios across two-time horizons - 2020 & 2050 allowing for multi-vector energy system analysis across two different world views.

The output of the modelling was reviewed alongside re-running an MCA assessment in the context of the more detailed modelling output to recommend a preferred solution.

The modelling process is illustrated on Figure 18 overleaf and in more details in subsequent sections.

# 6. Techno-economic modelling overview

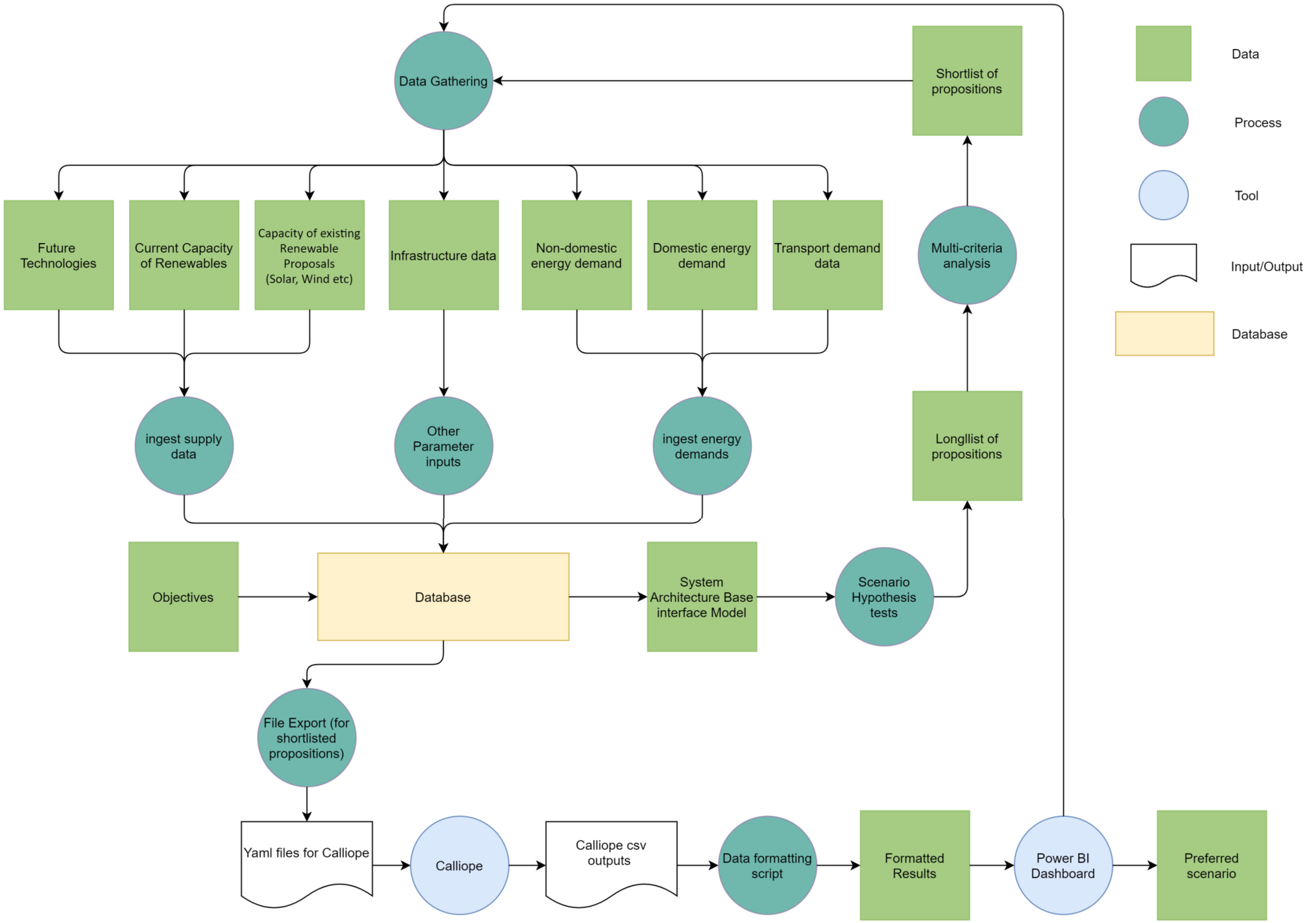


Figure 18: Workflow diagram for the techno-economic modelling process

MILFORD HAVEN: ENERGY KINGDOM

# Data gathering and energy demand data profiling

## Establishing detailed local energy demands for the shortlisted propositions

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# 7. Data gathering and energy demand data profiling

### i. Approach to data gathering

Following the first phase of gathering a broad range of data at a high-level from across the project boundary to inform the proposition longlisting, we used a more targeted approach to gather data specific to each proposition.

When collecting demand data for propositions we followed a hierarchical order of preference as shown in Figure 19.

1. Metered half hourly data

   Half hourly data for electricity and heat supply gives an accurate depiction as to how loads change over time based on actual energy use within the building, the local temperature conditions and the building fabric.

2. Monthly metered or billed data

   In the absence of half hourly data, monthly metered data provides useful insight into the building usage. A typical consumption profile was applied to monthly values based on assumed building occupancy use.

3. Quarterly metered or billed data

   Like monthly metered readings, quarterly metered data can be used with a typical profile applied.

4. EPC / DEC energy data

   In the absence of the above, an online search has been conducted for Display Energy Certificates (DECs) and Energy Performance Certificates (EPCs). These provide an annual fuel consumption per year per squared meter floor area. We have used assumed splits from the Department for Business, Energy and Industrial Strategy (BEIS) Building Energy Efficiency Strategy (BEES) between input heating fuel and electricity fuel to assume heat and electricity loads for each. Arup standard consumption profiles were applied based on building type.

5. Benchmarked energy demand

   We used BEES data to calculate heat and electricity consumption for remaining buildings based on floor areas established either from estimation or from documentation; for example we estimated the floor areas of the proposed buildings in Proposition 1 using the appendix of the Cardiff University Smart Living Demonstrator study *[5]*

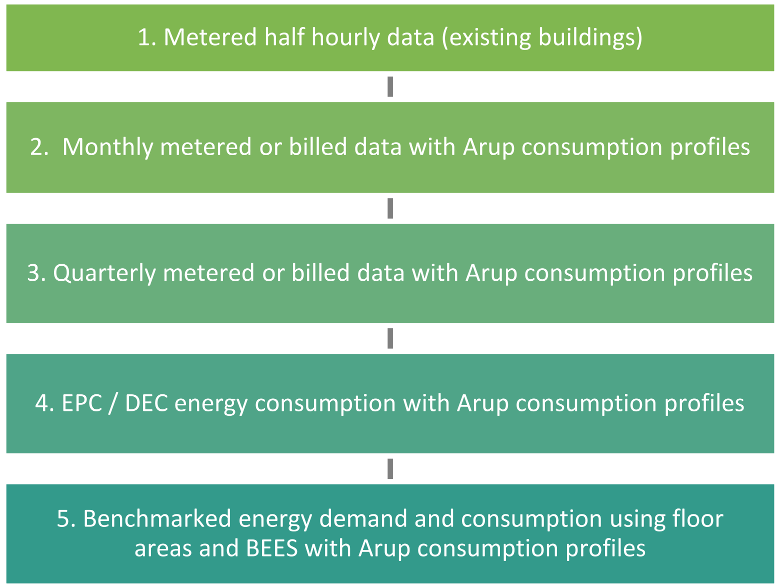


Figure 19: The hierarchy of the targeted data gathering process.

| Demand | Proposition 1 - The Milford Haven Marina SLES | Proposition 2 - The Pembrokeshire Food Park SLES | Proposition 3 - The Pembroke Schools, Leisure Centre and Dock SLES |
|---|---|---|---|
| Annual heat demand (MWh) | 9,921 | 1,748 | 4,251 |
| Peak heat demand (kW) | 4,810 | 783 | 4,046 |
| Annual electricity demand (MWh) | 12,293 | 2,226 | 882 |
| Peak electricity demand (kW) | 2,168 | 425 | 319 |
| Annual cooling demand (MWh) | - | 2,985 | - |
| Peak cooling demand (kW) | - | 397 | - |

Table 7: Annual and peak heating, electrical and cooling demand per proposition

### ii. Approach to energy demand profiling

The hierarchy of energy demand profiling methods used is consistent with the hierarchy of the initial demand data / load estimation – we used metered data as a priority and used benchmarks when metered data was not available.

In instances where half-hourly metered data was not available, we used a series of sector-specific, Arup developed consumption profiles. These profiles give a percentage of annual energy demand for each hour of the year and are informed by generic building energy models. The results have been aggregated for each building with domestic hot water and space heating demand combined.

The resulting hourly demand profiles were used as direct inputs to the optimisation process. Table 7 provides an overview of the annual energy consumption and peak energy consumption for each energy vector across the propositions. The detailed data gathering and profiling for each proposition is further discussed in the next sections.

# 7. Data gathering and energy demand data profiling

*Milford Haven Marina SLES*

### ii. Proposition 1 – The Milford Haven Marina SLES

The recommendations from the Cardiff University Smart Living Demonstrator study *[5]* were fed into the development in this study of Proposition 1 - The Milford Haven Marina SLES. The study demonstrated that utilisation of local renewable energy resources can enable a path to net-zero carbon by 2030. The study looked at development of a Low Carbon Zone around the Haven Waterway and assessed several energy generation combinations to inform a decarbonisation roadmap for the area whilst realising the expected rise in electrical and heat demand from 2020 to 2030. The preferred energy solution from this study aims at maximising the utilisation of the existing, Port owned Liddeston Ridge solar farm via expansion to onshore wind and a private wire and also included a hydrogen fuel cell combined heat and power (CHP) system, a marine source heat pump and electrolysis of hydrogen from excess electricity produced during the summer months.

For the Milford Haven Marina SLES proposition, most data is benchmarked due to unavailability of metered data and the high percentage of proposed buildings within the proposition.

Metered data was used where available and provided by PoMH. Where unavailable, following the data preference hierarchy, we derived the energy demand based on floor areas defined in the Cardiff University Smart Living Demonstrator study *[5]* for existing buildings. For proposed buildings, we assumed the building phasing plan and floor areas for proposed buildings based on the Port of Milford Haven Phasing Strategy *[6]* as per Table 8.

We received transport frequency and mileage data from PoMH and PCC for all their car, van, bus and heavy goods vehicle fleet. This data was used to calculate the transport energy demand per hour which was met by different proportions of electricity or hydrogen based on the scenario. We used this transport demand in this proposition and as part of the transport loads for propositions 2 and 3 and is referred to as the **core transport load** throughout this report.

For Proposition 1, we assumed that the core transport load would be doubled to account for public use of charging / refuelling infrastructure as advised by PoMH.

We also gathered supply side data from PoMH and this included curtailment plans for current renewable assets at Liddeston Ridge, previous feasibility studies for a range of renewable technologies and land ownership maps. This allowed us to estimate the renewable potential from the area considered to be available for future development.

We received current electricity and gas costs from PoMH. Private wire infrastructure costs were taken from the Services and Infrastructure Masterplanning MHPA report *[8]* and assumptions were made on the costs for using the local electricity network to distribute electricity around the site based on the Potential benefits of an Energy Local Cluster at Milford Haven Port report *[7]*.

| Proposed building development phases | Assumed building type | Assumed gross internal floor area (m2) | Assumed construction start date |
|---|---|---|---|
| Phase 1 | Hotel | 4285 | 2019 |
| Phase 2 | Shopping facilities | 1069 | 2019 |
| Phase 3 | Residential<br>Mixed use | 68 dwellings<br>1713 | 2020 |
| Phase 4 | Leisure<br>marina services | 8810<br>420 | 2023 |
| Phase 5 | Residential | 101 dwellings | 2026 |
| Phase 6 | Residential | 21 dwellings | 2027 |
| Phase 7 | Hotel,<br>restaurant<br>offices | 4070,<br>305<br>2230 | 2028 |
| Phase 8 | Fishing industry | 2000 | 2030 |

Table 8: The assumed building phasing plan and floor areas for proposed buildings


Figure 20: Site map of the proposed building phases of the Milford Haven Marina *[6]*

# 7. Data gathering and energy demand data profiling

*Milford Haven Marina SLES*

## ii. Proposition 1 – The Milford Haven Marina SLES (continued)

### Monthly demand profiles

Figure 21 and Figure 22 shows the monthly heating and electrical demand profiles. As most of the energy demands in Proposition 1 (The Milford Haven Marina SLES) were benchmarked and a significant proportion of the demand comes from proposed future developments rather than existing buildings, the resulting aggregated demand profiles are smooth, repetitive and lack the noise and variability of in-use operational buildings.

As expected, the heating demand was largest during the winter months when dominated by space heating. It then dropped significantly during the summer months to cover primarily the domestic hot water demand. The range between the heat consumption in the winter months and the summer months is large, from consistently above 1,000MWh per month to below 200MWh per month. This is due to the lack of a significant 'anchor' load that has a large year-round heating requirement.

The electrical demand is more consistent throughout the year. Given the high proportion of benchmarked data used during this feasibility stage, there is a lack of diversity in the resulting load profiles. For instance, we have assumed that any comfort cooling demand is captured in the electrical demand data. If developments are identified as having significant cooling demand In later stages of development, the electrical demand profile should be updated, which could lead to more seasonal variation in the electrical demand.

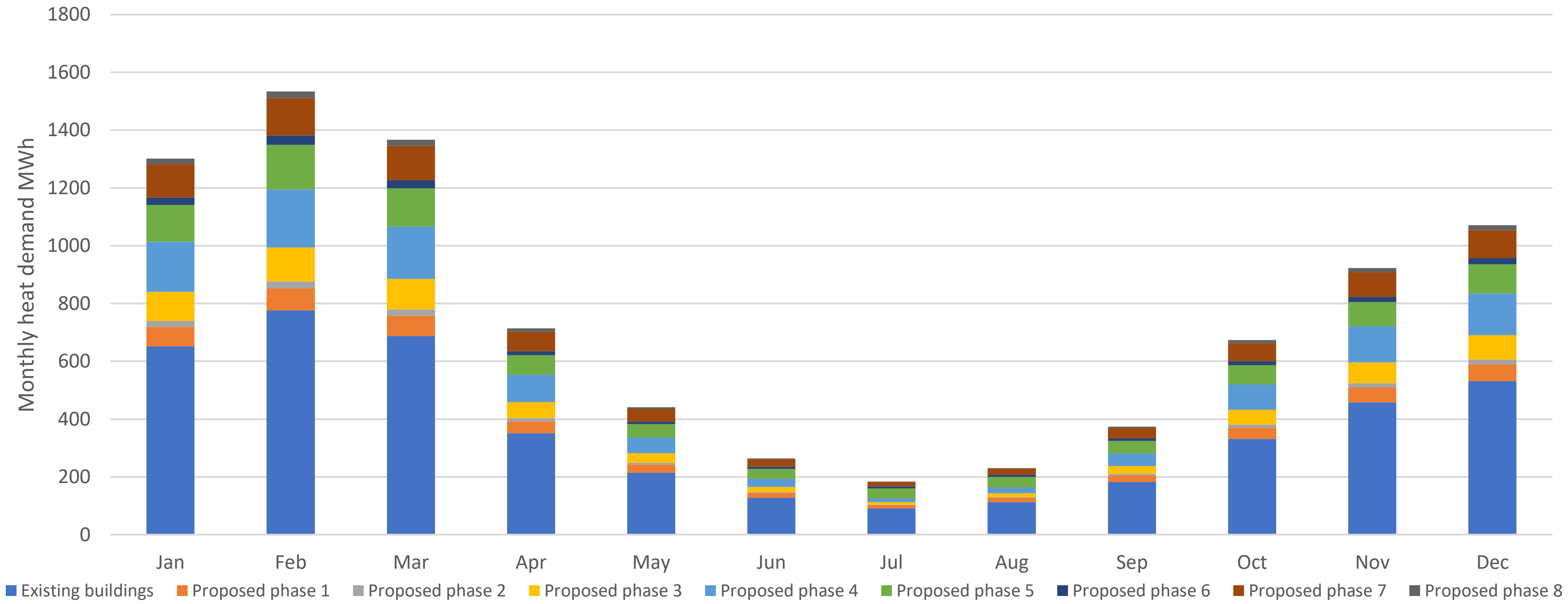


Figure 21: The monthly heat demand profile of the site phases for Proposition 1

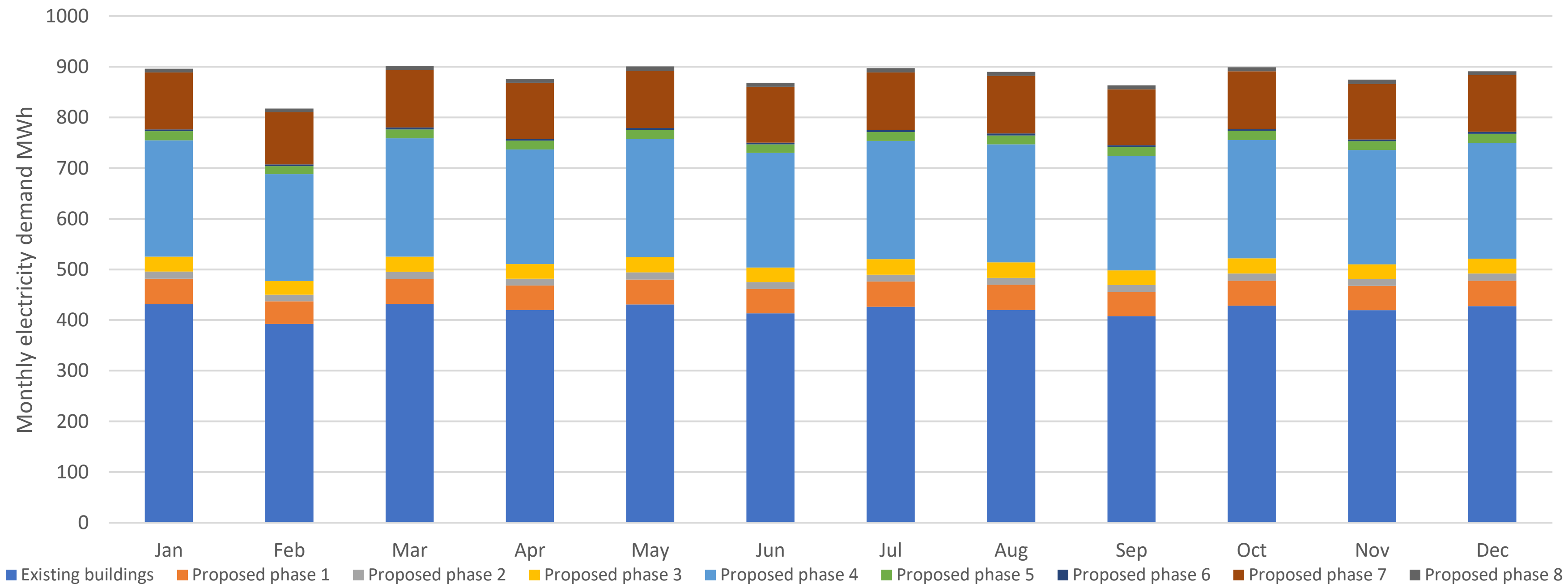


Figure 22: The monthly electricity demand profile of the site phases for Proposition 1

# 7. Data gathering and energy demand data profiling

*Milford Haven Marina SLES*

### ii. Proposition 1 – The Milford Haven Marina SLES (continued)

Daily demand profiles

The average hourly heating and electrical consumption is given in Figure 23 and Figure 24 respectively.

Profiles representing building phases with predominantly residential loads, exhibit morning and evening spikes in demand which is typical for how the UK heats residential buildings, as can be seen in the existing buildings profile in Figure 23. Building phases that contain more leisure and retail space, show a smoother hourly heat demand profile.

Most electrical profiles across the existing buildings and proposed building phases have a similar hourly demand curve. They show a significant baseload and then an increase in demand from 9am to 8pm. Phases with more leisure and retail show a peak later in the evening consistent with what would be expected from their activity.

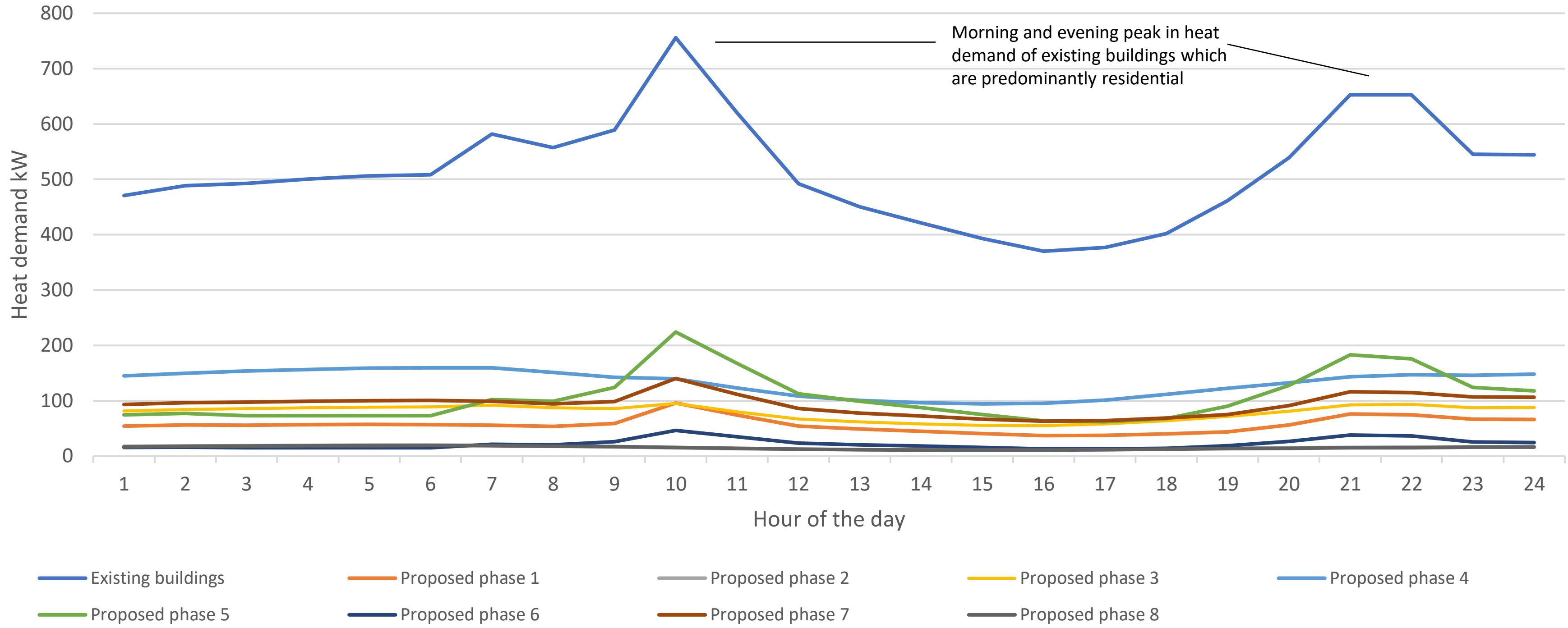


Figure 23: The average hourly heat demand profile of the site phases for Proposition 1

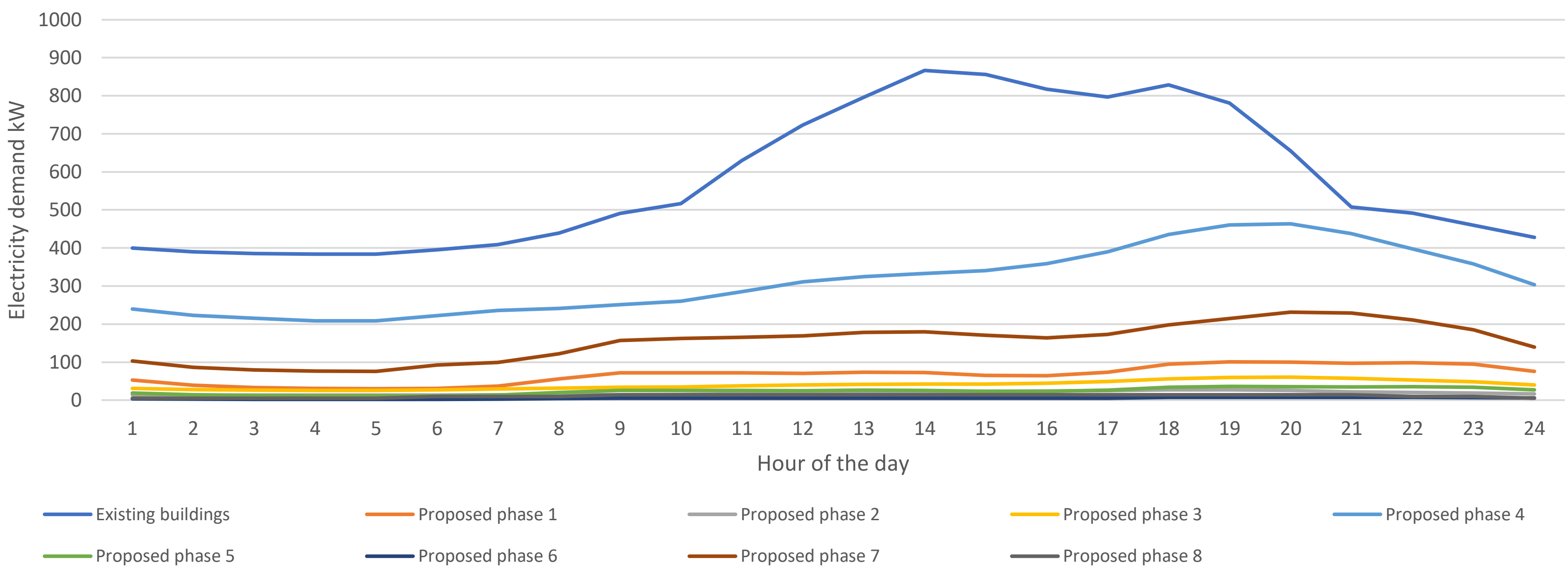


Figure 24: The average hourly electricity demand profile of the site phases for Proposition 1

# 7. Data gathering and energy demand data profiling

*Pembrokeshire Food Park SLES*

### iii. Proposition 2 - The Pembrokeshire Food Park SLES

We primarily received data for Proposition 2 – the Pembrokeshire food park from PCC. We reviewed the Stage two feasibility study at Withybush Food Park *[9]* which provided a background to the key aspirations and drivers for the site.

Demand data for heating, cooling and electricity loads was benchmarked from site layout plans for the proposed food park as shown in Figure 25.

The transport load for Proposition 2 includes the core transport load described in Proposition 1 and additional assumed demands from:

- The food park,
- Proposed Haverfordwest parking facilities, and
- The First Milk Ltd Haverfordwest creamery.

We have assumed fleet numbers based on site plans and car parking provisions for the new transport interchange at Haverfordwest. For the food park and creamery, we have made assumptions on the number of vehicles as this information was unavailable. Further investigation should be made into transport loads for these users during further stages of development. We assumed annual mileage data for cars and vans from studies produced by the Office for National Statistics *[26]* and the Department for Transport *[10, 27]*.

We estimated the rooftop PV supply for this proposition using the roof area from the site plans. Meanwhile, plans for solar developments at Haverfordwest airfield were supplied by PCC and existing renewable energy assets in the surrounding area were taken from the BEIS Renewable Energy Planning Database *[21]*

We have additionally engaged with First Milk Ltd to investigate the opportunity around integrating their Haverfordwest creamery asset into this proposition.

We learnt about their aspirations and targets to transition their business to net zero by 2040 and considered integrating their asset into Proposition 2. However, the organisation had not progressed into developing a transition action plan for their Haverfordwest site yet, and so although we included a small transport demand for the site in our analysis, we did not include any industrial heating, cooling or electricity demands in this stage of analysis for Proposition 2. The creamery is a significant local industrial energy user and remains an opportunity for scaling up this proposition in the future.

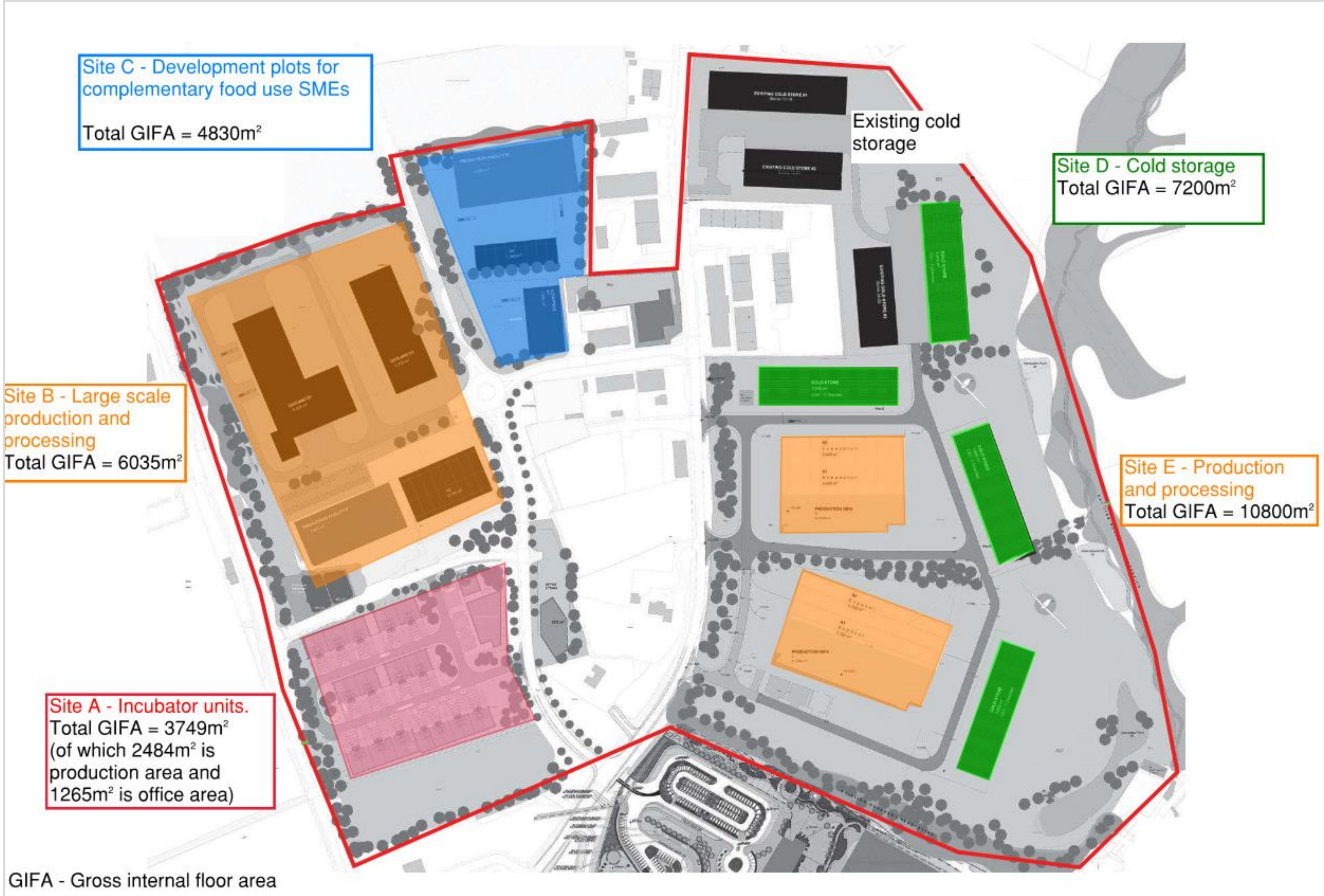


Figure 25: Sketch showing the site layout of the Pembrokeshire food park with assumed floor areas for the modelling. For information only

# 7. Data gathering and energy demand data profiling

*Pembrokeshire Food Park SLES*

### iii. Proposition 2 - The Pembrokeshire Food Park SLES (continued)

Monthly demand profiles

The monthly heating, cooling and electrical profiles for Proposition 2 are given in Figure 26, Figure 27, and Figure 28 respectively. As the Pembrokeshire food park was at an early design phase, all the demand was benchmarked from Arup standard sector specific consumption profiles. Cooling demand is expected to be significant in Proposition 2 and has therefore been included as its own energy vector. Cooling demand is dominated by Site D, the cold storage facility.

We have used the early plans of building use, but this could evolve and alter over the design process.

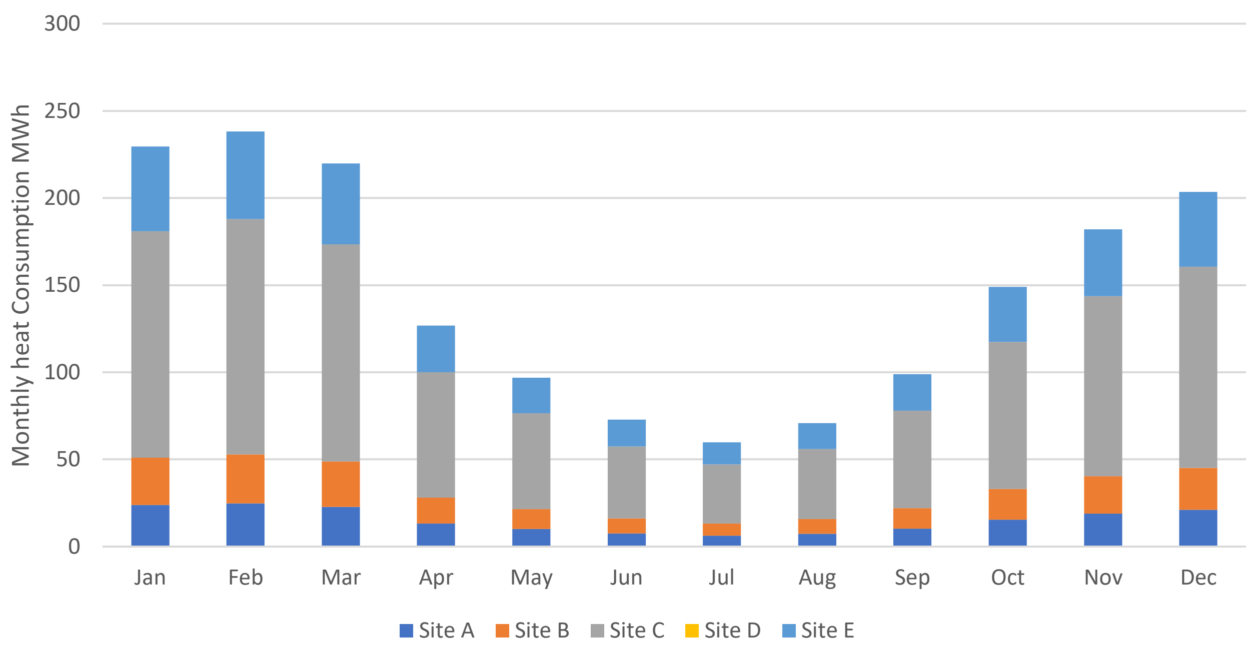


Figure 26: The monthly heat demand profile of the site phases for Proposition 2

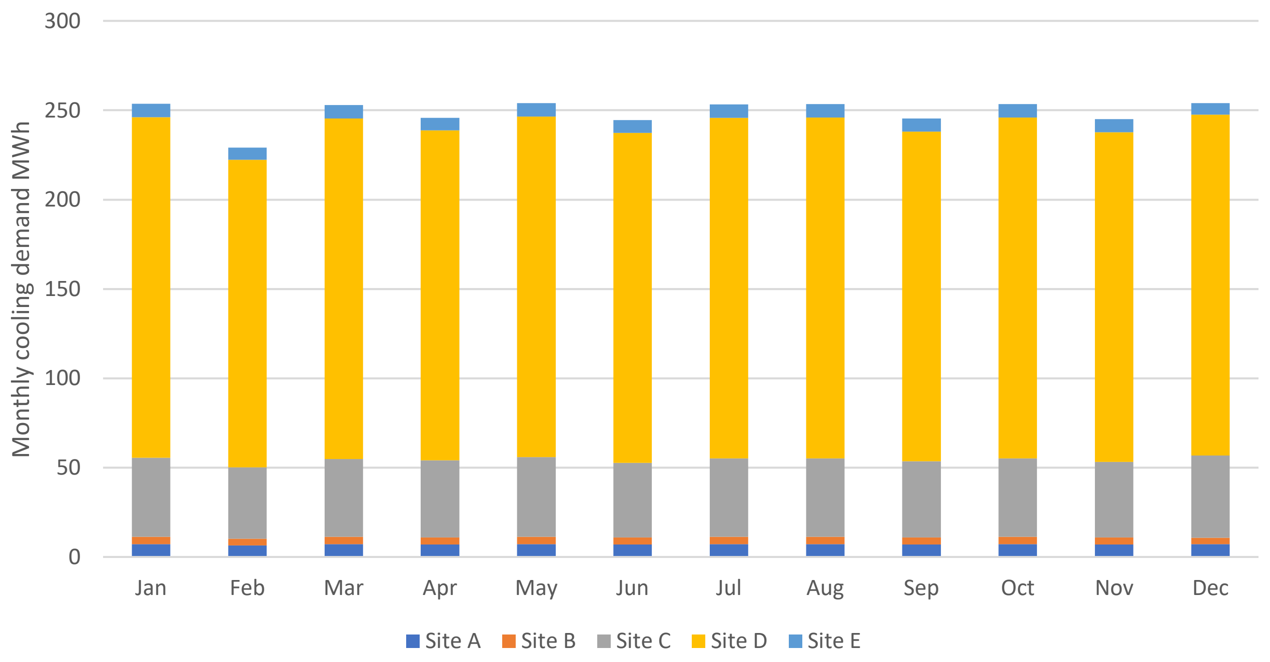


Figure 27: The monthly cooling demand profile of the site phases for Proposition 2

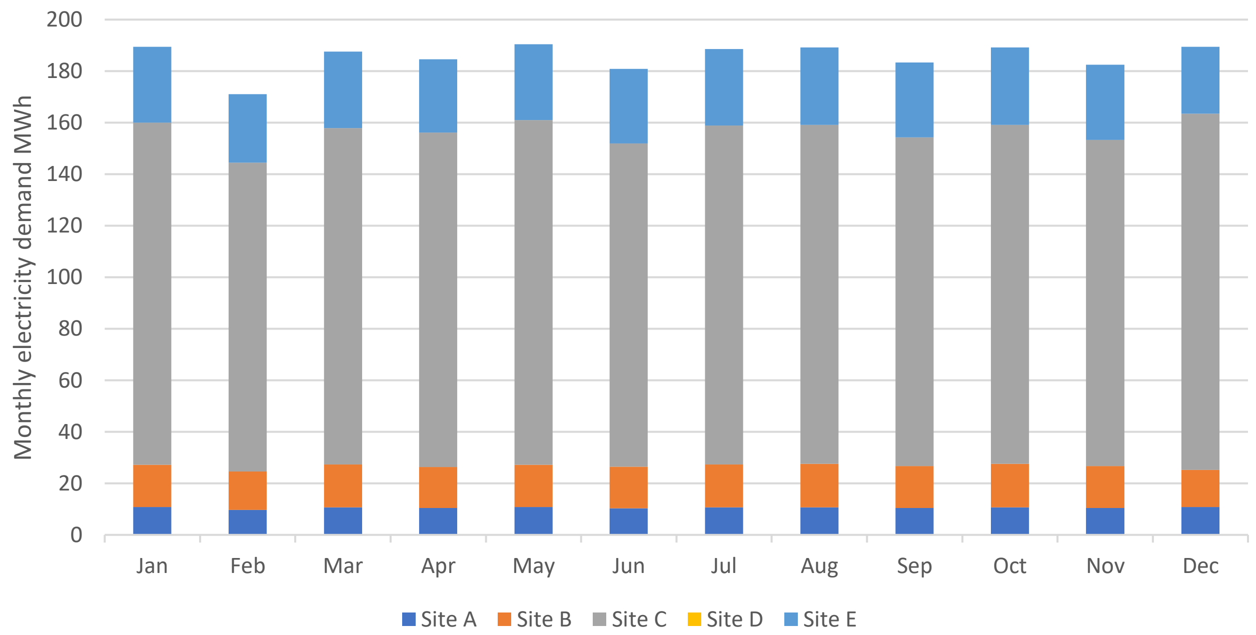


Figure 28: The monthly electricity demand profile of the site phases for Proposition 2

# 7. Data gathering and energy demand data profiling

*Pembrokeshire Food Park SLES*

### iii. Proposition 2 - The Pembrokeshire Food Park SLES (continued)

Daily demand profiles

The average hourly heating, cooling and electrical consumption is given in Figure 29, Figure 30 and Figure 31 respectively.

The heating demand profile for all sites follows a consistent profile where the heating demand was reduced in the morning hours after sunrise due to solar gain. The heating demand for site C, the development plots for complementary food use or catering, had the highest gas consumption per floor area and therefore showed the highest demand.

We have assumed that 100% of the electrical load for Site D, the cold storage facility, is attributed to cooling and that it is a constant 24-hour load throughout the year. The cooling load for the other sites was a subset of the electrical load and generally only increased during the operational hours of the facilities. Site C, the development plots for complementary food use or catering, has the highest electrical and cooling load. This is because we have assumed that the end use of food use and catering will include freezers and cold stores. This therefore showed a higher demand and shift towards the end of the day.

We would recommend refinement of this feasibility work with building thermal energy modelling in the next phases of development of this proposition.

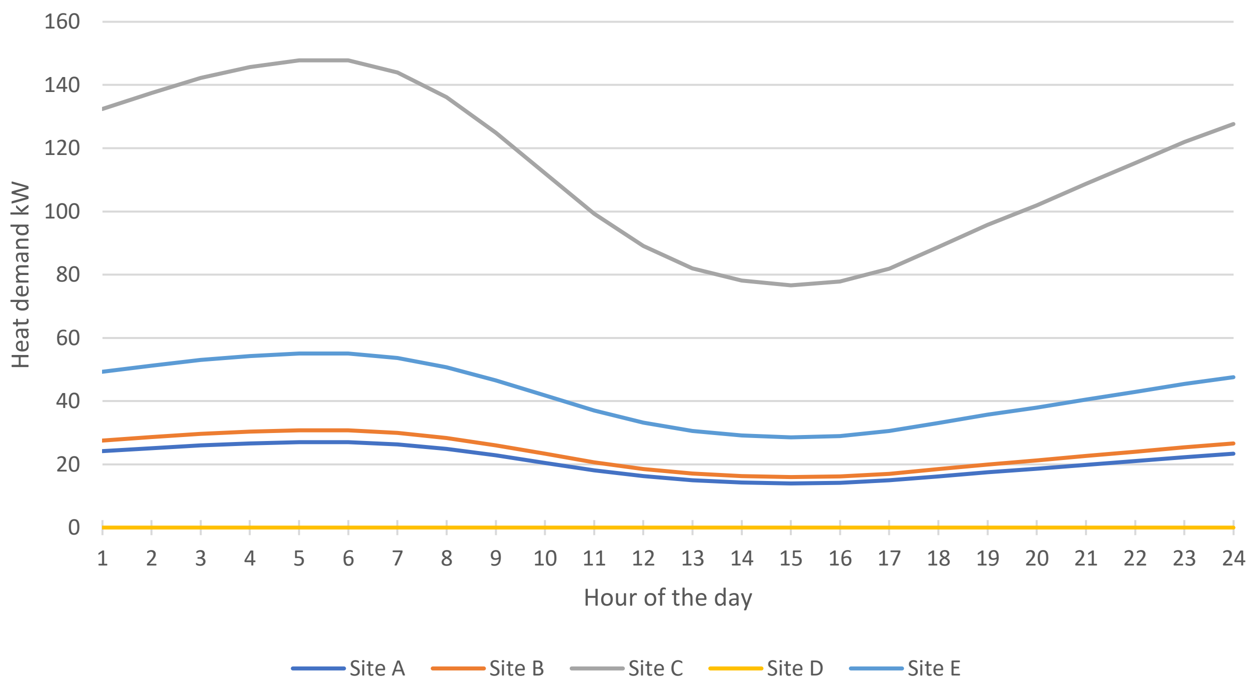


Figure 29: The average hourly heat demand profile of the site phases for Proposition 2

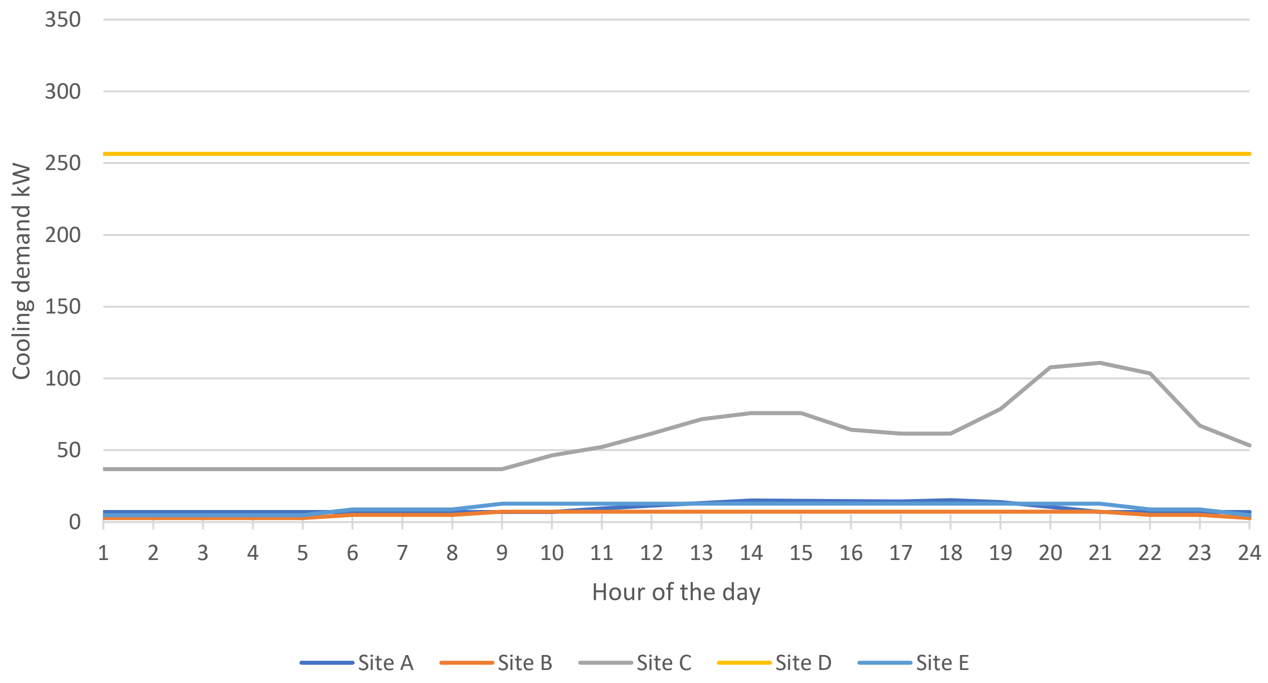


Figure 30: The average hourly cooling demand profile of the site phases for Proposition 2

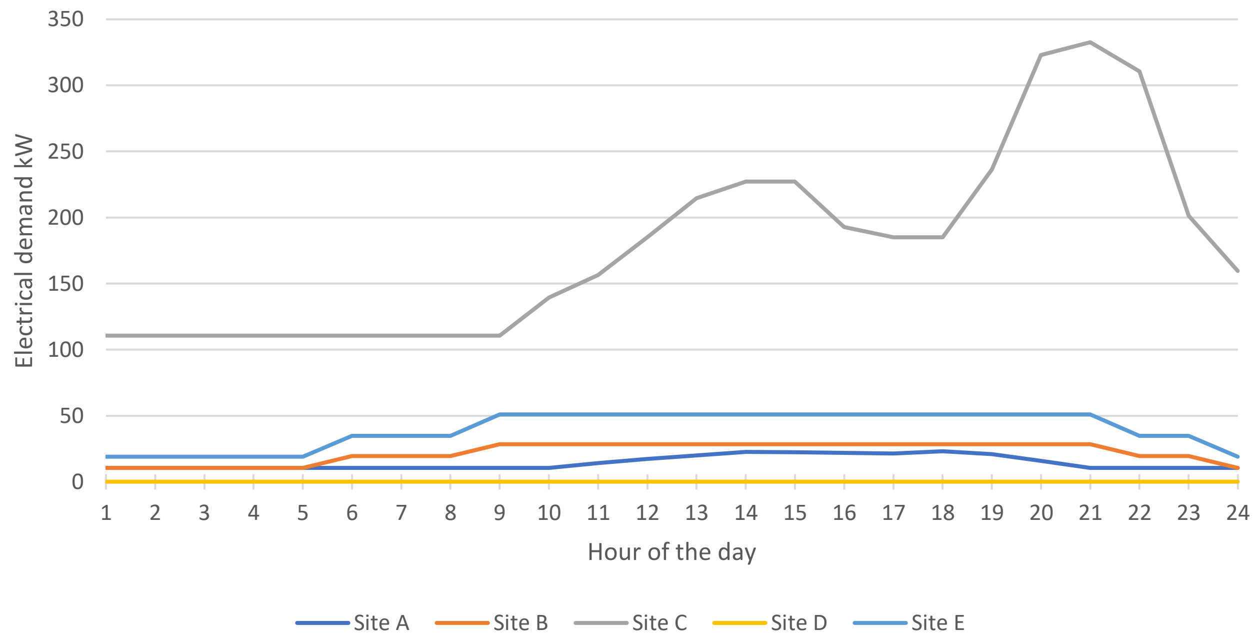


Figure 31: The average hourly electricity demand profile of the site phases for Proposition 2

# 7. Data gathering and energy demand data profiling

*Pembroke Schools, Leisure Centre and Dock SLES*

### iv. Proposition 3 - The Pembroke Schools, Leisure Centre and Dock SLES

For Proposition 3 - the Pembroke Schools, Leisure Centre and Dock SLES, we have taken electrical demand data from half hourly meter readings for each building provided by PCC.

Half hourly gas consumption meter data for the leisure centre and the Pembroke Dock community school was available, but only monthly metered data was available for Ysgol Harri Tudor. We applied and scaled the consumption profile for Pembroke Dock community school to the annual energy consumption of Ysgol Harri Tudor to give the heat profiles for the analysis. We applied an assumed efficiency of 90% to convert from gas demand to heat demand.

Transport demand included both the core transport demand detailed under Proposition 1 along with the energy demand for surface transport at Pembroke Dock as provided by PoMH.

We have taken supply capacities of existing local renewable assets from the BEIS Renewable Energy Planning Database *[21]*. We assumed energy could be directly purchased from these local assets. In addition, adjacent empty spaces were considered as potential sites for additional solar PV. We applied area to capacity ratios from Liddeston Ridge to estimate the site capacity. We then applied the solar generation profile of Liddeston Ridge to any solar assets in Proposition 3.

The energy demands from Proposition 3 (the Pembroke schools, leisure centre and dock SLES) all came from metered energy data from 2019 to 2020. This does not account for any behind the meter characteristics and generation. The metered data has been taken at face value.

#### Monthly demand profiles

The monthly heating and electrical demand profiles are given in Figure 32 and Figure 33 respectively.

Heat demand was taken from recorded meter data, which demonstrates the influence of school holidays on the profile of the schools. As was expected, there is a steady baseload from the leisure centre.

The electrical demand was more variable than those shown in Proposition 1 and 2. The effect of school holidays was also clear in the electrical data, as shown by the dips in July and August.

Cooling energy demand is expected to be minimal across Proposition 3 and would likely be captured within the electrical demand. This may be the reason for an increased electricity demand from the leisure centre in the summer months.

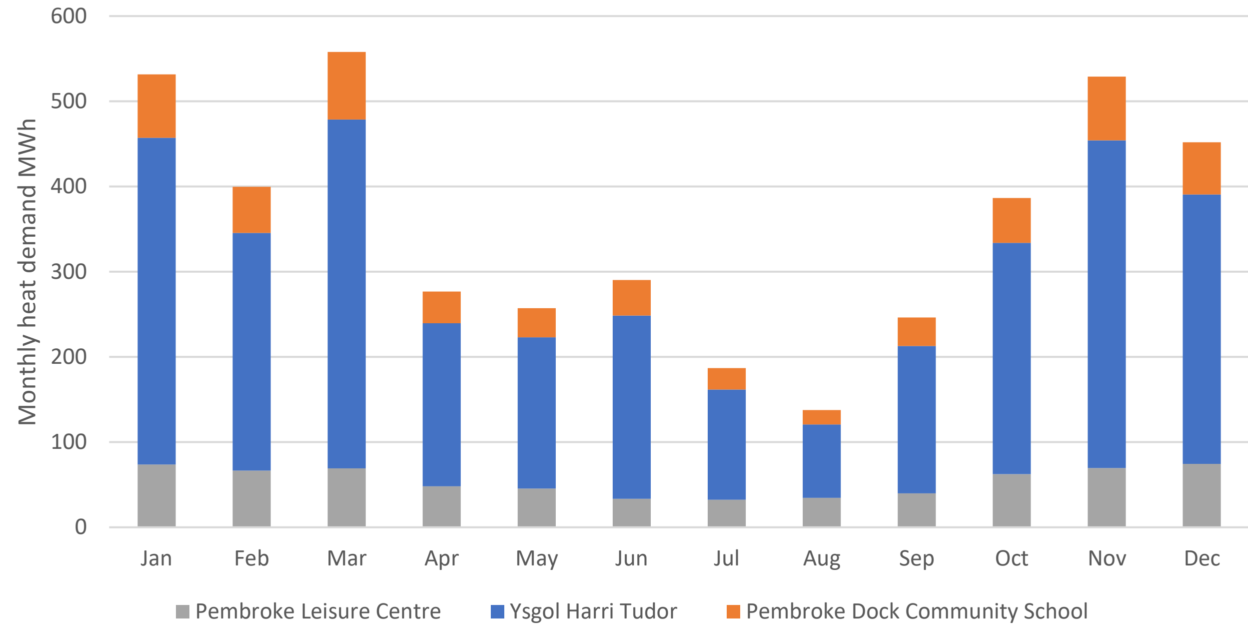


Figure 32: The monthly heat demand profile of the site phases for Proposition 2

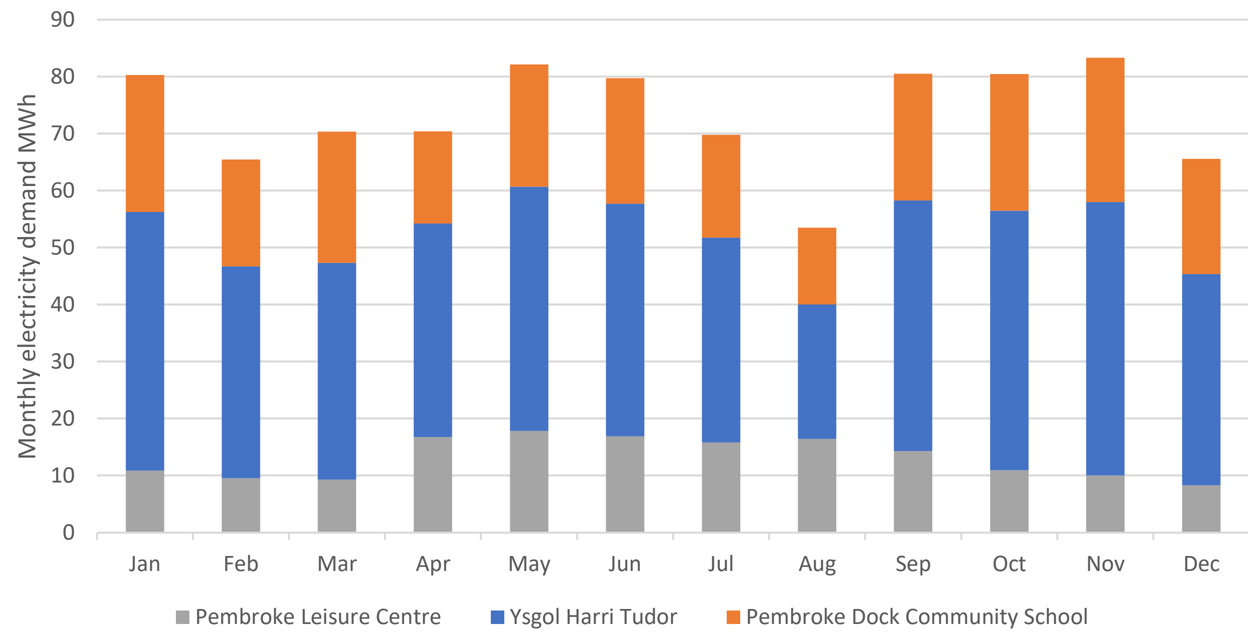


Figure 33: The monthly electricity demand profile of the site phases for Proposition 2

# 7. Data gathering and energy demand data profiling

*Pembroke Schools, Leisure Centre and Dock SLES*

### iv. Proposition 3 - The Pembroke Schools, Leisure Centre and Dock SLES (continued)

Daily demand profiles

The average hourly heating and electrical consumption is given in Figure 34 and Figure 35 respectively.

The Pembroke Dock community school meter data showed an unexpectedly early gas consumption to get the building up to target temperature and then the heating system turns off around 4pm. This profile was also applied to Ysgol Harri Tudor due to an absence of half hourly metered data.

We recommend that Pembroke Dock community school further investigates the reasons for the early morning peak in heat demand, and if insulation measures could improve building energy performance.

Electrical demand showed a more expected profile with peak electrical consumption across the school hours. The leisure centre electrical demand peaks over a longer period.

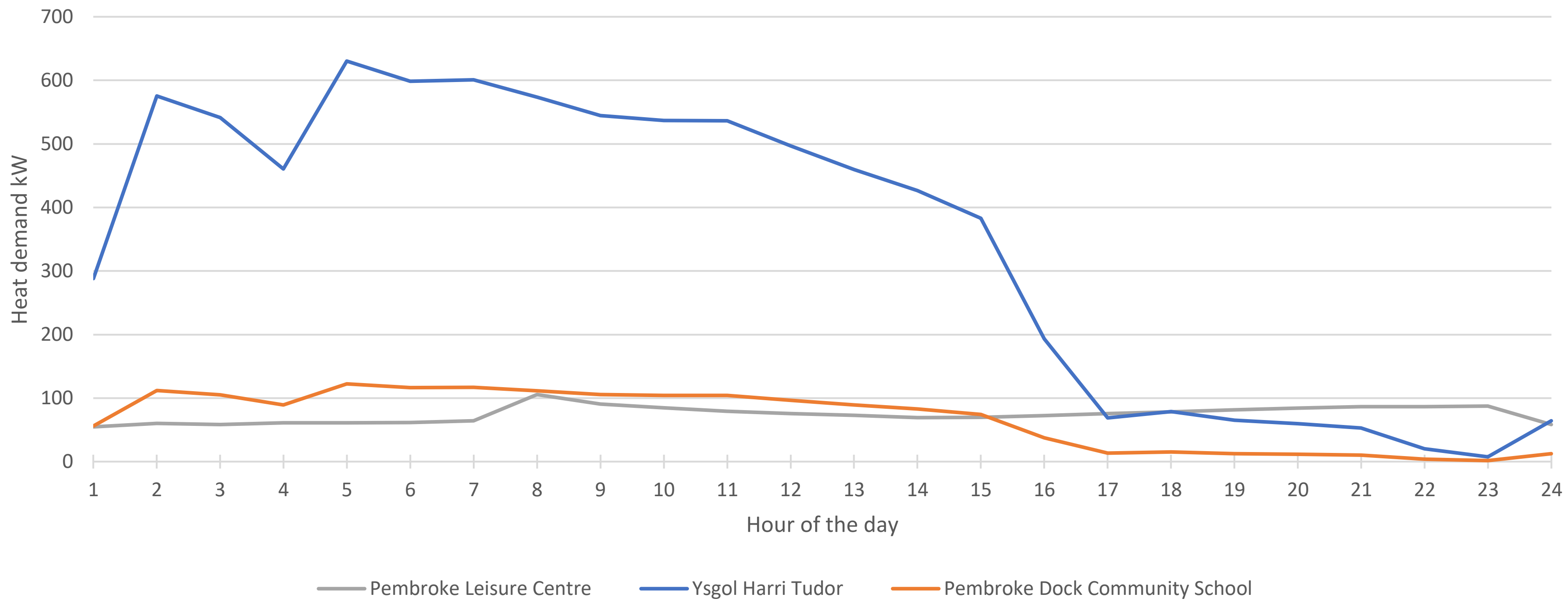


Figure 34 The average hourly heat demand profile of the site phases for Proposition 2

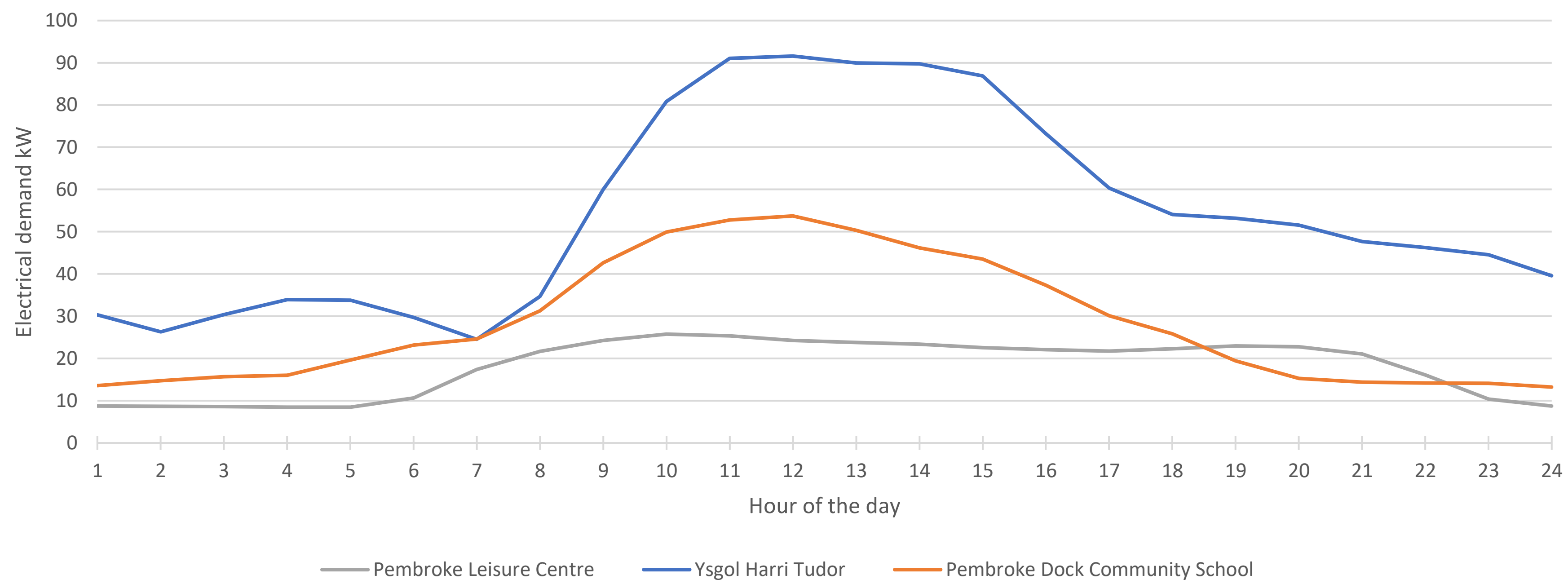


Figure 35: The average hourly electricity demand profile of the site phases for Proposition 2

# 7. Data gathering and energy demand data profiling

### iv. Transport demand profiles

We gathered the number and annual mileage of cars, vans, buses and HGVs within each proposition from a range of stakeholders (a summary of vehicle type per proposition is shown in Table 9). We then conducted research to understand the miles to energy consumption relationship for each vehicle type for both electric and hydrogen vehicles. Assumptions for hydrogen car kilowatts per mile were verified against test data provided by Riversimple for their Rasa vehicles. Combining the data allowed us to generate an annual energy demand per vector for each proposition and scenario as shown in Table 10.

Our assumptions for the scenarios are set out as follows:

- For the **high electric** and **electric counterfactual** scenarios - all the vehicles were assumed to be electric.
- For the **hybrid** scenarios, cars and existing electric vans were assumed to be electric while other vans, buses and HGVs were assumed to be hydrogen.
- For the **high hydrogen** and **hydrogen counterfactual** scenarios**,** all the vehicles were assumed to be hydrogen.

We applied an Arup standard electric or hydrogen transport profiles to each demand. Figure 36 and 37 overleaf present an example of the resulting transport demand profiles for Proposition 1 (The Milford Haven Marina SLES ), both in a daily and monthly format. Transport demands are relatively constant throughout the year with a slight dip in summer-time. In the hybrid scenarios, electric transport demand is significantly lower than hydrogen due to the lower energy demands of light vehicles. Over the course of a day, electric charging peaks in the morning to early evening. Meanwhile, the hydrogen transport demand is constant over time due to the assumed availability of hydrogen storage.

The transport profiles for Proposition 2 (the Pembrokeshire Food Park SLES) and Proposition 3 (The Pembroke Schools, Leisure Centre and Dock SLES) followed similar profiles.

| Phase | Proposition 1 - The Milford Haven Marina SLES | Proposition 2 - The Pembrokeshire Food Park SLES | Proposition 3 - The Pembroke Schools, Leisure Centre and Dock SLES | Average annual mileage per vehicle (miles/year) |
|---|---|---|---|---|
| Number of cars | 120 | 472 | 60 | 2,230 |
| Number of vans | 786 | 396 | 384 | 4,410 |
| Number of buses | 16 | 8 | 8 | 41,900 |
| Number of HGVs | 282 | 179 | 141 | 8,470 |
| Additional transport load – Pembroke Dock (MWh/year diesel equivalent) | | | 845 | |

Table 9: Summary of vehicle types and numbers assumed for the transport demand per proposition

| Scenario | Component | Proposition 1 - The Milford Haven Marina SLES (MWh/year) | Proposition 2 - The Pembrokeshire Food Park SLES (MWh/year) | Proposition 3 - The Pembroke Schools, Leisure Centre and Dock SLES (MWh/year) |
|---|---|---|---|---|
| High electric / electric counterfactuals | Electric transport demand | 11,000 | 11,000 | 5,800 |
| Hybrid | Electric transport demand | 100 | 900 | 300 |
| Hybrid | Hydrogen transport demand | 10,100 | 9,000 | 5,100 |
| High hydrogen / hydrogen counterfactuals | Hydrogen transport demand | 10,200 | 9,300 | 5,400 |

Table 10: Annual energy (transport) demand per proposition

Data gathering & review | Energy infrastructure map | Proposition longlist | Multi criteria assessment | Key stakeholder review | Proposition shortlist | Techno-economic modelling | **Targeted data gathering & energy demand data profiling** | Scenarios, assumptions, & technologies | Techno-economic modelling optimisation | Proposition preferred system

# 7. Data gathering and energy demand data profiling

*Milford Haven Marina SLES*

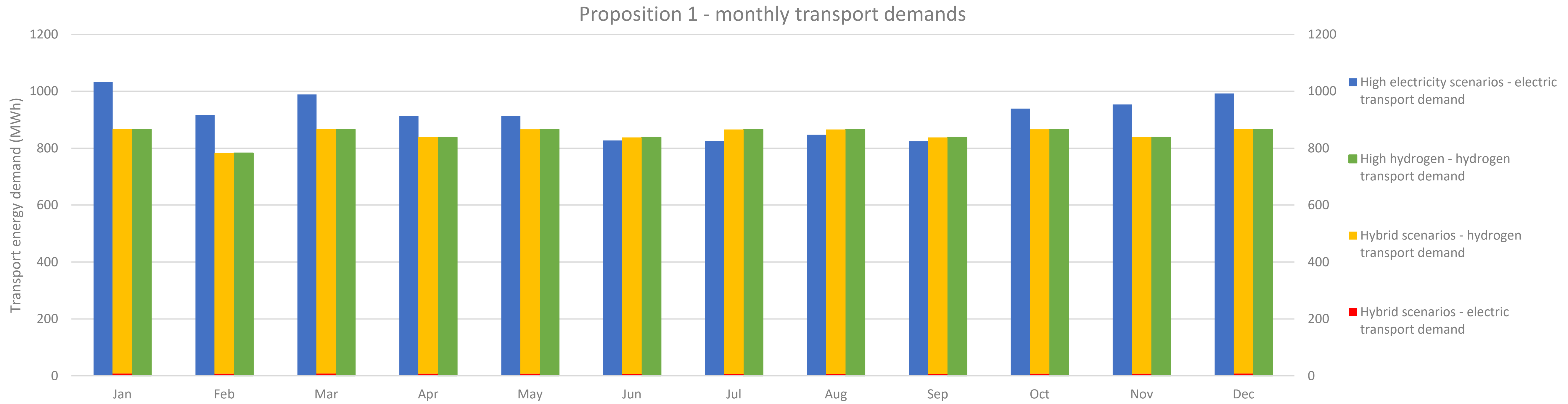


Figure 36: The monthly transport demand for proposition 1.

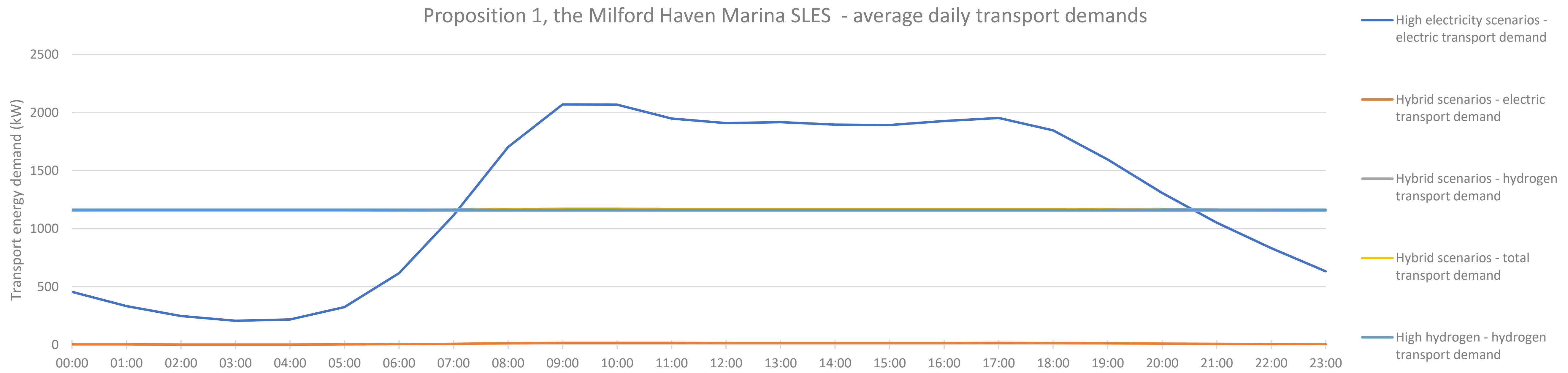


Figure 37: The average daily transport demand for proposition 1.

MILFORD HAVEN: ENERGY KINGDOM

# Techno-economic model set-up

## Building the model and key assumptions

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# 8. Techno-economic model set up

## i. Introduction to the techno-economic model set-up

### Technological options

Technological options to supply energy to the demand assets across heat, electricity and hydrogen generation out to 2050 were established based on a high-level screening process.

We carried out a first screening to qualitatively assess each technology against six key performance indicators (KPIs):

- Whole lifecycle costs
- Technology maturity
- Ability to meet demand
- Spatial and access requirements
- Carbon emissions
- Local environmental impact.

This first screening also considered if the deployment of the technology would be consistent with Pembrokeshire County Council's goal of net zero by 2030 *[4].* This screened out all technologies reliant on fossil fuels, SMR hydrogen without CCS, as well as biomass.

We undertook a high-level resource assessment for each technology to estimate how much heat and electricity can be generated from each technology within each proposition, considering the associated site constraints and opportunities. This enabled discounting of technologies with low resource availability and allowed an understanding of the contribution that could be made from each of the shortlisted technologies.

### Scenarios

The 'world views' or scenarios used in the modelling analysis are consistent across all the propositions and are based on our review of industry publications including the National Grid Future Energy Scenarios 2020 (FES) *[19]* and the Regen Net Zero South Wales 2050 (Regen) *[20]* studies.

Comparing industry future energy scenario work, we complied a long list of potential energy system scenarios for the Milford Haven boundary considering different levels of electricity and hydrogen within the energy system. We matched each of our identified scenarios against the most relevant FES and Regen scenarios. We then selected three scenarios to use for analysis to best represent the technologies that could be included within the SLES and the external energy system across two-time horizons – 2020 and 2050. A summary of the future energy scenarios publications reviewed is provided in Appendix A.

The three **future** decentralised energy scenarios:

- **High electricity:** electric heating technologies are prioritised, and any hydrogen heating is excluded. All vehicles are electric.
- **Hybrid:** the system optimises the technology mix to meet energy demands with a range of vectors and technologies. The transport component assumes all cars are electric along with existing hydrogen vans and all other vehicles are hydrogen.
- **High hydrogen:** electric heating options are excluded, and hydrogen prioritised. All vehicles are hydrogen powered.

The scenarios modelled also consisted of two **counterfactual** systems simulating 'business as usual' scenarios:

- **Counterfactual electric:** it is assumed that heating is provided by gas boilers until 2035 after which electric heating is then available in all buildings. All transportation is assumed to be electric.
- **Counterfactual hydrogen:** heating from hydrogen boilers is installed in 2030. All transport is assumed to be hydrogen powered.

We used the scenarios definition and assumptions to undertake a further screening of the technologies resulting in a shortlist of technologies to be modelled as shown on Figure 38 overleaf.

Using gathered cost data and findings from stakeholder engagement with network operators, we added whole life cost information to the technologies, existing and predicted fuel costs and network operational costs to the database as further discussed in the next sections.

Using Arup's suite of whole system energy modelling (WSEM) tools, we optimised the energy supply and storage capacities based on the cost and carbon emissions objectives for each scenario.

This allows a structured and comprehensive modelling of the monetary, technical, and environmental characteristics of each technology and system. Depending on the specific context of each proposition and scenario, the appropriate technologies and settings were applied.

The tool can find optimal solutions while considering spatial and temporal constraints.

# 8. Techno-economic model set up

Figure 38 shows the full range of modelled technologies that resulted from the technology shortlisting methodology. In addition, these are broken down into broad modelling categories or supply, storage, conversion, export, transmission and demand. The left colour indicates the input energy vector, the right colour indicates the output energy vector(s).


Figure 38: Complete list of available technologies across propositions highlighting their input and output energy vectors

# 8. Techno-economic model set up

## ii. Cost attribution and assumptions

To model the costs of different technologies or distribution, we viewed each proposition from the lens of the project 'anchor' or driving organisation.

The anchor is the party with the motivation to establish successful projects and who takes responsibility for driving delivery. In terms of cost, the anchor would most likely be responsible for identifying funding options, attracting developers, investors, operators and customers.

Note that the commercial modelling and definition of roles is covered in the Commercial Case section in the 'MH:EK strategic outline case for a smart local energy system' report *[28]*.

Table 11 summarises the cost attribution assumptions made for each of the propositions.

### Network distribution

We assumed that national level costs such as grid or gas network upgrades are covered by network distributors. Only the cost of the technologies required to implement the proposition at the local scale are assumed to be paid for by the anchor to enable more accurate cost attribution to modelling of the propositions.

Based on engagement with WPD we assumed that in the current context and for the purposes of modelling that the external network was unconstrained, and the model could choose to import and export any amount of hydrogen and electricity. The exception was Proposition 1 (The Milford Haven Marina SLES) which had historical data for their export curtailment and we applied this to the model.

The network in Pembrokeshire is at a tipping point of requiring implementation of the ANM system. Any future developments could result in requirements for electricity network upgrades which present a wider system cost and could also result in some of these costs being passed to any developer. These potential infrastructure costs are not accounted for in the modelling of the propositions.

| Scenario | Distribution and infrastructure assumptions |
|---|---|
| Hydrogen distribution | No cost to upgrade the gas network to hydrogen as it is assumed that this will fall to WWU.<br>Hydrogen import prices are based on a quoted local supplier price. |
| Electric distribution | An electrical connection sufficient to meet site electricity load is assumed and no upgrade costs have been accounted for, this is assumed to be within the remit of WPD.<br>In cases where there are private wire connections between renewable resources and consumers, a per kW infrastructure cost has been included based on the Services and Infrastructure Masterplanning MHPA *[8]*.<br>In Proposition 1, scenarios with a virtual PPA have been modelled. This assumes the existing electrical infrastructure could be used to transmit renewable generation to consumers by paying a transmission fee. This is based on the Potential benefits of an Energy Local Cluster at Milford Haven Port report *[7]* |
| Heat distribution | Any capital costs associated with installing any heating distribution pipework will fall to the proposition anchor and is included within the modelling. |
| Cooling distribution | Proposition 2 allows the selection of a district cooling network. Any capital costs associated with installing this will fall to the proposition anchor and is included within the modelling. A discounted rate is applied if heating and cooling pipework is laid as it is assumed they will share a trench. |
| Gas distribution | All gas distribution costs are covered by WWU: we have assumed sufficient distribution to meet site heat demand. |
| EV charging infrastructure | No EV charging infrastructure costs are included in the model as assumed already installed. |
| Hydrogen refueller | No hydrogen refueller costs are included in the model as it is assumed this would be owned and operated by a commercial partner. This enabled comparison to the same boundary as electric scenarios. This should be reviewed at each development stage if the propositions are taken forward as in reality hydrogen refueller costs may be within the ownership and remit of the anchor. |

Table 11: Summary of the cost attribution assumptions made for each of the propositions.

# 8. Techno-economic model set up

### iii. Other modelling assumptions

Fuel price

Fuel costs were modelled on a per proposition basis and vary depending on the modelled year. We applied a similar hierarchical approach to estimating building energy consumption to derive the fuel costs.

1. Where real data was available from proposition anchors or relevant parties, this was applied.
2. In the absence of real data, we used industry standard benchmarked figures from parties such as BEIS.
3. Where standard information was not available, we calculated forecast energy prices using the Energy market simulation tool, *PLEXOS*. *PLEXOS* is a national-scale model that completes a dispatch simulation with a 30-year time horizon to forecast the future wholesale cost of energy. Its key inputs include energy capacity mixes from the FES 2020 Leading the Way scenario, commodity prices including $CO_2$, forecast energy demand, and techno-economic parameters of generation technologies.
4. Where only wholesale prices were available, the import cost was multiplied by a factor of 2.4 to represent the expected retail price for the end consumer. The reverse operation was completed to determine export prices where only retail prices were available.

| Proposition | Time-horizon | | Fuel costs (£/kWh) | | | |
|---|---|---|---|---|---|---|
| | | | Electricity import | Electricity export | Hydrogen import | Hydrogen export |
| Proposition 1 - The Milford Haven Marina SLES* | 2020 | *Fuel costs assumed* | 0.26 | -0.10 | 0.135 | -0.079 |
| | 2020 | *Source* | PoMH | PoMH | Local supplier quote | PoMH |
| Proposition 2 - The Pembrokeshire Food Park SLES AND Proposition 3 - The Pembroke Schools, Leisure Centre and Dock SLES | 2020 | *Fuel costs assumed* | 0.137 | -0.051 | 0.135 | -0.055 |
| | 2020 | *Source* | BEIS | PLEXOS average | Local supplier quote | Local supplier cost adjusted to wholesale price |
| | 2050 | *Fuel costs assumed* | 0.143 | -0.053 | 0.146 | -0.06 |
| | 2050 | *Source* | EU reference scenario | PLEXOS average | PLEXOS adjust to retail price | PLEXOS average |

Table 12: Summary of the fuel costs assumed in the model and the source of the information.

*Proposition 1 final modelling was undertaken in detail for a 2020 world view only. This is further explained in the following section.

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# Techno-economic modelling results

## Proposition outputs and recommendations

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# 9. Techno-economic modelling results

### i. Overview of the shortlisted propositions


Figure 39: Map overview of the Milford Haven Marina and Liddeston Ridge site and the proposition boundary.

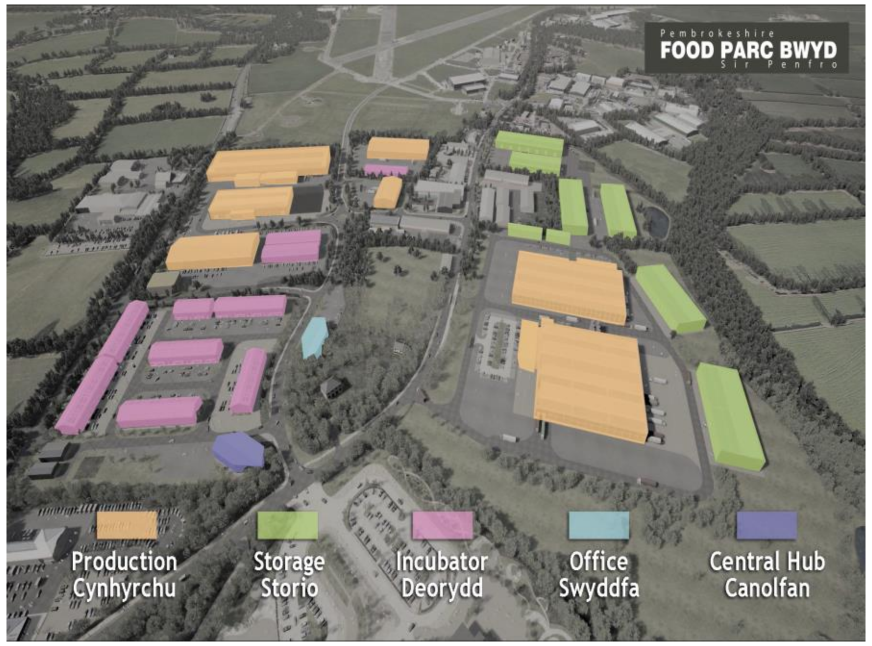


Figure 40: Visualisation of the proposed Pembrokeshire food park (©hacerdevelopments.com)


Figure 41: Pembroke Ysgol Harri Tudor School (© ysgolharritudur.cymru)

**Proposition 1 – The Milford Haven Marina SLES**

Proposition 1 focuses on the feasibility of developing a heat network and microgrid for the Milford Haven marina by forming a SLES incorporating the demand and supply assets owned by PoMH and the PCC and POMH transport demand, which has been doubled to allow for potential future to account for public use of charging / refuelling infrastructure.

**Proposition 2 – The Pembrokeshire Food Park SLES**

Proposition 2 focuses on the feasibility of using electricity from the nearby airfield PV to power the proposed Pembrokeshire Food Park operations as well as freight and other transport demand.

**Proposition 3 – The Pembroke Schools, Leisure Centre and Dock SLES**

Proposition 3 focuses on the feasibility of meeting the existing and future heat and power demand of existing PCC owned school and leisure assets as well as the PCC and POMH transport demand.

# Proposition 1 – The Milford Haven Marina SLES

## Proposition outputs and recommendations

*Milford Haven Marina SLES*

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# 9. Techno-economic modelling results

*Milford Haven Marina SLES*

## ii. Techno-economic modelling results – Proposition 1, The Milford Haven Marina SLES

Figure 42 shows the list of technologies that were included in the optimisation modelling for Proposition 1 as well as their input and output vectors.


Figure 42: List of technologies modelled in Proposition 1 and their input and output energy vectors

# 9. Techno-economic modelling results

*Milford Haven Marina SLES*

### ii. Techno-economic modelling results – Proposition 1, The Milford Haven Marina SLES (continued)

Optimisation outcomes

The modelling of Proposition 1 was conducted in two stages. The first phase adopted the same general methodology outlined in section 6 with high electric, high hydrogen and hybrid scenarios in 2020 and 2050.

The first phase of modelling demonstrated the general feasibility of Proposition 1 and raised further questions for the Port (PoMH) that required a more detailed level of analysis.

Following this initial phase, an additional second phase analysis was commissioned focusing on more immediate options based on the specific context of the Port's (PoMH) infrastructure assets and therefore, all scenarios were run taking a 2020 'world view'.

This modelling aimed to answer the following questions:

1. *What are the best opportunities for expanding Liddeston Ridge solar farm comparing no expansion; solar expansion and onshore wind expansion?*
2. *What is the best approach for sale of electricity from Liddeston Ridge (i.e. physical PPA, virtual PPA to the Port owned properties, virtual PPA agreement or sale to grid)?*
3. *What is the impact of grid curtailment on the optimised system?*
4. *What are the impacts on the remainder of the energy system (heating and hydrogen)?*

To answer the phase 2 questions, a series of technology scenarios and sensitivities were modelled. The output from the technology scenarios is shown in Figure 43 clearly indicating the benefit of 'Do Something' over business-as-usual and with addition of new onshore wind capacity at Liddeston Ridge shown to be favourable.

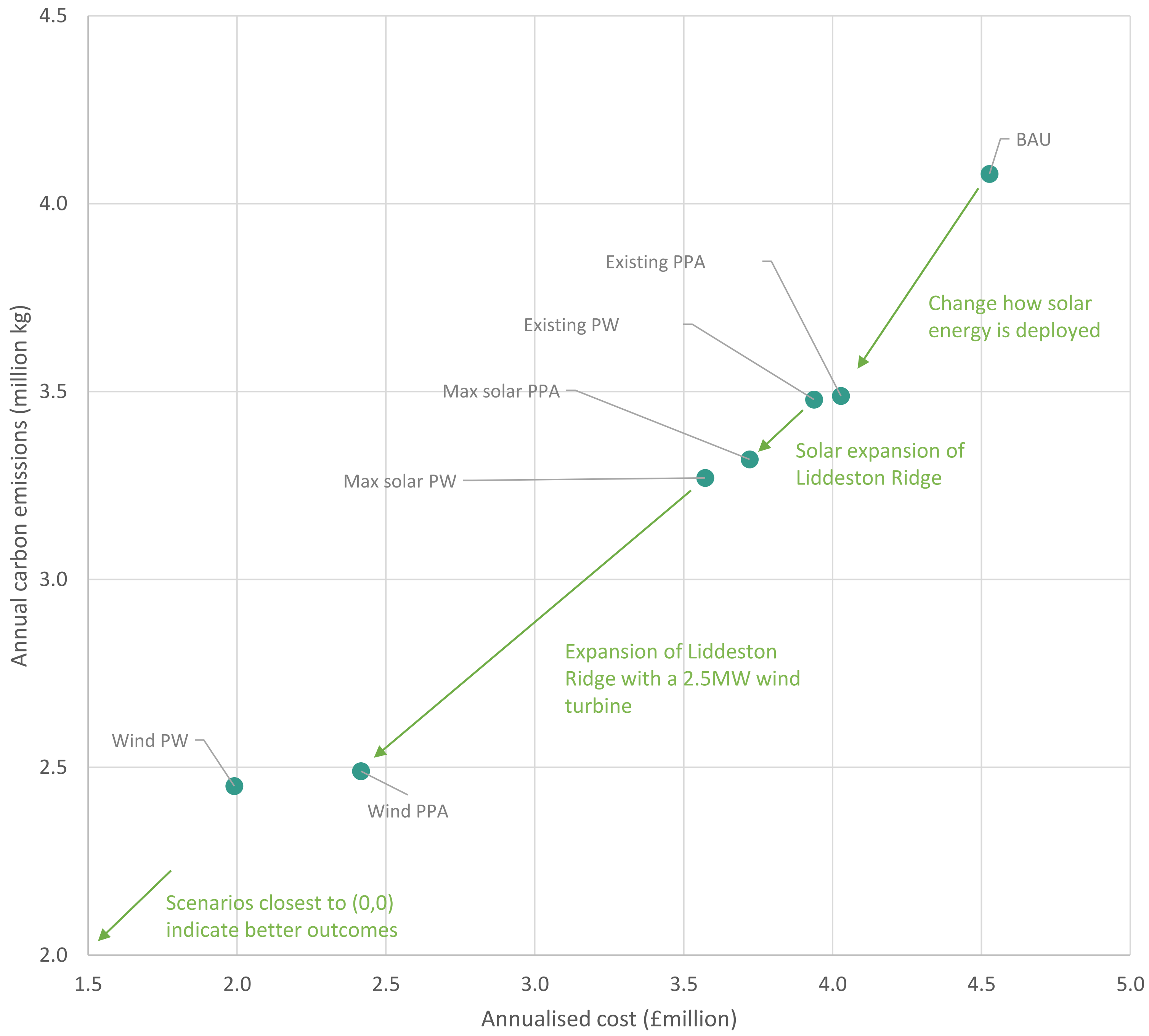


Figure 43: Annualised cost vs annual carbon emissions of the phase two options for proposition 1 (PW - Private Wire, PPA – Power Purchase Agreement, BAU - Business As Usual)

# 9. Techno-economic modelling results

*Milford Haven Marina SLES*

## ii. Techno-economic modelling results – Proposition 1, The Milford Haven Marina SLES (continued)

Figure 44 shows the annual energy flows in the form of a Sankey diagram of the optimal solution for the preferred phase 2 scenario, wind expansion with a private wire.

### No regrets

It was optimal to increase the renewable capacity adjacent to the existing solar farm at Liddeston Ridge. The 2.5MW wind turbine is preferable to solar expansion, despite the wind turbine having a lower capacity, the higher resource availability resulted in higher annual electricity generation. Installing a wind turbine could present planning permission challenges due to visual constraints compared to solar. Solar should be considered as the second preferred option with BAU being the least preferred option.

Even with no additional renewable capacity, it would be beneficial to build a private wire or strike a virtual PPA to consume the generated electricity locally and minimise expensive imports from the electricity grid. This assumed that the waterfront properties agreed to purchase renewable electricity, presumably at a lower cost than their current supply. This could be mutually beneficial because the port could receive a higher price than they would for external electricity export, whilst providing a long-term favourable price to the local community compared to electricity market price.

### Heating and cooling

Our starting premise for Proposition 1 was that the heat demand could be met by the existing gas infrastructure and existing gas boilers. These were modelled as having no capital cost and when coupled with the low gas prices, gas remained the most cost-effective form of heating. The heating system remained unintegrated with the electrical system with the exception of a small resistance heating capacity.

We further modelled sensitivities around the import prices and the exclusion of natural gas from the system. This is outlined in greater detail in section 9/v.

### Hydrogen

The optimised system for Proposition 1 had a very small quantity of electrolysed hydrogen. Most of the hydrogen transport demand is met by direct hydrogen imports. This was due to the highly favourable electricity export price of £0.10/kWh. In this situation, it was economically advantageous to export electricity, rather than convert to hydrogen. Hydrogen viability is highly sensitive to the interplay between electricity import and export cost, and hydrogen import costs.

### Batteries

Batteries are included with relatively modest capacities in all scenarios. Batteries were selected at greater capacities in solar scenarios compared to wind. Batteries had larger capacities when using a private wire compared to a virtual PPA. The inclusion of batteries enabled a greater level of self-consumption of electricity and hence reduces the cost of electricity imports.

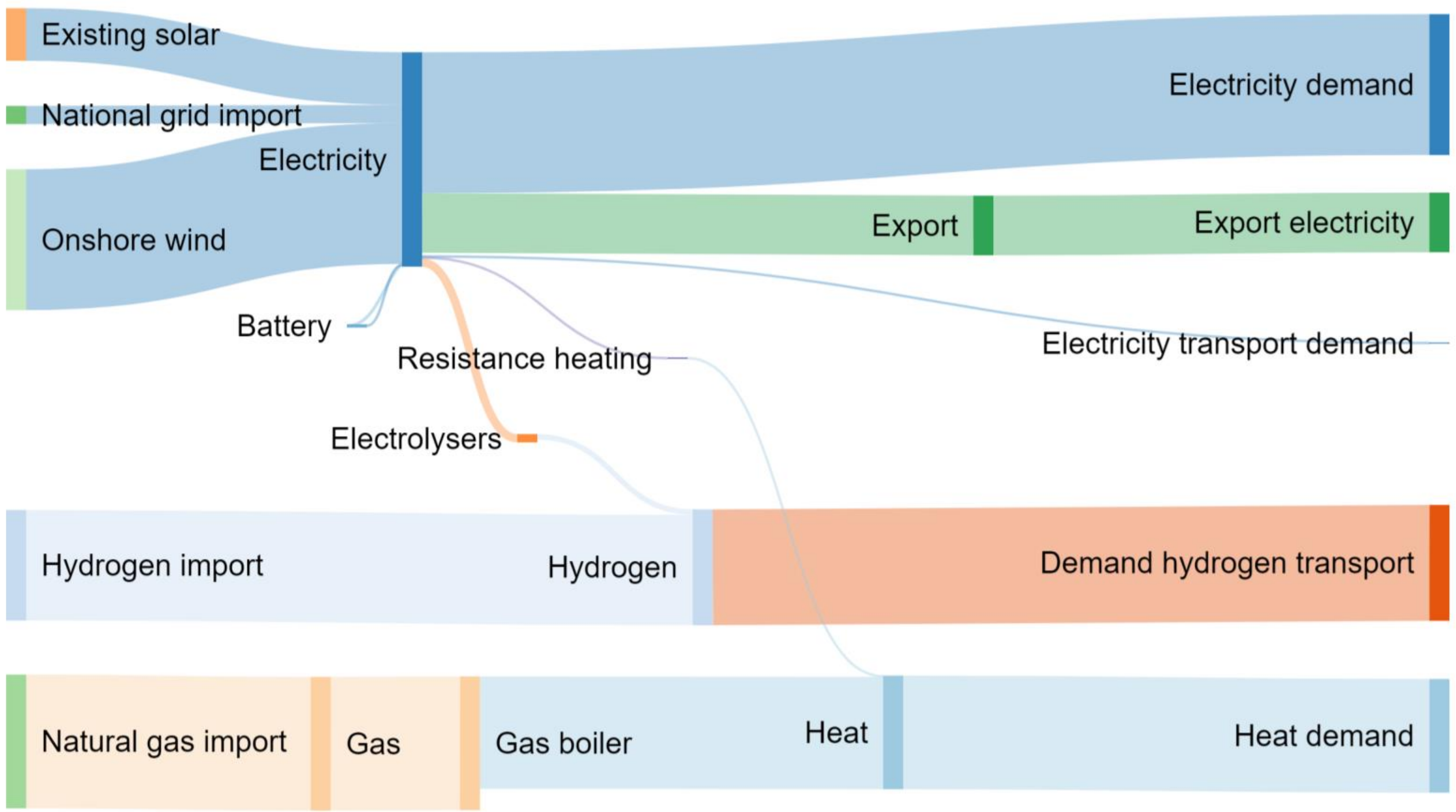


Figure 44: Example Sankey diagram of the optimised system with wind turbine expansion and a private wire. Sankey diagrams show the annual energy flows between generation sources on the left and final demands on the right.

# 9. Techno-economic modelling results

*Milford Haven Marina SLES*

### ii. Techno-economic modelling results – Proposition 1, The Milford Haven Marina SLES (continued)

#### Summary and proposition viability

Our analysis showed that further expansion of renewable assets with closer integration to the demand at the waterfront would be beneficial. Expanding Liddeston Ridge with a 2.5MW wind turbine and a private wire connection resulted in the lowest annualised cost and carbon emissions. This is emphasised by the LCOE shown for each scenario in Table 13. The inclusion of a wind turbine roughly halved the systemwide LCOE compared to a business-as-usual solution.

The preferred method of integrating waterfront demand with Liddeston Ridge supply is via a private wire. There were benefits from both a LCOE and $CO_2$ perspective as shown in Table 13. A private wire would cost an estimated £4.4m which accounts for most of the CAPEX in all private wire scenarios, this would pay for itself over the 40-year lifetime.

The annual benefit of the preferred scenario, wind expansion with private wire, against the business-as-usual scenario is estimated to be £2.8m which led to a simple payback of around 3 years. This would require private waterfront tenants to agree to be supplied by the Port's resources (or likely an ESCO operating on the Port's behalf). To encourage this, the cost of that supply would have to be competitive against existing external utility providers. Therefore, the estimated £2.8m annual benefit to the system is likely to be split between private tenants and the Port. Assuming a local electricity sale price of £0.18/kWh, annual revenue from this sale and external export would be approximately £1.8m.

There is limited use of local renewable electricity for heat or hydrogen in the current market. However, this is highly sensitive to future gas, electricity, and hydrogen prices. For future new developments, electrification of heating via air-source heat pumps would be preferable to hydrogen-based heating in these market conditions.

#### Risks, limitations and future work

Further investigations would be required in order to fully assess the feasibility of the preferred option and move to the development stage. This would be a two-part process of firstly investigating the feasibility of a private wire connection including operating costs and regulatory constraints; and secondly the feasibility of installing a wind turbine at Liddeston Ridge including technical feasibility, costs and planning risks.

If the commercial, legal and managerial challenges associated with a private wire would be too great to overcome, the virtual PPA option is shown to be highly preferrable to the business-as-usual operation. Similarly, if the development and planning risks associated with a wind turbine prove insurmountable, the second preference would be a 3.5MW solar PV expansion.

The recommended steps are explained in the decision-making flowchart shown in Appendix E. The flowchart aims to help the Port, the project anchor, understand the process to get to the most optimal 'Do Something' option.

| Scenario | CAPEX, without optimism bias (£million) | OPEX (£m/year) | $CO_2$ emissions (kg/kWh) | LCOE (£/kWh) |
|---|---|---|---|---|
| Business as usual | 0 | 4.510 | 0.126 | 0.140 |
| Existing renewables + PPA | 0 | 4.011 | 0.108 | 0.124 |
| Existing renewables + private wire | 4.45 | 3.809 | 0.107 | 0.121 |
| Maximum solar expansion + PPA | 2.27 | 3.618 | 0.102 | 0.115 |
| Maximum solar expansion + private wire | 7.24 | 3.314 | 0.101 | 0.110 |
| Wind expansion + PPA | 3.66 | 2.250 | 0.077 | 0.075 |
| Wind expansion + private wire | 8.12 | 1.704 | 0.076 | 0.061 |

Table 13: Summary of Key Performance Indicators (KPIs) across all Proposition 1 scenarios

# 9. Techno-economic modelling results

*Milford Haven Marina SLES*

### ii. Techno-economic modelling results – Proposition 1, The Milford Haven Marina SLES (continued)

Figure 45 shows a schematic of the preferred system for Proposition 1. The core recommended technologies are highlighted in light green and the supporting or situationally beneficial technologies to watch are highlighted in grey. Similarly, the preferred distribution option (e.g. private wire) is highlighted in light green and other options i.e PPA in grey.

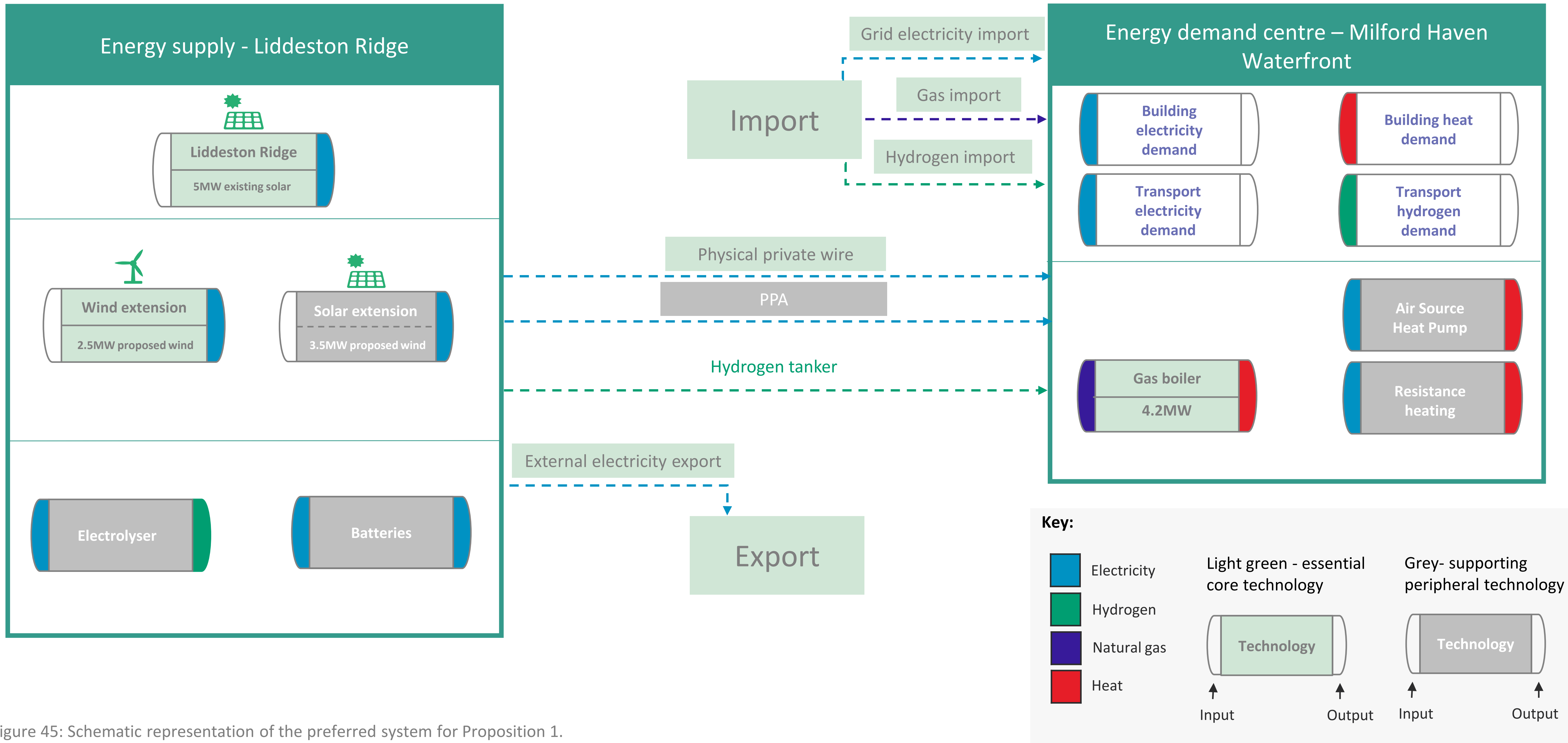


Figure 45: Schematic representation of the preferred system for Proposition 1.

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# Proposition 2 – The Pembrokeshire Food Park SLES

## Proposition outputs and recommendations

*Pembrokeshire Food Park SLES*

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# 9. Techno-economic modelling results

*Pembrokeshire Food Park SLES*

### iii. Techno-economic modelling results – Proposition 2, The Pembrokeshire food park SLES

Figure 46 shows the list of available technologies modelled in Proposition 2 as well as their input and output vectors.


Figure 46: List of technologies modelled in Proposition 2 and their input and output energy vectors

# 9. Techno-economic modelling results

*Pembrokeshire Food Park SLES*

### iii. Techno-economic modelling results – Proposition 2, The Pembrokeshire food park SLES (continued)

Optimisation outcomes

The annualised cost and carbon emissions of the optimised outcomes of the 2020 and 2050 scenarios are given in Figure 47. From this, we drew several high-level conclusions:

- When given more freedom to include additional technologies, the optimised solutions outperformed the more constrained counterfactuals. For example, high electric 2020 was preferable to electric counterfactual 2020 as it had greater flexibility to include technologies such as batteries and anaerobic digesters.
- The counterfactual scenarios being outperformed by their counterpart scenarios showed that designing the energy system in a more integrated way and including a wider range of technologies is beneficial compared to a business-as-usual approach.
- Electricity-based solutions tended to outperform hydrogen-based solutions in terms of cost. However, it is difficult to draw direct comparisons as high hydrogen scenarios must fulfil a significant hydrogen transport demand at a higher cost than electric vehicles. Our modelling is sensitive to external market factors such as the cost of hydrogen and the cost of electricity.
- Electrical scenarios in 2020 had much higher carbon emissions compared to hybrid and high hydrogen. However, this situation is reversed in 2050 due to the decarbonisation of the electricity grid.

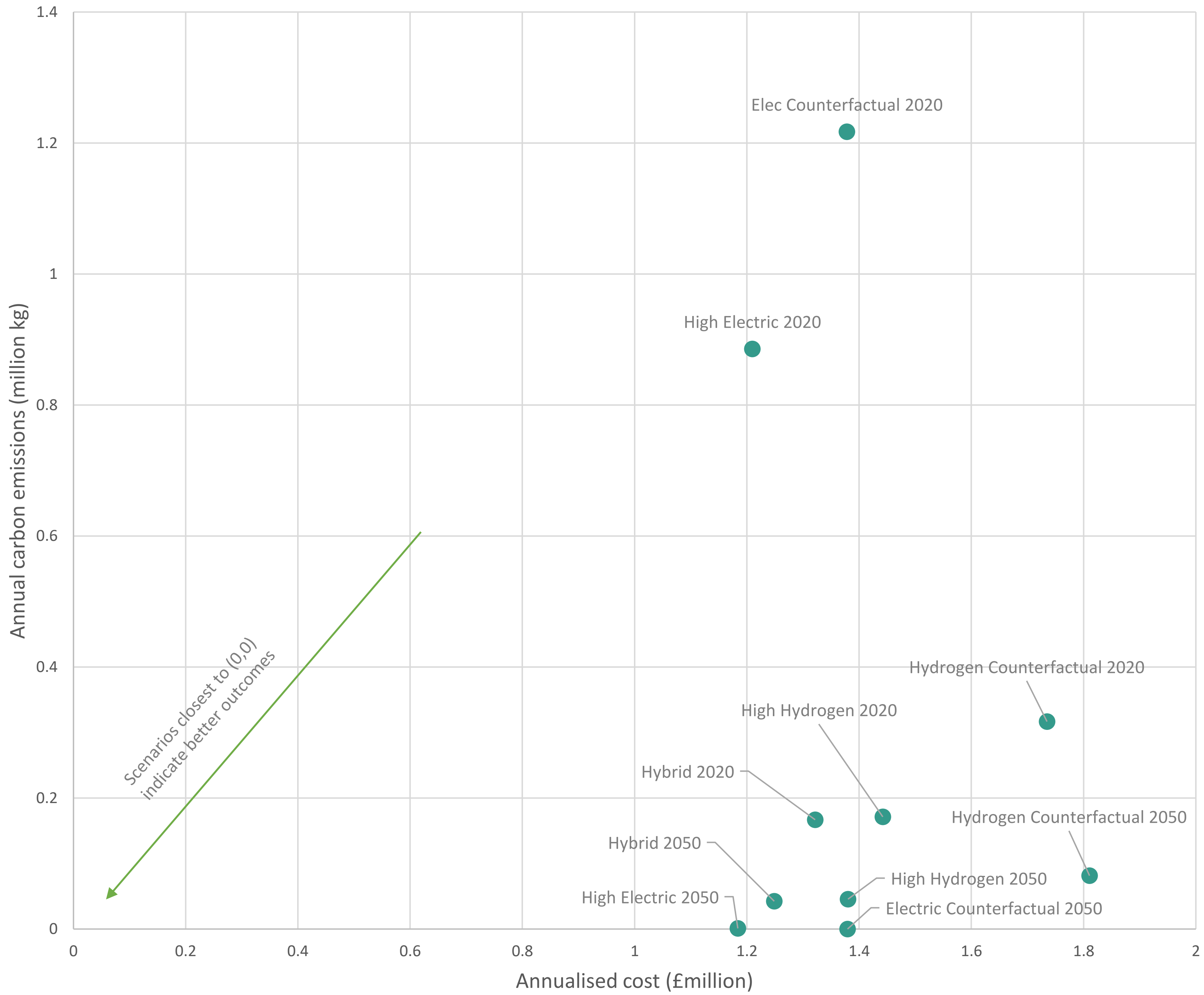


Figure 47: Annualised cost vs annual carbon emissions of the various scenarios for proposition 2

# 9. Techno-economic modelling results

*Pembrokeshire Food Park SLES*

### iii. Techno-economic modelling results – Proposition 2, The Pembrokeshire food park SLES (continued)

Figure 48 shows the annual energy flows in the form of a Sankey diagram of the optimal solution for just one scenario, hybrid 2050 as an example.

No regrets

Ground and rooftop PV were selected to their maximum possible capacity in all scenarios. PV reduces the reliance on costly national grid imports and allows some local production of hydrogen but is also profitable when excess electricity is exported to the electricity grid. This implies that if greater renewable capacity was available then this may result in greater local electrolysis and hydrogen supply.

Anaerobic digesters and biogas CCHPs were also selected in every scenario where they were not excluded (not the counterfactuals). The input food waste was assumed to be a free resource and the biogas CCHP was able to meet the baseload of three of the demand vectors; heating, cooling and electricity.

Polyvalent (simultaneous) heat pumps were shown to be highly advantageous in this proposition due to their high efficiencies when fulfilling simultaneous and consistent heating and cooling demands.

Heating and cooling

In the hybrid scenarios, where there was free choice between electric heating and hydrogen heating, electric heating was chosen. Polyvalent heat pumps (simultaneous heating and cooling heat pump) and a biogas CCHP produced the heating and cooling baseloads, topped up by resistance heating and a chiller respectively.

Even in high hydrogen scenarios where heat pumps were excluded, the optimisation minimised the amount of hydrogen boilers by shifting some of the biogas output to biogas boilers rather than to a biogas CCHP.

The heating and cooling solution does not vary significantly between 2020 and 2050 scenarios as natural gas is excluded in all scenarios of this proposition. Unlike the other propositions, this is a new-build project with no existing gas infrastructure.

Hydrogen

In scenarios with hydrogen transport demand, around one third of this was fulfilled by locally generated, electrolysed hydrogen with the remaining two-thirds imported. This was due to the variable amounts of excess electricity available from the PV throughout the year. It would not be cost effective to build electrolyser capacity to meet the entire demand and to then be only fully utilised in the summer months.

Batteries

Batteries were selected in the high electric and hybrid 2050 scenarios only. The battery capital cost is predicted to be lower in 2050 than 2020 and this outcome suggests battery costs are close to a tipping point. When included, they gave rise to reduced grid imports and exports and greater amounts of electrolysis. With storage technology progressing quite rapidly, batteries should remain under review. In the High Hydrogen scenario where batteries did not feature, the balancing function was provided using local electrolysis for hydrogen transport demand.

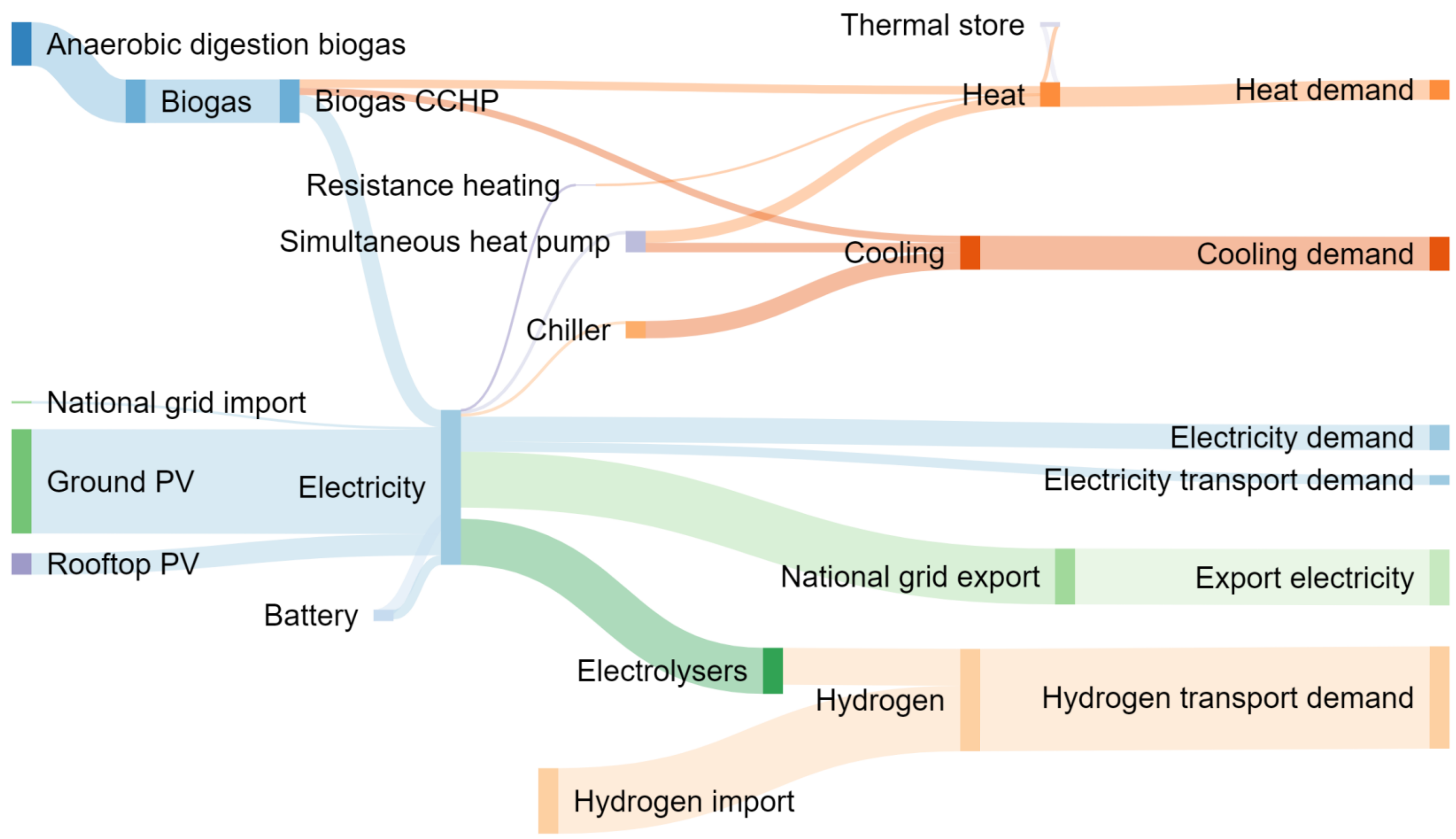


Figure 48: Example Sankey diagram of the optimised system for the hybrid_2050 scenario.

# 9. Techno-economic modelling results

*Pembrokeshire Food Park SLES*

### iii. Techno-economic modelling results – Proposition 2, The Pembrokeshire food park SLES (continued)

Summary and proposition viability

The results of the modelling showed strong interplay between the demand energy vectors (heating, cooling, electricity and hydrogen) and a significant opportunity to utilise local waste products to fulfil this demand.

A core aspect essential to each scenario is a solar farm located at Haverfordwest airfield connected to the food park via private wire. The renewable energy is beneficial to minimise the amount of electricity purchased via the national grid. However, it does account for a significant proportion of the CAPEX (£9.5m-£10.5m) for every scenario.

Compared to the baseline counterfactuals, optimised scenarios led to an uplift in CAPEX but a reduction in OPEX. Payback periods compared to counterfactuals varied based on the year and need to be compared to the relevant hydrogen or electric counterfactual. Note that hybrid doesn't have a direct comparison as it fulfills a mixed demand. Payback periods range between 5 and 8 years.

Table 14 shows a consistent decarbonisation from 2020 to 2050 across all scenarios, largely as a result of a decarbonising grid. Despite being very low carbon, 2050 solutions including hydrogen transport demand were not zero carbon due to carbon associated with imported hydrogen.

Given that Proposition 2 represents a new-build proposal, there is a real opportunity to integrate the no regret technologies in the design of the food park, particularly the anaerobic digestion, biogas CCHP and polyvalent heat pumps. These can be integrated via heating and cooling distribution networks with no disruption to existing services or replacement of legacy assets.

Utilising excess PV generation to electrolyse hydrogen locally would be a cost-effective method of meeting some of the hydrogen transport demand although the majority would still be imported.

If local hydrogen transport demand materialises and regular, consistent, consumers are identified, this proposition could begin to form the core of a local hydrogen transport hub.

Risks, limitations and future work

A significant feature of the optimised system is energy generation from the maximum capacity of rooftop and ground PV modelled. Infrastructure costs associated with a private wire from the proposed solar farm location at Haverfordwest airfield have been estimated and included in the modelling. However, the model assumes that the generated electricity can be deployed in the most beneficial way, i.e. distributed to meet building demand or exported to the national grid via a PPA. The practical and legal technicalities of mixing a private wire, importing from the national grid and selling to the national grid would likely give rise to additional constraints.

We estimated heating and cooling demand from benchmarked data. Due to the early stage of planning, we have not considered the flow and return temperatures of the heating and cooling systems. We assumed that any technology that produced a 'heating' or 'cooling' output vector could be blended together. In reality, to utilise heat pumps, a low heating flow temperature would be beneficial, and this would have to be integrated with the design. If there was to be a more significant freezing load, chilled water temperatures produced by a CCHP or polyvalent heat pump would not be appropriate. When a clearer understanding of end user demands is available, further analysis would be required to understand the feasibility of the proposed solution and adjust efficiencies if necessary.

We estimated the amount of food waste and hence possible biogas generation from initial planning material and rules of thumb. We assumed this to be a consistent, free (operationally) source of energy. The amount of biogas produced would be highly dependent on the type of businesses in the food park and the type and quantity of any food waste. Further assessment would be required when proposed tenants are selected. If less biogas was to be available, it is expected that the economic case would be less viable.

| Scenario | CAPEX without optimism bias (£million) | OPEX (£m/year) | $CO_2$ emissions (kg/kWh) | LCOE (£/kWh) |
|---|---|---|---|---|
| Elec counterfactual 2020 | 12.11 | 1.016 | 0.068 | 0.077 |
| Elec counterfactual 2050 | 11.11 | 1.046 | 0.000 | 0.077 |
| Hydrogen counterfactual 2020 | 12.02 | 1.376 | 0.019 | 0.104 |
| Hydrogen counterfactual 2050 | 11.02 | 1.480 | 0.005 | 0.108 |
| High electric 2020 | 14.84 | 0.684 | 0.049 | 0.067 |
| High electric 2050 | 14.84 | 0.606 | 0.000 | 0.066 |
| High hydrogen 2020 | 16.18 | 0.844 | 0.010 | 0.086 |
| High hydrogen 2050 | 14.62 | 0.833 | 0.003 | 0.082 |
| Hybrid 2020 | 15.60 | 0.765 | 0.010 | 0.079 |
| Hybrid 2050 | 14.48 | 0.705 | 0.003 | 0.074 |

Table 14: Summary of Key Performance Indicators (KPI) across all Proposition 2 scenarios

# 9. Techno-economic modelling results

*Pembrokeshire Food Park SLES*

### iii. Techno-economic modelling results – Proposition 2, The Pembrokeshire food park SLES (continued)

Figure 49 shows a schematic of the preferred system for Proposition 2. The core recommended technologies have been highlighted in light green and the supporting or situationally beneficial technologies to watch have been highlighted in grey.

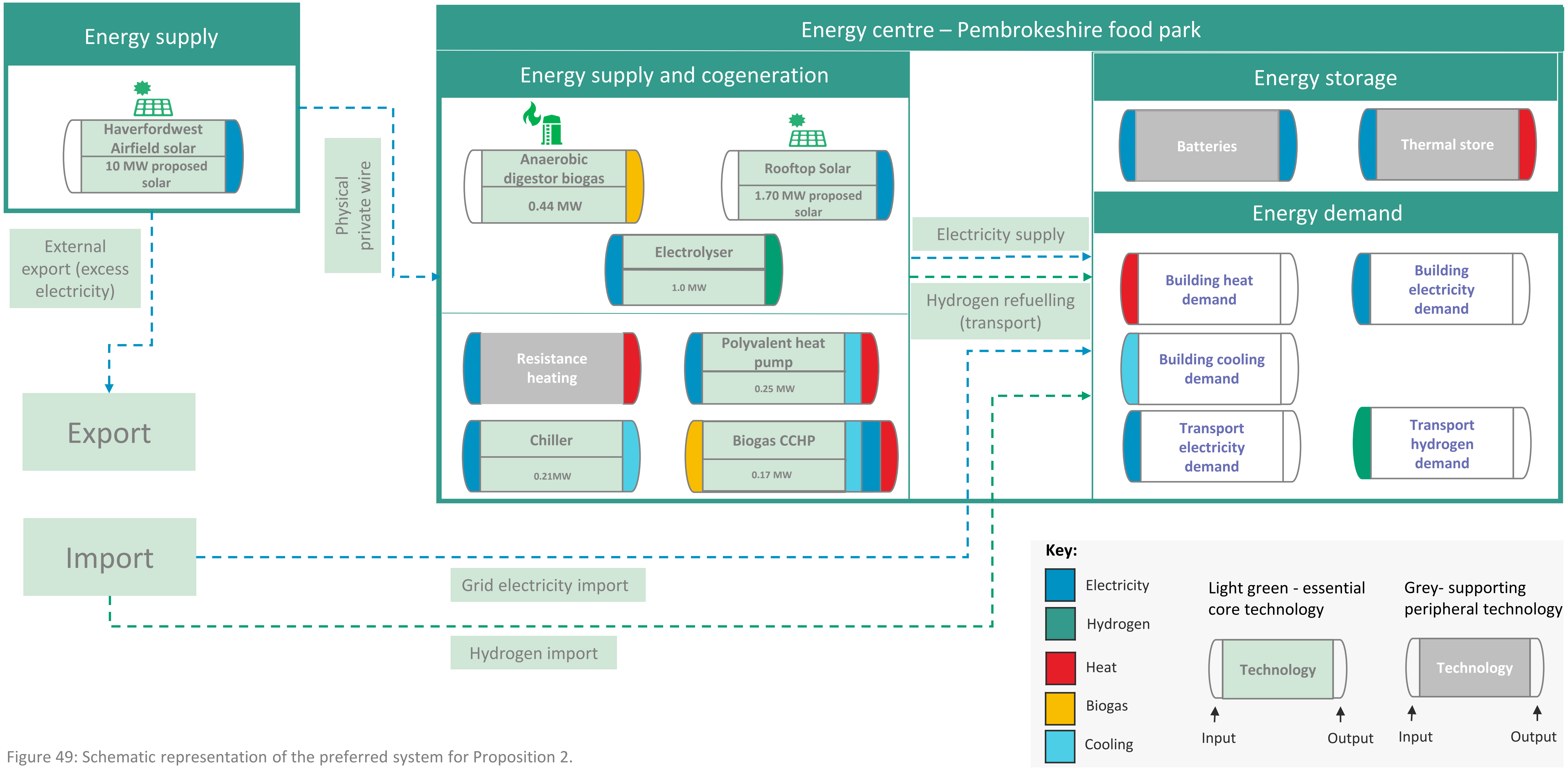


Figure 49: Schematic representation of the preferred system for Proposition 2.

# Proposition 3 – The Pembroke Schools, Leisure Centre and Dock SLES

## Proposition outputs and recommendations

*Pembroke Schools, Leisure Centre and Dock SLES*

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# 9. Techno-economic modelling results

*Pembroke Schools, Leisure Centre and Dock SLES*

### iv. Techno-economic modelling results – Proposition 3, The Pembroke schools, leisure centre and dock SLES

Figure 50 shows the list of available technologies specific to the context of Proposition 3 as well as their input and output vectors.

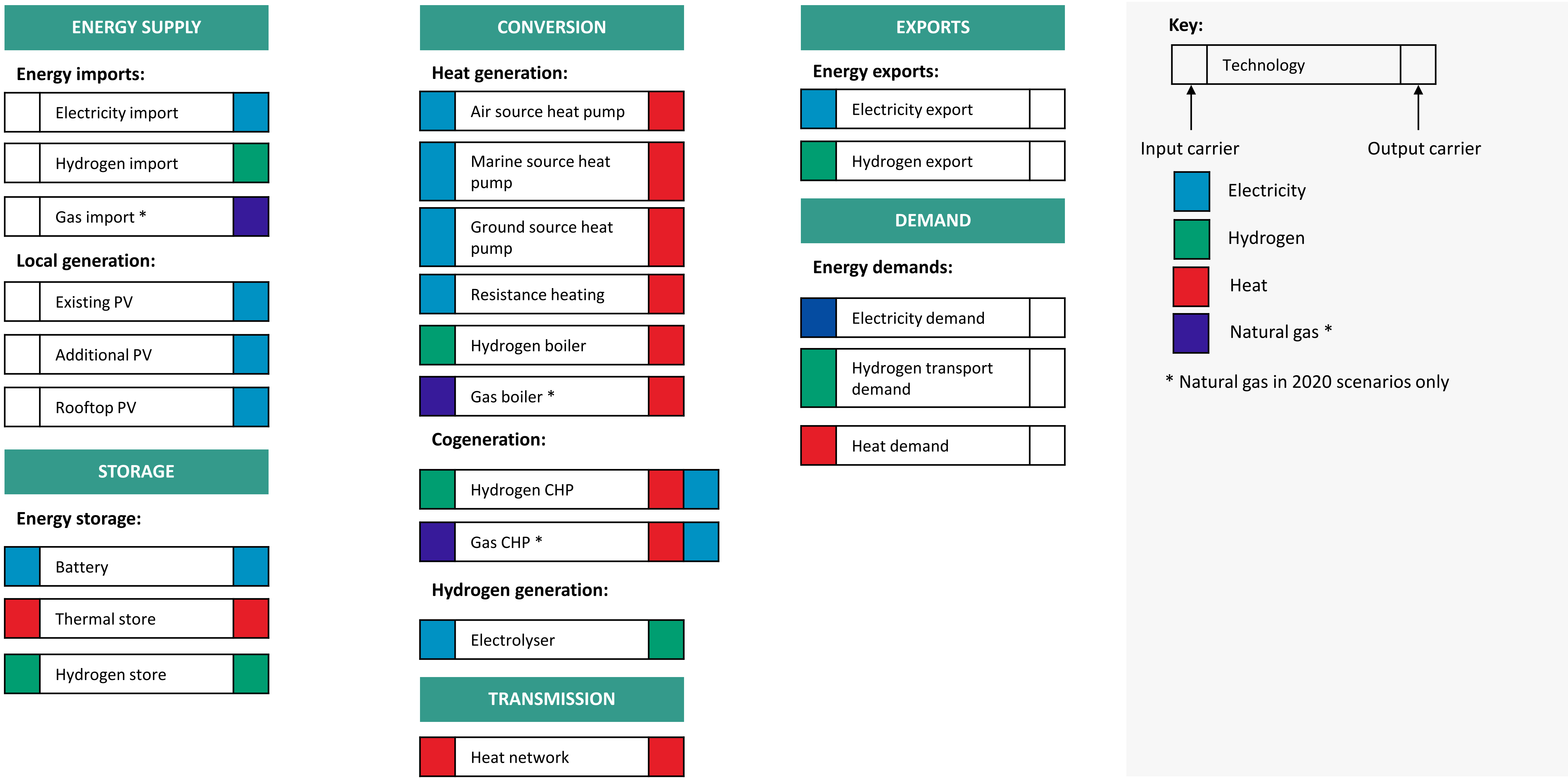


Figure 50: List of technologies modelled in Proposition 1 and their input and output energy vectors

# 9. Techno-economic modelling results

*Pembroke Schools, Leisure Centre and Dock SLES*

### iv. Techno-economic modelling results – Proposition 3, The Pembroke schools, leisure centre and dock SLES (continued)

Optimisation outcomes

The annualised cost and carbon emissions of the optimised outcomes of 2020 and 2050 scenarios are given in Figure 51. From this, we drew several high-level conclusions:

Similar themes were observed as with Proposition 2 and for the same reasons:

- The optimised solutions where there was more flexibility to choose low carbon technologies outperformed the more constrained counterfactuals. For example, the high electric 2020 had lower carbon compared to electric counterfactual 2020 as it had greater flexibility to include technologies such as batteries and air-source heat pumps but resulted in a slightly higher cost.
- Electricity-based scenarios achieve an annualised profit, hence the negative costs. This is due to the very large quantities of PV generation and sale to the electricity grid in this proposition. If electricity network upgrades and connection costs were not prohibitive (currently excluded from modelling) and if the generation can be fully utilised, the development of additional PV could be an attractive investment.
- Electric solutions outperformed hydrogen solutions in terms of cost due to high electricity exports. This indicates that until a tipping point in the price of hydrogen is reached (which could come due to economies of scale or import of cheaper hydrogen on an international market), the electrification of the heat and transport demand is expected to be a lower cost and lower carbon approach, with hydrogen predominantly used in specific applications where it is more suitable e.g. industrial and heavier transport applications.
- 2020 scenarios have significantly higher carbon emissions compared to 2050 scenarios due to the decarbonisation of the electricity grid.

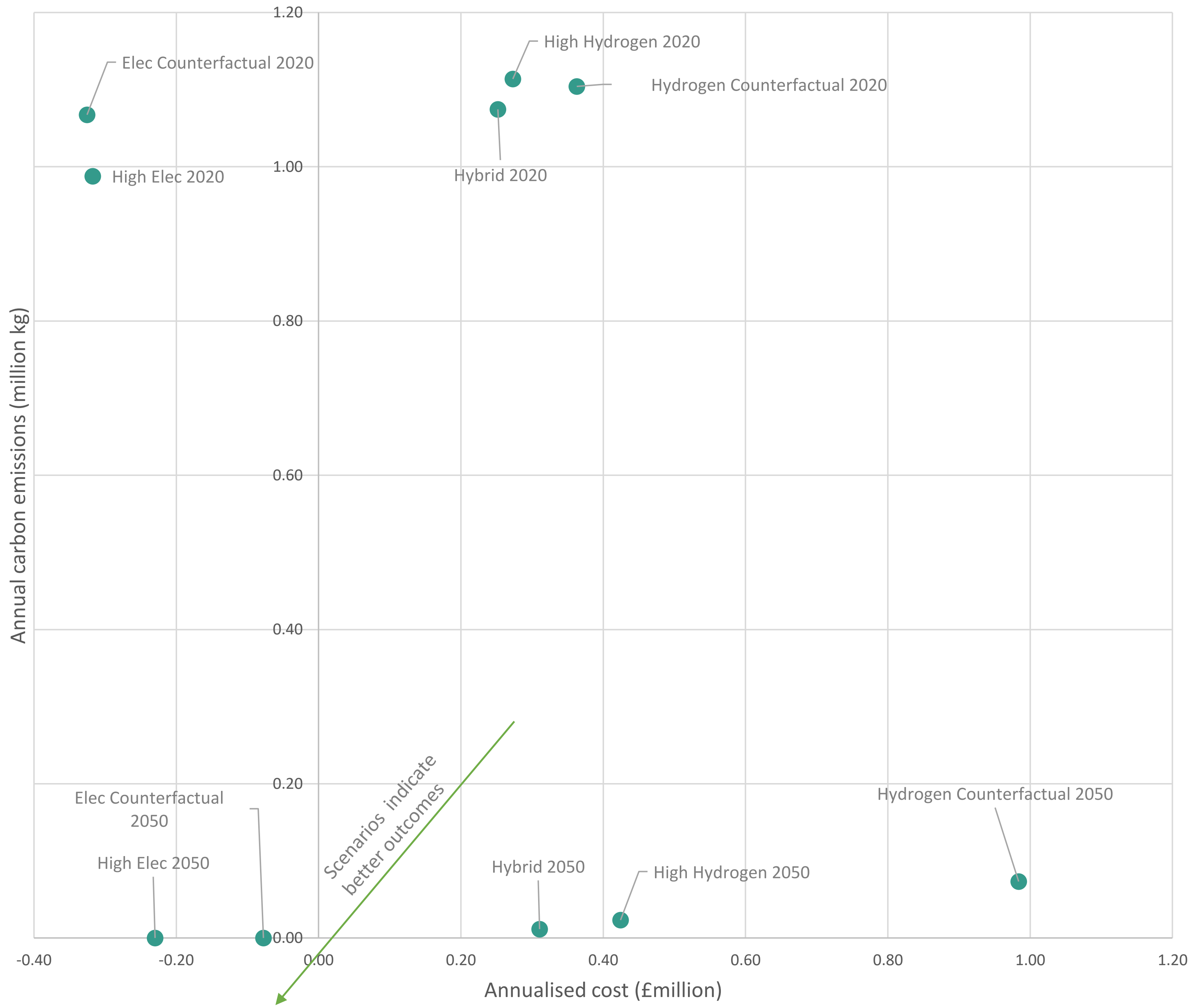


Figure 51: Annualised cost vs annual carbon emissions of the various scenarios for proposition 3

# 9. Techno-economic modelling results

*Pembroke Schools, Leisure Centre and Dock SLES*

### iv. Techno-economic modelling results – Proposition 3, The Pembroke schools, leisure centre and dock SLES (continued)

Figure 52 shows the annual energy flows in the form of a Sankey diagram of the optimal solution for just one scenario, hybrid 2050 as an example.

#### No regrets

Ground and rooftop PV were selected to their maximum possible capacity in all scenarios. This was by far the most dominant feature of each scenario and most of this electricity was exported for profit. There were small quantities of electricity import from the national grid and from existing solar farms via PPAs to cover periods of high demand and low generation.

#### Heating

The main source of heating in the 2020 scenarios remained the existing gas infrastructure. The gas input was shared between gas boilers and gas CHP with approximately an 80:20% split. In the hybrid and high electric scenarios, electric sources make a modest 10% contribution to the heat demand with the remaining 90% from gas. Even with the large quantity of low-cost solar electricity, gas heating was shown to be the most cost-effective way to fulfil the heat demand.

In 2050, when the gas infrastructure would no longer be able to supply natural gas, electric sources of heating were the most optimal solution. As demonstrated by the hybrid 2050 energy flow diagram, shown in Figure 52, most of the heat demand is supplied by air source heat pumps, with small contributions from a ground source heat pump and resistance heating. Air source heat pumps were selected at a building level rather than a centralised energy centre. A district heating system was not shown to be the most effective solution in this proposition due to the limited number and density of buildings. This could change if a broader boundary were to be considered in the modelling.

#### Hydrogen

In scenarios with hydrogen transport demand, around half of this was fulfilled by locally generated hydrogen with the remainder imported. However, in hybrid 2050, electrolysed hydrogen rises to 70% of annual demand with only 30% imported. This is due to the variable amounts of excess electricity available from the PV throughout the year. As with Proposition 2, it would not be cost effective to build an electrolyser at full capacity to then be only fully utilised in the summer months.

#### Batteries

The observations with batteries are in line with Proposition 2. Additionally, they are shown to work well in combination with very large quantities of variable solar generation.

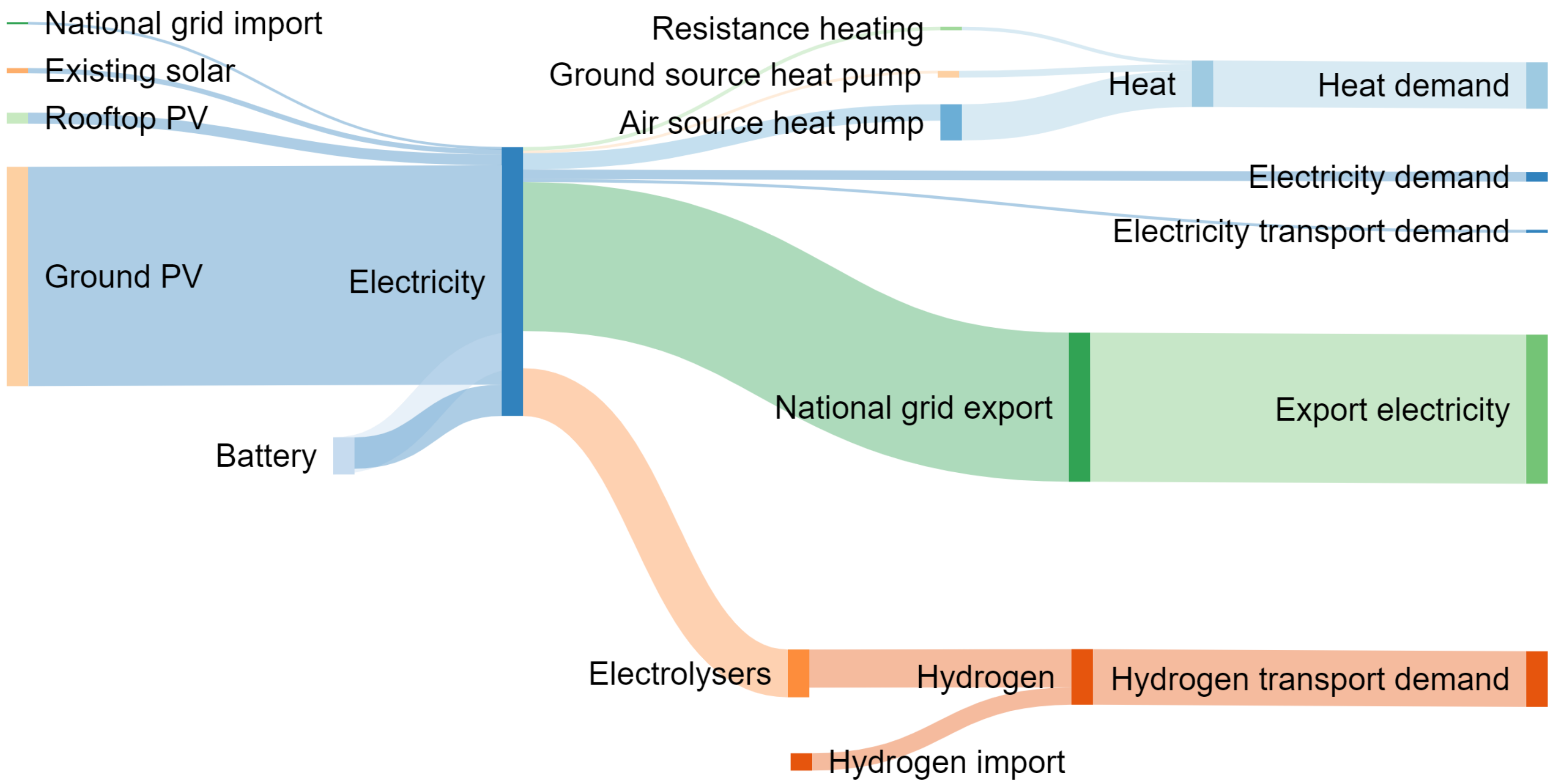


Figure 52: Example Sankey diagram of the optimised system for the Hybrid 2050 scenario.

# 9. Techno-economic modelling results

*Pembroke Schools, Leisure Centre and Dock SLES*

### iv. Techno-economic modelling results – Proposition 3, The Pembroke schools, leisure centre and dock SLES (continued)

#### Summary and proposition viability

The optimised outcome of each scenario mainly consisted of a large capacity of solar PV that predominantly exported its generation to the national grid for income. There was little to zero district-level integration between the buildings' heating systems and very limited interaction between the energy vectors. As such, the outcomes demonstrate that the proposition is not a strong candidate for a decentralised integrated SLES. Proposition 3 was shortlisted on the basis of identifying interconnected demand but then was not realised during more detailed assessment.

The main component of the CAPEX across all scenarios was the additional ground PV, estimated between £9.5m and £11.5m. The annual revenue resulting from the electricity export alone ranged between £0.75m and £1.1, without accounting for the cost benefits achieved by reducing electricity and hydrogen imports. This was the cause of the negative OPEX (i.e. annual profit) shown in Table 15. In comparison to the PV energy exports, the building and transport demands are of secondary importance. This analysis is highly dependent on electricity export prices, and as discussed previously infrastructure upgrades required by the DNO and curtailment which are not included in our analysis.

The optimised outcome demonstrates the potential of a limited ground PV installation coupled with an electrolysis refuelling station provided there is sufficient and reliable hydrogen transport demand. This would be highly sensitive to the expected hydrogen sale price compared with the possible electricity sale price.

The buildings' heating demand should transition to electric solutions when the use of natural gas is phased out. However, the use of a heat network for the selection of buildings included in this proposition has not been shown to be viable.

The building density is too low, and the concurrent peak demand means there could only be a limited reduction in heating capacity, and this would not outweigh the CAPEX associated with a heat network. If a broader boundary including a greater volume of the Pembroke building density was to be included this could potentially be viable pending further analysis.

Table 15 shows that carbon emissions remain high in the 2020 scenarios due to the use of natural gas heating and the relatively high electricity carbon factor, but this reduces to near zero in 2050.

#### Risks, limitations and future work

Due to the locality of the proposed ground solar installations, costs for large private wire infrastructure was not included in the modelling. However, depending on the arrangement between the buildings, any electrolyser facility and an export agreement, some infrastructure would be required. This would likely increase the cost of PV generation and therefore alter the optimised outcomes.

Furthermore, such a large electrical installation could require significant upgrades at a DNO level which have not be accounted for at this stage.

We have modelled a significant hydrogen transport demand. However, wholesale and immediate transition to hydrogen-based vehicles is unlikely. Finding reliable, consistent consumers of hydrogen for transport may be challenging and therefore a gradual phased development of electrolyser capacity could be more beneficial.

In contrast to Proposition 2, the buildings are in operation and have existing systems in place to meet the demand. The age and asset condition of the existing systems are not known. If the existing assets are relatively new and don't require replacement, the 2020 counterfactual costs may have been overstated in the analysis.

| Scenario | CAPEX, without optimism bias (£million) | OPEX (£m/year) | $CO_2$ emissions (kg/kWh) | LCOE (£/kWh) |
|---|---|---|---|---|
| Elec counterfactual 2020 | 12.84 | -0.731 | 0.198 | -0.060 |
| Elec counterfactual 2050 | 10.55 | -0.390 | 0.000 | -0.014 |
| Hydrogen counterfactual 2020 | 12.84 | -0.042 | 0.105 | 0.035 |
| Hydrogen counterfactual 2050 | 10.55 | 0.649 | 0.007 | 0.094 |
| High electric 2020 | 13.17 | -0.729 | 0.182 | -0.058 |
| High electric 2050 | 11.95 | -0.661 | 0.000 | -0.042 |
| High hydrogen 2020 | 13.66 | -0.161 | 0.105 | 0.026 |
| High hydrogen 2050 | 13.70 | -0.057 | 0.002 | 0.040 |
| Hybrid 2020 | 13.60 | -0.176 | 0.102 | 0.024 |
| Hybrid 2050 | 13.40 | -0.236 | 0.001 | 0.030 |

Table 15: Summary of Key Performance Indicators (KPI) across all Proposition 3 scenarios

# 9. Techno-economic modelling results

*Pembroke Schools, Leisure Centre and Dock SLES*

### iv. Techno-economic modelling results – Proposition 3, The Pembroke schools, leisure centre and dock SLES (continued)

Figure 53 shows a schematic of the preferred system for Proposition 3. The core recommended technologies have been highlighted in light green and the supporting or situationally beneficial technologies to watch have been highlighted in grey.

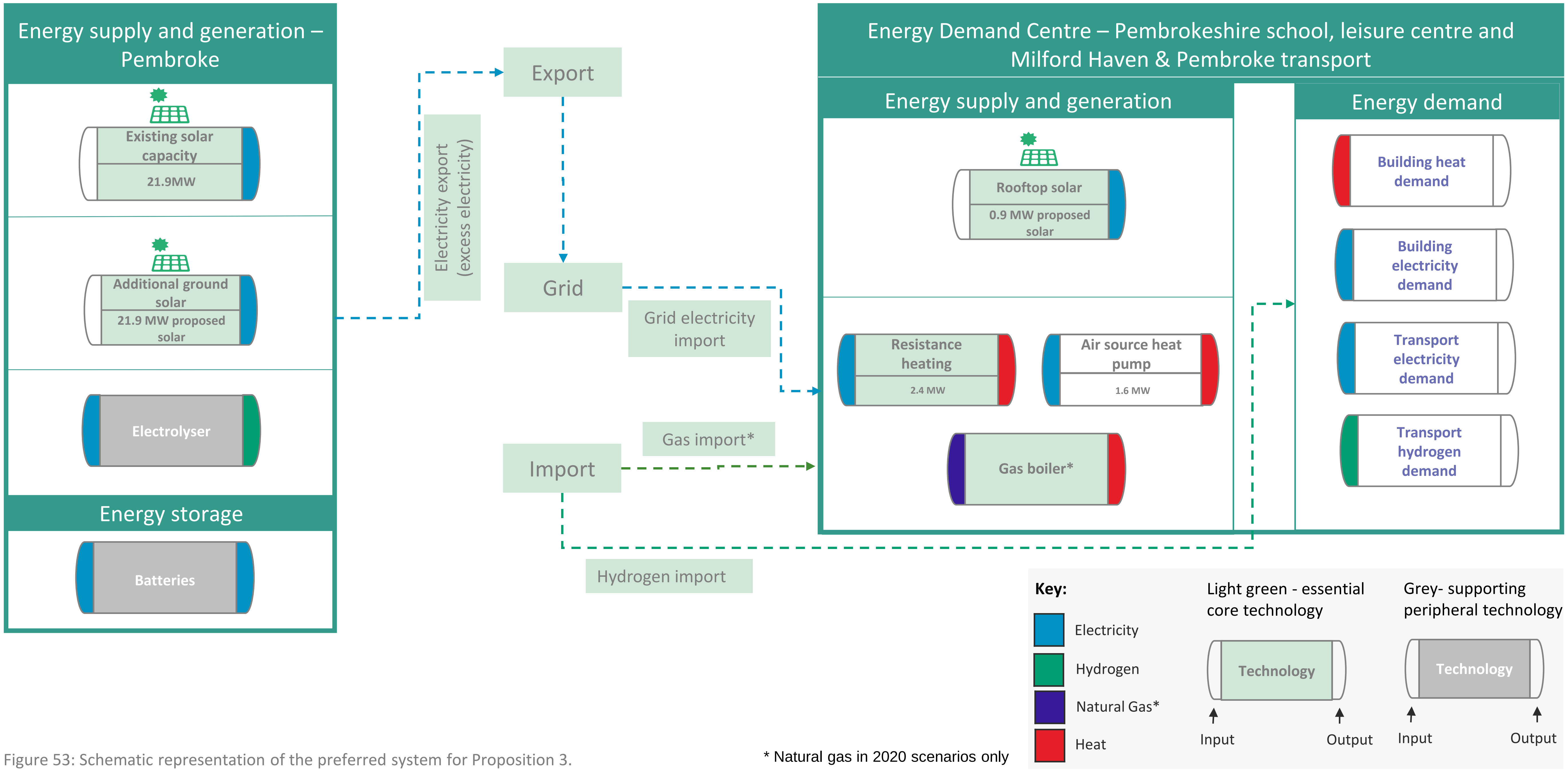


Figure 53: Schematic representation of the preferred system for Proposition 3.

# 9. Techno-economic modelling results

### v. Sensitivity analysis

All sensitivity analyses were conducted on Proposition 1 as part of the more detailed analysis undertaken in phase 2. However, it is expected that the broad lessons learned from Proposition 1 will be applicable to propositions 2 and 3.

#### The impact of hydrogen import prices

***Q. What is the tipping point where hydrogen import and onsite production becomes cost comparable with the optimised solution for the proposition?***

Varying hydrogen prices had a significant impact on the makeup of the energy system.

At the lower extreme, with hydrogen the same price as natural gas, gas boilers were almost entirely replaced by hydrogen boilers and hydrogen becomes the primary source of heat. This hydrogen was all imported with no onsite electrolysis.

At the highest hydrogen import price of 0.18 £/kWh, the model increased the amount of electrolysis to reduce reliance on hydrogen imports to satisfy hydrogen transport demand. No hydrogen was used for heat. Electrolysis was highest in scenarios where there was a highest proportion of local renewables (the onshore wind scenario in Proposition 1) where around 37% of hydrogen is produced locally. Exports of electricity to the national grid were reduced and instead the model produced green hydrogen with that electricity.

When the hydrogen price was modelled at the mid-point between the core scenarios (central case) and current gas prices, there was little difference in system operation compared to the central case. No hydrogen boilers were selected and there was only a very small amount of electrolysis in scenarios where there was a highest proportion of local renewables (the onshore wind scenario in Proposition 1). All imported hydrogen was used to satisfy hydrogen transport demand alone.

This sensitivity suggests current hydrogen prices of 0.135 to 0.18 £/kWh (£4.5 to £6/kg based on a lower bound heating value of hydrogen of 33.3kWh/kg) are close to a tipping point in making electrolysis viable. If the grid export price decreases slightly, or the hydrogen import price increases slightly, electrolysis is a good use of excess electricity after local electrical demand is met.

#### No natural gas

***Q. What mixture of energy technologies would the system select if gas was no longer an available option?***

When natural gas imports and gas boilers were excluded from the model, heat was largely electrified with air-source heat pumps as the dominant technology. Hydrogen boilers did appear in all scenarios but only met 5-7% of the heat demand. This suggests that electrification of heat is preferable to hydrogen boilers if gas was removed from the system.

Electrolysis and electricity exports were decreased compared to the central case as greater priority was given to using the renewable electricity for heat.

This sensitivity led to very large decreases in carbon emissions, in the range of 45-75% compared to the core proposition scenarios but an inevitable increase in cost (25-32%) compared to the central case where gas boilers had no capital cost. However, for any new buildings, air-source heat pumps are likely to be cost competitive when compared to new gas boilers and therefore should be adopted as the primary heat technologies for new buildings.

#### Lower battery prices

***Q. What is the tipping point where battery storage becomes a viable option for the site if not part of the optimised solution?***

With lower battery capital costs, batteries were selected in every scenario. However, capacity varied considerably, with higher installed capacities in private wire scenarios and maximum solar scenarios (Proposition 1).

The inclusion of higher capacity batteries resulted in less electricity being imported from and exported to the national grid and instead promoted self-consumption. The heating and hydrogen vectors remained largely unchanged. These changes produced a very marginal decrease in annualised costs and carbon emissions. With grid price fluctuations, it may be possible to buy low-cost electricity at certain times to be stored for periods of higher demand.

#### Lower electricity price, higher gas price

***Q. If policy changes increased the cost of gas and reduced the cost of electricity, what would be the impact on the system?***

In this sensitivity, the system started to switch over to electrification of heating via air-source heat pumps. In scenarios with local solar renewables, the balance was around 50% electric heating and 50% from gas boilers, but this rose to a high of 80% electric heating in the scenarios with onshore wind distributed through private wire connection (Proposition 1).

This sensitivity resulted in lower national grid exports and higher national grid imports especially in PPA scenarios. This result suggests a prioritisation of meeting the heating demand with the local renewable generation rather than the electrical demand.

# Conclusions

## Are the propositions viable and what are the next steps?

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# 10. Conclusion

## i. High-level conclusions

Our work demonstrates the value of interconnected systems, such as a SLES and the potential for hydrogen to be part of a 2050 decarbonised MH:EK energy system. Annualised cost and carbon emissions are lower in all scenarios against the counterfactuals, and further decreases from 2020 to 2050, with additional low carbon technologies selected wherever allowed. 'Do Something' is preferable to 'Do Nothing'; and the earlier the action, the faster carbon emissions reductions will be achieved.

Looking back at the project objectives and the questions the MH:EK project is trying to answer (section 4):

What are the short-term actions within the Milford Haven project boundary to deliver net zero by 2050?

Across all the propositions, scenarios and sensitivity testing, the hierarchy of the energy supply-demand relationship has been:

1. Use locally generated electricity locally where possible, first for power and then to satisfy heating (where there is opportunity for new technologies to be installed) and EV transport.
2. If excess electricity is generated beyond the power and heat demand baseload, this is often used to support local electrolysis and green hydrogen production, where there is a local hydrogen transport demand, ahead of exporting excess electricity to the national grid.
3. Any remaining excess electricity (or where an electrolyser is not sized to the maximum seasonal excess such that it is not underutilised) is exported to the national grid.
4. Imported electricity is used to support balancing of fluctuations for both power and electric-heating, where new technologies have been installed.
5. Where existing buildings are connected to the gas network (2020 scenarios), these remain until gas boilers are phased out. In 2050 scenarios, where natural gas is no longer an option electric heating systems dominate with hydrogen boilers featuring to a lesser extent and dependent on the scenario. Hybrid heating systems can provide resilience to future system but the timescales of system level transfer from natural gas to Hydrogen (including 20% hydrogen blend to 100% transition over time) are unknown.
6. Locally produced hydrogen is not favoured for heating demand. New hydrogen boilers are generally a much lower proportion of the overall heating mix due to their lower efficiencies, even once gas is phased out, in the current market context.
7. If electricity export prices decrease, a greater proportion of locally generated electricity may be used to produce hydrogen to satisfy a greater proportion of any hydrogen transport demand (though generally not heating).
8. Where there is a significant proportion of hydrogen transport demand, this is only partially met locally with hydrogen imports. This presents an opportunity for greater local hydrogen production if hydrogen transport demand does develop in the region.
9. Batteries feature in all scenarios, but are not a strong 'no regrets' option, we suggest they are kept in review. Based on the battery price assumptions taken in the model across 2020 (higher cost) and 2050 (lower cost), batteries are at a price tipping point and are expected to feature more predominantly and be a more favourable balancing solution soon.

Additional low carbon generation is adopted in most scenarios, with the cost-benefit and pay-back demonstrated as part of a whole systems view. The revenue, and benefits, to potential investors looking to solely develop renewable generation and sell into local systems would need further financial assessment and consideration of electricity network connection costs (which could be high due to the current constraints), and curtailment risks.

Where is the tipping point in hydrogen, carbon, electricity pricing within a multi-vector system?

Electric solutions outperformed hydrogen solutions in terms of cost due to high electricity exports and high hydrogen import costs, in the current market context.

Heat was largely electrified across the scenarios with air-source heat pumps as the dominant technology because they are more efficient than other electric heating types. Hydrogen boilers did appear in all scenarios but met less than 10% of the heat demand. Their efficiency (x0.84) is also significantly lower than air-source heat pumps (x2.21). This suggests that electrification of heat would be preferable to hydrogen boilers if natural gas was removed from the system, based on the current external market context.

Until a tipping point in the price of hydrogen is reached, which could come due to economies of scale or import of cheaper hydrogen on an international market, the electrification of the heat and transport demand is expected to be a lower cost and lower carbon approach.

Additionally, the cost of batteries is expected to continue to decrease which may result in batteries being preferable as a balancing or storage option compared to electrolysis.

This external context is expected to change over time to 2050, and sensitivity testing of hydrogen pricing indicates that current hydrogen prices of 0.135 to 0.18 £/kWh (£4.5 to £6 /kg) are close to a tipping point in making local electrolysis viable to satisfy a local hydrogen transport demand.

# 10. Conclusion

## i. High-level conclusions (continued)

How 'best' to integrate hydrogen into the energy system to decarbonise energy supply?

Our modelling shows that utilising excess renewable generation to electrolyse hydrogen locally would be a cost-effective method of meeting some of the hydrogen transport demand although the majority would still be imported. If the local hydrogen transport demand materialises and regular, consistent, consumers are identified, there will be a stronger opportunity to form the core of a local hydrogen transport hub.

In the short-term, hydrogen would still be predominantly used in specific applications where it is more suitable e.g. industrial and heavier transport applications, however if a tipping point in the price of hydrogen is reached, there will be a stronger case for hydrogen for transport, and potentially heat. The role of hydrogen to decarbonise the energy supply is more significant when looking at the longer-term energy pathways for Milford Haven and considering the large-scale industrial activity in the region. This is further discussed in the 'MH:EK strategic outline case for a smart local energy system' *[28]*.

What does a 2050 decarbonised MH:EK energy system look like and the short-term investments to achieve this, on the route to net-zero by 2050?

Smart local energy systems are shown to have significant benefits in terms of costs and carbon emissions, where there is strong interplay between the demand energy vectors (heating, cooling, electricity and hydrogen) supporting system balancing and greater flexibility of supply.

The key facets of PfER SLESs are electricity, heating and mobility interaction and being mutually supportive of one another towards net-zero goals. Our work demonstrates the value of interconnected SLESs and the potential for hydrogen production as an alternative vector where electricity networks are currently constrained.

SLESs and heat networks are not always the preferred solution, this is dependent on the mix and scale of demand energy vectors. Where a SLES is not appropriate, adoption of low carbon technologies would be encouraged on an individual basis for example, rooftop PV, retrofit of ASHPs in schools, and further development of renewable generation projects.

The value of an interconnected system may not always be demonstrated where there are fewer component parts, and the supply-demand is not balanced. For instance, if a proposition solely consisted of hydrogen derived from grid or local electricity, and the local electricity generation is not used to satisfy the local electricity demand, the proposition would not be considered a SLES.

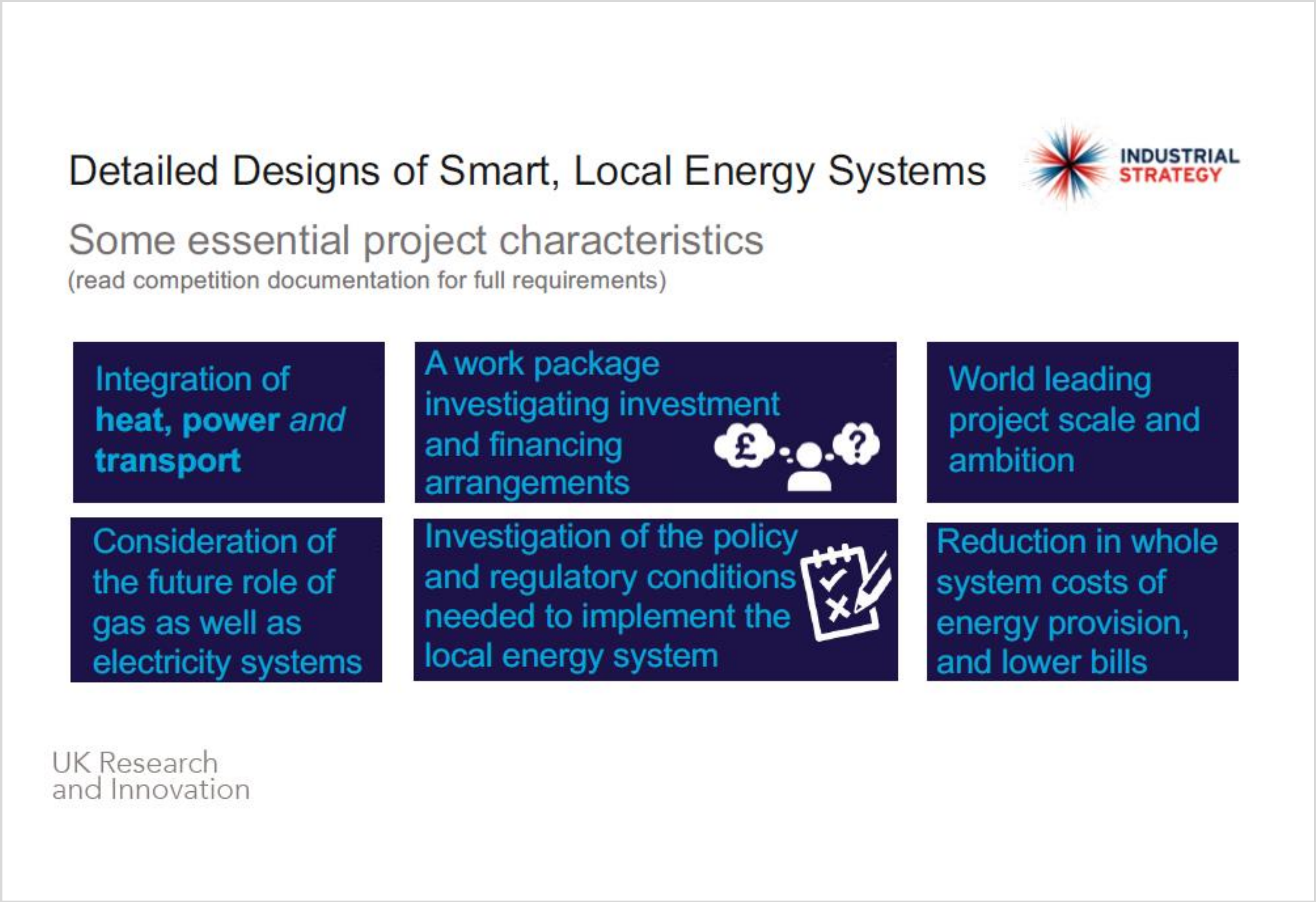


Figure 54: Key PfER facets for SLESs.

# 10. Conclusion

## ii. Summary of propositions

Table 16 provides a summary of the CAPEX, OPEX, LCOE and carbon emissions for each proposition. The $CO_2$ emissions have been scaled to the size / capacity of the proposition to allow for ease of comparison between propositions.

The upfront capital cost (CAPEX) for the recommended system for each proposition is provided in Table 16. In line with the HM Treasury Green book guidance, an optimism bias (OB) of 6-66% should be allowed for non-standard Civil Engineering projects. At this stage of the project, the upper bound 66% is applied, as there is not enough information to reduce the optimism bias. This total CAPEX represents the upfront budget for each proposition (also provided in Table 16.)

Carbon emissions from Proposition 1 are relatively high when compared to Proposition 2 and 3 across the same year. All scenarios for Proposition 1 are based in 2020, so they still have significant carbon for electricity imports, and remains a predominantly natural gas-based heating system. The carbon emissions shown for Proposition 1 with a 2050 view in Table 16 have been adjusted to exclude gas heating emissions that are present in 2020 in order to compare 'like-for-like' with Proposition 2 and 3. The three propositions are then broadly comparable.

It should be noted that these quantitative outputs present only part of the picture, and the following notes should be considered alongside the recommendations.

- **Proposition 1** - expanding Liddeston Ridge with onshore wind and distributing the energy through a private wire is lowest cost but has higher CO2 emissions due to the use of gas boilers for heating in 2020. This option results in payback (at a whole system level) within three years and could present an attractive investment, but further financial assessment is required to confirm this.

| Proposition | | 1 – MH Marina SLES | | 2 – Pembrokeshire Food Park SLES | | 3 - Pembroke Schools, Leisure Centre and Dock SLES | |
|---|---|---|---|---|---|---|---|
| Scenario | | Onshore wind expansion with private wire | Onshore wind expansion with private wire and no gas* | Hybrid | Hybrid | Hybrid | Hybrid |
| | | 2020 | 2050* | 2020 | 2050 | 2020 | 2050 |
| KPI | CAPEX (£million) | 8.12 | 9.87* | 15.6 | 14.5 | 13.6 | 13.4 |
| | CAPEX with 66% OB (£million) | 13.5 | 16.4* | 25.9 | 24.1 | 22.6 | 22.2 |
| | OPEX (£m/year) | 1.704 | 2.204* | 0.765 | 0.705 | -0.176 | -0.236 |
| | $CO_2$ emissions (kg/kWh) | 0.076 | 0.002* | 0.01 | 0.003 | 0.102 | 0.001 |
| | LCOE (£/kWh) | 0.061 | 0.081* | 0.079 | 0.074 | 0.024 | 0.03 |

Table 16: Summary of the CAPEX, OPEX, LCOE and carbon emissions for each proposition scaled to the size / capacity of the proposition. *$CO_2$ emissions are shown adjusted to a 2050 view and excluding gas heating emissions in order to compare like-for-like with proposition 2 and 3.

- **Proposition 2** has the lowest LCOE and CO2 emissions of the viable smart local energy system propositions and represents a viable opportunity for a developer. There is strong interplay between the demand energy vectors (heating, cooling, electricity and hydrogen) and a significant opportunity to utilise local waste products to fulfil this demand.

- Taking a 2050 world view, **Proposition 3** has the lowest LCOE and $CO_2$ emissions, however this proposition has a significant limitation in the mismatch of supply to demand, so the system exports a large proportion of the electricity produced due to the high export prices in 2050. The demand assets modelled are not sufficient to offtake the energy produced, and this proposition does not represent a good model for a SLES. It does however demonstrate the opportunity to increase local renewables but there is a need to understand the wider system constraints and connection cost implications for any specific site under consideration for new renewables development.

Data gathering & review | Energy infrastructure map | Proposition longlist | Multi criteria assessment | Key stakeholder review | Proposition shortlist | Techno-economic modelling | Targeted data gathering & energy demand data profiling | Scenarios, assumptions, & technologies | Techno-economic modelling optimisation | **Proposition preferred system**

# 10. Conclusion


Figure 55: Graphical representation of the CAPEX, OPEX, LCOE and carbon emissions for each proposition scaled to the size / capacity of the proposition. *$CO_2$ emissions are shown adjusted to a 2050 view and excluding gas heating emissions in order to compare like-for-like with proposition 2 and 3.

# 10. Conclusion

### iii. Re-evaluation using the MCA

In addition to the quantitative output and modelling conclusions, we revisited how the propositions align with the project objectives and critical success factors after having completed the detailed modelling and established an updated MCA score. Below is a summary of the updated MCA score and commentary on the alignment of the propositions against the five absolute key requirements identified by the SLES decision tree framework.

| | Proposition 1 – Milford Haven Marina SLES | Proposition 2 - Pembrokeshire Food Park SLES | Proposition 3 - Pembroke Schools, Leisure Centre and Dock SLES |
|---|---|---|---|
| MCA score | 3.44 | 3.89 | 2.08 |
| Is it a SLES? (Multi-vector, scalable and replicable) | Proposition 1 scores highly and is recommended to be progressed by the PoMH with key 'no regrets' recommendations strongly suggested to be adopted and consideration of the broader smart local energy system opportunity to be further considered.<br><br>This proposition provides a roadmap on how existing buildings can be retrofitted to be integrated as part of a SLES and makes the case for increasing the local renewable energy generation. | Proposition 2 scores the highest and is recommended to be progressed as a SLES, led by PCC. There is a strong interplay of the energy vectors, and the proposition demonstrates a diverse mix of technologies alongside use of waste (moving towards a circular economy), with a strong potential use of hydrogen for transport.<br><br>There is a significant scaling opportunity around the proposed new development with its proximity to other light industrial sites including the nearby First Milk Ltd. creamery as well as growing into an EV and hydrogen transport hub. This SLES approach is also replicable to any future light industrial and commercial projects. | Proposition 3 is not considered to be a suitable SLES. This proposition has highlighted the fact that smart local energy systems and heat networks are not always going to be the answer to transitioning the energy sector to net zero. Proposition 3 was shortlisted on the basis of identifying interconnected demand that then was not realised during more detailed assessment.<br><br>There is no interplay of energy vectors due to fewer component parts, and the supply-demand is not balanced. There is an opportunity to increase the local renewables energy generation, but until there is demand that is interconnected, this proposition does not represent a SLES. |
| Need | Achieves near zero annual $CO_2$ emissions in 2050 compared to counterfactuals. This is a small and local scale system and therefore the impact on the overall UK net-zero pathway is small but the proposition has a strong opportunity for awareness raising and transition of public opinion.<br><br>With less reliance on grid and hydrogen imports, this proposition promotes better energy resilience by connecting the Port owned supply and demand assets. | Achieves near zero annual $CO_2$ emissions in 2050 compared to counterfactuals. This is still a small and local scale system, but involves proposed developments with a stronger scaling opportunity.<br>This proposition presents a strong opportunity for electrolysis should the hydrogen price be more favourable.<br>Circular economy principles are applied through the production of energy from waste. Strong opportunity to engage the community to demonstrate the application of a SLES at light industrial level and how it can be scaled to include public use. | Does not represent an interconnected system; it achieves near zero annual $CO_2$ emissions in 2050 compared to counterfactuals but promotes export of electricity rather than to fulfil the energy demand of the system.<br><br>The impact on net-zero targets is considered to be negligible. With so much reliance on export prices, this proposition doesn't promote energy resilience. |
| Anchor | Has a strong project anchor in PoMH to drive progress to further development stages.<br>There are greater development challenges across multiple factors from planning application approval for a wind turbine, to getting buy-in from multiple tenants and stakeholders which could stretch the Port's resources. | Has a strong anchor in PCC to ensure coordination and integration with the proposed developments and to investigate potential funding streams. There are lower perceived asset ownership risks as tenants are not existing and could be part of the SLES design process. The food park development had previously undergone a first stage feasibility assessment, and with a strong focus on energy resilience and sustainable food production, the development risk is considered relatively low. | As the existing buildings are not integrated in the SLES and with future development plans unknown, PCC is not considered to be a strong anchor. Furthermore, existing PV owners will have existing export agreements and proposed PV asset ownership will depend on investment and local development strategies. |
| Technology | Technologies are well developed. Hydrogen refuelling has been demonstrated on the MH:EK project. Further work required on the energy distribution infrastructure and the operating costs. | Technologies are novel but there is a strong opportunity to engage the development design teams in the SLES design process to influence the operational requirements and energy distribution mechanisms. | Interface with existing buildings with unknown asset life. Operational requirements and network distribution mechanisms are unknown. Network costs which are not accounted for could be onerous. |
| Finance | Potential revenue for the PoMH through sale of electricity at a more favourable price to local consumers. Potential funding from PoMH as the project anchor and asset owner as well as Welsh Government. | With PCC as the project anchor, the council's environmental agenda could catalyse potential funding streams. Investors / tenants could have interest to invest into the SLES, with potential higher returns than exporting electricity to the grid / cost savings compared to grid imports respectively. | Individual and more localized decisions around investment in low carbon technologies and new renewable generation are still shown to be advantageous. |

# 10. Conclusion

### iv. Recommendations

#### MH:EK SLES project recommendations

- It is recommended that the MH:EK project pursues both Proposition 1 and Proposition 2 as SLESs.
- Further work and more detailed analysis of both propositions is required, as these propositions progress along their development journeys.
- Both present real opportunities for a catalytic stepping-stone SLES that could result in a longer term larger SLES for the Pembrokeshire region, through expansion over time to include a broader boundary of residential and industrial demands.
- These two propositions present differences in 'flavour' with Proposition 1 being more focused around local community demand and Proposition 2 encompassing more commercial / light industrial use.

#### Proposition 1 recommendations

The analysis shows that further expansion of renewable assets and closer integration between those assets and the demand at the waterfront would be beneficial. The preferred option for expansion is a 2.5MW wind turbine with a 3.5MW solar PV expansion as second preference.

The preferred method of integrating waterfront demand with Liddeston Ridge supply is via a private wire. However, a private wire would cost an estimated £4.4m (without OB) which accounts for most of the CAPEX in all private wire scenarios. This would pay for itself over the 40-year lifetime, but the initial investment could be challenging. The annual benefit of the preferred scenario, wind expansion with private wire, against the business-as-usual scenario is estimated to be £2.8m which led to a simple payback of around 3 years when considering the system as a whole.

If the commercial, legal and managerial challenges associated with a private wire prove insurmountable, the virtual PPA option could be preferrable to the business-as-usual operation, if it can be achieved at the 33kV scale.

#### Proposition 2 recommendations

This proposition represents a viable opportunity for a SLES. There is strong interplay between the demand energy vectors (heating, cooling, electricity and hydrogen) and a significant opportunity to utilise local waste products to fulfil this demand.

A core aspect essential to each scenario is a solar farm located at Haverfordwest airfield connected to the food park via private wire. The renewable energy is beneficial to minimise the amount of electricity purchased via the national grid. However, it does account for a significant proportion of the CAPEX (£9.5m-£10.5m) for every scenario.

Given that Proposition 2 represents a new-build proposal, the food park could be designed from the beginning to take advantage of no regret technologies, particularly anaerobic digestion, biogas CCHP and polyvalent heat pumps. These can be integrated via heating and cooling distribution networks with no disruption to existing services or replacement of legacy assets unlike Proposition 1 and 3.

Utilising excess PV generation to electrolyse hydrogen locally would be a cost-effective method of meeting some of the hydrogen transport demand although the majority would still be imported.

If local hydrogen transport demand becomes a reality and regular, consistent, consumers are identified, this proposition could begin to form the core of a local hydrogen transport hub. Further work on the Hydrogen refueller costs and business case would be required.

When a clearer understanding of end user demands is available, further analysis is required to understand the feasibility of the proposed solution and adjust efficiencies if necessary. We would also recommend to undertake a more detailed level of modelling to model different system configurations (as with Proposition 1).

#### Proposition 3 recommendations

The outcome of Proposition 3 suggests that it is not a strong SLES candidate. Proposition 3 was shortlisted on the basis of identifying interconnected demand but was not realised during more detailed assessment. So, the proposition became less attractive under detailed scrutiny.

The optimised outcome of each scenario mainly consisted of a large capacity of solar PV that mainly exports its generation to the national grid for income. There is little to no district-level integration between the buildings heating systems and very limited interaction between the energy vectors.

It does however demonstrate the opportunity to increase local renewables but there is a need to understand the wider system constraints and connection cost implications for any specific site under consideration for new renewables development.

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# Appendices

Appendix A - Summary of key documents reviewed
Appendix B - Longlist of proposition cards
Appendix C - MCA report and SLES Decision Tree
Appendix D - Assumptions log
Appendix E - Decision making flowchart for Proposition 1
Appendix F - Updated MCA report for the propositions

MH2
ENERGY KINGDOM
DEYRNAS YNNI

# Appendix A - Summary of key documents reviewed

## Setting the broader context

ENERGY KINGDOM
DEYRNAS YNNI

# Appendix A - Summary of key documents reviewed

## Literature review

### Overview of literature review

At the project outset, we sought to gather as much background information and context for the local area as possible. The core findings from our literature review are presented below along with the relevance to the propositions.  Key policy documents appraised are outlined in Figure A.1.

### UK Committee on Climate Change

In 2019, the UK Committee on Climate Change (CCC) set out the need and ambition for the UK to have net-zero greenhouse gas emissions by 2050. the CCC recommended a Welsh greenhouse gas emissions reduction of 95% from 1990 levels. Welsh ministers set out the ambition to go beyond this target and align with the wider UK ambition of net-zero by 2050. In December 2020, the CCC endorsed this increased ambition. The CCC lists “transforming Wales’ buildings” as the top sectoral priority for achieving these targets including the need to move entirely to low carbon heating systems. It recommends low-carbon heat networks as one solution to achieving this.

### Welsh carbon targets

Alongside the carbon targets set out above, Welsh planning policy and the Wellbeing of Future Generations act sets an ambition for Wales to be prosperous, resilient and globally responsible.

### Welsh Government National Development Framework

In 2019, Welsh Government issued a draft version of their National Development Framework (NDF). This document sets out spatially, the areas for development across Wales between 2020 and 2040. We have reviewed the NDF in line with targeted area for wind, solar and district heating development. The Milford Haven project boundary does not feature within NDF priority areas however, the study highlights the importance of the Haven Waterway in the development of Wales: “The Haven Waterway has a unique combination of a natural harbour, long established industries and the potential for new strategic development. Development plans should recognise this and provide a framework for managing future growth.” The report also highlights that large scale mixed used development should, where feasible, have a district heating network.

### Pembrokeshire County Council targets

On May 9th 2019, Pembrokeshire County Council (PCC) declared a climate emergency and committed to a net zero carbon local authority by 2030.

### Implications

The policy context outlined highlights a clear drive for low and zero carbon solutions within the local area. This supports the prioritisation of low carbon technologies within a SLES design.



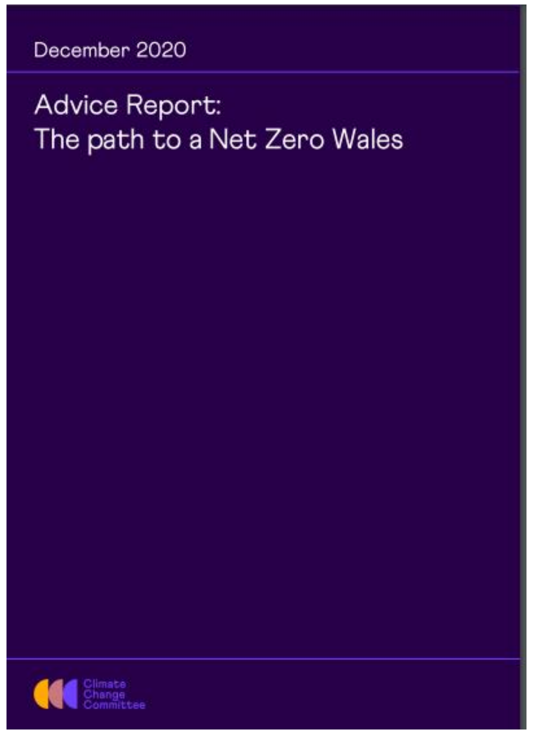


Figure A.1: Selection of key policy documents appraised

# Appendix A - Summary of key documents reviewed

## Literature review (continued)

### Scenario analysis

The future direction of the energy system, the energy mix and energy supply is uncertain. Any SLES identified through this project should therefore perform well when placed in the external context of a range of future energy system environments. Several studies (Figure A.2) explore the various driving factors and possible pathways. We reviewed these scenarios to inform the scenarios taken for analysis in this study.

### National Grid Future Energy Scenarios - 2020

National Grid annually publishes Future Energy Scenarios (FES) representing a range of different pathways to decarbonise the energy system. Due to the timing of our literature review and initial modelling, FES 2020 was reviewed for this project although more recent iterations are now available. FES presented four different scenarios based on speed of decarbonisation and level of societal change. A brief overview of each scenario is presented below:

- **Leading the Way:** This is the fastest credible decarbonisation pathway; it involves a significant level of consumer change and involves a mixture of hydrogen and electrification for heating.
- **Consumer Transformation:** This is a highly electrified option involving significant levels of energy efficiency improvement and demand side flexibility.
- **System Transformation:** This scenario relies primarily on hydrogen for heating with consumers less inclined to change behaviour and so any system flexibility tends to be supply side.
- **Steady Progression:** This is the only scenario that does not reach net-zero by 2050 and includes minimal behaviour change and decarbonisation in power and transport but not heat.

### Regen Net Zero South Wales 2050

In 2020 Regen published a Net Zero South Wales 2050 study for Wales and West Utilities and Western Power Distribution which took an integrated approach to gas and electricity scenario planning. It explored the following three options for net zero pathways:

- **High electrification:** Majority of domestic and commercial heat is electrified, and hydrogen is used for heavy transport and industrial uses.
- **Core hydrogen:** A hydrogen network replaces the current gas network in 2035 within the densest areas (covering approximately 57% of current connections) and any off-gas customers have electrified heating.
- **High hydrogen:** The majority of the gas network is converted to hydrogen from 2035 and off-gas customers have electrified heating.

### Implications

Comparing external scenario work, we complied a long list of potential energy system scenarios for the Milford Haven boundary considering different levels of electricity and hydrogen within the energy system. These scenarios are shown in Figure A.3 overleaf. We matched each of our identified scenarios against the most relevant FES and Regen scenarios. We then selected three scenarios to use for our analysis to best represent the technologies that could be included within the SLES and the external energy system:

- **High electricity:** In this scenario, electric heating technologies are prioritised and any hydrogen heating is limited.
- **Hybrid:** In this scenario, the system is able to meet energy demands with a range of vectors and technologies.
- **High hydrogen:** In this scenario, electric heating options are limited and hydrogen prioritised.

We also used the Leading the Way FES scenario to inform energy prices forecast for the techno-economic modelling, described in further detail in Section 8.


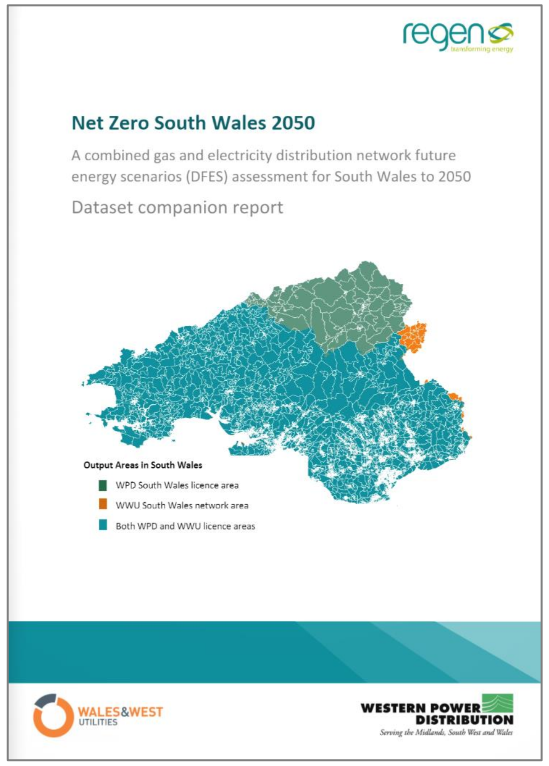


Figure A.2: Scenario documents appraised

# Appendix A - Summary of key documents reviewed

| | Scenario 1 – Low Electric : Low Hydrogen | Scenario 2 – High Electric | Scenario 3 – Medium Electric : Low Hydrogen | Scenario 4 – Balanced Electric : Green Hydrogen | Scenario 4A – Balanced Electric : Blue Hydrogen | Scenario 5 – Medium Hydrogen : Low Electric | Scenario 6 – High Green Hydrogen | Scenario 6A: High Blue Hydrogen |
|---|---|---|---|---|---|---|---|---|
| Electricity | Assumes current trajectory for migration to renewable electricity | Predominantly renewable electricity | Moderate transition to renewable electricity supply | Predominantly renewable electricity, curtailed electricity used to produce green hydrogen | Predominantly renewable electricity, curtailed electricity used to produce green hydrogen | Assumes current trajectory for migration to renewable electricity | Hydrogen generated through electrolysis and transported via hydrogen fuel cells | Fuel cells of hydrogen from SMR used to provide electricity |
| Heat | Heating largely natural gas with some heat pumps | Heating – air source heat pumps | Heating split between natural gas and heat pumps | Hybrid heating systems in on-gas homes, heat pumps in off-gas homes | Hybrid heating system optimising between renewable electricity, green hydrogen & blue hydrogen | Hydrogen heating in some pockets of the gas network | Green hydrogen and biomethane injected into all of the gas network, off-gas properties electric where possible | Blue hydrogen and biomethane injected into all of the gas network, off-gas properties electric where possible |
| Transport | Mix of EV & Diesel across personal, (PCC) & freight | EV Transport | Mainly EV vehicles for personal and public vehicles use however diesel remains across freight with some hydrogen adoption | Majority of personal vehicles are EV, public are a mix of EV and hydrogen and freight vehicles are hydrogen fuelled | Majority of personal vehicles are EV, public are a mix of EV and hydrogen and freight vehicles are hydrogen fuelled | A small number of EVs and hydrogen vehicles for personal use, public and freight vehicles are hydrogen | Fully hydrogen transport fleet | Fully hydrogen transport fleet |
| Industry | Industry – no substantial transition | Industrial processes powered by renewable electricity – some direct wire or on-site generation | Some migration to industry powered by electricity & to a less extent hydrogen use in industrial clusters | Industry relies on hydrogen mixed with biomethane | Industrial sites are used to produce green hydrogen via SMR | Some industry migrates to use of hydrogen as a fuel while the rest sees no substantial transition | Industrial processes are powered by hydrogen | Industrial sites are used to produce green hydrogen via SMR |
| | "Do Minimum" | Majority electric limited hydrogen in system | Integrated system with balance in favour of electric | Hydrogen and electric fully integrated in system – green hydrogen only | Hydrogen and electric fully integrated in system – green and blue hydrogen | Integrated system with balance in favour of hydrogen | Majority green hydrogen limited electric in system | Majority green and blue hydrogen limited electric in system |

Figure A.3: Arup scenario development

# Appendix A - Summary of key documents reviewed

## Literature review (continued)

### Cardiff University Smart Living Demonstrator study *[5]*

#### Overview of study

A 2020 study by Cardiff University on the development of a Low Carbon Zone around the Haven Waterway fed into the development of Proposition 1 - The Milford Haven Marina SLES.

The study assessed several energy generation combinations to inform a decarbonisation roadmap for the area whilst realising the expected rise in electrical and heat demand from 2020 to 2030. Alongside a business-as-usual strategy, three further options were assessed from a techno-economic and environmental perspective. These options had different combinations of solar PV, wind turbines, marine source heat pumps, natural gas and hydrogen fuel cell CHPs. Figure A.4 show the buildings included within this study and the output 2030 heat demand from the study.

#### Key findings

Of the options considered, the preferred energy solution included a combination of 5MW solar PV farm plus maximising rooftop solar PV, a 2.5MW wind turbine, a hydrogen fuel cell combined heat and power (CHP) system, and a marine source heat pump. This option maximised the utilisation of the existing, Port owned Liddeston Ridge solar farm via private wire. During the summer months, excess electricity generated was used to generate green hydrogen via electrolysis. The hydrogen acted as a long-term seasonal store of energy to be deployed in the winter months when solar generation was reduced.

#### Implications

The results have demonstrated that utilisation of local renewable energy resources can enable a path to net-zero carbon by 2030. Many of the recommendations made in the Cardiff University study were explored further within the analysis of Proposition 1 - The Milford Haven Marina SLES.

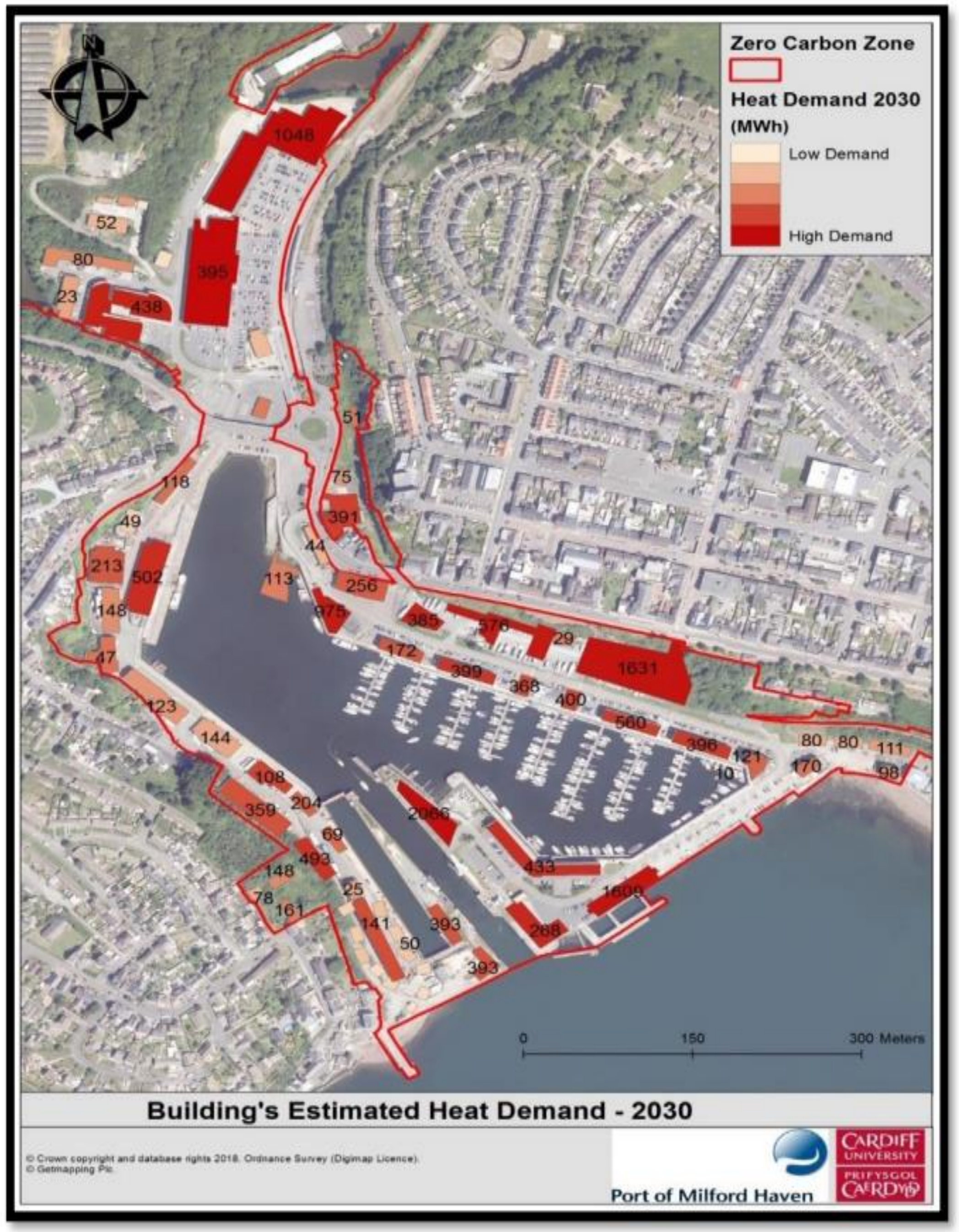


Figure A.4: Output future 2030 heat demands from the Cardiff University Smart Living Demonstrator study *[5]*

# Appendix B – Longlist of propositions

## Proposition summary cards for the longlist

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# Proposition 1-A - Milford Haven Heat Network and Microgrid

*Feasibility of developing a heat network and microgrid for Milford Marina for heat and power supply through electrolysis of excess energy from PoMH energy supply assets*

| Core Value | Potential Value | Core Supply (MW) | Core Supply (GWh/year) | Core Demand (GWh/year) |
|---|---|---|---|---|
| Provides more efficient & resilient local system | Enables development of additional renewables on the system | 16.9MW solar<br>2.5MW wind | 21.0 | 26.8 |


Liddestone Ridge
Conversion | Existing | Heat | Power | Proposed | Supply

PoMH Buildings rooftop solar
Heat | Power | Proposed | Supply

PoMH Buildings
Conversion | Demand | Existing | Heat | Power | Proposed

Proposition Elements

Criteria Satisfied

Time Horizon

2025 2030 2040 2050

Development Readiness Level

25% 50% 75% 100%

## VECTORS

POWER

HEAT

TRANSPORT

## NETWORK & TRANSMISSION SUMMARY

WPD DN

Potential for private wire connection

## OWNERSHIP OF ASSETS

PoMH

QUALITATIVE TRIAGE RAG MATRIX

| Criteria | Criteria Icon | Benefit | Constraint |
|---|---|---|---|
| **Key Objective:** Achieves emissions reductions, significant contribution to net-zero 2050 pathway | | | |
| **Key Objective:** Catalyst / First of a kind & supports future expansion *Potential to develop seed markets for hydrogen in the fields of heat, transport, gas & power.* | | | |
| **Key Objective:** Jobs & Prosperity *Stimulate growth in local community, Potential for job creation/upskilling, Decarbonises heating or transport for local community, Contribute to the alleviation of fuel poverty* | | | |
| **Key Objective:** Optimises social value (social, economic and environmental), in terms of the potential costs, benefits and risks | | | |
| **Key Objective:** Stakeholder / Community Acceptability & Awareness raising | | | |
| **Critical Success Factor:** Technical: Balance of supply & demand | | | |
| **Critical Success Factor:** Technical: Technology maturity *Existing vs novel technologies Supply chain - availability / investment required* | | | |
| **Critical Success Factor:** Contributes to Energy Resilience | | | |
| **Critical Success Factor:** Immediate Need / Opportunity Readiness | | | |
| **Critical Success Factor:** Commercial Opportunity | | | |
| **Critical Success Factor:** Commercial: Capex investment required | | | |
| **Critical Success Factor:** Investor Interest / Funding Streams | | | |
| **Critical Success Factor:** Complexity / Asset ownership / Number of parties | | | |
| **Critical Success Factor:** Policy & Regulatory Considerations | | | |
| **Critical Success Factor:** Development Risks & Scheme Constraints | | | |
| **Wider Benefits:** WFGA Goals *Prosperous / Resilient / Healthier / More equal / Cohesive communities / Vibrant culture / Globally responsible* | | | |
| **Wider Benefits:** WFGA Ways of Working *Long term / Prevention / Integration / Collaboration / Involvement* | | | |
| **Wider Benefits:** Waste Reduction / Circular Economy | | | |

KEY

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# Proposition 1-B: Milford Haven Comprehensive heat and power demand

*Feasibility of meeting the existing and future heat and power demand of the Milford Haven Comprehensive school by Hydrogen through electrolysis of excess energy from PCC and PoMH owned assets.*

| Core Value | Potential Value | Core Supply (MW) | Core Supply (GWh/year) | Core Demand (GWh/year) |
|---|---|---|---|---|
| Linking up local supply-demand, releasing grid capacity for future renewables development. | Greater renewables development - growth of SLES. | 10MW solar<br>2.5 MW wind | 14.8 | 1.4 |


Liddestone Ridge
Conversion | Existing | Heat | Power | Proposed | Supply

MH Comprehensive
Existing | Heat | Power | Proposed | Supply

MH Comprehensive
Demand | Existing | Heat | Power | Proposed

Proposition Elements

Criteria Satisfied

Time Horizon

2025 | 2030 | 2040 | 2050

Development Readiness Level

25% | 50% | 75% | 100%

## VECTORS

POWER

HEAT

TRANSPORT

## NETWORK & TRANSMISSION SUMMARY

Potential to isolate gas network connection to Milford Haven Comprehensive and replace with hydrogen connection (either via hydrogen pipeline or tanks).

## OWNERSHIP OF ASSETS

PCC and PoMH

QUALITATIVE TRIAGE RAG MATRIX

| Criteria | Criteria Icon | Benefit | Constraint |
|---|---|---|---|
| **Key Objective:** Achieves emissions reductions, significant contribution to net-zero 2050 pathway | | | |
| **Key Objective:** Catalyst / First of a kind & supports future expansion *Potential to develop seed markets for hydrogen in the fields of heat, transport, gas & power.* | | | |
| **Key Objective:** Jobs & Prosperity *Stimulate growth in local community, Potential for job creation/upskilling, Decarbonises heating or transport for local community, Contribute to the alleviation of fuel poverty* | | | |
| **Key Objective:** Optimises social value (social, economic and environmental), in terms of the potential costs, benefits and risks | | | |
| **Key Objective:** Stakeholder / Community Acceptability & Awareness raising | | Opportunity to demnstrate benefits through education | |
| **Critical Success Factor:** Technical: Balance of supply & demand | | | Supply could exceed demand significantly, at this scale is Hydrogen economical? |
| **Critical Success Factor:** Technical: Technology maturity *Existing vs novel technologies* *Supply chain - availability / investment required* | | | |
| **Critical Success Factor:** Contributes to Energy Resilience | | | |
| **Critical Success Factor:** Immediate Need / Opportunity Readiness | | Redevelopment - need to understand timeframe but proposed giving opportunity for move to zero carbon heating / power. | |
| **Critical Success Factor:** Commercial Opportunity | | | |
| **Critical Success Factor:** Commercial: Capex investment required | | | |
| **Critical Success Factor:** Investor Interest / Funding Streams | | | |
| **Critical Success Factor:** Complexity / Asset ownership / Number of parties | | | |
| **Critical Success Factor:** Policy & Regulatory Considerations | | | |
| **Critical Success Factor:** Development Risks & Scheme Constraints | | | |
| **Wider Benefits:** WFGA Goals *Prosperous / Resilient / Healthier / More equal / Cohesive communities / Vibrant culture / Globally responsible* | | | |
| **Wider Benefits:** WFGA Ways of Working *Long term / Prevention / Integration / Collaboration / Involvement* | | | |
| **Wider Benefits:** Waste Reduction / Circular Economy | | | |

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# Proposition 1-C - Milford Haven transport demand

*Feasibility of meeting the existing and future PCC and PoMH transport demand from Hydrogen through electrolysis of excess electricity from PCC and PoMH owned assets.*

| Core Value | Potential Value | Core Supply (MW) | Core Supply (GWh/year) | Core Demand (GWh/year) |
| --- | --- | --- | --- | --- |
| Transport considered most commercially viable across H and electric. | Transport hub - potential seed market. | 10MW solar<br>2.5MW wind | 14.8 | 2.1 |

Proposition Elements

Criteria Satisfied

Time Horizon

2025 2030 2040 2050

Development Readiness Level

25% 50% 75% 100%


Liddestone Ridge

Conversion | Existing | Heat | Power | Proposed | Supply

PCC & PoMH Transport fleet

Conversion | Demand | Proposed | Transport

## VECTORS

| | |
| --- | --- |
| POWER | ○ |
| HEAT | ○ |
| TRANSPORT | ● |

## NETWORK & TRANSMISSION SUMMARY

Hydrogen to be elctrolysed at renewable assets and transported by tanker to point of vehicle refuelling

## OWNERSHIP OF ASSETS

PCC & PoMH

QUALITATIVE TRIAGE RAG MATRIX

| Criteria | Criteria Icon | Benefit | Constraint |
| --- | --- | --- | --- |
| **Key Objective:** Achieves emissions reductions, significant contribution to net-zero 2050 pathway | | | |
| **Key Objective:** Catalyst / First of a kind & supports future expansion *Potential to develop seed markets for hydrogen in the fields of heat, transport, gas & power.* | | | |
| **Key Objective:** Jobs & Prosperity *Stimulate growth in local community, Potential for job creation/upskilling, Decarbonises heating or transport for local community, Contribute to the alleviation of fuel poverty* | | | |
| **Key Objective:** Optimises social value (social, economic and environmental), in terms of the potential costs, benefits and risks | | | |
| **Key Objective:** Stakeholder / Community Acceptability & Awareness raising | | | |
| **Critical Success Factor:** Technical: Balance of supply & demand | | | |
| **Critical Success Factor:** Technical: Technology maturity *Existing vs novel technologies Supply chain - availability / investment required* | | | |
| **Critical Success Factor:** Contributes to Energy Resilience | | | |
| **Critical Success Factor:** Immediate Need / Opportunity Readiness | | There may be an intermediate need to have electric vehicle fleet in the transition to Hydrogen vehicle fleet. Hydrogen for shipping is less ready considering refuelling of vessesl is usually done at different ports. | |
| **Critical Success Factor:** Commercial Opportunity | | | |
| **Critical Success Factor:** Commercial: Capex investment required | | | |
| **Critical Success Factor:** Investor Interest / Funding Streams | | | |
| **Critical Success Factor:** Complexity / Asset ownership / Number of parties | | | Opportunity to expand to vessel/hydrogen for shipping and individual/public transport demand but with asset ownership complexities |
| **Critical Success Factor:** Policy & Regulatory Considerations | | | |
| **Critical Success Factor:** Development Risks & Scheme Constraints | | | |
| **Wider Benefits:** WFGA Goals *Prosperous / Resilient / Healthier / More equal / Cohesive communities / Vibrant culture / Globally responsible* | | | |
| **Wider Benefits:** WFGA Ways of Working *Long term / Prevention / Integration / Collaboration / Involvement* | | | |
| **Wider Benefits:** Waste Reduction / Circular Economy | | | |

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# Proposition 1-D - PCC Recycling Facility

*This proposition integrates a proposed recycling centre at the current Milford Haven Puma Energy site with existing local renewable energy supplies.*

| Core Value | Potential Value | Core Supply (MW) | Core Supply (GWh/year) | Core Demand (GWh/year) |
|---|---|---|---|---|
| | | | | |


Liddestone Ridge

Conversion | Existing | Heat | Power | Proposed | Supply

Proposition Elements

Criteria Satisfied

Time Horizon

2025 | 2030 | 2040 | 2050

Development Readiness Level

25% | 50% | 75% | 100%

## VECTORS

POWER

HEAT

TRANSPORT

## NETWORK & TRANSMISSION SUMMARY

Hydrogen to be elctrolysed at renewable assets and transported by tanker to point of vehicle refuelling

## OWNERSHIP OF ASSETS

PCC & PoMH

QUALITATIVE TRIAGE RAG MATRIX

| Criteria | Criteria Icon | Benefit | Constraint |
|---|---|---|---|
| **Key Objective:** Achieves emissions reductions, significant contribution to net-zero 2050 pathway | | | |
| **Key Objective:** Catalyst / First of a kind & supports future expansion *Potential to develop seed markets for hydrogen in the fields of heat, transport, gas & power.* | | | |
| **Key Objective:** Jobs & Prosperity *Stimulate growth in local community, Potential for job creation/upskilling, Decarbonises heating or transport for local community, Contribute to the alleviation of fuel poverty* | | | |
| **Key Objective:** Optimises social value (social, economic and environmental), in terms of the potential costs, benefits and risks | | | |
| **Key Objective:** Stakeholder / Community Acceptability & Awareness raising | | | |
| **Critical Success Factor:** Technical: Balance of supply & demand | | | |
| **Critical Success Factor:** Technical: Technology maturity *Existing vs novel technologies Supply chain - availability / investment required* | | | |
| **Critical Success Factor:** Contributes to Energy Resilience | | | |
| **Critical Success Factor:** Immediate Need / Opportunity Readiness | | | |
| **Critical Success Factor:** Commercial Opportunity | | | |
| **Critical Success Factor:** Commercial: Capex investment required | | | |
| **Critical Success Factor:** Investor Interest / Funding Streams | | | |
| **Critical Success Factor:** Complexity / Asset ownership / Number of parties | | | |
| **Critical Success Factor:** Policy & Regulatory Considerations | | | |
| **Critical Success Factor:** Development Risks & Scheme Constraints | | | |
| **Wider Benefits:** WFGA Goals *Prosperous / Resilient / Healthier / More equal / Cohesive communities / Vibrant culture / Globally responsible* | | | |
| **Wider Benefits:** WFGA Ways of Working *Long term / Prevention / Integration / Collaboration / Involvement* | | | |
| **Wider Benefits:** Waste Reduction / Circular Economy | | | |

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|---|---|---|

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# Proposition 2-A - Haverfordwest High School (Prendergast and Portfield Campus)

*Meeting power demand of Haverfordwest High School campuses from nearby renewable energy assets and heat demand through the electrolysis of excess renewable energy.*

| Core Value | Potential Value | Core Supply (MW) | Core Supply (GWh/year) | Core Demand (GWh/year) |
|---|---|---|---|---|
| Redevelopment opportunity & stepping stone to wider cluster. | | 65MW solar | 58.1 | 3.7 |


Proposition Elements

Criteria Satisfied

Time Horizon

2025 2030 2040 2050

Development Readiness Level

25% 50% 75% 100%

## VECTORS

POWER

HEAT

TRANSPORT

## NETWORK & TRANSMISSION SUMMARY

## OWNERSHIP OF ASSETS

Demand assets PCC ownership
Multiple supply assets private owners

QUALITATIVE TRIAGE RAG MATRIX

| Criteria | Criteria Icon | Benefit | Constraint |
|---|---|---|---|
| **Key Objective:** Achieves emissions reductions, significant contribution to net-zero 2050 pathway | | | |
| **Key Objective:** Catalyst / First of a kind & supports future expansion *Potential to develop seed markets for hydrogen in the fields of heat, transport, gas & power.* | | | |
| **Key Objective:** Jobs & Prosperity *Stimulate growth in local community, Potential for job creation/upskilling, Decarbonises heating or transport for local community, Contribute to the alleviation of fuel poverty* | | | |
| **Key Objective:** Optimises social value (social, economic and environmental), in terms of the potential costs, benefits and risks | | | |
| **Key Objective:** Stakeholder / Community Acceptability & Awareness raising | | | |
| **Critical Success Factor:** Technical: Balance of supply & demand | | | |
| **Critical Success Factor:** Technical: Technology maturity *Existing vs novel technologies* *Supply chain - availability / investment required* | | | |
| **Critical Success Factor:** Contributes to Energy Resilience | | Multiple independent energy supply points | |
| **Critical Success Factor:** Immediate Need / Opportunity Readiness | | High School - need to understand timeframe and scale of proposed works, giving opportunity to move to zero carbon heating / power as well as more low carbon energy generation. | |
| **Critical Success Factor:** Commercial Opportunity | | | |
| **Critical Success Factor:** Commercial: Capex investment required | | | |
| **Critical Success Factor:** Investor Interest / Funding Streams | | | |
| **Critical Success Factor:** Complexity / Asset ownership / Number of parties | | Multiple Renewables asset owners | |
| **Critical Success Factor:** Policy & Regulatory Considerations | | | |
| **Critical Success Factor:** Development Risks & Scheme Constraints | | | |
| **Wider Benefits:** WFGA Goals *Prosperous / Resilient / Healthier / More equal / Cohesive communities / Vibrant culture / Globally responsible* | | Local and multiple energy supply points. | |
| **Wider Benefits:** WFGA Ways of Working *Long term / Prevention / Integration / Collaboration / Involvement* | | | |
| **Wider Benefits:** Waste Reduction / Circular Economy | | | |

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# Proposition 2-B - Haverfordwest Hospitals (BroCerwyn and Whitybush)

*Providing Hydrogen for heat and transport demand as well as potential oxygen demand for Haverfordwest hospitals through the electrolysis of excess renewable energy from nearby assets.*

| Core Value | Potential Value | Core Supply (MW) | Core Supply (GWh/year) | Core Demand (GWh/year) |
|---|---|---|---|---|
| Integration of multiple vectors. | | 59MW solar<br>2MW wind | 56.4 | 20.8 |


Proposition Elements

$O_2$

Criteria Satisfied

Time Horizon

2025 2030 2040 2050

Development Readiness Level

25% 50% 75% 100%

## VECTORS

POWER

HEAT

TRANSPORT

## NETWORK & TRANSMISSION SUMMARY

Hydrogen delivered via tanker to hospital and ambulance base sites

## OWNERSHIP OF ASSETS

Demand assets PCC & NHS ownership. Welsh Water required further engagement for potential transport demand

Multiple supply assets private owners

QUALITATIVE TRIAGE RAG MATRIX

| Criteria | Criteria Icon | Benefit | Constraint |
|---|---|---|---|
| **Key Objective:** Achieves emissions reductions, significant contribution to net-zero 2050 pathway | | | |
| **Key Objective:** Catalyst / First of a kind & supports future expansion *Potential to develop seed markets for hydrogen in the fields of heat, transport, gas & power.* | | Using oxygen for hospital demand is an opportunity to reap more benefits from electrolysis | |
| **Key Objective:** Jobs & Prosperity *Stimulate growth in local community, Potential for job creation/upskilling, Decarbonises heating or transport for local community, Contribute to the alleviation of fuel poverty* | | | |
| **Key Objective:** Optimises social value (social, economic and environmental), in terms of the potential costs, benefits and risks | | | |
| **Key Objective:** Stakeholder / Community Acceptability & Awareness raising | | | |
| **Critical Success Factor:** Technical: Balance of supply & demand | | | |
| **Critical Success Factor:** Technical: Technology maturity *Existing vs novel technologies Supply chain - availability / investment required* | | | Are there any additional processes to ensure oxygen from electolysis can be used for medical purposes? |
| **Critical Success Factor:** Contributes to Energy Resilience | | | |
| **Critical Success Factor:** Immediate Need / Opportunity Readiness | | | |
| **Critical Success Factor:** Commercial Opportunity | | | |
| **Critical Success Factor:** Commercial: Capex investment required | | | |
| **Critical Success Factor:** Investor Interest / Funding Streams | | | |
| **Critical Success Factor:** Complexity / Asset ownership / Number of parties | | Multiple supply and demand assets owners | |
| **Critical Success Factor:** Policy & Regulatory Considerations | | | Regulation around medical use of oxygen |
| **Critical Success Factor:** Development Risks & Scheme Constraints | | | |
| **Wider Benefits:** WFGA Goals *Prosperous / Resilient / Healthier / More equal / Cohesive communities / Vibrant culture / Globally responsible* | | | |
| **Wider Benefits:** WFGA Ways of Working *Long term / Prevention / Integration / Collaboration / Involvement* | | | |
| **Wider Benefits:** Waste Reduction / Circular Economy | | | |

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# Proposition 2-C - Haverfordwest Creamery

Meeting heat demand of Haverfordwest creamery using hydrogen from biomass conversion of sewage sludge and power demand from nearby renewable energy assets.

| Core Value | Potential Value | Core Supply (MW) | Core Supply (GWh/year) | Core Demand (GWh/year) |
|---|---|---|---|---|
| Integration of multiple vectors. | | 23MW solar | 20.6 | 3.3 |


Proposition Elements

Criteria Satisfied

Time Horizon

2025 2030 2040 2050

Development Readiness Level

25% 50% 75% 100%

## VECTORS

POWER

HEAT

TRANSPORT

## NETWORK & TRANSMISSION SUMMARY

Hydrogen delivered by tanker or hydrogen pipelines from point of electrolysis to demand centres

## OWNERSHIP OF ASSETS

PCC owned housing
Creamery is privately owned (First Milk)
Multiple supply asset private owners
Sewage water treatment owned by Welsh Water

QUALITATIVE TRIAGE RAG MATRIX

| Criteria | Criteria Icon | Benefit | Constraint |
|---|---|---|---|
| **Key Objective:** Achieves emissions reductions, significant contribution to net-zero 2050 pathway | | | |
| **Key Objective:** Catalyst / First of a kind & supports future expansion *Potential to develop seed markets for hydrogen in the fields of heat, transport, gas & power.* | | | |
| **Key Objective:** Jobs & Prosperity *Stimulate growth in local community, Potential for job creation/upskilling, Decarbonises heating or transport for local community, Contribute to the alleviation of fuel poverty* | | | |
| **Key Objective:** Optimises social value (social, economic and environmental), in terms of the potential costs, benefits and risks | | | |
| **Key Objective:** Stakeholder / Community Acceptability & Awareness raising | | | |
| **Critical Success Factor:** Technical: Balance of supply & demand | | | |
| **Critical Success Factor:** Technical: Technology maturity *Existing vs novel technologies Supply chain - availability / investment required* | | | |
| **Critical Success Factor:** Contributes to Energy Resilience | | | |
| **Critical Success Factor:** Immediate Need / Opportunity Readiness | | | |
| **Critical Success Factor:** Commercial Opportunity | | | |
| **Critical Success Factor:** Commercial: Capex investment required | | | |
| **Critical Success Factor:** Investor Interest / Funding Streams | | | |
| **Critical Success Factor:** Complexity / Asset ownership / Number of parties | | | |
| **Critical Success Factor:** Policy & Regulatory Considerations | | | |
| **Critical Success Factor:** Development Risks & Scheme Constraints | | | |
| **Wider Benefits:** WFGA Goals *Prosperous / Resilient / Healthier / More equal / Cohesive communities / Vibrant culture / Globally responsible* | | | |
| **Wider Benefits:** WFGA Ways of Working *Long term / Prevention / Integration / Collaboration / Involvement* | | | |
| **Wider Benefits:** Waste Reduction / Circular Economy | | | |

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# Proposition 2-D - Bolton Hill Water Treatment Works Oxygen demand

*Proposition to supply oxygen to the Bolton Hill sewage water treatment works through the electrolysis of excess energy from nearby renewable assets.*

| Core Value | Potential Value | Core Supply (MW) | Core Supply (GWh/year) | Core Demand (GWh/year) |
|---|---|---|---|---|
| Integration of multiple vectors. | | 23MW solar<br>2MW wind | 51.2 | 3.3 |


Proposition Elements

Criteria Satisfied

Time Horizon

2025 2030 2040 2050

Development Readiness Level

25% 50% 75% 100%

## VECTORS

POWER

HEAT

TRANSPORT

## NETWORK & TRANSMISSION SUMMARY

Hydrogen delivered by tanker or hydrogen pipelines from point of electrolysis to demand centres

## OWNERSHIP OF ASSETS

PCC owned housing

Creamery is privately owned (First Milk).

Water treatment works owned by Welsh Water

Multiple supply asset private owners

QUALITATIVE TRIAGE RAG MATRIX

| Criteria | Criteria Icon | Benefit | Constraint |
|---|---|---|---|
| **Key Objective:** Achieves emissions reductions, significant contribution to net-zero 2050 pathway | | | |
| **Key Objective:** Catalyst / First of a kind & supports future expansion<br>*Potential to develop seed markets for hydrogen in the fields of heat, transport, gas & power.* | | Using oxygen for hospital demand is an opportunity to reap more benefits from electrolysis | |
| **Key Objective:** Jobs & Prosperity<br>*Stimulate growth in local community, Potential for job creation/upskilling, Decarbonises heating or transport for local community, Contribute to the alleviation of fuel poverty* | | | |
| **Key Objective:** Optimises social value (social, economic and environmental), in terms of the potential costs, benefits and risks | | | |
| **Key Objective:** Stakeholder / Community Acceptability & Awareness raising | | | |
| **Critical Success Factor:** Technical: Balance of supply & demand | | | |
| **Critical Success Factor:** Technical: Technology maturity<br>*Existing vs novel technologies*<br>*Supply chain - availability / investment required* | | | Are there any additional processes to for use of oxygen for water treatment works? |
| **Critical Success Factor:** Contributes to Energy Resilience | | | |
| **Critical Success Factor:** Immediate Need / Opportunity Readiness | | | |
| **Critical Success Factor:** Commercial Opportunity | | | |
| **Critical Success Factor:** Commercial: Capex investment required | | | |
| **Critical Success Factor:** Investor Interest / Funding Streams | | | |
| **Critical Success Factor:** Complexity / Asset ownership / Number of parties | | | |
| **Critical Success Factor:** Policy & Regulatory Considerations | | | |
| **Critical Success Factor:** Development Risks & Scheme Constraints | | | |
| **Wider Benefits:** WFGA Goals<br>*Prosperous / Resilient / Healthier / More equal / Cohesive communities / Vibrant culture / Globally responsible* | | | |
| **Wider Benefits:** WFGA Ways of Working<br>*Long term / Prevention / Integration / Collaboration / Involvement* | | | |
| **Wider Benefits:** Waste Reduction / Circular Economy | | | |

KEY

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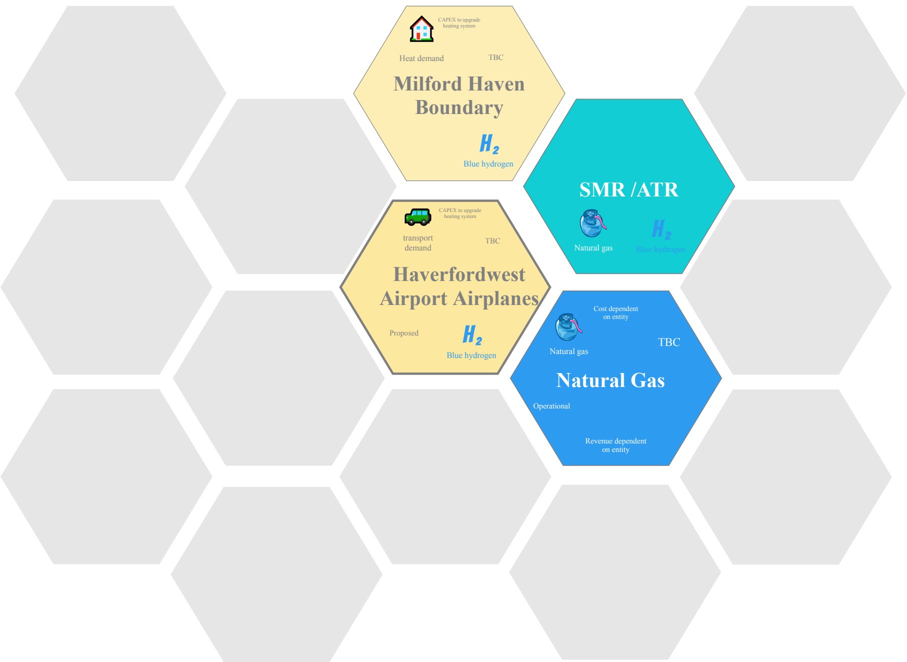
# Proposition 2-E - Haverfordwest Airport airplane (transport) demand

*Longer term proposition to supply blue hydrogen for airplane refuelling at Haverfordwest airport and general heat demand within the MH boundary through reformation of natural gas*

| Core Value | Potential Value | Core Supply (MW) | Core Supply (GWh/year) | Core Demand (GWh/year) |
|---|---|---|---|---|
| | Future transport opportunity. | | | |




Proposition Elements

Criteria Satisfied

Time Horizon

2025 2030 2040 2050

Development Readiness Level

25% 50% 75% 100%

## VECTORS

POWER

HEAT

TRANSPORT

## NETWORK & TRANSMISSION SUMMARY

Milford Haven boundary is isolated and gas network is reconfigured to become an isolated hydrogen distribution network.

## OWNERSHIP OF ASSETS

Complex asset ownership including industrial, commercial and residential for the future heat demand of MH

QUALITATIVE TRIAGE RAG MATRIX

| Criteria | Criteria Icon | Benefit | Constraint |
|---|---|---|---|
| **Key Objective:** Achieves emissions reductions, significant contribution to net-zero 2050 pathway | | | |
| **Key Objective:** Catalyst / First of a kind & supports future expansion *Potential to develop seed markets for hydrogen in the fields of heat, transport, gas & power.* | | | |
| **Key Objective:** Jobs & Prosperity *Stimulate growth in local community, Potential for job creation/upskilling, Decarbonises heating or transport for local community, Contribute to the alleviation of fuel poverty* | | | |
| **Key Objective:** Optimises social value (social, economic and environmental), in terms of the potential costs, benefits and risks | | | |
| **Key Objective:** Stakeholder / Community Acceptability & Awareness raising | | | |
| **Critical Success Factor:** Technical: Balance of supply & demand | | | |
| **Critical Success Factor:** Technical: Technology maturity *Existing vs novel technologies Supply chain - availability / investment required* | | | |
| **Critical Success Factor:** Contributes to Energy Resilience | | | |
| **Critical Success Factor:** Immediate Need / Opportunity Readiness | | | |
| **Critical Success Factor:** Commercial Opportunity | | | |
| **Critical Success Factor:** Commercial: Capex investment required | | | |
| **Critical Success Factor:** Investor Interest / Funding Streams | | | |
| **Critical Success Factor:** Complexity / Asset ownership / Number of parties | | | |
| **Critical Success Factor:** Policy & Regulatory Considerations | | | |
| **Critical Success Factor:** Development Risks & Scheme Constraints | | | |
| **Wider Benefits:** WFGA Goals *Prosperous / Resilient / Healthier / More equal / Cohesive communities / Vibrant culture / Globally responsible* | | | |
| **Wider Benefits:** WFGA Ways of Working *Long term / Prevention / Integration / Collaboration / Involvement* | | | |
| **Wider Benefits:** Waste Reduction / Circular Economy | | | |

KEY

| | | |
|---|---|---|
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# Proposition 2-F - Riverside Shopping Centre

*Proposition to provide heat and power to Riverside Shopping Centre in Haverfordwest. This will most likely be via a microgrid due to current electric heating infrastructure.*

| Core Value | Potential Value | Core Supply (MW) | Core Supply (GWh/year) | Core Demand (GWh/year) |
|---|---|---|---|---|
| | | | | |


Proposition Elements

Criteria Satisfied

Time Horizon

2025 2030 2040 2050

Development Readiness Level

25% 50% 75% 100%

## VECTORS

POWER

HEAT

TRANSPORT

## NETWORK & TRANSMISSION SUMMARY

Hydrogen produced on site or delivered by tanker or hydrogen pipelines from point of electrolysis to demand centres

## OWNERSHIP OF ASSETS

PCC owned housing and shopping centre however, multiple tenants within shopping centre

Water vehicle hub owned by Welsh Water

Multiple supply asset private owners

QUALITATIVE TRIAGE RAG MATRIX

| Criteria | Criteria Icon | Benefit | Constraint |
|---|---|---|---|
| **Key Objective:** Achieves emissions reductions, significant contribution to net-zero 2050 pathway | | | |
| **Key Objective:** Catalyst / First of a kind & supports future expansion *Potential to develop seed markets for hydrogen in the fields of heat, transport, gas & power.* | | | |
| **Key Objective:** Jobs & Prosperity *Stimulate growth in local community, Potential for job creation/upskilling, Decarbonises heating or transport for local community, Contribute to the alleviation of fuel poverty* | | | |
| **Key Objective:** Optimises social value (social, economic and environmental), in terms of the potential costs, benefits and risks | | | |
| **Key Objective:** Stakeholder / Community Acceptability & Awareness raising | | | |
| **Critical Success Factor:** Technical: Balance of supply & demand | | | |
| **Critical Success Factor:** Technical: Technology maturity *Existing vs novel technologies Supply chain - availability / investment required* | | | |
| **Critical Success Factor:** Contributes to Energy Resilience | | | |
| **Critical Success Factor:** Immediate Need / Opportunity Readiness | | | |
| **Critical Success Factor:** Commercial Opportunity | | | |
| **Critical Success Factor:** Commercial: Capex investment required | | | |
| **Critical Success Factor:** Investor Interest / Funding Streams | | | |
| **Critical Success Factor:** Complexity / Asset ownership / Number of parties | | | |
| **Critical Success Factor:** Policy & Regulatory Considerations | | | |
| **Critical Success Factor:** Development Risks & Scheme Constraints | | | Risks due to requirement of river crossing |
| **Wider Benefits:** WFGA Goals *Prosperous / Resilient / Healthier / More equal / Cohesive communities / Vibrant culture / Globally responsible* | | | |
| **Wider Benefits:** WFGA Ways of Working *Long term / Prevention / Integration / Collaboration / Involvement* | | | |
| **Wider Benefits:** Waste Reduction / Circular Economy | | | Would need to replace all electrical heating systems which would increase waste |

KEY

| | | |
|---|---|---|
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ARUP

MH2 ENERGY KINGDOM DEYRNAS YNNI

# Proposition 2-G - Pembrokeshire Food Park

Electricity from the nearby airport is used to create hydrogen to power freight from Pembrokeshire Food Park.

| Core Value | Potential Value | Core Supply (MW) | Core Supply (GWh/year) | Core Demand (GWh/year) |
|---|---|---|---|---|
| | | | | |


Proposition Elements

Criteria Satisfied

Time Horizon

2025 2030 2040 2050

Development Readiness Level

25% 50% 75% 100%

## VECTORS

POWER

HEAT

TRANSPORT

## NETWORK & TRANSMISSION SUMMARY

Private wire or new hydrogen pipes used to transport energy from airport to nearby food park. Potential for hydrogen to be tankered to Creamery.

## OWNERSHIP OF ASSETS

QUALITATIVE TRIAGE RAG MATRIX

| Criteria | Criteria Icon | Benefit | Constraint |
|---|---|---|---|
| **Key Objective:** Achieves emissions reductions, significant contribution to net-zero 2050 pathway | | | |
| **Key Objective:** Catalyst / First of a kind & supports future expansion *Potential to develop seed markets for hydrogen in the fields of heat, transport, gas & power.* | | | |
| **Key Objective:** Jobs & Prosperity *Stimulate growth in local community, Potential for job creation/upskilling, Decarbonises heating or transport for local community, Contribute to the alleviation of fuel poverty* | | | |
| **Key Objective:** Optimises social value (social, economic and environmental), in terms of the potential costs, benefits and risks | | | |
| **Key Objective:** Stakeholder / Community Acceptability & Awareness raising | | | |
| **Critical Success Factor:** Technical: Balance of supply & demand | | | |
| **Critical Success Factor:** Technical: Technology maturity *Existing vs novel technologies Supply chain - availability / investment required* | | | |
| **Critical Success Factor:** Contributes to Energy Resilience | | | |
| **Critical Success Factor:** Immediate Need / Opportunity Readiness | | | |
| **Critical Success Factor:** Commercial Opportunity | | | |
| **Critical Success Factor:** Commercial: Capex investment required | | | |
| **Critical Success Factor:** Investor Interest / Funding Streams | | | |
| **Critical Success Factor:** Complexity / Asset ownership / Number of parties | | | |
| **Critical Success Factor:** Policy & Regulatory Considerations | | | |
| **Critical Success Factor:** Development Risks & Scheme Constraints | | | |
| **Wider Benefits:** WFGA Goals *Prosperous / Resilient / Healthier / More equal / Cohesive communities / Vibrant culture / Globally responsible* | | | |
| **Wider Benefits:** WFGA Ways of Working *Long term / Prevention / Integration / Collaboration / Involvement* | | | |
| **Wider Benefits:** Waste Reduction / Circular Economy | | | |

KEY

| | | |
|---|---|---|
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ARUP

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# Proposition 3 - Pembroke Schools & Leisure (Henry Tudor, Pembroke Dock Community & Pembroke Leisure Centre)

*Feasibility of meeting the existing and future heat and power demand of existing PCC school & leisure assets from renewable assets and by Hydrogen through electrolysis of excess energy.*

| Core Value | Potential Value | Core Supply (MW) | Core Supply (GWh/year) | Core Demand (GWh/year) |
|---|---|---|---|---|
| Significant local renewables, increasing localised use. | Relieving network locally creates greater opportunity for renewables development. | 44MW solar | 38.9 | 2.0 |


Proposition Elements

Criteria Satisfied

Time Horizon

2025 2030 2040 2050

Development Readiness Level

25% 50% 75% 100%

## VECTORS

POWER

HEAT

TRANSPORT

## NETWORK & TRANSMISSION SUMMARY

Hydrogen delivered by tanker or hydrogen pipelines from point of electrolysis to demand centres

## OWNERSHIP OF ASSETS

PCC owned demand assets
PCC owned supply asset with potential for expansion
Multiple other supply assets, private owners

QUALITATIVE TRIAGE RAG MATRIX

| Criteria | Criteria Icon | Benefit | Constraint |
|---|---|---|---|
| **Key Objective:** Achieves emissions reductions, significant contribution to net-zero 2050 pathway | | | |
| **Key Objective:** Catalyst / First of a kind & supports future expansion *Potential to develop seed markets for hydrogen in the fields of heat, transport, gas & power.* | | | |
| **Key Objective:** Jobs & Prosperity *Stimulate growth in local community, Potential for job creation/upskilling, Decarbonises heating or transport for local community, Contribute to the alleviation of fuel poverty* | | | |
| **Key Objective:** Optimises social value (social, economic and environmental), in terms of the potential costs, benefits and risks | | | |
| **Key Objective:** Stakeholder / Community Acceptability & Awareness raising | | | |
| **Critical Success Factor:** Technical: Balance of supply & demand | | | |
| **Critical Success Factor:** Technical: Technology maturity *Existing vs novel technologies Supply chain - availability / investment required* | | | |
| **Critical Success Factor:** Contributes to Energy Resilience | | | |
| **Critical Success Factor:** Immediate Need / Opportunity Readiness | | | |
| **Critical Success Factor:** Commercial Opportunity | | | |
| **Critical Success Factor:** Commercial: Capex investment required | | | |
| **Critical Success Factor:** Investor Interest / Funding Streams | | | |
| **Critical Success Factor:** Complexity / Asset ownership / Number of parties | | | |
| **Critical Success Factor:** Policy & Regulatory Considerations | | | |
| **Critical Success Factor:** Development Risks & Scheme Constraints | | | |
| **Wider Benefits:** WFGA Goals *Prosperous / Resilient / Healthier / More equal / Cohesive communities / Vibrant culture / Globally responsible* | | | |
| **Wider Benefits:** WFGA Ways of Working *Long term / Prevention / Integration / Collaboration / Involvement* | | | |
| **Wider Benefits:** Waste Reduction / Circular Economy | | | |

KEY

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|---|---|---|

ARUP

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# Proposition 4-A - Industrial scale H2 Hub, Pembroke & Milford Haven

*Transition of the Haven waterway industrial energy sector towards being a major UK H and CO2 hub. Includes H production, storage, import/export and CO2 storage and export in the longer term.*

| Core Value | Potential Value | Core Capacity | Potential Capacity | Core Demand | Potential Demand |
|---|---|---|---|---|---|
| Provides transition for existing industry and job security. | MH as UK H Hub - creating greater regional prosperity & job growth. | | | | |


Proposition Elements

Criteria Satisfied

Time Horizon

2025 2030 2040 2050

Development Readiness Level

25% 50% 75% 100%

## VECTORS

POWER

HEAT

TRANSPORT

## NETWORK & TRANSMISSION SUMMARY

Hydrogen and natural gas pipelines into the port area, hydrogen pipelines or repurposed gas network to transport hydrogen to point of use

## OWNERSHIP OF ASSETS

Valero
Dragon LNG
RWE
Blue Gem Wind

QUALITATIVE TRIAGE RAG MATRIX

| Criteria | Criteria Icon | Benefit | Constraint |
|---|---|---|---|
| **Key Objective:** Achieves emissions reductions, significant contribution to net-zero 2050 pathway | | | |
| **Key Objective:** Catalyst / First of a kind & supports future expansion *Potential to develop seed markets for hydrogen in the fields of heat, transport, gas & power.* | | | |
| **Key Objective:** Jobs & Prosperity *Stimulate growth in local community, Potential for job creation/upskilling, Decarbonises heating or transport for local community, Contribute to the alleviation of fuel poverty* | | Securing jobs for the Hydrocarbon workforce | |
| **Key Objective:** Optimises social value (social, economic and environmental), in terms of the potential costs, benefits and risks | | | |
| **Key Objective:** Stakeholder / Community Acceptability & Awareness raising | | | |
| **Critical Success Factor:** Technical: Balance of supply & demand | | | |
| **Critical Success Factor:** Technical: Technology maturity *Existing vs novel technologies Supply chain - availability / investment required* | | | |
| **Critical Success Factor:** Contributes to Energy Resilience | | | |
| **Critical Success Factor:** Immediate Need / Opportunity Readiness | | | |
| **Critical Success Factor:** Commercial Opportunity | | | |
| **Critical Success Factor:** Commercial: Capex investment required | | | |
| **Critical Success Factor:** Investor Interest / Funding Streams | | | |
| **Critical Success Factor:** Complexity / Asset ownership / Number of parties | | | |
| **Critical Success Factor:** Policy & Regulatory Considerations | | | |
| **Critical Success Factor:** Development Risks & Scheme Constraints | | | |
| **Wider Benefits:** WFGA Goals *Prosperous / Resilient / Healthier / More equal / Cohesive communities / Vibrant culture / Globally responsible* | | | |
| **Wider Benefits:** WFGA Ways of Working *Long term / Prevention / Integration / Collaboration / Involvement* | | | |
| **Wider Benefits:** Waste Reduction / Circular Economy | | | |

KEY

| | | |
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ARUP

MH2 ENERGY KINGDOM DEYRNAS YNNI

# Proposition 4-B Pembroke SLES inc. industrial scale H2 Hub

*Transition of the Pembroke area to a smart interconnected local system balancing electric or hydrogen supply based on availability & seasonality. Import of green H for UK transmission.*

| Core Value | Potential Value | Core Capacity | Potential Capacity | Core Demand | Potential Demand |
|---|---|---|---|---|---|
| Provides stimulus for greater renewables deployment, contributing beyond MH. | Green recovery / growth & replicable model. | | | | |


Proposition Elements

Criteria Satisfied

Time Horizon

2025 2030 2040 2050

Development Readiness Level

25% 50% 75% 100%

## VECTORS

POWER

HEAT

TRANSPORT

## NETWORK & TRANSMISSION

Greenlink Interconnector

Upgrade of DN locally to enable better use / balancing of additional renewables

H international import / national export as UK hub

## OWNERSHIP OF ASSETS

Valero

Dragon LNG

RWE

Blue Gem Wind

QUALITATIVE TRIAGE RAG MATRIX

| Criteria | Criteria Icon | Benefit | Constraint |
|---|---|---|---|
| **Key Objective:** Achieves emissions reductions, significant contribution to net-zero 2050 pathway | | | Is the energy supplied from RWE power station low carbon? |
| **Key Objective:** Catalyst / First of a kind & supports future expansion *Potential to develop seed markets for hydrogen in the fields of heat, transport, gas & power.* | | | |
| **Key Objective:** Jobs & Prosperity *Stimulate growth in local community, Potential for job creation/upskilling, Decarbonises heating or transport for local community, Contribute to the alleviation of fuel poverty* | | | |
| **Key Objective:** Optimises social value (social, economic and environmental), in terms of the potential costs, benefits and risks | | | |
| **Key Objective:** Stakeholder / Community Acceptability & Awareness raising | | | |
| **Critical Success Factor:** Technical: Balance of supply & demand | | | |
| **Critical Success Factor:** Technical: Technology maturity *Existing vs novel technologies Supply chain - availability / investment required* | | | |
| **Critical Success Factor:** Contributes to Energy Resilience | | | |
| **Critical Success Factor:** Immediate Need / Opportunity Readiness | | | |
| **Critical Success Factor:** Commercial Opportunity | | | |
| **Critical Success Factor:** Commercial: Capex investment required | | | |
| **Critical Success Factor:** Investor Interest / Funding Streams | | | |
| **Critical Success Factor:** Complexity / Asset ownership / Number of parties | | | |
| **Critical Success Factor:** Policy & Regulatory Considerations | | | |
| **Critical Success Factor:** Development Risks & Scheme Constraints | | | |
| **Wider Benefits:** WFGA Goals *Prosperous / Resilient / Healthier / More equal / Cohesive communities / Vibrant culture / Globally responsible* | | | |
| **Wider Benefits:** WFGA Ways of Working *Long term / Prevention / Integration / Collaboration / Involvement* | | | |
| **Wider Benefits:** Waste Reduction / Circular Economy | | | |

KEY

| | | |
|---|---|---|
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ARUP

MH2 ENERGY KINGDOM DEYRNAS YNNI

# Proposition 5 - Middle Scoveson Solar Farm, Neyland

*Heat demand of Neyland Health centre through the electrolysis of excess energy from existing and proposed renewable energy assets.*

| Core Value | Potential Value | Core Supply (MW) | Core Supply (GWh/year) | Core Demand (GWh/year) |
|---|---|---|---|---|
| Localised use of existing assets. | Potential to isolate area of network & develop early SLES. | 10MW solar<br>8MW wind | 0.1 | 28.3 |

Proposition Elements

Criteria Satisfied

Time Horizon

2025 2030 2040 2050

Development Readiness Level

25% 50% 75% 100%


## VECTORS

POWER

HEAT

TRANSPORT

## NETWORK & TRANSMISSION SUMMARY

Hydrogen delivered by tanker or hydrogen pipelines from point of electrolysis to demand centres

## OWNERSHIP OF ASSETS

PCC owned demand assets

Privately owned supply assets

QUALITATIVE TRIAGE RAG MATRIX

| Criteria | Criteria Icon | Benefit | Constraint |
|---|---|---|---|
| **Key Objective:** Achieves emissions reductions, significant contribution to net-zero 2050 pathway | | | |
| **Key Objective:** Catalyst / First of a kind & supports future expansion *Potential to develop seed markets for hydrogen in the fields of heat, transport, gas & power.* | | | |
| **Key Objective:** Jobs & Prosperity *Stimulate growth in local community, Potential for job creation/upskilling, Decarbonises heating or transport for local community, Contribute to the alleviation of fuel poverty* | | | |
| **Key Objective:** Optimises social value (social, economic and environmental), in terms of the potential costs, benefits and risks | | | |
| **Key Objective:** Stakeholder / Community Acceptability & Awareness raising | | | |
| **Critical Success Factor:** Technical: Balance of supply & demand | | | |
| **Critical Success Factor:** Technical: Technology maturity *Existing vs novel technologies Supply chain - availability / investment required* | | | |
| **Critical Success Factor:** Contributes to Energy Resilience | | | |
| **Critical Success Factor:** Immediate Need / Opportunity Readiness | | | |
| **Critical Success Factor:** Commercial Opportunity | | | |
| **Critical Success Factor:** Commercial: Capex investment required | | | |
| **Critical Success Factor:** Investor Interest / Funding Streams | | | |
| **Critical Success Factor:** Complexity / Asset ownership / Number of parties | | | |
| **Critical Success Factor:** Policy & Regulatory Considerations | | | |
| **Critical Success Factor:** Development Risks & Scheme Constraints | | | |
| **Wider Benefits:** WFGA Goals *Prosperous / Resilient / Healthier / More equal / Cohesive communities / Vibrant culture / Globally responsible* | | | |
| **Wider Benefits:** WFGA Ways of Working *Long term / Prevention / Integration / Collaboration / Involvement* | | | |
| **Wider Benefits:** Waste Reduction / Circular Economy | | | |

KEY

| | | |
|---|---|---|
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ARUP

MH2 ENERGY KINGDOM DEYRNAS YNNI

# Appendix C – MCA report and SLES Decision Tree

## Complete MCA report

ENERGY KINGDOM
DEYRNAS YNNI

# MH:EK Propositions MCA scoring

ARUP

## Proposition 1-A - Milford Haven Heat Network and Microgrid

Overall Score

| Partner Score | Average Score | Arup Score |
|---|---|---|
| 3.54 | 3.48 | 3.48 |

Individual Criteria Score

*Achieves emissions reductions*

| Score | Comment |
|---|---|
| 3 | [1 - Neutral, 5 - positive contribution]<br>Local setting but order of magnitude of emission reduction can be significant.<br>Technology adoption.<br>Opportunity for PoMH to decentralise their energy supply. |

*Catalyst*

| Score | Comment |
|---|---|
| 4 | [1 - Neutral, 5 - positive contribution]<br>Local but gives a step change. Allows testing of new technologies and concepts. |

*Jobs & Prosperity*

| Score | Comment |
|---|---|
| 1 | Doesn't really stimulates that much growth.<br>Promotes new technologies to local contractors but not at an industrial scale.<br>Only limited to some training and maintenance |

*Social Value*

| Score | Comment |
|---|---|
| 3 | Promoting new ways of providing heating<br>Additional revenue streams/models<br>Risk that the HN should be designed to keep price to the end consumers reasonable. Considering price of H2 is higher than electricity |

*Stakeholder acceptability*

| Score | Comment |
|---|---|
| 4 | [1 - negative, 3- neutral, 5- positive]<br>PoMH would be very supportive<br>Tenants and local residents may not be keen on the disruption during construction<br>But generally there is an appetite for HNs. |

*Design*

| Score | Comment |
|---|---|
| 3 | [1 - negative, 3- neutral, 5- positive] |

*Construction*

| Score | Comment |
|---|---|

| | |
|---|---|
| 2 | [1 - negative, 3- neutral, 5- positive]<br>Aligning construction of the heat pump with the developments can help but there are lead times for equipment/materials. There can be transitional equipment or temporary energy centres but adds complexity. |

*Operation*

| Score | Comment |
|---|---|
| 3 | [1 - negative, 3- neutral, 5- positive]<br>New connected kit for the asset owners and users to operate/maintain but there are less boilers to maintain than the current situation. Requires skilled/trained operatives to maintain. |

*Decommissioning*

| Score | Comment |
|---|---|
| 4 | There is opportunity for expansion but for buried pipeworks will not be easy.<br>Usually a design life of 20 years but expected to last for 50-100 years.<br>To consider how robust is it to external scenarios |

*Impact*

| Score | Comment |
|---|---|
| 3 | [1 - negative impact, 5 - positive impact] |

*Mitigation*

| Score | Comment |
|---|---|
| 4 | 4 |

*Water Bodies*

| Score | Comment |
|---|---|
| 1 | Requires water as a source for the heat pump and electrolyser. Can also increase the temperature of the water. |

*Biodiversity*

| Score | Comment |
|---|---|
| 3 | No expected change |

*Commercial Opportunity*

| Score | Comment |
|---|---|
| 3 | |

*Capital Cost (CAPEX)*

| Score | Comment |
|---|---|
| 2 | High cost with an electrolyser |

*Maintenance Cost (OPEX)*

| Score | Comment |
|---|---|

| | |
|---|---|
| 4 | low cost |

*Price Resilience*

| Score | Comment |
|---|---|
| 4 | |

*Levelised Cost of Energy (LCOE)*

| Score | Comment |
|---|---|
| 3 | 3 |

*Supply chain*

| Score | Comment |
|---|---|
| 3 | Electrolyser may need investment in the supply chain |

*Investor Interest / Funding Streams*

| Score | Comment |
|---|---|
| 4 | Good interest with WG and HN investment |

*Immediate Need / Opportunity Readiness*

| Score | Comment |
|---|---|
| 4 | |

*Complexity of asset ownership*

| Score | Comment |
|---|---|
| 5 | PoMH owned assets only a few leasehold people to get on board |

*Policy & Regulatory Considerations*

| Score | Comment |
|---|---|
| 4 | not really new or not already implemented unless H2 is incorporated which will reduce the score |

*Development Risk*

| Score | Comment |
|---|---|
| 3 | |

*Scheme Constraints*

| Score | Comment |
|---|---|
| 4 | low risk with less complex asset ownership for e,g |

*Future Expansion*

| Score | Comment |
|---|---|
| 4 | Strong opportunity for expansion |

*Visual Impact*

# MH:EK Propositions MCA scoring

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| Score | Comment |
|---|---|
| 4 | low impact apart from the electrolyser |

*Low-Carbon Technologies*

| Score | Comment |
|---|---|
| 5 | introducing a lot of new technologies and can be a zero carbon hub |

*Energy Resilience*

| Score | Comment |
|---|---|
| 4 | supply assets are port owned and has opportunities for change or adaptation |

*Innovation*

| Score | Comment |
|---|---|
| 3 | relatively innovative |

*WFGA Goals*

| Score | Comment |
|---|---|
| 5 | community based energy hub and decentralised |

*WFGA Ways of Working*

| Score | Comment |
|---|---|
| 5 | |

*Waste Reduction / Circular Economy*

| Score | Comment |
|---|---|
| 3 | less waste from not having to install individual equipment |

*Air Quality*

| Score | Comment |
|---|---|
| 4 | no gas boilers and no wood burners |

*Education*

| Score | Comment |
|---|---|
| 3 | creates awareness but doesn't educate the wider community. Opportunity to have energy education centres |

# MH:EK Propositions MCA scoring

ARUP

## Proposition 1-B: Milford Haven Comprehensive heat and power demand

Overall Score

| Partner Score | Average Score | Arup Score |
|---|---|---|
| 3.14 | 3.10 | 3.12 |

Individual Criteria Score

*Achieves emissions reductions*

| Score | Comment |
|---|---|
| 2 | [1 - Neutral, 5 - positive contribution]<br>Very localised, only a few demand assets considered.<br>Considers opportunity to use tankered hydrogen, what will be the carbon emissions associated with transporting H2? |

*Catalyst*

| Score | Comment |
|---|---|
| 4 | [1 - Neutral, 5 - positive contribution]<br>Local but allows for a step change for the energy demands of schools. |

*Jobs & Prosperity*

| Score | Comment |
|---|---|
| 1 | Doesn't really stimulate growth due to local setting and limited to training for maintenance and operation. Opportunity to promote new technologies to local contractors |

*Social Value*

| Score | Comment |
|---|---|
| 3 | Promotion of new ways of meeting energy demand through renewable sources, promotes education within a school setting.<br>Cost of H2 is currently higher than electricity but provides additional revenue streams. |

*Stakeholder acceptability*

| Score | Comment |
|---|---|
| 4 | [1 - negative, 3- neutral, 5- positive]<br>PCC and PoMH would be very supportive<br>Awareness raising of new technologies for the current and new generation. |

*Design*

| Score | Comment |
|---|---|
| 2 | [1 - negative, 3- neutral, 5- positive]<br>Energy supply-demand balance currently off. Opportunity to connect additional loads but increase other risks.<br>Incorporating new technologies in existing buildings may be challenging but can be integrated with the design of the new developments.<br>Electrolysers is a relatively known technology but depends on the scale of H2 production. |

# MH:EK Propositions MCA scoring

ARUP

*Construction*

| Score | Comment |
|---|---|
| 3 | [1 - negative, 3- neutral, 5- positive]<br>Disruption to the school activities but opportunity to schedule works during school holidays. Lead times of materials can be the critical path activity regardless.<br>With new developments, opportunity to integrate in the design and construction programme. |

*Operation*

| Score | Comment |
|---|---|
| 3 | [1 - negative, 3- neutral, 5- positive]<br>New connected kit for the asset owners and users to operate/maintain.<br>Requires skilled/trained operatives to maintain. |

*Decommissioning*

| Score | Comment |
|---|---|
| 4 | Opportunity for expansion and connection of additional loads. |

*Impact*

| Score | Comment |
|---|---|
| 3 | [1 - negative, 3- neutral, 5- positive] |

*Mitigation*

| Score | Comment |
|---|---|
| 4 | 4 |

*Water Bodies*

| Score | Comment |
|---|---|
| 2 | [1 - negative, 3- neutral, 5- positive]<br>Requires water as a source for the electrolyser. |

*Biodiversity*

| Score | Comment |
|---|---|
| 3 | No expected change |

*Commercial Opportunity*

| Score | Comment |
|---|---|
| 2 | Very local, with supply exceeding demand by so much, is H2 economical at this scale? |

*Capital Cost (CAPEX)*

| Score | Comment |
|---|---|
| 2 | High cost with an electrolyser |

# MH:EK Propositions MCA scoring

ARUP

*Maintenance Cost (OPEX)*

| Score | Comment |
|---|---|
| 4 | Low cost compared to existing boilers |

*Price Resilience*

| Score | Comment |
|---|---|
| 4 | |

*Levelised Cost of Energy (LCOE)*

| Score | Comment |
|---|---|
| 2 | 2 |

*Supply chain*

| Score | Comment |
|---|---|
| 3 | [1 - significant change required, 3- Supply chain is already preparing for this technology, 5 - supply chain ready and already implementing this technology]<br>Electrolyser may need investment in the supply chain |

*Investor Interest / Funding Streams*

| Score | Comment |
|---|---|
| 2 | Not identified and small scale and may not be economical. |

*Immediate Need / Opportunity Readiness*

| Score | Comment |
|---|---|
| 3 | Complexity to integrate in existing buildings<br>Timeframe of the new or redevelopments need to be understood |

*Complexity of asset ownership*

| Score | Comment |
|---|---|
| 5 | PoMH and PCC asset ownership |

*Policy & Regulatory Considerations*

| Score | Comment |
|---|---|
| 3 | Implementing H2 for heat demand of schools is new |

*Development Risk*

| Score | Comment |
|---|---|
| 3 | |

*Scheme Constraints*

| Score | Comment |
|---|---|
| 2 | [1- High risk, 3- Neutral, 5-low risk] |

*Future Expansion*

| Score | Comment |
|---|---|
| 3 | Opportunity for expansion and opportunity to use hydrogen pipeline or tanks as demand increases |

*Visual Impact*

| Score | Comment |
|---|---|
| 4 | low impact apart from the electrolyser |

*Low-Carbon Technologies*

| Score | Comment |
|---|---|
| 4 | Introducing low carbon heating technology |

*Energy Resilience*

| Score | Comment |
|---|---|
| 4 | supply assets are port owned and has opportunities for change or adaptation |

*Innovation*

| Score | Comment |
|---|---|
| 3 | Relatively innovative but small scale |

*WFGA Goals*

| Score | Comment |
|---|---|
| 3 | Local scale |

*WFGA Ways of Working*

| Score | Comment |
|---|---|
| 4 | Promotes collaboration between the port and PCC and other local contractors but project is at a small scale |

*Waste Reduction / Circular Economy*

| Score | Comment |
|---|---|
| 3 | Potentially less wasted energy from excess not taken by the grid |

*Air Quality*

| Score | Comment |
|---|---|
| 4 | No gas boilers |

*Education*

| Score | Comment |
|---|---|
| 4 | High potential to use the school heating system as a case study for educating children and parents. Can have an onsite energy education centre. |

## Proposition 1-C - Milford Haven transport demand

Overall Score

| Partner Score | Average Score | Arup Score |
|---|---|---|
| 3.27 | 3.26 | 3.30 |

Individual Criteria Score

*Achieves emissions reductions*

| Score | Comment |
|---|---|
| 3 | [1 - Neutral, 5 - positive contribution]<br>Hydrogen is more rapidly adopted in transport, with an outlook at using ULEV and H2 fleet as well as vessel refueling, which will have a significant contribution to net zero. However, this is still at a local scale. Tankered H2 can be contradictory if not using ULEV or H2 transportation. |

*Catalyst*

| Score | Comment |
|---|---|
| 4 | [1 - Neutral, 5 - positive contribution]<br>Local but allows for a step change for the transport demand including vessel refueling |

*Jobs & Prosperity*

| Score | Comment |
|---|---|
| 2 | Limited growth due to local setting and limited to training for maintenance and operation. Opportunity to promote new technologies to local contractors and to redevelop the ports for H2 marine vessels. |

*Social Value*

| Score | Comment |
|---|---|
| 3 | Promotion of new ways of meeting energy demand through renewable sources, promotion of alternative transport fuels including shipping.<br>Cost of H2 is currently higher than electricity but provides additional revenue streams. |

*Stakeholder acceptability*

| Score | Comment |
|---|---|
| 4 | [1 - negative, 3- neutral, 5- positive]<br>PCC and PoMH would be very supportive<br>Awareness raising of new technologies to port users (marine vessels) and the wider community. |

*Design*

| Score | Comment |
|---|---|
| 3 | [1 - negative, 3- neutral, 5- positive]<br>Energy supply-demand balance currently off. Opportunity to connect additional loads but uncertainties around timeframes. Electrolysers is a relatively known technology but depends on the scale of H2 production. |

# MH:EK Propositions MCA scoring

ARUP

*Construction*

| Score | Comment |
|---|---|
| 3 | Less impact from installing ULEV charging points and electrolysers. |

*Operation*

| Score | Comment |
|---|---|
| 3 | [1 - negative, 3- neutral, 5- positive]<br>New equipment for the asset owners to operate/maintain. Requires skilled/trained operatives to maintain. |

*Decommissioning*

| Score | Comment |
|---|---|
| 4 | Opportunity for expansion |

*Impact*

| Score | Comment |
|---|---|
| 3 | [1 - negative, 3- neutral, 5- positive] |

*Mitigation*

| Score | Comment |
|---|---|
| 4 | 4 |

*Water Bodies*

| Score | Comment |
|---|---|
| 2 | [1 - negative, 3- neutral, 5- positive]<br>Requires water as a source for the electrolyser. |

*Biodiversity*

| Score | Comment |
|---|---|
| 3 | No expected change |

*Commercial Opportunity*

| Score | Comment |
|---|---|
| 3 | Local setting and supply-demand energy balance is off due to known demand. Opportunity to increase the scale by having H2 fleet and H2 vessel refuelling for longer term. |

*Capital Cost (CAPEX)*

| Score | Comment |
|---|---|
| 2 | High cost with an electrolyser and transporting H2 |

*Maintenance Cost (OPEX)*

| Score | Comment |
|---|---|
| 2 | OPEX of electrolysers will be additional to the current situation |

# MH:EK Propositions MCA scoring

ARUP

*Price Resilience*

| Score | Comment |
|---|---|
| 4 | |

*Levelised Cost of Energy (LCOE)*

| Score | Comment |
|---|---|
| 2 | 2 |

*Supply chain*

| Score | Comment |
|---|---|
| 3 | [1 - significant change required, 3- Supply chain is already preparing for this technology, 5 - supply chain ready and already implementing this technology] Electrolyser may need investment in the supply chain |

*Investor Interest / Funding Streams*

| Score | Comment |
|---|---|
| 3 | Not identified but as the demand asset grows/becomes more certain, the offer can be more attractive. |

*Immediate Need / Opportunity Readiness*

| Score | Comment |
|---|---|
| 2 | There may be an intermediate need to have electric vehicle fleet in the transition to Hydrogen vehicle fleet. Hydrogen for shipping is less ready considering refuelling of vessesl is usually done at different ports. |

*Complexity of asset ownership*

| Score | Comment |
|---|---|
| 5 | PoMH and PCC asset ownnership |

*Policy & Regulatory Considerations*

| Score | Comment |
|---|---|
| 3 | Implementing H2 for transport demand is relatively new but exists already. H2 for vessel refuelling is new |

*Development Risk*

| Score | Comment |
|---|---|
| 3 | |

*Scheme Constraints*

| Score | Comment |
|---|---|
| 2 | |

*Future Expansion*

| Score | Comment |
|---|---|

| | |
|---|---|
| 3 | Opportunity for expansion to H2 shipping |

*Visual Impact*

| Score | Comment |
|---|---|
| 4 | low impact apart from the electrolyser |

*Low-Carbon Technologies*

| Score | Comment |
|---|---|
| 4 | Promoting ULEV and H2 vehicles on a larger scale within the communities and public sector. H2 vessels refuelling will also promote low carbon marine transportation and shipping |

*Energy Resilience*

| Score | Comment |
|---|---|
| 4 | supply assets are port owned and has opportunities for change or adaptation |

*Innovation*

| Score | Comment |
|---|---|
| 4 | Innovative, although at a local scale, can expand to interface with the wider region |

*WFGA Goals*

| Score | Comment |
|---|---|
| 4 | |

*WFGA Ways of Working*

| Score | Comment |
|---|---|
| 4 | Promotes collaboration between the port and PCC and other local contractors |

*Waste Reduction / Circular Economy*

| Score | Comment |
|---|---|
| 3 | Potentially less wasted energy from excess not taken by the grid |

*Air Quality*

| Score | Comment |
|---|---|
| 4 | Significantly reduced emissions from PCC and PoMH transport fleet. opportunity to reduce emissions from vessels as well |

*Education*

| Score | Comment |
|---|---|
| 4 | With more vehicles using ULEV and H2 on display and becoming the norm, opportunity to educate the community and promote behavioural change |

# MH:EK Propositions MCA scoring

ARUP

## Proposition 1-D - PCC Recycling Facility

Overall Score

| Partner Score | Average Score | Arup Score |
|---|---|---|
| 3.18 | 3.16 | 3.22 |

Individual Criteria Score

*Achieves emissions reductions*

| Score | Comment |
|---|---|
| 3 | [1 - Neutral, 5 - positive contribution]<br>Hydrogen is more rapidly adopted in transport, with an outlook at using ULEV and H2 fleet, which will have a significant contribution to net zero. However, this is still at a local scale. Tankered H2 can be contradictory if not using ULEV or H2 transportation. |

*Catalyst*

| Score | Comment |
|---|---|
| 4 | Local but allows for a step change for the transport and heating demand |

*Jobs & Prosperity*

| Score | Comment |
|---|---|
| 2 | Limited growth due to local setting and limited to training for maintenance and operation. Opportunity to promote new technologies to local contractors |

*Social Value*

| Score | Comment |
|---|---|
| 3 | Promotion of new ways of meeting energy demand through renewable sources, promotion of alternative transport fuels. Cost of H2 is currently higher than electricity but provides additional revenue streams. |

*Stakeholder acceptability*

| Score | Comment |
|---|---|
| 4 | [1 - negative, 3- neutral, 5- positive]<br>PCC would be very supportive. Some level of community awareness raising during operation of the bin lorries |

*Design*

| Score | Comment |
|---|---|
| 3 | [1 - negative, 3- neutral, 5- positive]<br>Energy supply-demand balance not assessed and considers a local setting. Electrolysers is a relatively known technology but depends on the scale of H2 production. |

*Construction*

| Score | Comment |
|---|---|
| 2 | Some construction disruption for installation of boilers and electrolysers but |

ARUP

| | |
|---|---|
| | localised |

*Operation*

| Score | Comment |
|---|---|
| 3 | [1 - negative, 3- neutral, 5- positive]<br>New equipment for the asset owners to operate/maintain. Requires skilled/trained operatives to maintain. |

*Decommissioning*

| Score | Comment |
|---|---|
| 4 | Opportunity for expansion |

*Impact*

| Score | Comment |
|---|---|
| 3 | |

*Mitigation*

| Score | Comment |
|---|---|
| 4 | 4 |

*Water Bodies*

| Score | Comment |
|---|---|
| 2 | [1 - negative, 3- neutral, 5- positive]<br>Requires water as a source for the electrolyser. |

*Biodiversity*

| Score | Comment |
|---|---|
| 3 | No expected change |

*Commercial Opportunity*

| Score | Comment |
|---|---|
| 2 | Local scale and may not be economical |

*Capital Cost (CAPEX)*

| Score | Comment |
|---|---|
| 2 | High cost with an electrolyser and transporting H2 |

*Maintenance Cost (OPEX)*

| Score | Comment |
|---|---|
| 2 | OPEX of electrolysers will be additional to the current situation |

*Price Resilience*

| Score | Comment |
|---|---|

| | |
|---|---|
| 4 | |

*Levelised Cost of Energy (LCOE)*

| Score | Comment |
|---|---|
| 2 | 2 |

*Supply chain*

| Score | Comment |
|---|---|
| 3 | [1 - significant change required, 3- Supply chain is already preparing for this technology, 5 - supply chain ready and already implementing this technology] Electrolyser may need investment in the supply chain |

*Investor Interest / Funding Streams*

| Score | Comment |
|---|---|
| 2 | Not identified and small scale opportunity |

*Immediate Need / Opportunity Readiness*

| Score | Comment |
|---|---|
| 4 | |

*Complexity of asset ownership*

| Score | Comment |
|---|---|
| 5 | PCC and PoMH asset ownership |

*Policy & Regulatory Considerations*

| Score | Comment |
|---|---|
| 3 | Implementing H2 for transport and heat demand is relatively new |

*Development Risk*

| Score | Comment |
|---|---|
| 3 | |

*Scheme Constraints*

| Score | Comment |
|---|---|
| 2 | |

*Future Expansion*

| Score | Comment |
|---|---|
| 3 | Opportunity for expansion |

*Visual Impact*

| Score | Comment |
|---|---|
| 4 | low impact apart from the electrolyser |

# MH:EK Propositions MCA scoring

ARUP

*Low-Carbon Technologies*

| Score | Comment |
|---|---|
| 4 | |

*Energy Resilience*

| Score | Comment |
|---|---|
| 4 | supply assets are port owned and has opportunities for change or adaptation |

*Innovation*

| Score | Comment |
|---|---|
| 3 | relatively innovative |

*WFGA Goals*

| Score | Comment |
|---|---|
| 4 | |

*WFGA Ways of Working*

| Score | Comment |
|---|---|
| 4 | Promotes collaboration between the port and PCC and other local contractors |

*Waste Reduction / Circular Economy*

| Score | Comment |
|---|---|
| 3 | Potentially less wasted energy from excess not taken by the grid |

*Air Quality*

| Score | Comment |
|---|---|
| 3 | |

*Education*

| Score | Comment |
|---|---|
| 4 | With more vehicles using ULEV and H2 on display and becoming the norm, opportunity to educate the community and promote behavioural change |

## Proposition 2-A - Haverfordwest High School (Prendergast and Portfield Campus)

Overall Score

| Partner Score | Average Score | Arup Score |
|---|---|---|
| 2.66 | 2.61 | 2.52 |

Individual Criteria Score

*Achieves emissions reductions*

| Score | Comment |
|---|---|
| 2 | New campus already planned with ASHP - slight improvement on reduction however not significant |

*Catalyst*

| Score | Comment |
|---|---|
| 3 | [1 - Neutral, 5 - positive contribution]<br>Local but gives a step change. Allows testing of new technologies and concepts. |

*Jobs & Prosperity*

| Score | Comment |
|---|---|
| 1 | Doesn't really stimulates that much growth.<br>Promotes new technologies to local contractors but not at an industrial scale.<br>Only limited to some training and maintenance |

*Social Value*

| Score | Comment |
|---|---|
| 2 | Promotes new ways of heating and has some educational element however little stimulation to local economy and only marginal benefits compared to developments currently underway. |

*Stakeholder acceptability*

| Score | Comment |
|---|---|
| 2 | [1 - negative, 3- neutral, 5- positive]<br>Exciting opportunity to have hydrogen school however, likely to delay construction and therefore may not appeal to the public |

*Design*

| Score | Comment |
|---|---|
| 2 | [1 - negative, 3- neutral, 5- positive]<br>All existing technologies. Eletrolysers are relatively immature but possible.<br>Poor balance of supply and demand but can be remedied by decreasing renewable assets included in scheme. |

*Construction*

| Score | Comment |
|---|---|

ARUP

| | |
|---|---|
| 1 | [1 - negative, 3- neutral, 5- positive]<br>Challenge of aligning with development which is already planned and underway |

*Operation*

| Score | Comment |
|---|---|
| 2 | [1 - negative, 3- neutral, 5- positive]<br>New kit will be more challenging for school janitor to monitor compared to existing scheme. |

*Decommissioning*

| Score | Comment |
|---|---|
| 3 | Heat supply can be somewhat resilient to external supply and has balance of different energy vectors supplying |

*Impact*

| Score | Comment |
|---|---|
| 3 | [1 - negative impact, 5 - positive impact] |

*Mitigation*

| Score | Comment |
|---|---|
| 3 | 3 |

*Water Bodies*

| Score | Comment |
|---|---|
| 2 | Water bodies affected due to water demand for electrolysis |

*Biodiversity*

| Score | Comment |
|---|---|
| 3 | No expected change |

*Commercial Opportunity*

| Score | Comment |
|---|---|
| 3 | No large revenues expected from this scheme |

*Capital Cost (CAPEX)*

| Score | Comment |
|---|---|
| 2 | Electrolyser is expensive especially given the small demand here |

*Maintenance Cost (OPEX)*

| Score | Comment |
|---|---|
| 3 | Opex will be high due to use of an electrolyser |

*Price Resilience*

| Score | Comment |
| --- | --- |
| 0 | Resilient due to lack of vulnerability to external factors however, private wire contracts required to mitigate against renewable energy providers taking advantage of dependency on their assets. Challenge overcome if electricity is supplied from PCC owned solar at Haverfordwest Airport. |

*Levelised Cost of Energy (LCOE)*

| Score | Comment |
| --- | --- |
| 2 | 2 |

*Supply chain*

| Score | Comment |
| --- | --- |
| 3 | Electrolyser may need investment in the supply chain |

*Investor Interest / Funding Streams*

| Score | Comment |
| --- | --- |
| 2 | Unlikely to be as popular compared to other schemes as construction is already underway |

*Immediate Need / Opportunity Readiness*

| Score | Comment |
| --- | --- |
| 2 | Lack of need for development due to existing designs |

*Complexity of asset ownership*

| Score | Comment |
| --- | --- |
| 2 | Multiple asset owners included in proposition however renewable energy suppliers could be limited |

*Policy & Regulatory Considerations*

| Score | Comment |
| --- | --- |
| 4 | New policy and regulation unlikely to be required for the scheme |

*Development Risk*

| Score | Comment |
| --- | --- |
| 3 | Risk due to utilities and lack of drive for project however not as significant as in other propositions. |

*Scheme Constraints*

| Score | Comment |
| --- | --- |
| 2 | Timing constraint due to current development |

*Future Expansion*

| Score | Comment |
| --- | --- |
| 3 | Medium opportunity for expansion |

# MH:EK Propositions MCA scoring

ARUP

*Visual Impact*

| Score | Comment |
|---|---|
| 4 | Low visual impact |

*Low-Carbon Technologies*

| Score | Comment |
|---|---|
| 3 | Some opportunity of low carbon integration however, not on significant scale |

*Energy Resilience*

| Score | Comment |
|---|---|
| 3 | Depends on ownership of renewable assets however vulnerable to changes in PW contract |

*Innovation*

| Score | Comment |
|---|---|
| 3 | Relatively innovative |

*WFGA Goals*

| Score | Comment |
|---|---|
| 4 | Opportunity for community learning and provides clean energy supply |

*WFGA Ways of Working*

| Score | Comment |
|---|---|
| 4 | Some collaboration with between local organisations and across different energy vectors |

*Waste Reduction / Circular Economy*

| Score | Comment |
|---|---|
| 2 | Minimal integration of circular economy principles compared to other scenarios |

*Air Quality*

| Score | Comment |
|---|---|
| 4 | no gas boilers, grid elec |

*Education*

| Score | Comment |
|---|---|
| 4 | Creates awareness and opportunity to educate school children |

# MH:EK Propositions MCA scoring

ARUP

## Proposition 2-B - Haverfordwest Hospitals (BroCerwyn and Whitybush)

Overall Score

| Partner Score | Average Score | Arup Score |
|---|---|---|
| 2.85 | 2.84 | 2.93 |

Individual Criteria Score

*Achieves emissions reductions*

| Score | Comment |
|---|---|
| 3 | [1 - Neutral, 5 - positive contribution]<br>Reduced emission of hospital and wider area but moderately significant compared to other opportunities. |

*Catalyst*

| Score | Comment |
|---|---|
| 4 | [1 - Neutral, 5 - positive contribution]<br>Local but gives a step change. Allows testing of new technologies and concepts. |

*Jobs & Prosperity*

| Score | Comment |
|---|---|
| 2 | Opportunities to create new hydrogen vehicle fleets and stimulate hydrogen transport network in South Wales |

*Social Value*

| Score | Comment |
|---|---|
| 3 | Providing new pathways for healthcare assets to become zero carbon |

*Stakeholder acceptability*

| Score | Comment |
|---|---|
| 3 | [1 - negative, 3- neutral, 5- positive]<br>Resilience of energy supply to hospitals and ambulances is key so risks of poor public perception here |

*Design*

| Score | Comment |
|---|---|
| 2 | Good balance of supply and demand, hydrogen not common fuel source for ambulances currently |

*Construction*

| Score | Comment |
|---|---|
| 2 | [1 - negative, 3- neutral, 5- positive]<br>Construction likely to be disruptive to hospital current running as energy centre plant will need to be replaced |

*Operation*

| Score | Comment |
|---|---|
| 2 | [1 - negative, 3- neutral, 5- positive]<br>Some challenges of balancing load between heating and transport demands as all loads will be critical, real time monitoring may be required to balance |

*Decommissioning*

| Score | Comment |
|---|---|
| 2 | Will be challenging to decommission / re-purpose hydrogen ambulance fleet and is dependent on future direction of transport sector in South Wales. |

*Impact*

| Score | Comment |
|---|---|
| 3 | [1 - negative impact, 5 - positive impact] |

*Mitigation*

| Score | Comment |
|---|---|
| 4 | 4 |

*Water Bodies*

| Score | Comment |
|---|---|
| 2 | Electrolysis will have impact on water bodies |

*Biodiversity*

| Score | Comment |
|---|---|
| 3 | No expected change |

*Commercial Opportunity*

| Score | Comment |
|---|---|
| 2 | Public sector and so unlikely to yield large returns |

*Capital Cost (CAPEX)*

| Score | Comment |
|---|---|
| 2 | High costs due to electrolyser |

*Maintenance Cost (OPEX)*

| Score | Comment |
|---|---|
| 2 | Likely to be expensive to maintain hydrogen fleet |

*Price Resilience*

| Score | Comment |
|---|---|
| 2 | Depended on supply from a variety of renewable sources and therefore vulnerable to changes in costs for these |

*Levelised Cost of Energy (LCOE)*

| Score | Comment |
|---|---|
| 3 | 3 |

*Supply chain*

| Score | Comment |
|---|---|
| 2 | Supply chain for hydrogen ambulances immature |

*Investor Interest / Funding Streams*

| Score | Comment |
|---|---|
| 3 | Potential investment from PCC / WG |

*Immediate Need / Opportunity Readiness*

| Score | Comment |
|---|---|
| 2 | Energy demand currently met here |

*Complexity of asset ownership*

| Score | Comment |
|---|---|
| 3 | Relatively complex due to multiple parties included |

*Policy & Regulatory Considerations*

| Score | Comment |
|---|---|
| 2 | Regulatory requirements to safeguard hospital supply and fleet potential |

*Development Risk*

| Score | Comment |
|---|---|
| 2 | Changing something installed and built for something new and innovative |

*Scheme Constraints*

| Score | Comment |
|---|---|
| 2 | Constraints of providing hospital resilience and security of supply. Challenge of finding agreement to serve and satisfy all parties involved. Will require hydrogen transport to happen in tandem in other areas. |

*Future Expansion*

| Score | Comment |
|---|---|
| 4 | Opportunities for expansion or for development into a hydrogen village |

*Visual Impact*

| Score | Comment |
|---|---|
| 4 | Low impact apart from electrolyser and potentially charging stations |

*Low-Carbon Technologies*

| Score | Comment |
|---|---|
| 4 | |

# MH:EK Propositions MCA scoring

ARUP

*Energy Resilience*

| Score | Comment |
|---|---|
| 2 | Assets become dependent on hydrogen supply although these can be switched out for |

*Innovation*

| Score | Comment |
|---|---|
| 4 | Innovation within health care system |

*WFGA Goals*

| Score | Comment |
|---|---|
| 4 | Community based, low-carbon energy |

*WFGA Ways of Working*

| Score | Comment |
|---|---|
| 4 | Integrated approach to energy supply and provision |

*Waste Reduction / Circular Economy*

| Score | Comment |
|---|---|
| 2 | Some contribution due to centralised energy |

*Air Quality*

| Score | Comment |
|---|---|
| 4 | Removes gas boilers and diesel powered vehicles |

*Education*

| Score | Comment |
|---|---|
| 3 | creates awareness but doesn't educate the wider community. |

# MH:EK Propositions MCA scoring

ARUP

## Proposition 2-C - Haverfordwest Creamery

Overall Score

| Partner Score | Average Score | Arup Score |
|---|---|---|
| 3.04 | 3.04 | 3.17 |

Individual Criteria Score

*Achieves emissions reductions*

| Score | Comment |
|---|---|
| 4 | [1 - Neutral, 5 - positive contribution]<br>Reduces emissions across a number of operations in and around Haverfordwest |

*Catalyst*

| Score | Comment |
|---|---|
| 5 | [1 - Neutral, 5 - positive contribution]<br>Innovative technologies give opportunities to test and expand development |

*Jobs & Prosperity*

| Score | Comment |
|---|---|
| 3 | New technology will promote some growth. Small opportunities for new job and prosperity within local area such as operating hydrogen production facility |

*Social Value*

| Score | Comment |
|---|---|
| 3 | Some social value due to short-term job opportunities |

*Stakeholder acceptability*

| Score | Comment |
|---|---|
| 3 | [1 - negative, 3- neutral, 5- positive]<br>Stakeholders not yet engaged however, likely to be favorable to Welsh Water |

*Design*

| Score | Comment |
|---|---|
| 2 | Unknown method for creation of hydrogen |

*Construction*

| Score | Comment |
|---|---|
| 1 | Challenge of new methods of producing hydrogen and interfacing with WWTW |

*Operation*

| Score | Comment |
|---|---|
| 2 | Will require significant man-power to operate hydrogen production facility |

# MH:EK Propositions MCA scoring

ARUP

*Decommissioning*

| Score | Comment |
|---|---|
| 2 | Challenge / risk to creamery if WWTW is decommissioned first |

*Impact*

| Score | Comment |
|---|---|
| 3 | |

*Mitigation*

| Score | Comment |
|---|---|
| 4 | 4 |

*Water Bodies*

| Score | Comment |
|---|---|
| 2 | Impact on water bodies if electrolysis is included |

*Biodiversity*

| Score | Comment |
|---|---|
| 3 | No expected change |

*Commercial Opportunity*

| Score | Comment |
|---|---|
| 4 | Strong commercial opportunity for external parties |

*Capital Cost (CAPEX)*

| Score | Comment |
|---|---|
| 2 | High CAPEX anticipated due to new and immature plant requirements |

*Maintenance Cost (OPEX)*

| Score | Comment |
|---|---|
| 2 | Potentially expensive to operate and maintain |

*Price Resilience*

| Score | Comment |
|---|---|
| 2 | Multiple parties and therefore end users vulnerable to be locked in to pricing agreements |

*Levelised Cost of Energy (LCOE)*

| Score | Comment |
|---|---|
| 2 | 2 |

*Supply chain*

| Score | Comment |
|---|---|

| | |
|---|---|
| 1 | Supply chain does not yet exist |

*Investor Interest / Funding Streams*

| Score | Comment |
|---|---|
| 4 | Welsh Water / SWIC / WG potential to invest |

*Immediate Need / Opportunity Readiness*

| Score | Comment |
|---|---|
| 2 | WW hydrogen fleet may be a current need but the remainder currently has energy supply to meet business operational needs |

*Complexity of asset ownership*

| Score | Comment |
|---|---|
| 2 | A number of parties are involved here |

*Policy & Regulatory Considerations*

| Score | Comment |
|---|---|
| 2 | New process may have regulatory constraints within the water industry |

*Development Risk*

| Score | Comment |
|---|---|
| 2 | High risk due to new technologies and lack of supply chain |

*Scheme Constraints*

| Score | Comment |
|---|---|
| 3 | Complex ownership and requirement for significant stakeholder buy-in |

*Future Expansion*

| Score | Comment |
|---|---|
| 4 | Opportunities to provide hydrogen to a range of assets around Haverfordwest |

*Visual Impact*

| Score | Comment |
|---|---|
| 3 | Potential for biomass conversion to have poor visual impact |

*Low-Carbon Technologies*

| Score | Comment |
|---|---|
| 3 | Conversion from biomass will release CO2 although arguably better that use of nat gas |

*Energy Resilience*

| Score | Comment |
|---|---|
| 2 | End users and suppliers are different parties |

*Innovation*

# MH:EK Propositions MCA scoring

ARUP

| Score | Comment |
|---|---|
| 5 | Promotes new technology |

*WFGA Goals*

| Score | Comment |
|---|---|
| 4 | Reduced environmental impact, benefits for local area |

*WFGA Ways of Working*

| Score | Comment |
|---|---|
| 4 | Promotes discussion and energy load balancing between a range of local parties |

*Waste Reduction / Circular Economy*

| Score | Comment |
|---|---|
| 5 | Strong circular economy principles advocated here |

*Air Quality*

| Score | Comment |
|---|---|
| 3 | Improvement to air quality due to decarbonisation however will still release $CO_2$ into atmosphere |

*Education*

| Score | Comment |
|---|---|
| 5 | Strong educational opportunity for energy industry |

# MH:EK Propositions MCA scoring

ARUP

## Proposition 2-D - Bolton Hill Water Treatment Works Oxygen demand

Overall Score

| Partner Score | Average Score | Arup Score |
|---|---|---|
| 3.32 | 3.32 | 3.50 |

Individual Criteria Score

*Achieves emissions reductions*

| Score | Comment |
|---|---|
| 4 | [1 - Neutral, 5 - positive contribution]<br>Results in decarbonisation across a number of energy systems and users |

*Catalyst*

| Score | Comment |
|---|---|
| 4 | [1 - Neutral, 5 - positive contribution]<br>Makes significant difference towards multi-vector SLES including hydrogen |

*Jobs & Prosperity*

| Score | Comment |
|---|---|
| 3 | New job in monitoring digital systems and in distribution / prioritisation of hydrogen end use |

*Social Value*

| Score | Comment |
|---|---|
| 4 | Creates some new jobs and allows local businesses to decarbonise existing transport systems. |

*Stakeholder acceptability*

| Score | Comment |
|---|---|
| 3 | [1 - negative, 3- neutral, 5- positive]<br>Require conversations with DWCC and creamery |

*Design*

| Score | Comment |
|---|---|
| 2 | [1 - negative, 3- neutral, 5- positive]<br>Poor balance of supply and demand however, this can be remedied by reduced solar input and some new components of design required |

*Construction*

| Score | Comment |
|---|---|
| 3 | [1 - negative, 3- neutral, 5- positive]<br>Possible to have phased construction as different components come on one by one creating local hydrogen economy |

*Operation*

| Score | Comment |
|---|---|
| 2 | [1 - negative, 3- neutral, 5- positive]<br>New connected kit for the asset owners and users to operate/maintain and will require hydrogen distribution system around local area |

*Decommissioning*

| Score | Comment |
|---|---|
| 2 | [1 - negative, 3- neutral, 5- positive]<br>Potential to leave stranded assets (e.g. creamery or housing) if hydrogen production and distribution dries up. |

*Impact*

| Score | Comment |
|---|---|
| 3 | [1 - negative impact, 5 - positive impact] |

*Mitigation*

| Score | Comment |
|---|---|
| 4 | 4 |

*Water Bodies*

| Score | Comment |
|---|---|
| 2 | Impact on local water bodies due to water demand for electrolysis |

*Biodiversity*

| Score | Comment |
|---|---|
| 3 | No expected change |

*Commercial Opportunity*

| Score | Comment |
|---|---|
| 4 | Strong opportunity for local organisations to decarbonise their systems |

*Capital Cost (CAPEX)*

| Score | Comment |
|---|---|
| 2 | High cost with electrolyser |

*Maintenance Cost (OPEX)*

| Score | Comment |
|---|---|
| 3 | Medium cost due to distribution of hydrogen |

*Price Resilience*

| Score | Comment |
|---|---|
| 3 | End users are vulnerable to changes in PW agreement |

*Levelised Cost of Energy (LCOE)*

# MH:EK Propositions MCA scoring

ARUP

| Score | Comment |
| --- | --- |
| 3 | 3 |

*Supply chain*

| Score | Comment |
| --- | --- |
| 2 | Supply chain for creamery hydrogen facilities and oxygen recycling unlikely to be ready however other systems will be |

*Investor Interest / Funding Streams*

| Score | Comment |
| --- | --- |
| 3 | Likely to have strong interest from government, slightly more challenging to find a single entity to fund due to complex range of stakeholders included |

*Immediate Need / Opportunity Readiness*

| Score | Comment |
| --- | --- |
| 4 | DWCC likely to have some readiness along with new housing development however, other organisations already operating comfortably. |

*Complexity of asset ownership*

| Score | Comment |
| --- | --- |
| 2 | Relatively complex ownership |

*Policy & Regulatory Considerations*

| Score | Comment |
| --- | --- |
| 2 | Circulation of oxygen back into WWTW might have regulatory constraints |

*Development Risk*

| Score | Comment |
| --- | --- |
| 2 | Some new technologies included here and risk of individual parties pulling out |

*Scheme Constraints*

| Score | Comment |
| --- | --- |
| 2 | A number of stakeholders and technical components |

*Future Expansion*

| Score | Comment |
| --- | --- |
| 4 | Strong potential to expand |

*Visual Impact*

| Score | Comment |
| --- | --- |
| 4 | Low impact with exception of electrolyser and new hydrogen distribution facilities |

*Low-Carbon Technologies*

| Score | Comment |
| --- | --- |

| | |
|---|---|
| 5 | Allows the creation of a low carbon system in Haverfordwest using green hydrogen |

*Energy Resilience*

| Score | Comment |
|---|---|
| 2 | Systems become fairly dependent on availability of hydrogen |

*Innovation*

| Score | Comment |
|---|---|
| 5 | [1 - negative impact, 5 - positive impact]<br>Recycling of oxygen and use of hydrogen of creamery are innovative |

*WFGA Goals*

| Score | Comment |
|---|---|
| 5 | Low carbon area, creation of new jobs |

*WFGA Ways of Working*

| Score | Comment |
|---|---|
| 5 | Community links |

*Waste Reduction / Circular Economy*

| Score | Comment |
|---|---|
| 5 | Recycling of oxygen into waste water system |

*Air Quality*

| Score | Comment |
|---|---|
| 4 | Improved air quality due to improved transport services, reduction CO2 emitted by industry |

*Education*

| Score | Comment |
|---|---|
| 4 | Education to energy industry around new uses of byproducts of electrolysis |

# MH:EK Propositions MCA scoring

ARUP

## Proposition 2-E - Haverfordwest Airport airplane (transport) demand

Overall Score

| Partner Score | Average Score | Arup Score |
|---|---|---|
| 2.71 | 2.76 | 3.11 |

Individual Criteria Score

*Achieves emissions reductions*

| Score | Comment |
|---|---|
| 4 | [1 - Neutral, 5 - positive contribution]<br>Potential to deliver large scale carbon reduction however dependent on CCUS |

*Catalyst*

| Score | Comment |
|---|---|
| 5 | World leading innovation |

*Jobs & Prosperity*

| Score | Comment |
|---|---|
| 5 | System change in energy system creates large scale prosperity within area |

*Social Value*

| Score | Comment |
|---|---|
| 4 | Stimulates economy and growth. Risk of creating fuel poverty or widening social inequality. |

*Stakeholder acceptability*

| Score | Comment |
|---|---|
| 1 | Likely to be some push back from local stakeholders as will required to replace all of their systems |

*Design*

| Score | Comment |
|---|---|
| 1 | Brand new technologies |

*Construction*

| Score | Comment |
|---|---|
| 1 | Enormous scale of construction, supply chains and infrastructure not yet available |

*Operation*

| Score | Comment |
|---|---|
| 2 | [1 - negative, 3- neutral, 5- positive]<br>Will require |

# MH:EK Propositions MCA scoring

ARUP

*Decommissioning*

| Score | Comment |
|---|---|
| 1 | Stranded assets if hydrogen supply becomes unavailable |

*Impact*

| Score | Comment |
|---|---|
| 3 | [1 - negative impact, 5 - positive impact] |

*Mitigation*

| Score | Comment |
|---|---|
| 5 | 5 |

*Water Bodies*

| Score | Comment |
|---|---|
| 3 | No impact on water bodies |

*Biodiversity*

| Score | Comment |
|---|---|
| 2 | Biodiversity challenges due to CCUS |

*Commercial Opportunity*

| Score | Comment |
|---|---|
| 5 | Strong commercial opportunity for utilities providers |

*Capital Cost (CAPEX)*

| Score | Comment |
|---|---|
| 1 | Highest capital costs of propositions |

*Maintenance Cost (OPEX)*

| Score | Comment |
|---|---|
| 1 | High OPEX to maintain pipework however assume no more significant than operating and maintaining gas network. Hydrogen planes also likely to have a high OPEX |

*Price Resilience*

| Score | Comment |
|---|---|
| 2 | Lack of resilience due to reliance on cost of hydrogen and cost of hydrogen boilers |

*Levelised Cost of Energy (LCOE)*

| Score | Comment |
|---|---|
| 2 | 2 |

*Supply chain*

| Score | Comment |
|---|---|
| 1 | Immature supply chain particularly for hydrogen planes |

*Investor Interest / Funding Streams*

| Score | Comment |
|---|---|
| 5 | Likely to be a strong commercial opportunity for a large investor however unclear where revenue would come from - potentially the planes |

*Immediate Need / Opportunity Readiness*

| Score | Comment |
|---|---|
| 1 | Lack of immediate need for proposition and lack of technology readiness |

*Complexity of asset ownership*

| Score | Comment |
|---|---|
| 1 | Complex asset ownership as includes gas network infrastructure and all of the properties within the project boundary |

*Policy & Regulatory Considerations*

| Score | Comment |
|---|---|
| 1 | Extensive new policy and regulation would be required to underpin this proposition |

*Development Risk*

| Score | Comment |
|---|---|
| 1 | High risk associated with this proposition due to scale and due to hydrogen planes currently being at concept level |

*Scheme Constraints*

| Score | Comment |
|---|---|
| 1 | Heavily constrained by current regulation and need for stakeholder buy-in |

*Future Expansion*

| Score | Comment |
|---|---|
| 2 | Scheme is heavily dependent on future direction of national energy system. Strong opportunities to expand but conditional on other areas following suit |

*Visual Impact*

| Score | Comment |
|---|---|
| 2 | May be a visual impact from requirement for CCUS |

*Low-Carbon Technologies*

| Score | Comment |
|---|---|
| 4 | Enables low carbon techs however, only low carbon if CCUS in enabled. |

*Energy Resilience*

| Score | Comment |
| --- | --- |
| 1 | Scheme lacks resilience if future UK energy supply becomes all electric |

*Innovation*

| Score | Comment |
| --- | --- |
| 5 | Highly innovative, first of a kind |

*WFGA Goals*

| Score | Comment |
| --- | --- |
| 5 | Creates new jobs and new supply chains |

*WFGA Ways of Working*

| Score | Comment |
| --- | --- |
| 4 | Some cross links between different industries |

*Waste Reduction / Circular Economy*

| Score | Comment |
| --- | --- |
| 2 | Fairly significant waste due to replacing all boilers within the boundary |

*Air Quality*

| Score | Comment |
| --- | --- |
| 4 | Improvement to air quality due to lack of dependence on gas boilers |

*Education*

| Score | Comment |
| --- | --- |
| 4 | Huge learnings to the energy and aviation industry can be achieved through this proposition |

# MH:EK Propositions MCA scoring

ARUP

## Proposition 2-F - Riverside Shopping Centre

Overall Score

| Partner Score | Average Score | Arup Score |
|---|---|---|
| 3.43 | 3.39 | 3.44 |

Individual Criteria Score

*Achieves emissions reductions*

| Score | Comment |
|---|---|
| 3 | [1 - Neutral, 5 - positive contribution]<br>Local reduction in emissions - potential to create a zero-carbon transport fleet around town centre area with H or electric vehicle charge points & transport hub in former car-park. |

*Catalyst*

| Score | Comment |
|---|---|
| 4 | [1 - Neutral, 5 - positive contribution]<br>Local but gives a step change. Allows testing of new technologies and concepts. |

*Jobs & Prosperity*

| Score | Comment |
|---|---|
| 1 | Minimal creation of new jobs within local context |

*Social Value*

| Score | Comment |
|---|---|
| 4 | Low-carbon / net-zero development opportunity & revitalisation of town centre. Promotes new ways of heating and thinking about energy within the local area. |

*Stakeholder acceptability*

| Score | Comment |
|---|---|
| 3 | [1 - negative, 3- neutral, 5- positive]<br>PCC likely to support however, multiple tenants within the shopping centre may be unhappy with changes to energy centre |

*Design*

| Score | Comment |
|---|---|
| 3 | [1 - negative, 3- neutral, 5- positive]<br>Have to cross river in order to include library. Shopping centre is all elec heating currently and so changing heating system likely to be costly. |

*Construction*

| Score | Comment |
|---|---|
| 3 | Complicated infrastructure requirements due to crossing river. |

*Operation*

# MH:EK Propositions MCA scoring

ARUP

| Score | Comment |
|---|---|
| 3 | [1 - negative, 3- neutral, 5- positive]<br>Load balancing required between heat, electricity and power demands |

*Decommissioning*

| Score | Comment |
|---|---|
| 4 | Distribution heating leaves relatively open to changes in heating technology. Pipework may last slightly longer |

*Impact*

| Score | Comment |
|---|---|
| 3 | [1 - negative impact, 5 - positive impact] |

*Mitigation*

| Score | Comment |
|---|---|
| 4 | 4 |

*Water Bodies*

| Score | Comment |
|---|---|
| 2 | Electrolyser use and WSHP |

*Biodiversity*

| Score | Comment |
|---|---|
| 3 | No expected change |

*Commercial Opportunity*

| Score | Comment |
|---|---|
| 4 | |

*Capital Cost (CAPEX)*

| Score | Comment |
|---|---|
| 3 | High cost due to electrolyser |

*Maintenance Cost (OPEX)*

| Score | Comment |
|---|---|
| 4 | Low cost |

*Price Resilience*

| Score | Comment |
|---|---|
| 2 | Welsh Water and PCC will be vulnerable to changes in costs in electricity supply |

*Levelised Cost of Energy (LCOE)*

ARUP

| Score | Comment |
| --- | --- |
| 3 | 3 |

*Supply chain*

| Score | Comment |
| --- | --- |
| 3 | Electrolysers are available but have long lead in time |

*Investor Interest / Funding Streams*

| Score | Comment |
| --- | --- |
| 5 | Potential interest from Welsh Government |

*Immediate Need / Opportunity Readiness*

| Score | Comment |
| --- | --- |
| 4 | Planned redevelopment of Wilko site and shopping centre.<br>Library and shopping centre are existing with current energy supplies so don't have immediate need. Winch Lane will have a need if timing aligns. |

*Complexity of asset ownership*

| Score | Comment |
| --- | --- |
| 4 | Demand assets primarily PCC owned. Potential to limit complexity by supply coming from PCC owned solar at airport. |

*Policy & Regulatory Considerations*

| Score | Comment |
| --- | --- |
| 2 | Hydrogen sale to tenants isn't regulated yet, unclear if it is to vehicles. |

*Development Risk*

| Score | Comment |
| --- | --- |
| 3 | Risk due to infrastructure crossing river in Haverfordwest |

*Scheme Constraints*

| Score | Comment |
| --- | --- |
| 2 | Constrained due to river, timing of development and existing heat supply within the shopping centre which does not lend itself well to conversion to decentralised heat. |

*Future Expansion*

| Score | Comment |
| --- | --- |
| 4 | Opportunity for expansion and extending zero-carbon town centre hub. |

*Visual Impact*

| Score | Comment |
| --- | --- |
| 4 | Low impact visually |

*Low-Carbon Technologies*

| Score | Comment |
|---|---|
| 4 | Enables implementation of low carbon technologies |

*Energy Resilience*

| Score | Comment |
|---|---|
| 3 | Demand assets may be impacted by changes in contractual agreements for example. |

*Innovation*

| Score | Comment |
|---|---|
| 4 | The hydrogen transport here increases the innovation involved in this proposition |

*WFGA Goals*

| Score | Comment |
|---|---|
| 5 | Community based balance on energy |

*WFGA Ways of Working*

| Score | Comment |
|---|---|
| 4 | Collaboration between multiple parties and stakeholders |

*Waste Reduction / Circular Economy*

| Score | Comment |
|---|---|
| 3 | Decentralised energy plant advocated here however, in some instances will be replacing existing plant, pipework and systems |

*Air Quality*

| Score | Comment |
|---|---|
| 4 | No gas boilers and no wood burners |

*Education*

| Score | Comment |
|---|---|
| 5 | Opportunities to showcase system in library and creates some awareness |

# MH:EK Propositions MCA scoring

ARUP

## Proposition 2-G - Pembrokeshire Food Park

Overall Score

| Partner Score | Average Score | Arup Score |
|---|---|---|
| 3.43 | 3.42 | 3.65 |

Individual Criteria Score

*Achieves emissions reductions*

| Score | Comment |
|---|---|
| 4 | [1 - Neutral, 5 - positive contribution]<br>Strong opportunity to decarbonise local logistics fleet |

*Catalyst*

| Score | Comment |
|---|---|
| 4 | [1 - Neutral, 5 - positive contribution]<br>Catalyses hydrogen freight around the Pembrokeshire region |

*Jobs & Prosperity*

| Score | Comment |
|---|---|
| 4 | Opportunity for hydrogen fueled freight and logistics centre and for the area to become a hydrogen transport hub |

*Social Value*

| Score | Comment |
|---|---|
| 4 | Leads the way in decarbonisation of transport demand |

*Stakeholder acceptability*

| Score | Comment |
|---|---|
| 3 | [1 - negative, 3- neutral, 5- positive]<br>Strong and non-intrusive opportunity |

*Design*

| Score | Comment |
|---|---|
| 3 | Supply and demand balance not yet calculated however renewable demand can be tailored to meet need |

*Construction*

| Score | Comment |
|---|---|
| 2 | Hydrogen lorries in infancy however potential to start small and build up |

*Operation*

| Score | Comment |
|---|---|
| 3 | [1 - negative, 3- neutral, 5- positive]<br>Unlikely to be more challenging that existing fuel |

# MH:EK Propositions MCA scoring

ARUP

*Decommissioning*

| Score | Comment |
|---|---|
| 3 | Risk of other hydrogen fuel stations not coming online and assets being stranded |

*Impact*

| Score | Comment |
|---|---|
| 3 | [1 - negative impact, 5 - positive impact] |

*Mitigation*

| Score | Comment |
|---|---|
| 4 | 4 |

*Water Bodies*

| Score | Comment |
|---|---|
| 2 | Water used for electrolysis |

*Biodiversity*

| Score | Comment |
|---|---|
| 3 | No change expected |

*Commercial Opportunity*

| Score | Comment |
|---|---|
| 4 | Strong commercial opportunity for changing transport system |

*Capital Cost (CAPEX)*

| Score | Comment |
|---|---|
| 2 | High cost due to requirement for hydrogen bus |

*Maintenance Cost (OPEX)*

| Score | Comment |
|---|---|
| 4 | Relatively low maintenance costs |

*Price Resilience*

| Score | Comment |
|---|---|
| 3 | PCC own food park and would own solar farm, becomes more challenging as other parties become involved |

*Levelised Cost of Energy (LCOE)*

| Score | Comment |
|---|---|
| 2 | 2 |

*Supply chain*

| Score | Comment |
|---|---|
| 2 | Supply chain not yet available for hydrogen lorries |

*Investor Interest / Funding Streams*

| Score | Comment |
|---|---|
| 5 | This is an exciting opportunity for hydrogen lorry developers, PCC and Welsh Government |

*Immediate Need / Opportunity Readiness*

| Score | Comment |
|---|---|
| 4 | Food park and solar farm under development |

*Complexity of asset ownership*

| Score | Comment |
|---|---|
| 4 | PCC own core assets in this proposition however, more complex as more parties become involved |

*Policy & Regulatory Considerations*

| Score | Comment |
|---|---|
| 2 | New policy and regulation for hydrogen logisitics required |

*Development Risk*

| Score | Comment |
|---|---|
| 2 | This is risky if a hydrogen transport network does not develop |

*Scheme Constraints*

| Score | Comment |
|---|---|
| 2 | Dependent on future direction of transport industry |

*Future Expansion*

| Score | Comment |
|---|---|
| 4 | Strong opportunity for expansion |

*Visual Impact*

| Score | Comment |
|---|---|
| 4 | Low impact apart from electrolyser |

*Low-Carbon Technologies*

| Score | Comment |
|---|---|
| 5 | Enables decarbonisation of transport system |

*Energy Resilience*

| Score | Comment |
|---|---|
| 3 | Lack of resilience if whole transport system becomes electric however, |

| | |
|---|---|
| | hydrogen more suited for HGVs |

*Innovation*

| Score | Comment |
|---|---|
| 5 | FOAK |

*WFGA Goals*

| Score | Comment |
|---|---|
| 4 | New job creation, safeguarding future energy supply |

*WFGA Ways of Working*

| Score | Comment |
|---|---|
| 5 | Promotes interest in Pembrokeshire food industry and new ways of working together |

*Waste Reduction / Circular Economy*

| Score | Comment |
|---|---|
| 3 | |

*Air Quality*

| Score | Comment |
|---|---|
| 4 | Improves air quality through decarbonised transport |

*Education*

| Score | Comment |
|---|---|
| 4 | Strong educational opportunity for energy industry |

## Proposition 3 - Pembroke Schools & Leisure (Henry Tudor, Pembroke Dock Community & Pembroke Leisure

Overall Score

| Partner Score | Average Score | Arup Score |
|---|---|---|
| 3.41 | 3.36 | 3.34 |

Individual Criteria Score

*Achieves emissions reductions*

| Score | Comment |
|---|---|
| 3 | [1 - Neutral, 5 - positive contribution]<br>Local but will give emissions reduction for local area |

*Catalyst*

| Score | Comment |
|---|---|
| 4 | [1 - Neutral, 5 - positive contribution]<br>Local but gives a step change. Allows testing of new technologies and concepts. |

*Jobs & Prosperity*

| Score | Comment |
|---|---|
| 1 | Doesn't stimulate significant growth however, could be improved if a transport demand is included |

*Social Value*

| Score | Comment |
|---|---|
| 3 | Promotes new heating types and migration away from dependence on fossil fuels within schools |

*Stakeholder acceptability*

| Score | Comment |
|---|---|
| 3 | [1 - negative, 3- neutral, 5- positive]<br>Need engagement with schools, leisure centre and renewable asset owners |

*Design*

| Score | Comment |
|---|---|
| 3 | [1 - negative, 3- neutral, 5- positive]<br>Supply and demand are mismatched however no novel approaches here |

*Construction*

| Score | Comment |
|---|---|
| 2 | [1 - negative, 3- neutral, 5- positive]<br>Aligning construction particularly for existing buildings may be challenging particularly with timing of use of school buildings |

*Operation*

| Score | Comment |
| --- | --- |
| 3 | [1 - negative, 3- neutral, 5- positive]<br>New connected kit for the asset owners and users to operate/maintain but there are less boilers to maintain than the current situation. Requires skilled/trained operatives to maintain. |

*Decommissioning*

| Score | Comment |
| --- | --- |
| 4 | Leaves properties relatively open to changes in external energy market. Pipework will remain in ground for a long time |

*Impact*

| Score | Comment |
| --- | --- |
| 3 | [1 - negative impact, 5 - positive impact] |

*Mitigation*

| Score | Comment |
| --- | --- |
| 4 | 4 |

*Water Bodies*

| Score | Comment |
| --- | --- |
| 2 | Impact on water bodies due to electrolyser water demand |

*Biodiversity*

| Score | Comment |
| --- | --- |
| 3 | No expected change |

*Commercial Opportunity*

| Score | Comment |
| --- | --- |
| 3 | Medium commercial opportunity |

*Capital Cost (CAPEX)*

| Score | Comment |
| --- | --- |
| 2 | High cost with an electrolyser and large pipework lengths required |

*Maintenance Cost (OPEX)*

| Score | Comment |
| --- | --- |
| 4 | Low |

*Price Resilience*

| Score | Comment |
| --- | --- |
| 3 | PCC assets vulnerable to changes in private wire agreements from renewable owners |

# MH:EK Propositions MCA scoring

ARUP

*Levelised Cost of Energy (LCOE)*

| Score | Comment |
|---|---|
| 4 | 4 |

*Supply chain*

| Score | Comment |
|---|---|
| 3 | Relatively mature supply chain however, long lead in times for electrolysers |

*Investor Interest / Funding Streams*

| Score | Comment |
|---|---|
| 4 | Likely to be interest from Welsh Government and HNIP |

*Immediate Need / Opportunity Readiness*

| Score | Comment |
|---|---|
| 3 | New school creates immediate need however, other assets are already in operation |

*Complexity of asset ownership*

| Score | Comment |
|---|---|
| 3 | All demand propositions owned by PCC however there is complexity in renewable energy providers |

*Policy & Regulatory Considerations*

| Score | Comment |
|---|---|
| 4 | not really new or not already implement unless H2 is incorporated which will reduce the score |

*Development Risk*

| Score | Comment |
|---|---|
| 3 | |

*Scheme Constraints*

| Score | Comment |
|---|---|
| 3 | Some risk due to different supply and demand ownership. If hydrogen is tankered from renewable site then limited constraint due to transport |

*Future Expansion*

| Score | Comment |
|---|---|
| 4 | Strong opportunity for expansion in trunk pipe network sufficiently sized |

*Visual Impact*

| Score | Comment |
|---|---|
| 4 | Low impact with exception of new electrolyser and potential hydrogen transportation |

# MH:EK Propositions MCA scoring

ARUP

*Low-Carbon Technologies*

| Score | Comment |
| --- | --- |
| 5 | Enables low carbon technologies within the area |

*Energy Resilience*

| Score | Comment |
| --- | --- |
| 3 | Supply assets owned by third parties however, heat network means that new technologies can come online |

*Innovation*

| Score | Comment |
| --- | --- |
| 3 | Relatively innovative |

*WFGA Goals*

| Score | Comment |
| --- | --- |
| 5 | community based energy hub and decentralised |

*WFGA Ways of Working*

| Score | Comment |
| --- | --- |
| 5 | |

*Waste Reduction / Circular Economy*

| Score | Comment |
| --- | --- |
| 3 | Some waste due to new plant in existing buildings |

*Air Quality*

| Score | Comment |
| --- | --- |
| 4 | no gas boilers and no wood burners |

*Education*

| Score | Comment |
| --- | --- |
| 4 | Opportunity for educational element due to positioning in local leisure and school setting |

# MH:EK Propositions MCA scoring

ARUP

## Proposition 4-A - Industrial scale H2 Hub, Pembroke & Milford Haven

Overall Score

| Partner Score | Average Score | Arup Score |
|---|---|---|
| 3.34 | 3.33 | 3.57 |

Individual Criteria Score

*Achieves emissions reductions*

| Score | Comment |
|---|---|
| 4 | Large scale emissions reductions opportunity, although expected blue hydrogen production with CCS requirement. |

*Catalyst*

| Score | Comment |
|---|---|
| 5 | Significant influence on surrounding project boundary and broader South Wales & National energy transition and hydrogen economy. |

*Jobs & Prosperity*

| Score | Comment |
|---|---|
| 5 | Allows transition and diversification of local hydrocarbon industry and new green job creation. |

*Social Value*

| Score | Comment |
|---|---|
| 5 | Likely to maintain or enhance Milford Haven role in national energy landscape, with H2 hub. |

*Stakeholder acceptability*

| Score | Comment |
|---|---|
| 4 | Local jobs<br>Hydrocarbon industry transition<br>Port as H2 hub<br>Could be some negative impact from industrial activity / development and less community ownership opportunities. |

*Design*

| Score | Comment |
|---|---|
| 2 | This proposition scores fairly low across all technical aspects as it incorporates new technologies and approaches at scale which influences design, construction, operation and decommissioning. |

*Construction*

| Score | Comment |
|---|---|
| 2 | This proposition scores fairly low across all technical aspects as it incorporates new technologies and approaches at scale which influences design, construction, operation and decommissioning. |

# MH:EK Propositions MCA scoring

ARUP

*Operation*

| Score | Comment |
|---|---|
| 2 | This proposition scores fairly low across all technical aspects as it incorporates new technologies and approaches at scale which influences design, construction, operation and decommissioning. |

*Decommissioning*

| Score | Comment |
|---|---|
| 2 | This proposition scores fairly low across all technical aspects as it incorporates new technologies and approaches at scale which influences design, construction, operation and decommissioning. |

*Impact*

| Score | Comment |
|---|---|
| 3 | New development will be on existing industrial sites and will present opportunity to reduce environmental impact effects. But based on the scale of this opportunity is set to neutral. |

*Mitigation*

| Score | Comment |
|---|---|
| 3 | 3 |

*Water Bodies*

| Score | Comment |
|---|---|
| 1 | Additional water use/requirements are possible, alongside potential need to discharge warmed water to watercourses. |

*Biodiversity*

| Score | Comment |
|---|---|
| 3 | Expected to remain neutral regarding biodiversity. |

*Commercial Opportunity*

| Score | Comment |
|---|---|
| 4 | Commercial opportunity is expected to be significant if the business case for large scale hydrogen production, storage and import/export is realised.<br>Expected local demand across transport & heating vector, with export both in tankered export/import hub & national pipelines.<br>Scores lower than 4-B due to lower incorporation of renewables. |

*Capital Cost (CAPEX)*

| Score | Comment |
|---|---|
| 5 | Capital Cost is unknown but expected to be substantial to realise the infrastructure modifications to realise this system level change.<br>Investment required at industrial sites, port facilities and across gas network/pipelines. |

*Maintenance Cost (OPEX)*

| Score | Comment |
|---|---|
| 4 | Maintenance costs are anticipated to be higher than status-quo in the short-mid term with lowering costs as the technologies mature in the longer term. |

*Price Resilience*

| Score | Comment |
|---|---|
| 4 | This proposition presents a variety of renewable electricity generation, green and blue hydrogen production and demand uses so is considered fairly price resilient.<br>It also assumes infrastructure development to support a global H market with ability to import H.<br>However, if the price of H remains high and network infrastructure restricts renewables development then this proposition presents a substantial risk of higher prices during a transitionary period that may not be met by public investment. |

*Levelised Cost of Energy (LCOE)*

| Score | Comment |
|---|---|
| 3 | 3 |

*Supply chain*

| Score | Comment |
|---|---|
| 2 | Supply chain requires investment and quantifiable demand to transition.<br>Supply chain for blue hydrogen + CCS and transition of industrial processes not yet proven. |

*Investor Interest / Funding Streams*

| Score | Comment |
|---|---|
| 2 | Investors identified who could be interested in this scale of opportunity, but the business case needs to be understood better. |

*Immediate Need / Opportunity Readiness*

| Score | Comment |
|---|---|
| 2 | There is a mid-term need for transition to protect hydrocarbon industry jobs - societal benefit.<br>Industrial organisations plans / intentions for transition of sites is unknown - refer to SWIC plans ones released. |

*Complexity of asset ownership*

| Score | Comment |
|---|---|
| 1 | Proposition presents several possible opportunities.<br>All options require collaboration across several asset owners. |

*Policy & Regulatory Considerations*

| Score | Comment |
|---|---|
| 2 | Policy & Reg for hydrogen market/economy are not developed so unknown.<br>Offshore wind / offshore renewables support has reasonable short-term clarity through CfD mechanism. |

| | |
|---|---|
| | Onshore renewables currently less well supported with greater onshore planning constraints. |

*Development Risk*

| Score | Comment |
|---|---|
| 1 | All elements include substantial planning / DCO / EIA review as well as local community and industry support. |

*Scheme Constraints*

| Score | Comment |
|---|---|
| 1 | All elements include substantial planning / DCO / EIA review as well as local community and industry support. |

*Future Expansion*

| Score | Comment |
|---|---|
| 5 | The scheme will be capable of connecting to additional loads, and bring benefits to the wider area.<br>The scheme will be capable of supporting future expansion of energy capacity / be adaptable to future new technologies. |

*Visual Impact*

| Score | Comment |
|---|---|
| 2 | All elements include substantial planning / DCO / EIA review as well as local community and industry support. |

*Low-Carbon Technologies*

| Score | Comment |
|---|---|
| 4 | The scheme will allow for low-carbon technologies to be on display at scale, but will also still include blue H+CCS. |

*Energy Resilience*

| Score | Comment |
|---|---|
| 5 | Considered high based on the breadth of possible elements within the proposition. |

*Innovation*

| Score | Comment |
|---|---|
| 5 | Scores very highly based on the breadth, scale and interconnected nature of the proposed elements in this proposition. |

*WFGA Goals*

| Score | Comment |
|---|---|
| 4 | Scores highly, but less so on communities as potential less community involvement in this proposition. |

*WFGA Ways of Working*

| Score | Comment |
|---|---|

| | |
|---|---|
| 4 | Long term benefits are considered to be positive, with a risk that consumers/communities face higher costs during a mid-term transitionary period. |

*Waste Reduction / Circular Economy*

| Score | Comment |
|---|---|
| 4 | Improves industrial energy use, moving away from hydrocarbons. |

*Air Quality*

| Score | Comment |
|---|---|
| 4 | Improves industrial energy use, moving away from hydrocarbons. |

*Education*

| Score | Comment |
|---|---|
| 4 | Presence of low carbon technologies at scale supports broader education. |

# MH:EK Propositions MCA scoring

ARUP

## Proposition 4-B  Pembroke SLES inc. industrial scale H2 Hub

Overall Score

| Partner Score | Average Score | Arup Score |
|---|---|---|
| 3.62 | 3.60 | 3.87 |

Individual Criteria Score

*Achieves emissions reductions*

| Score | Comment |
|---|---|
| 5 | Regional level net-zero energy supply achieved through this proposition with green H production locally, import/export H hub, significant offshore wind development & onshore renewables growth. |

*Catalyst*

| Score | Comment |
|---|---|
| 5 | Catalyst both for further growth in region and as exemplar across UK. Considered to be an early 'hydrogen village'. |

*Jobs & Prosperity*

| Score | Comment |
|---|---|
| 5 | Strong diversification of local formerly hydrocarbon jobs. Growth of opportunities around offshore renewables. |

*Social Value*

| Score | Comment |
|---|---|
| 4 | Significant optimisation of social & economic aspects of energy security & access. |

*Stakeholder acceptability*

| Score | Comment |
|---|---|
| 5 | Expected to be strongly supported by local community & industry as proposition embodies significant 'green growth'. |

*Design*

| Score | Comment |
|---|---|
| 2 | This proposition scores fairly low across all technical aspects as it incorporates new technologies and approaches at scale which influences design, construction, operation and decommissioning. |

*Construction*

| Score | Comment |
|---|---|
| 2 | This proposition scores fairly low across all technical aspects as it incorporates new technologies and approaches at scale which influences design, construction, operation and decommissioning. |

*Operation*

| Score | Comment |
|---|---|
| 2 | This proposition scores fairly low across all technical aspects as it incorporates new technologies and approaches at scale which influences design, construction, operation and decommissioning. |

*Decommissioning*

| Score | Comment |
|---|---|
| 3 | Improved decommissioning score over 4-A, as includes greater renewables and green H production over blue (reliant on CCS). |

*Impact*

| Score | Comment |
|---|---|
| 3 | New development will be on existing industrial sites and will present opportunity to reduce environmental impact effects. But based on the scale of this opportunity is set to neutral. |

*Mitigation*

| Score | Comment |
|---|---|
| 3 | 3 |

*Water Bodies*

| Score | Comment |
|---|---|
| 1 | Additional water use/requirements are possible, alongside potential need to discharge warmed water to watercourses. |

*Biodiversity*

| Score | Comment |
|---|---|
| 3 | Expected to remain neutral regarding biodiversity. |

*Commercial Opportunity*

| Score | Comment |
|---|---|
| 5 | Commercial opportunity is expected to be significant if the business case for large scale hydrogen production, storage and import/export is realised.<br>Expected local demand across transport & heating vector, with export both in tankered export/import hub & national pipelines.<br>Scores higher than 4-A due to greater incorporation & focus on renewables. |

*Capital Cost (CAPEX)*

| Score | Comment |
|---|---|
| 5 | Capital Cost is unknown but expected to be substantial to realise the infrastructure modifications to realise this system level change.<br>Investment required at industrial sites, port facilities and across gas network/pipelines. |

*Maintenance Cost (OPEX)*

| Score | Comment |
|---|---|

| | |
|---|---|
| 4 | Maintenance costs are anticipated to be higher than status-quo in the short-mid term with lowering costs as the technologies mature in the longer term.<br>Will always be higher than currently because hydrogen needs more compression. |

*Price Resilience*

| Score | Comment |
|---|---|
| 4 | This proposition presents a variety of renewable electricity generation, green hydrogen production and demand uses so is considered fairly price resilient.<br>It also assumes infrastructure development to support a global H2 market with ability to import H2.<br>However, if the price of H2 remains high and network infrastructure restricts renewables development then this proposition presents a substantial risk of higher prices during a transitionary period that may not be met by public investment. |

*Levelised Cost of Energy (LCOE)*

| Score | Comment |
|---|---|
| 3 | 3 |

*Supply chain*

| Score | Comment |
|---|---|
| 3 | Supply chain requires investment and quantifiable demand to transition.<br>Scores higher than 4-A as doesn't rely on large scale blue hydrogen + CCS. |

*Investor Interest / Funding Streams*

| Score | Comment |
|---|---|
| 3 | Investors identified who could be interested in this scale of opportunity, but the business case needs to be understood better.<br>Scores higher than 4-A as there are known developers/investors interested in large scale offshore wind + hydrogen production. |

*Immediate Need / Opportunity Readiness*

| Score | Comment |
|---|---|
| 3 | There is a mid-term need for transition to protect hydrocarbon industry jobs - societal benefit.<br>Industrial organisations plans / intentions for transition of sites is unknown - refer to SWIC plans ones released.<br>The business case needs to be better understood. |

*Complexity of asset ownership*

| Score | Comment |
|---|---|
| 1 | Proposition presents several possible opportunities.<br>All options require collaboration across several asset owners. |

*Policy & Regulatory Considerations*

| Score | Comment |
|---|---|
| 2 | Policy & Reg for hydrogen market/economy are not developed so unknown.<br>Offshore wind / offshore renewables support has reasonable short-term clarity |

| | |
|---|---|
| | through CfD mechanism.<br>Onshore renewables currently less well supported with greater onshore planning constraints. |

*Development Risk*

| Score | Comment |
|---|---|
| 1 | All elements include substantial planning / DCO / EIA review as well as local community and industry support. |

*Scheme Constraints*

| Score | Comment |
|---|---|
| 1 | All elements include substantial planning / DCO / EIA review as well as local community and industry support. |

*Future Expansion*

| Score | Comment |
|---|---|
| 5 | The scheme will be capable of connecting to additional loads, and bring benefits to the wider area.<br>The scheme will be capable of supporting future expansion of energy capacity / be adaptable to future new technologies. |

*Visual Impact*

| Score | Comment |
|---|---|
| 1 | All elements include substantial planning / DCO / EIA review as well as local community and industry support - particularly including significant large scale renewables development. |

*Low-Carbon Technologies*

| Score | Comment |
|---|---|
| 5 | The scheme will allow for low-carbon technologies to be on display at scale, including significant large scale renewables development. |

*Energy Resilience*

| Score | Comment |
|---|---|
| 5 | Considered high based on the breadth of possible elements within the proposition. |

*Innovation*

| Score | Comment |
|---|---|
| 5 | Scores very highly based on the breadth, scale and interconnected nature of the proposed elements in this proposition. |

*WFGA Goals*

| Score | Comment |
|---|---|
| 5 | Scores higher than 4-A based on greater opportunity for community involvement through additional renewables development. |

*WFGA Ways of Working*

| Score | Comment |
|---|---|
| 4 | Long term benefits are considered to be positive, with a risk that consumers/communities face higher costs during a mid-term transitionary period. |

*Waste Reduction / Circular Economy*

| Score | Comment |
|---|---|
| 4 | Improves industrial energy use, moving away from hydrocarbons. |

*Air Quality*

| Score | Comment |
|---|---|
| 5 | Improves industrial energy use, moving away from hydrocarbons. |

*Education*

| Score | Comment |
|---|---|
| 5 | Presence of low carbon technologies at scale supports broader education. |

# MH:EK Propositions MCA scoring

ARUP

## Proposition 5 - Middle Scoveson Solar Farm, Neyland

Overall Score

| Partner Score | Average Score | Arup Score |
|---|---|---|
| 3.01 | 2.97 | 3.01 |

Individual Criteria Score

*Achieves emissions reductions*

| Score | Comment |
|---|---|
| 3 | [1 - Neutral, 5 - positive contribution]<br>Local setting but order of magnitude of emission reduction can be significant.<br>Technology adoption. |

*Catalyst*

| Score | Comment |
|---|---|
| 3 | [1 - Neutral, 5 - positive contribution]<br>Local but gives a step change. Allows testing of new technologies and concepts. |

*Jobs & Prosperity*

| Score | Comment |
|---|---|
| 1 | Doesn't really stimulates that much growth.<br>Promotes new technologies to local contractors but not at an industrial scale.<br>Only limited to some training and maintenance |

*Social Value*

| Score | Comment |
|---|---|
| 3 | Promoting new ways of providing heating<br>Additional revenue streams/models |

*Stakeholder acceptability*

| Score | Comment |
|---|---|
| 3 | [1 - negative, 3- neutral, 5- positive]<br>PCC likely to be supportive |

*Design*

| Score | Comment |
|---|---|
| 3 | [1 - negative, 3- neutral, 5- positive]<br>Timing aligns well with timing of Windsor Garden development however, health centre already build and so not ideal timing from that point of view |

*Construction*

| Score | Comment |
|---|---|
| 2 | [1 - negative, 3- neutral, 5- positive]<br>Aligning construction and heat on date likely to be tricky however demand sites are within close proximity |

# MH:EK Propositions MCA scoring

ARUP

*Operation*

| Score | Comment |
|---|---|
| 3 | [1 - negative, 3- neutral, 5- positive]<br>New connected kit for the asset owners and users to operate/maintain but there are less boilers to maintain than the current situation. Requires skilled/trained operatives to maintain. |

*Decommissioning*

| Score | Comment |
|---|---|
| 3 | Leaves sites fairly technology agnostic but are required to invest heavily in hydrogen technology |

*Impact*

| Score | Comment |
|---|---|
| 3 | [1 - negative impact, 5 - positive impact] |

*Mitigation*

| Score | Comment |
|---|---|
| 4 | 4 |

*Water Bodies*

| Score | Comment |
|---|---|
| 2 | Water supply required for electrolysis |

*Biodiversity*

| Score | Comment |
|---|---|
| 3 | No expected change |

*Commercial Opportunity*

| Score | Comment |
|---|---|
| 2 | No real opportunity to generate revenue |

*Capital Cost (CAPEX)*

| Score | Comment |
|---|---|
| 2 | High CAPEX for heating system due to electrolyser |

*Maintenance Cost (OPEX)*

| Score | Comment |
|---|---|
| 3 | Relatively high cost for a heating system |

*Price Resilience*

| Score | Comment |
|---|---|
| 3 | Dependent on external electricity provider |

# MH:EK Propositions MCA scoring

ARUP

*Levelised Cost of Energy (LCOE)*

| Score | Comment |
|---|---|
| 2 | 2 |

*Supply chain*

| Score | Comment |
|---|---|
| 3 | Electrolyser may need investment in the supply chain |

*Investor Interest / Funding Streams*

| Score | Comment |
|---|---|
| 3 | May be some interest from public bodies however unlikely to attract large external investors as limited opportunity for high revenue |

*Immediate Need / Opportunity Readiness*

| Score | Comment |
|---|---|
| 3 | No immediate need from health centre point of view however Windsor Garden timing aligns well |

*Complexity of asset ownership*

| Score | Comment |
|---|---|
| 3 | Mainly PCC and port however, may include more if Wier Point is included |

*Policy & Regulatory Considerations*

| Score | Comment |
|---|---|
| 3 | No new regulation provided however, likely to be requirements to safeguard electricity supply to health centre |

*Development Risk*

| Score | Comment |
|---|---|
| 3 | Risk to energy supply to health centre. Risk due to civils works in road. |

*Scheme Constraints*

| Score | Comment |
|---|---|
| 3 | Some risk due to ownership and lack of need for health centre |

*Future Expansion*

| Score | Comment |
|---|---|
| 4 | Strong opportunity for expansion particularly due to imbalance in supply and demand |

*Visual Impact*

| Score | Comment |
|---|---|
| 4 | Low visual impact with exception of energy centre |

# MH:EK Propositions MCA scoring

ARUP

*Low-Carbon Technologies*

| Score | Comment |
|---|---|
| 4 | Introduces some low carbon technologies |

*Energy Resilience*

| Score | Comment |
|---|---|
| 3 | Some resilience but potentially dependent on external providers |

*Innovation*

| Score | Comment |
|---|---|
| 3 | Some innovation however, marginal compared to other opportunities |

*WFGA Goals*

| Score | Comment |
|---|---|
| 4 | Community based energy |

*WFGA Ways of Working*

| Score | Comment |
|---|---|
| 4 | Cross-working between health care and housing |

*Waste Reduction / Circular Economy*

| Score | Comment |
|---|---|
| 2 | Decentralised plant will lead to savings however new infrastructure will also be required |

*Air Quality*

| Score | Comment |
|---|---|
| 4 | No gas boilers or wood burners |

*Education*

| Score | Comment |
|---|---|
| 3 | Creates awareness but does not educate the wider community |

# Appendix C – MCA report and SLES Decision Tree

## SLES decision tree framework

ENERGY KINGDOM
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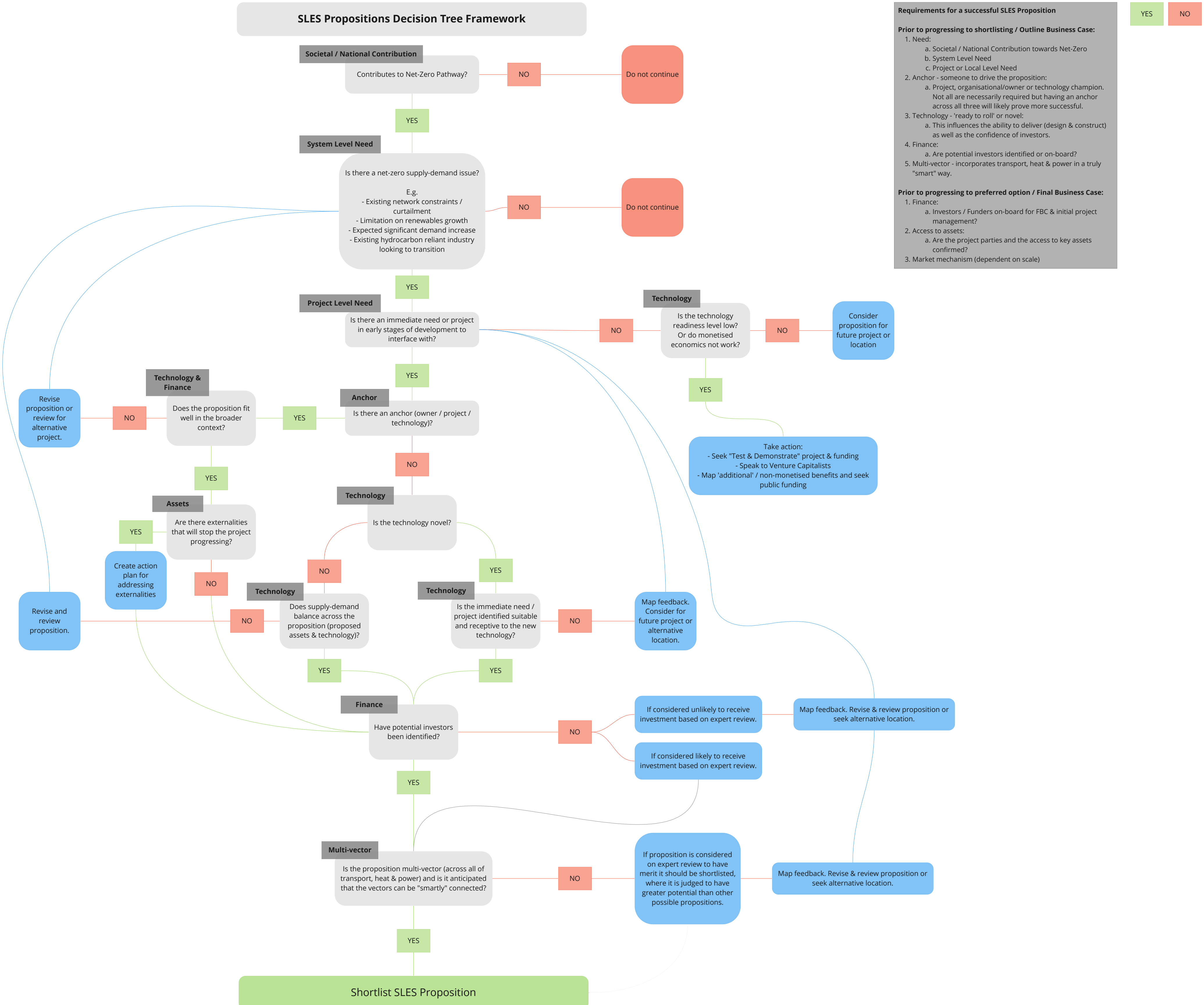

SLES Propositions Decision Tree Framework
YES
NO
Requirements for a successful SLES Proposition
Prior to progressing to shortlisting / Outline Business Case:
1. Need:
a. Societal / National Contribution towards Net-Zero
b. System Level Need
c. Project or Local Level Need
2. Anchor - someone to drive the proposition:
a. Project, organisational/owner or technology champion. Not all are necessarily required but having an anchor across all three will likely prove more successful.
3. Technology - 'ready to roll' or novel:
a. This influences the ability to deliver (design & construct) as well as the confidence of investors.
4. Finance:
a. Are potential investors identified or on-board?
5. Multi-vector - incorporates transport, heat & power in a truly "smart" way.
Prior to progressing to preferred option / Final Business Case:
1. Finance:
a. Investors / Funders on-board for FBC & initial project management?
2. Access to assets:
a. Are the project parties and the access to key assets confirmed?
3. Market mechanism (dependent on scale)
Societal / National Contribution
Contributes to Net-Zero Pathway?
NO
Do not continue
YES
System Level Need
Is there a net-zero supply-demand issue?
E.g.
- Existing network constraints / curtailment
- Limitation on renewables growth
- Expected significant demand increase
- Existing hydrocarbon reliant industry looking to transition
NO
Do not continue
YES
Project Level Need
Is there an immediate need or project in early stages of development to interface with?
NO
Technology
Is the technology readiness level low? Or do monetised economics not work?
NO
Consider proposition for future project or location
YES
Take action:
- Seek "Test & Demonstrate" project & funding
- Speak to Venture Capitalists
- Map 'additional' / non-monetised benefits and seek public funding
YES
Anchor
Is there an anchor (owner / project / technology)?
YES
Technology & Finance
Does the proposition fit well in the broader context?
NO
Revise proposition or review for alternative project.
YES
Assets
Are there externalities that will stop the project progressing?
YES
Create action plan for addressing externalities
NO
NO
Technology
Is the technology novel?
NO
Technology
Does supply-demand balance across the proposition (proposed assets & technology)?
NO
Revise and review proposition.
YES
YES
Technology
Is the immediate need / project identified suitable and receptive to the new technology?
NO
Map feedback. Consider for future project or alternative location.
YES
Finance
Have potential investors been identified?
NO
If considered unlikely to receive investment based on expert review.
Map feedback. Revise & review proposition or seek alternative location.
If considered likely to receive investment based on expert review.
YES
Multi-vector
Is the proposition multi-vector (across all of transport, heat & power) and is it anticipated that the vectors can be "smartly" connected?
NO
If proposition is considered on expert review to have merit it should be shortlisted, where it is judged to have greater potential than other possible propositions.
Map feedback. Revise & review proposition or seek alternative location.
YES
Shortlist SLES Proposition

# Appendix C – MCA report and SLES Decision Tree

## SLES decision tree outputs for emerging shortlist

ENERGY KINGDOM
DEYRNAS YNNI

# SLES Propositions Decision Tree Framework
## Proposition 1A - Milford Haven heat network & microgrid

**Requirements for a successful SLES Proposition**

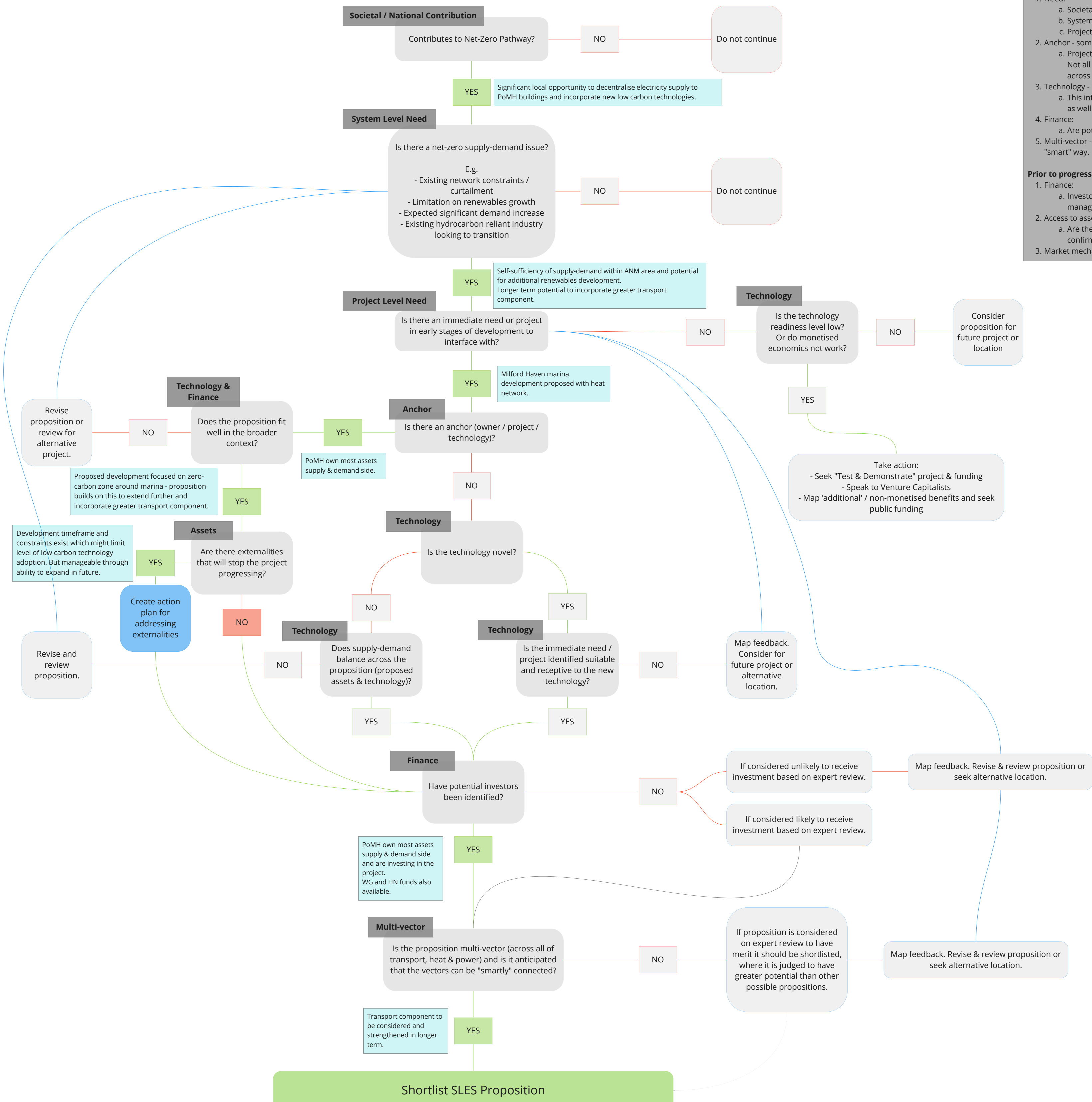
**Prior to progressing to shortlisting / Outline Business Case:**

1. Need:
   a. Societal / National Contribution towards Net-Zero
   b. System Level Need
   c. Project or Local Level Need
2. Anchor - someone to drive the proposition:
   a. Project, organisational/owner or technology champion. Not all are necessarily required but having an anchor across all three will likely prove more successful.
3. Technology - 'ready to roll' or novel:
   a. This influences the ability to deliver (design & construct) as well as the confidence of investors.
4. Finance:
   a. Are potential investors identified or on-board?
5. Multi-vector - incorporates transport, heat & power in a truly "smart" way.

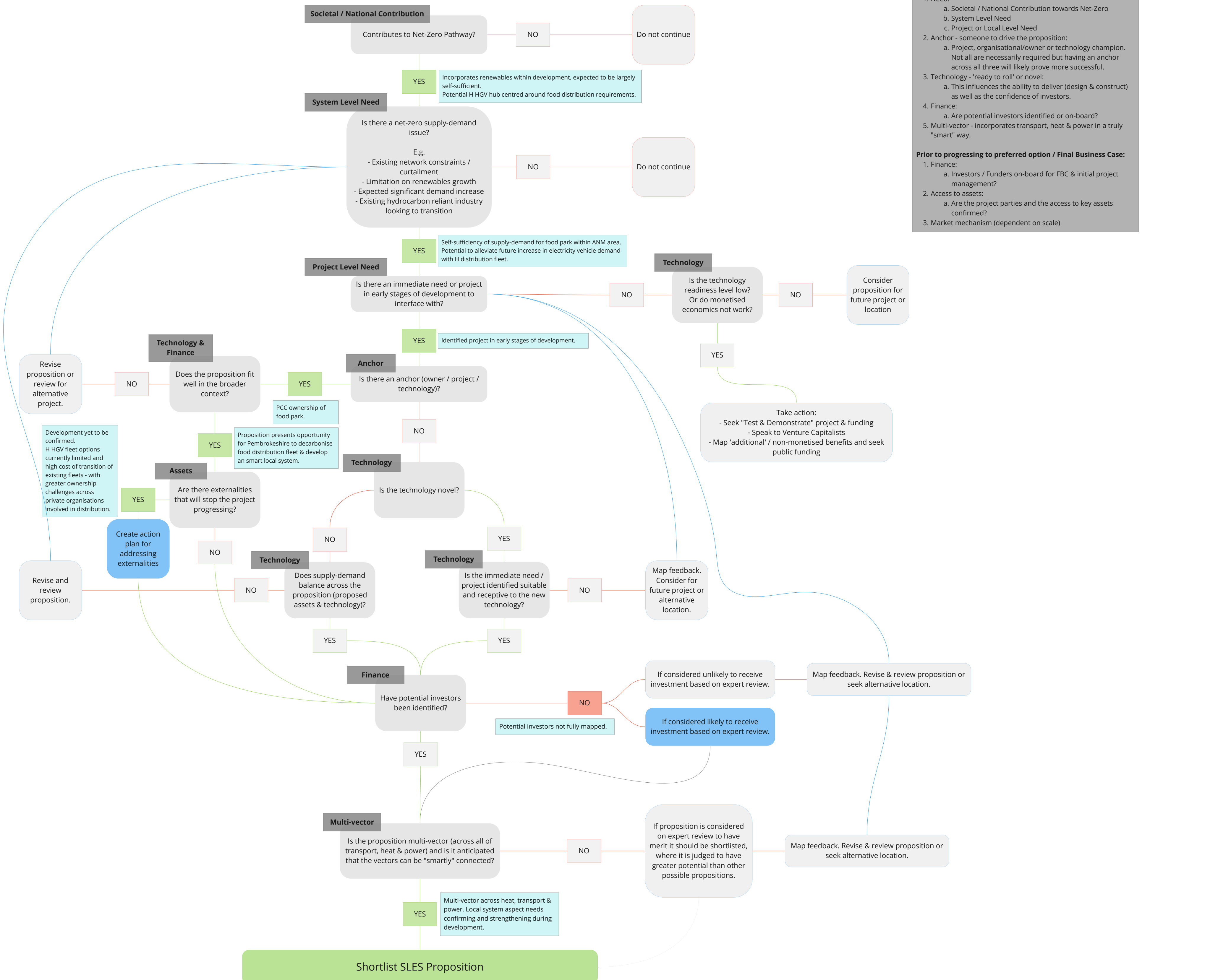
**Prior to progressing to preferred option / Final Business Case:**

1. Finance:
   a. Investors / Funders on-board for FBC & initial project management?
2. Access to assets:
   a. Are the project parties and the access to key assets confirmed?
3. Market mechanism (dependent on scale)

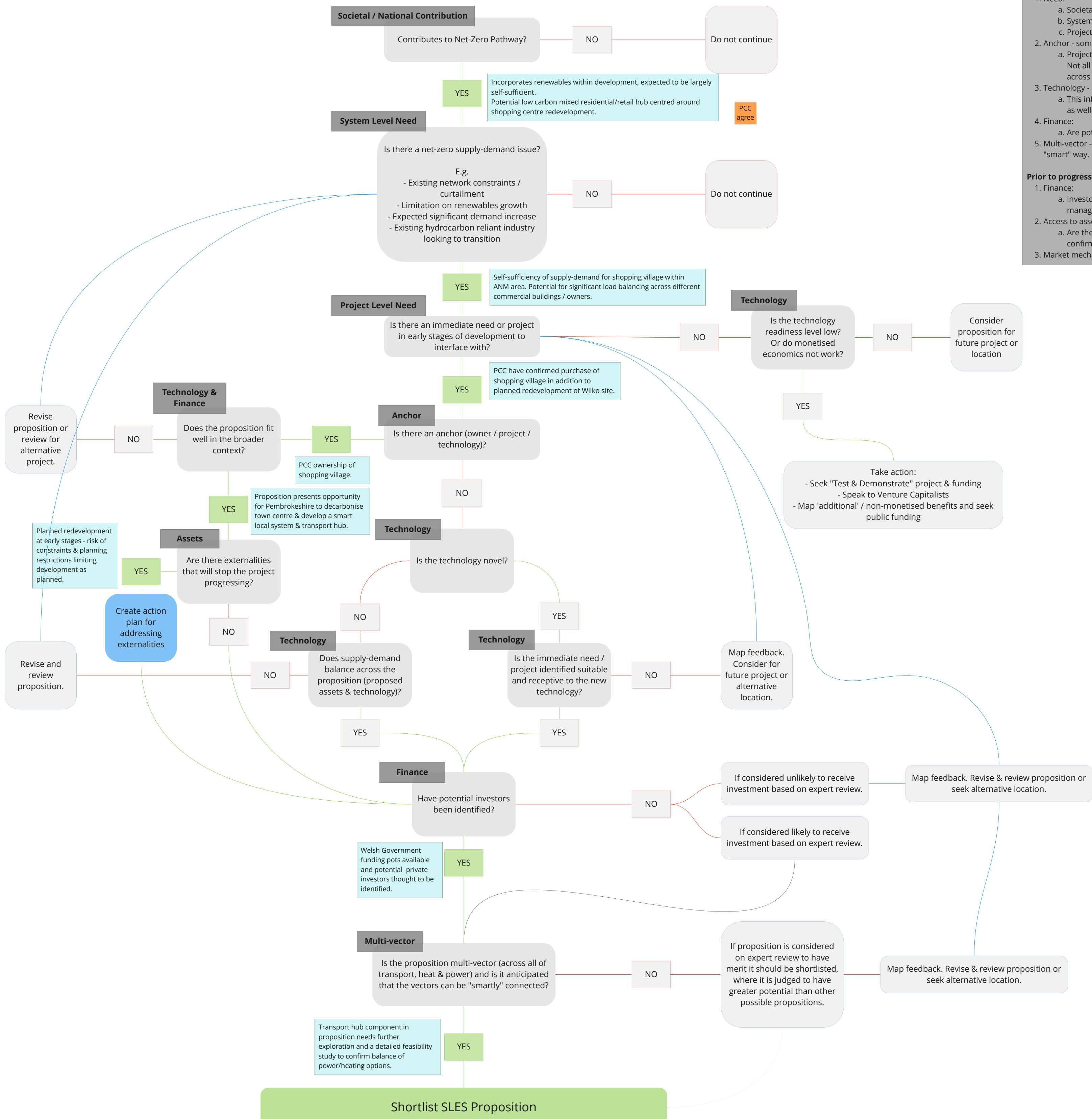
YES | NO



# SLES Propositions Decision Tree Framework
## Proposition 2G - Pembrokeshire Food Park



## SLES Propositions Decision Tree Framework
## Proposition 2F - Riverside shopping centre




**Requirements for a successful SLES Proposition**

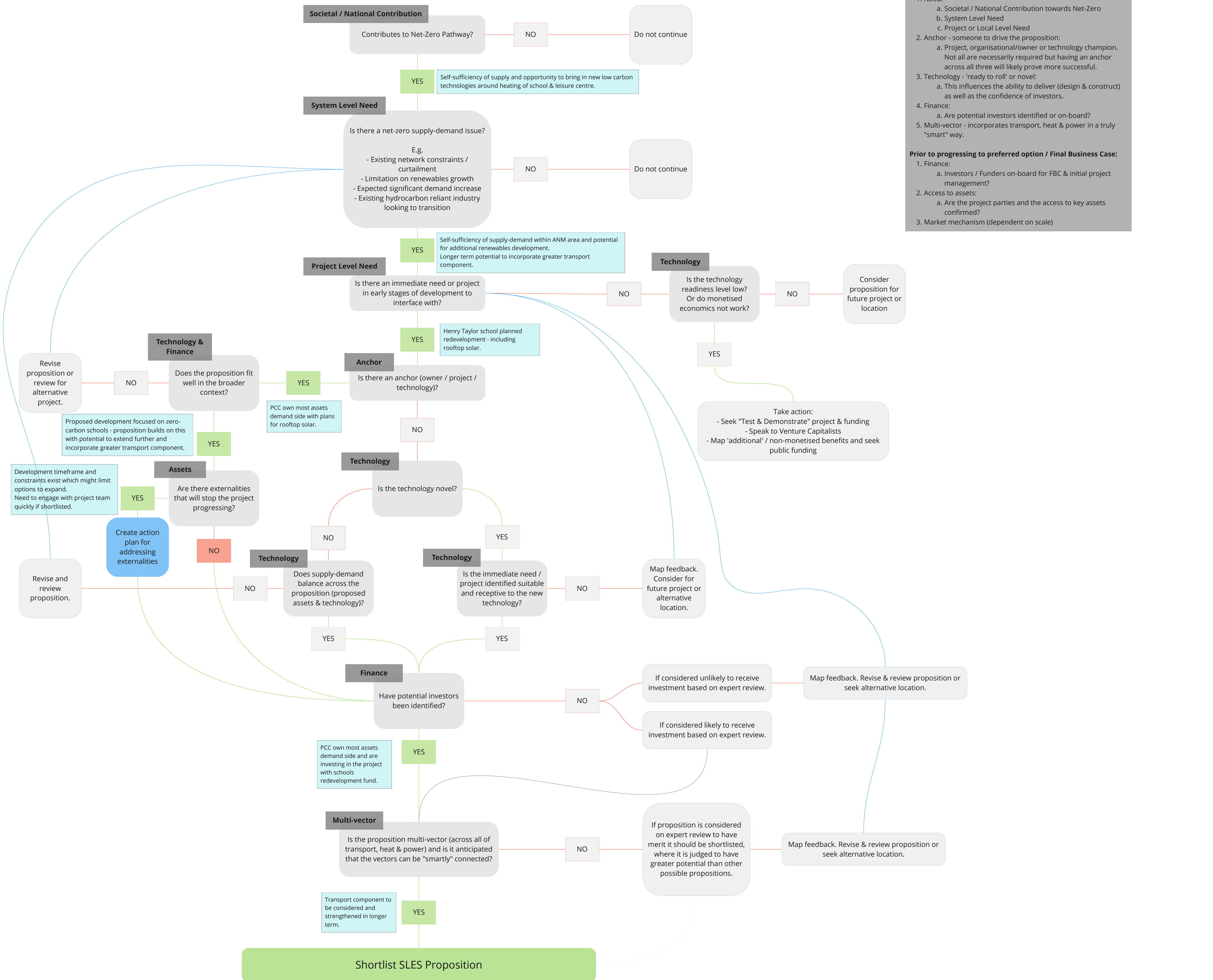
**Prior to progressing to shortlisting / Outline Business Case:**

1. Need:
   a. Societal / National Contribution towards Net-Zero
   b. System Level Need
   c. Project or Local Level Need
2. Anchor - someone to drive the proposition:
   a. Project, organisational/owner or technology champion. Not all are necessarily required but having an anchor across all three will likely prove more successful.
3. Technology - 'ready to roll' or novel:
   a. This influences the ability to deliver (design & construct) as well as the confidence of investors.
4. Finance:
   a. Are potential investors identified or on-board?
5. Multi-vector - incorporates transport, heat & power in a truly "smart" way.

**Prior to progressing to preferred option / Final Business Case:**

1. Finance:
   a. Investors / Funders on-board for FBC & initial project management?
2. Access to assets:
   a. Are the project parties and the access to key assets confirmed?
3. Market mechanism (dependent on scale)

# SLES Propositions Decision Tree Framework
## Proposition 3 - Pembrokeshire schools redevelopment and leisure centre




**Requirements for a successful SLES Proposition**

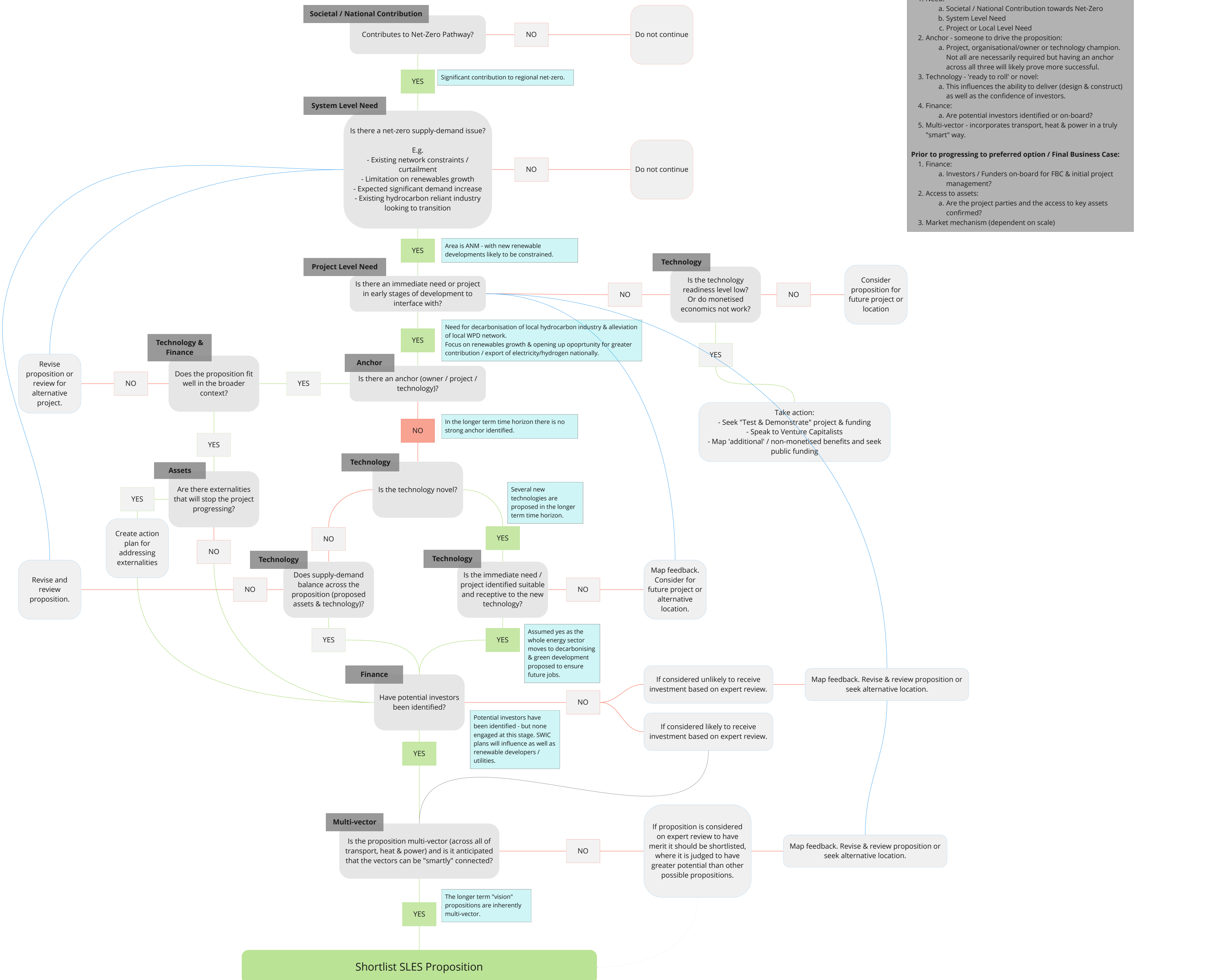
**Prior to progressing to shortlisting / Outline Business Case:**

1. Need:
   a. Societal / National Contribution towards Net-Zero
   b. System Level Need
   c. Project or Local Level Need
2. Anchor - someone to drive the proposition:
   a. Project, organisational/owner or technology champion. Not all are necessarily required but having an anchor across all three will likely prove more successful.
3. Technology - 'ready to roll' or novel:
   a. This influences the ability to deliver (design & construct) as well as the confidence of investors.
4. Finance:
   a. Are potential investors identified or on-board?
5. Multi-vector - incorporates transport, heat & power in a truly "smart" way.

**Prior to progressing to preferred option / Final Business Case:**

1. Finance:
   a. Investors / Funders on-board for FBC & initial project management?
2. Access to assets:
   a. Are the project parties and the access to key assets confirmed?
3. Market mechanism (dependent on scale)

# SLES Propositions Decision Tree Framework
# Proposition 4B - Longer term industrial scale H2 hub



MILFORD HAVEN: ENERGY KINGDOM

# Appendix D – Assumptions log

## A record of the techno-economic modelling assumptions

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# Technologies Costs

| Tech Type | Setting | Value | Units | Notes | Reference | Scenario | Proposition |
|---|---|---|---|---|---|---|---|
| battery | energy_cap | 203.4 | £ / kW | CAPEX includes infrastructure costs, design costs, capital costs and installation costs. Medium value | Mott MacDonald for BEIS (2018) Storage cost and technical assumptions for BEIS. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/910261/storage-costs-technical-assumptions-2018.pdf 50MW Frequency Management battery | high_elec_2050 hybrid_2050 high_hydrogen_2050 | All |
| ground_pv | om_prod | 0.01 | £ / kWh generated | OPEX includes Fixed O&M, Variable O&M, Fuel Costs, Decommissioning and waste, Steam Revenue, Additional Costs (all provided in £/MWh) | BEIS (2020) BEIS Electricity Generation Costs (2020). https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020 | baseline | All |
| battery | om_annual | 3 | £/kW/year | OPEX includes Operation, Inspection, Maintenance, Replenishment / refurbishment of consumables, Insurance, Security. Medium Value | Mott MacDonald for BEIS (2018) Storage cost and technical assumptions for BEIS. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/910261/storage-costs-technical-assumptions-2018.pdf 50MW Frequency Management battery | high_elec_2050 hybrid_2050 high_hydrogen_2050 | All |
| hydrogen_storage_tank | om_prod | 0.34 | £ / kWh | Medium pressure tank - Unlikely to decrease over time. | https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/760479/H2_supply_chain_evidence_-_publication_version.pdf | baseline | All |
| hydrogen_chp | om_annual | 14.2 | £/kW/year | Converted using 0.71USD to GBP | https://www.energy.gov/sites/prod/files/2016/07/f33/fcto_battelle_mfg_cost_analysis_pp_chp_fc_systems.pdf | baseline | All |
| electrolysers | om_annual_investment_fraction | 0.022 | (fraction) of capex | | IEA, Global average levelised cost of hydrogen production by energy source and technology, 2019 and 2050, IEA, Paris https://www.iea.org/data-and-statistics/charts/global-average-levelised-cost-of-hydrogen-production-by-energy-source-and-technology-2019-and-2050 | baseline | All |
| battery | energy_cap | 203.4 | £ / kW | CAPEX includes infrastructure costs, design costs, capital costs and installation costs. Medium value | Mott MacDonald for BEIS (2018) Storage cost and technical assumptions for BEIS. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/910261/storage-costs-technical-assumptions-2018.pdf 50MW Frequency Management battery | elec_counterfactual_2050 hy_counterfactual_2050 | All |
| marine_source_heat_pump | om_prod | 0.001548 | £/kWh | Assumed to be the same as a standard heat pump for now - if this comes out reassess. | https://core.ac.uk/download/pdf/141667173.pdf | baseline | All |
| heat_distribution | energy_cap_per_distance | 0.344 | £/m/kW | | https://arup.sharepoint.com/:x:/t/prj-27967400/EZSpkNsF0AxEqoLfFuKhDFABKqF_JrlVHpdrxhn9fKvGEA?e=mn3Dcc | baseline | All |

# Technologies Costs

| Tech Type | Setting | Value | Units | Notes | Reference | Scenario | Proposition |
|---|---|---|---|---|---|---|---|
| sewage_gas | energy_cap | 5906.66666666667 | £ / kW | CAPEX includes Pre-development cost (medium scenario) in £/kW, Construction cost (medium scenario) in £/kW and Infrastructure cost. Infrastructure cost (£'000) is converted to £/kW by dividing by reference plant size (MW*1000). Assumed price in 2020 is equivalent to projected 2025 price. No change across years | BEIS (2020) BEIS Electricity Generation Costs (2020). https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020 | baseline | All |
| onshore_wind | energy_cap | 1188.62745098039 | £ / kW | CAPEX includes Pre-development cost (medium scenario) in £/kW, Construction cost (medium scenario) in £/kW and Infrastructure cost. Infrastructure cost (£'000) is converted to £/kW by dividing by reference plant size (MW*1000). Assumed price in 2020 is equivalent to projected 2025 price | BEIS (2020) BEIS Electricity Generation Costs (2020). https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020 | baseline | All |
| battery | om_annual | 3 | £/kW/year | OPEX includes Operation, Inspection, Maintenance, Replenishment / refurbishment of consumables, Insurance, Security. Medium Value | Mott MacDonald for BEIS (2018) Storage cost and technical assumptions for BEIS. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/910261/storage-costs-technical-assumptions-2018.pdf 50MW Frequency Management battery | elec_counterfactual_2050<br>hy_counterfactual_2050 | All |
| offshore_wind | energy_cap | 1974.8 | £ / kW | CAPEX includes Pre-development cost (medium scenario) in £/kW, Construction cost (medium scenario) in £/kW and Infrastructure cost. Infrastructure cost (£'000) is converted to £/kW by dividing by reference plant size (MW*1000). Assumed price in 2020 is equivalent to projected 2025 price | BEIS (2020) BEIS Electricity Generation Costs (2020). https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020 | baseline | All |
| biomethane_supply | om_prod | 0.03075 | £ / kWh | Reduction of 25% in price assumed (projection for 2040 is -25%) | International Energy Agency (2020) Outlook for biogas and Biomethane Prospects for organic growth World Energy Outlook Special Report biomethane 2970 (iea.org) page 38. Reduction in price by 25% in 2040 is predicted | high_elec_2050<br>hybrid_2050<br>high_hydrogen_2050<br>elec_counterfactual_2050<br>hy_counterfactual_2050 | All |
| anaerobic_digestion | energy_cap | 4760 | £ / kW | CAPEX includes Pre-development cost (medium scenario) in £/kW, Construction cost (medium scenario) in £/kW and Infrastructure cost. Infrastructure cost (£'000) is converted to £/kW by dividing by reference plant size (MW*1000). Assumed price in 2020 is equivalent to projected 2025 price. No change across years | BEIS (2020) BEIS Electricity Generation Costs (2020). https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020 | baseline | All |

# Technologies Costs

| Tech Type | Setting | Value | Units | Notes | Reference | Scenario | Proposition |
|---|---|---|---|---|---|---|---|
| rooftop_pv | energy_cap | 800 | £ / kW | Solar PV 10-50 kW, assume 10 kW. CAPEX includes Pre-development cost (medium scenario) in £/kW, Construction cost (medium scenario) in £/kW and Infrastructure cost. Infrastructure cost (£'000) is converted to £/kW by dividing by reference plant size (MW*1000). Rooftop PV costs do not change | BEIS (2020) BEIS Electricity Generation Costs (2020). https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020 | baseline | All |
| ground_pv | energy_cap | 531.25 | £ / kW | Large-scale Solar. CAPEX includes Pre-development cost (medium scenario) in £/kW, Construction cost (medium scenario) in £/kW and Infrastructure cost. Infrastructure cost (£'000) is converted to £/kW by dividing by reference plant size (MW*1000). | BEIS (2020) BEIS Electricity Generation Costs (2020). https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020 | baseline | All |
| electricity_distribution | energy_cap | 517.65 | £/kW | Forces the £4.4m private wire to be built | | max_solar_pw wind_pw | Proposition 1 |
| hydrogen_storage_tank | storage_cap | 11.45 | £ / kWh | Medium pressure tank - Unlikely to decrease over time. | https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/760479/H2_supply_chain_evidence_-_publication_version.pdf | baseline | All |
| hydrogen_chp | energy_cap | 2094 | £ / kW | | https://www.energy.gov/sites/prod/files/2016/07/f33/fcto_battelle_mfg_cost_analysis_pp_chp_fc_systems.pdf | baseline | All |
| hydrogen_boiler_to_heat | energy_cap | 90 | £ / kW | CAPEX includes unit and installation costs. Values used for Medium size business + industry. Does not change through the years. | Imperial College London for CCC (2018) Analysis of alternative UK heat decarbonisation pathways. https://www.theccc.org.uk/publication/analysis-of-alternative-uk-heat-decarbonisation-pathways. | baseline | All |
| electrolysers | energy_cap | 750 | £ / kW | | https://www.energynetworks.org/industry-hub/resource-library/gas-goes-green-hydrogen-cost-to-customer-report.pdf | baseline | All |
| electricity_distribution | energy_cap | 517.65 | £/kW | Forces the £4.4m private wire to be built | | wind_pw | Proposition 1 |
| electricity_distribution | om_prod | 0.05 | £/kW | Energy Local virtual PPA costs - use the existing grid infrastructure rather than a private wire but pay for that. | | max_solar_ppa wind_ppa | Proposition 1 |
| electricity_distribution | om_prod | 0.05 | £/kW | Energy Local virtual PPA costs - use the existing grid infrastructure rather than a private wire but pay for that. | | wind_ppa | Proposition 1 |
| gas_boiler_to_heat | energy_cap | 75 | £ / kW | CAPEX includes unit and installation costs. Values used for Medium size business + industry. Does not change through the years. | Imperial College London for CCC (2018) Analysis of alternative UK heat decarbonisation pathways. https://www.theccc.org.uk/publication/analysis-of-alternative-uk-heat-decarbonisation-pathways. | baseline | All |

# Technologies Costs

| Tech Type | Setting | Value | Units | Notes | Reference | Scenario | Proposition |
|---|---|---|---|---|---|---|---|
| resistance_heating | energy_cap | 90 | £ / kW | CAPEX includes unit and installation costs. Values used for Medium size business + industry. Does not change through the years. | Imperial College London for CCC (2018) Analysis of alternative UK heat decarbonisation pathways. https://www.theccc.org.uk/publication/analysis-of-alternative-uk-heat-decarbonisation-pathways. | baseline | All |
| air_source_heat_pump | energy_cap | 647 | £ / kW | CAPEX includes unit and installation costs. Values used for Medium size business + industry. Does not change through the years. | Imperial College London for CCC (2018) Analysis of alternative UK heat decarbonisation pathways. https://www.theccc.org.uk/publication/analysis-of-alternative-uk-heat-decarbonisation-pathways. | baseline | All |
| ground_source_heat_pump | energy_cap | 2000 | £ / kW | | Installing A Ground Source Heat Pump (GSHP) Cost (priceyourjob.co.uk) | baseline | All |
| electrolysers | om_annual_investment_fraction | 0.015 | (fraction) of capex | | IEA, Global average levelised cost of hydrogen production by energy source and technology, 2019 and 2050, IEA, Paris https://www.iea.org/data-and-statistics/charts/global-average-levelised-cost-of-hydrogen-production-by-energy-source-and-technology-2019-and-2055 | hybrid_2050 high_hydrogen_2050 | All |
| electrolysers | energy_cap | 128 | £ / kW | These figures are much lower than the element energy report cited for storage | https://www.energynetworks.org/industry-hub/resource-library/gas-goes-green-hydrogen-cost-to-customer-report.pdf | high_elec_2050 hybrid_2050 high_hydrogen_2050 | All |
| marine_source_heat_pump | energy_cap | 1800 | £ / kW | This is a value for river source heat pumps. If this comes out, we need to follow up in marine source heat pumps cost more than river source... | https://www.theccc.org.uk/wp-content/uploads/2015/11/Element-Energy-for-CCC-Research-on-district-heating-and-local-approaches-to-heat-decarbonisation.pdf | baseline | All |
| battery | energy_cap | 480.3 | £ / kW | CAPEX includes infrastructure costs, design costs, capital costs and installation costs. Medium value | Mott MacDonald for BEIS (2018) Storage cost and technical assumptions for BEIS. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/910261/storage-costs-technical-assumptions-2018.pdf 50MW Frequency Management battery | baseline | All |
| electrolysers | om_annual_investment_fraction | 0.015 | (fraction) of capex | | IEA, Global average levelised cost of hydrogen production by energy source and technology, 2019 and 2050, IEA, Paris https://www.iea.org/data-and-statistics/charts/global-average-levelised-cost-of-hydrogen-production-by-energy-source-and-technology-2019-and-2054 | high_elec_2050 elec_counterfactual_2050 hy_counterfactual_2050 | All |

# Technologies Costs

| Tech Type | Setting | Value | Units | Notes | Reference | Scenario | Proposition |
|---|---|---|---|---|---|---|---|
| pumped_storage | energy_cap | 1362.9 | £ / kW | CAPEX includes infrastructure costs, design costs, capital costs and installation costs. Medium value | Mott MacDonald for BEIS (2018) Storage cost and technical assumptions for BEIS. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/910261/storage-costs-technical-assumptions-2018.pdf Connected peak lopping, 200MW | baseline | All |
| ground_pv | om_prod | 0.009 | £ / kWh generated | OPEX includes Fixed O&M, Variable O&M, Fuel Costs, Decommissioning and waste, Steam Revenue, Additional Costs (all provided in £/MWh). 2050 assumed to equal projected 2040 values | BEIS (2020) BEIS Electricity Generation Costs (2020). https://www.gov.uk/government/publications/beis-electricity-generation-costs-2024 | high_elec_2050 hybrid_2050 high_hydrogen_2050 | All |
| electricity_distribution | energy_cap_per_distance | 0 | £/kW/km | | Set to 0 and assumed in the remit of WPD | baseline | All |
| gas_distribution | energy_cap_per_distance | 0 | £/kW/km | | Set to 0 as assumed to be covered by WWU | baseline | All |
| hydrogen_distribution | energy_cap_per_distance | 0 | £/kW/km | | Set to 0 because assumed to be the covered by WWU | baseline | All |
| resistance_heating | om_annual | 0 | £/kW/year | Annual maintenance costs for resistance heaters zero. Does not change between years | Imperial College London for CCC (2018) Analysis of alternative UK heat decarbonisation pathways. https://www.theccc.org.uk/publication/analysis-of-alternative-uk-heat-decarbonisation-pathways. | baseline | All |
| hydrogen_boiler_to_heat | om_annual | 3.6 | £/kW/year | Annual maintenance costs for medium business +industry hyrogen boiler £1080 Divided by the reference size (300kw) does not change between years | Imperial College London for CCC (2018) Analysis of alternative UK heat decarbonisation pathways. https://www.theccc.org.uk/publication/analysis-of-alternative-uk-heat-decarbonisation-pathways. | baseline | All |
| air_source_heat_pump | om_annual | 19.77 | £/kW/year | Annual maintenance costs for medium business +industry ASHP £2966.04 Divided by the reference size (150kw) does not change between years | Imperial College London for CCC (2018) Analysis of alternative UK heat decarbonisation pathways. https://www.theccc.org.uk/publication/analysis-of-alternative-uk-heat-decarbonisation-pathways. | baseline | All |
| gas_boiler_to_heat | om_annual | 3.6 | £/kW/year | Annual maintenance costs for medium business +industry hyrogen boiler £1080 Divided by the reference size (300kw) does not change between years | Imperial College London for CCC (2018) Analysis of alternative UK heat decarbonisation pathways. https://www.theccc.org.uk/publication/analysis-of-alternative-uk-heat-decarbonisation-pathways. | baseline | All |
| ground_source_heat_pump | om_annual | 2.58 | £/kW/year | | https://core.ac.uk/download/pdf/141667173.pdf | baseline | All |

# Technologies Costs

| Tech Type | Setting | Value | Units | Notes | Reference | Scenario | Proposition |
|---|---|---|---|---|---|---|---|
| battery | om_annual | 7.3 | £/kW/year | OPEX includes Operation, Inspection, Maintenance, Replenishment / refurbishment of consumables, Insurance, Security. Medium Value | Mott MacDonald for BEIS (2018) Storage cost and technical assumptions for BEIS. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/910261/storage-costs-technical-assumptions-2018.pdf 50MW Frequency Management battery | baseline | All |
| ground_pv | energy_cap | 431.25 | £ / kW | Large-scale Solar. CAPEX includes Pre-development cost (medium scenario) in £/kW, Construction cost (medium scenario) in £/kW and Infrastructure cost. Infrastructure cost (£'000) is converted to £/kW by dividing by reference plant size (MW*1000). Assume 2050 cost equals projected 2040 cost | BEIS (2020) BEIS Electricity Generation Costs (2020). https://www.gov.uk/government/publications/beis-electricity-generation-costs-2024 | high_elec_2050 hybrid_2050 high_hydrogen_2050 | All |
| pumped_storage | om_annual | 17.8 | £/kW/year | OPEX includes Operation, Inspection, Maintenance, Replenishment / refurbishment of consumables, Insurance, Security. Medium Value | Mott MacDonald for BEIS (2018) Storage cost and technical assumptions for BEIS. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/910261/storage-costs-technical-assumptions-2018.pdf Connected peak lopping, 200MW | baseline | All |
| ground_pv | om_prod | 0.009 | £ / kWh generated | OPEX includes Fixed O&M, Variable O&M, Fuel Costs, Decommissioning and waste, Steam Revenue, Additional Costs (all provided in £/MWh). 2050 assumed to equal projected 2040 values | BEIS (2020) BEIS Electricity Generation Costs (2020). https://www.gov.uk/government/publications/beis-electricity-generation-costs-2026 | hy_counterfactual_2050 elec_counterfactual_2050 | All |
| national_grid_import | om_prod | 0.144 | £ / kWh | Eventually from plexos, for now set to PoMH prices | Tam Bardell | baseline | All |
| ground_pv | energy_cap | 431.27 | £ / kW | Large-scale Solar. CAPEX includes Pre-development cost (medium scenario) in £/kW, Construction cost (medium scenario) in £/kW and Infrastructure cost. Infrastructure cost (£'000) is converted to £/kW by dividing by reference plant size (MW*1000). Assume 2050 cost equals projected 2040 cost | BEIS (2020) BEIS Electricity Generation Costs (2020). https://www.gov.uk/government/publications/beis-electricity-generation-costs-2028 | elec_counterfactual_2050 | All |
| ground_pv | energy_cap | 431.29 | £ / kW | Large-scale Solar. CAPEX includes Pre-development cost (medium scenario) in £/kW, Construction cost (medium scenario) in £/kW and Infrastructure cost. Infrastructure cost (£'000) is converted to £/kW by dividing by reference plant size (MW*1000). Assume 2050 cost equals projected 2040 cost | BEIS (2020) BEIS Electricity Generation Costs (2020). https://www.gov.uk/government/publications/beis-electricity-generation-costs-2030 | hy_counterfactual_2050 | All |

# Technologies Costs

| Tech Type | Setting | Value | Units | Notes | Reference | Scenario | Proposition |
|---|---|---|---|---|---|---|---|
| national_grid_export | om_prod | -0.0524 | £ / kWh | Feed in tariff | https://www.gov.uk/feed-in-tariffs#:~:text=The%20export%20tariff%20%2D%20selling%20surplus,units%20of%20electricity%20you%20generate. | baseline | All |
| ground_pv | energy_cap | 951.25 | £ / kW | Large-scale Solar. CAPEX includes Pre-development cost (medium scenario) in £/kW, Construction cost (medium scenario) in £/kW and Infrastructure cost. Infrastructure cost (£'000) is converted to £/kW by dividing by reference plant size (MW*1000). | BEIS (2020) BEIS Electricity Generation Costs (2020). https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020. Plus private wire costs of 520 £/kW, Hoare Lea Liddeston Ridge quote minus Liddeston Ridge upgrade and reinforcing costs. | high_elec_2050<br>hybrid_2050<br>high_hydrogen_2050<br>elec_counterfactual_2050<br>hy_counterfactual_2050 | Proposition 2 |
| natural_gas_import | om_prod | 0.0160370640435034 | £ / kWh | Taken from the Reference scenario, wholesale natural gas, converted from 47 p/therm. | BEIS 2019 Updated Energy and Emissions Projections. Annex M. https://www.gov.uk/government/publications/updated-energy-and-emissions-projections-2019 | baseline | All |
| ground_source_heat_pump | energy_cap | 1780 | £ / kW | | Installing A Ground Source Heat Pump (GSHP) Cost (priceyourjob.co.uk) | high_elec_2050<br>hybrid_2050<br>high_hydrogen_2050<br>elec_counterfactual_2050<br>hy_counterfactual_2050 | All |
| hydrogen_import | om_prod | 0.135 | £ / kWh | | Statkraft price | baseline | All |
| hydrogen_export | om_prod | -0.135 | £ / kWh | | Negative of Statkraft price | baseline | All |
| hydrogen_export | om_prod | -0.0766 | £ / kWh | PLEXOS OUTPUTS | Progessive analysis SW 2050 | high_elec_2050<br>hybrid_2050<br>high_hydrogen_2050 | All |
| sewage_gas | om_prod | 0.04 | £ / kWh generated | OPEX includes Fixed O&M, Variable O&M, Fuel Costs, Decommissioning and waste, Steam Revenue, Additional Costs (all provided in £/MWh) No change across years | BEIS (2020) BEIS Electricity Generation Costs (2020). https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020 | baseline | All |
| onshore_wind | om_prod | 0.016 | £ / kWh generated | OPEX includes fixed O+M, Variable O+M, fuel costs, decommissioning & waste, Steam revenue, and additional costs. Costs are assumed constant between 2040 and 2050. No change across years | BEIS (2020) BEIS Electricity Generation Costs (2020). https://www.gov.uk/government/publications/beis-electricity-generation-costs-2021 | baseline | All |
| offshore_wind | om_prod | 0.023 | £ / kWh generated | OPEX includes fixed O+M, Variable O+M, fuel costs, decommissioning & waste, Steam revenue, and additional costs. Costs are assumed constant between 2040 and 2050. | BEIS (2020) BEIS Electricity Generation Costs (2020). https://www.gov.uk/government/publications/beis-electricity-generation-costs-2021 | baseline | All |
| hydrogen_export | om_prod | 0.0766 | £ / kWh | | Progessive analysis SW 2052 | elec_counterfactual_2050<br>hy_counterfactual_2050 | All |

# Technologies Costs

| Tech Type | Setting | Value | Units | Notes | Reference | Scenario | Proposition |
|---|---|---|---|---|---|---|---|
| anaerobic_digestion | om_prod | 0.07 | £ / kWh generated | OPEX includes Fixed O&M, Variable O&M, Fuel Costs, Decommissioning and waste, Steam Revenue, Additional Costs (all provided in £/MWh). No change across years | BEIS (2020) BEIS Electricity Generation Costs (2020). https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020 | baseline | All |
| biomethane_supply | om_prod | 0.041 | £ / kWh | | International Energy Agency (2020) Outlook for biogas and Biomethane Prospects for organic growth World Energy Outlook Special Report biomethane 2970 (iea.org) page 38. Reduction in price by 25% in 2040 is predicted | baseline | All |
| hydrogen_export | om_prod | -0.06 | £/kWh | | PLEXOS outputs | high_elec_2050 hybrid_2050 high_hydrogen_2050 elec_counterfactual_2050 hy_counterfactual_2050 | Proposition 2 |
| rooftop_pv | om_prod | 0.008 | £ / kWh generated | OPEX includes Fixed O&M, Variable O&M, Fuel Costs, Decommissioning and waste, Steam Revenue, Additional Costs (all provided in £/MWh). | BEIS (2020) BEIS Electricity Generation Costs (2020). https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020 | baseline | All |
| ground_source_heat_pump | om_prod | 0.001548 | £/kWh | | https://core.ac.uk/download/pdf/141667173.pdf | baseline | All |
| hydrogen_export | om_prod | -0.06 | £/kWh | | PLEXOS outputs | high_elec_2050 hybrid_2050 high_hydrogen_2050 elec_counterfactual_2050 hy_counterfactual_2050 | Proposition 3 |
| hydrogen_import | om_prod | 0.0777 | £ / kWh | PLEXOS OUTPUTS | Progessive analysis SW 2050 | high_elec_2050 hybrid_2050 high_hydrogen_2050 elec_counterfactual_2050 hy_counterfactual_2050 | All |
| hydrogen_import | om_prod | 0.146 | £/kWh | | PLEXOS outputs | high_elec_2050 hybrid_2050 high_hydrogen_2050 elec_counterfactual_2050 hy_counterfactual_2050 | Proposition 2 |
| hydrogen_import | om_prod | 0.146 | £/kWh | | PLEXOS outputs | high_elec_2050 hybrid_2050 high_hydrogen_2050 elec_counterfactual_2050 hy_counterfactual_2050 | Proposition 3 |
| national_grid_export | om_prod | 0.0524 | £ / kWh | PLEXOS OUTPUTS in the future | https://www.gov.uk/feed-in-tariffs#:~:text=The%20export%20tariff%20%2D%20selling%20surplus,units%20of%20electricity%20you%20generate. | high_elec_2050 hybrid_2050 high_hydrogen_2050 elec_counterfactual_2050 hy_counterfactual_2050 | All |

# Technologies Costs

| Tech Type | Setting | Value | Units | Notes | Reference | Scenario | Proposition |
|---|---|---|---|---|---|---|---|
| national_grid_export | om_prod | -0.051 | £/kWh | | PLEXOS outputs average | high_elec_2020<br>hybrid_2020<br>high_hydrogen_2020<br>elec_counterfactual_2020<br>hy_counterfactual_2020 | Proposition 2 |
| national_grid_export | om_prod | -0.053 | £/kWh | | PLEXOS outputs | high_elec_2050<br>hybrid_2050<br>high_hydrogen_2050<br>elec_counterfactual_2050<br>hy_counterfactual_2050 | Proposition 2 |
| national_grid_export | om_prod | -0.051 | £/kWh | | PLEXOS outputs | high_elec_2020<br>hybrid_2020<br>high_hydrogen_2020<br>elec_counterfactual_2020<br>hy_counterfactual_2020 | Proposition 3 |
| marine_source_heat_pump | om_annual | 7.5 | £/kW/year | This is the value for river source heat pumps, need to update if marine source heat pumps are chosen. Central scenario in source used | https://www.theccc.org.uk/wp-content/uploads/2015/11/Element-Energy-for-CCC-Research-on-district-heating-and-local-approaches-to-heat-decarbonisation.pdf | baseline | All |
| existing_solar | om_prod | 0.085 | £/kWh | | Discussion with Port - this is current PPA for a solar - for 1 year. | baseline | All |
| gas_CHP | om_annual | 14.2 | £/kW/year | Same as Hydrogen CHP | | baseline | Proposition 3 |
| gas_CHP | energy_cap | 2094 | £/kW | Same as Hydrogen CHP | | baseline | Proposition 3 |
| chiller | om_prod | 0.0002 | £ / kWh generated | Copied value from Jersey | | baseline | Proposition 2 |
| chiller | energy_cap | 200 | £/ kW | Copied value from Jersey - Originally from Gleeds | | baseline | Proposition 2 |
| simultaneous_heat_pump | energy_cap | 647 | £ / kW | | Assumed same as ASHP | baseline | Proposition 2 |
| simultaneous_heat_pump | om_annual | 19.77 | £ / year | | Assumed same as ASHP | baseline | Proposition 2 |
| cooling_distribution | energy_cap_per_distance | 0.258 | £/m/kW | Same as heating distribution | Same as heating distribution - 25% discount due to to heating and cooling pipework at the same time | baseline | Proposition 2 |
| absorption_chiller | energy_cap | 284 | £ / kW | Converted from 1370 $/refrigerated ton to £/kW | US DOE https://www.energy.gov/sites/prod/files/2017/06/f35/CHP-Absorption%20Chiller-compliant.pdf | baseline | Proposition 2 |
| absorption_chiller | om_prod | 0.0004 | £ / kWh | Converted from 0.2 US cents/refrigerated ton hour to £/kW | US DOE https://www.energy.gov/sites/prod/files/2017/06/f35/CHP-Absorption%20Chiller-compliant.pdf | baseline | Proposition 2 |
| anaerobic_digestion_biogas | energy_cap | 5000 | £/kW | | https://natwestbusinesshub.com/articles/does-anaerobic-digestion-pay-off-on-smaller-farms | baseline | Proposition 2 |
| anaerobic_digestion_biogas | om_annual | 40 | £/kW/year | | https://natwestbusinesshub.com/articles/does-anaerobic-digestion-pay-off-on-smaller-farms | baseline | Proposition 2 |
| biogas_boiler | energy_cap | 75 | £/kW | Same as gas boiler | | baseline | Proposition 2 |
| biogas_boiler | om_annual | 3.6 | £/kW/year | Same as gas boielr | | baseline | Proposition 2 |

# Technologies Costs

| Tech Type | Setting | Value | Units | Notes | Reference | Scenario | Proposition |
|---|---|---|---|---|---|---|---|
| biogas_chp | energy_cap | 2094 | £/kW | Same as gas CHP | | baseline | Proposition 2 |
| biogas_chp | om_annual | 14.2 | £/kW/year | Same as gas CHP | | baseline | Proposition 2 |
| biogas_cchp | energy_cap | 2378 | £/kW | Addition of gas CHP and absorption chiller | | baseline | Proposition 2 |
| biogas_cchp | om_annual | 17.7 | £/kW/year | Addition of gas CHP and absorption chiller | | baseline | Proposition 2 |
| hydrogen_cchp | energy_cap | 2378 | £/kW | Addition of gas CHP and absorption chiller | | baseline | Proposition 2 |
| hydrogen_cchp | om_annual | 17.7 | £/kW/year | Addition of gas CHP and absorption chiller | | baseline | Proposition 2 |
| thermal_store | storage_cap | 29 | £/kWh stored | Assumes store larger than 100m3 | Vital Energy (2015 prices) | baseline | All |
| national_grid_export | om_prod | -0.053 | £/kWh | | PLEXOS outputs | high_elec_2050<br>hybrid_2050<br>high_hydrogen_2050<br>elec_counterfactual_2050<br>hy_counterfactual_2050 | Proposition 3 |
| national_grid_import | om_prod | 0.137 | £/kWh | | BEIS | high_elec_2020<br>hybrid_2020<br>high_hydrogen_2020<br>elec_counterfactual_2020<br>hy_counterfactual_2020 | Proposition 2 |
| national_grid_import | om_prod | 0.143 | £/kWh | | EU Reference Scenario 2016 - UK Value | high_elec_2050<br>hybrid_2050<br>high_hydrogen_2050<br>elec_counterfactual_2050<br>hy_counterfactual_2050 | Proposition 2 |
| national_grid_import | om_prod | 0.137 | £/kWh | | BEIS | high_elec_2020<br>hybrid_2020<br>high_hydrogen_2020<br>elec_counterfactual_2020<br>hy_counterfactual_2020 | Proposition 3 |
| national_grid_import | om_prod | 0.143 | £/kWh | | EU Reference Scenario 2016 - UK Value | high_elec_2050<br>hybrid_2050<br>high_hydrogen_2050<br>elec_counterfactual_2050<br>hy_counterfactual_2050 | Proposition 3 |
| natural_gas_import | om_prod | 0.0218 | £ / kWh | Taken from the Reference scenario, wholesale natural gas, Value for 2035 is 64 p / therm, converted to £/kwh | BEIS 2019 Updated Energy and Emissions Projections. Annex M. https://www.gov.uk/government/publications/updated-energy-and-emissions-projections-2019 | high_elec_2050<br>hybrid_2050<br>high_hydrogen_2050<br>elec_counterfactual_2050<br>hy_counterfactual_2050 | All |

# Technologies Costs

| Tech Type | Setting | Value | Units | Notes | Reference | Scenario | Proposition |
|---|---|---|---|---|---|---|---|
| offshore_wind | energy_cap | 1574.8 | £ / kW | CAPEX includes Pre-development cost (medium scenario) in £/kW, Construction cost (medium scenario) in £/kW and Infrastructure cost. Infrastructure cost (£'000) is converted to £/kW by dividing by reference plant size (MW*1000). Assumed price in 2020 is equivalent to projected 2025 price. assumed price in 2040 from BEIS is equivalent to 2050 price | BEIS (2020) BEIS Electricity Generation Costs (2020). https://www.gov.uk/government/publications/beis-electricity-generation-costs-2024 | high_elec_2050 hybrid_2050 high_hydrogen_2050 | All |
| offshore_wind | om_prod | 0.019 | £ / kWh generated | OPEX includes fixed O+M, Variable O+M, fuel costs, decommissioning & waste, Steam revenue, and additional costs. Costs are assumed constant between 2040 and 2050. | BEIS (2020) BEIS Electricity Generation Costs (2020). https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020 | high_elec_2050 hybrid_2050 high_hydrogen_2050 | All |
| offshore_wind | energy_cap | 1574.10 | £ / kW | CAPEX includes Pre-development cost (medium scenario) in £/kW, Construction cost (medium scenario) in £/kW and Infrastructure cost. Infrastructure cost (£'000) is converted to £/kW by dividing by reference plant size (MW*1000). Assumed price in 2020 is equivalent to projected 2025 price. assumed price in 2040 from BEIS is equivalent to 2050 price | BEIS (2020) BEIS Electricity Generation Costs (2020). https://www.gov.uk/government/publications/beis-electricity-generation-costs-2028 | elec_counterfactual_2050 hy_counterfactual_2050 | All |
| offshore_wind | om_prod | 0.019 | £ / kWh generated | OPEX includes fixed O+M, Variable O+M, fuel costs, decommissioning & waste, Steam revenue, and additional costs. Costs are assumed constant between 2040 and 2050. | BEIS (2020) BEIS Electricity Generation Costs (2020). https://www.gov.uk/government/publications/beis-electricity-generation-costs-2022 | elec_counterfactual_2050 hy_counterfactual_2050 | All |
| onshore_wind | energy_cap | 1088.6 | £ / kW | CAPEX includes Pre-development cost (medium scenario) in £/kW, Construction cost (medium scenario) in £/kW and Infrastructure cost. Infrastructure cost (£'000) is converted to £/kW by dividing by reference plant size (MW*1000). Assumed price in 2020 is equivalent to projected 2025 price | BEIS (2020) BEIS Electricity Generation Costs (2020). https://www.gov.uk/government/publications/beis-electricity-generation-costs-2024 | high_elec_2050 hybrid_2050 high_hydrogen_2050 elec_counterfactual_2050 hy_counterfactual_2050 | All |
| pumped_storage | energy_cap | 1243.7 | £ / kW | CAPEX includes infrastructure costs, design costs, capital costs and installation costs. Medium value | Mott MacDonald for BEIS (2018) Storage cost and technical assumptions for BEIS. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/910261/storage-costs-technical-assumptions-2018.pdf Connected peak lopping, 200MW | high_elec_2050 hybrid_2050 high_hydrogen_2050 | All |

# Technologies Costs

| Tech Type | Setting | Value | Units | Notes | Reference | Scenario | Proposition |
|---|---|---|---|---|---|---|---|
| pumped_storage | om_annual | 16.2 | £/kW/year | OPEX includes Operation, Inspection, Maintenance, Replenishment / refurbishment of consumables, Insurance, Security. Medium Value | Mott MacDonald for BEIS (2018) Storage cost and technical assumptions for BEIS. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/910261/storage-costs-technical-assumptions-2018.pdf Connected peak lopping, 200MW | high_elec_2050 hybrid_2050 high_hydrogen_2050 | All |
| heat_distribution | energy_cap_per_distance | 0.258 | £/m/kW | | https://arup.sharepoint.com/:x:/t/prj-27967400/EZSpkNsF0AxEqoLfFuKhDFABKqF_JrlVHpdrxhn9fKvGEA?e=mn3Dcc - 25% discount due to heating and cooling at the same time | baseline | Proposition 2 |
| ground_pv | energy_cap | 1051.25 | £ / kW | Large-scale Solar. CAPEX includes Pre-development cost (medium scenario) in £/kW, Construction cost (medium scenario) in £/kW and Infrastructure cost. Infrastructure cost (£'000) is converted to £/kW by dividing by reference plant size (MW*1000). | BEIS (2020) BEIS Electricity Generation Costs (2020). https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020. Plus private wire costs of 520 £/kW, Hoare Lea Liddeston Ridge quote minus Liddeston Ridge upgrade and reinforcing costs. | baseline | Proposition 2 |
| pumped_storage | energy_cap | 1243.7 | £ / kW | CAPEX includes infrastructure costs, design costs, capital costs and installation costs. Medium value | Mott MacDonald for BEIS (2018) Storage cost and technical assumptions for BEIS. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/910261/storage-costs-technical-assumptions-2018.pdf Connected peak lopping, 200MW | elec_counterfactual_2050 hy_counterfactual_2050 | All |
| pumped_storage | om_annual | 16.2 | £/kW/year | OPEX includes Operation, Inspection, Maintenance, Replenishment / refurbishment of consumables, Insurance, Security. Medium Value | Mott MacDonald for BEIS (2018) Storage cost and technical assumptions for BEIS. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/910261/storage-costs-technical-assumptions-2018.pdf Connected peak lopping, 200MW | elec_counterfactual_2050 hy_counterfactual_2050 | All |
| rooftop_pv | om_prod | 0.007 | £ / kWh generated | OPEX includes Fixed O&M, Variable O&M, Fuel Costs, Decommissioning and waste, Steam Revenue, Additional Costs (all provided in £/MWh). | | high_elec_2050 hybrid_2050 high_hydrogen_2050 elec_counterfactual_2050 hy_counterfactual_2050 | All |
| national_grid_import | om_prod | 0.26 | £/kWh | Current port import cost | | baseline | Proposition 1 |
| national_grid_export | om_prod | -0.1 | £/kWh | Octopus guaranteed export price | | baseline | Proposition 1 |
| existing_solar | om_prod | 0.01 | £/kWh | | Want to model the existing 5MW farm as no cap cost, just maintenance cost | baseline | Proposition 1 |
| electricity_distribution | energy_cap | 0 | | | | baseline | Proposition 1 |
| electricity_distribution | energy_cap | 517.65 | £/kW | Forces the £4.4m private wire to be built | | existing_pw | Proposition 1 |
| electricity_distribution | om_prod | 0.05 | £/kW | Energy Local virtual PPA costs - use the existing grid infrastructure rather than a private wire but pay for that. | | existing_ppa | Proposition 1 |

# Technologies Costs

| Tech Type | Setting | Value | Units | Notes | Reference | Scenario | Proposition |
|---|---|---|---|---|---|---|---|
| gas_boiler_to_heat | energy_cap | 0 | £ / kW | Prop 4 assumes using boilers that are already built - hence no cap cost | | baseline | Proposition 4 |
| natural_gas_import | om_prod | 0.023 | £ / kWh | | Client meeting - PoMH May 2021 | baseline | Proposition 4 |

# Technologies carbon emissions

| Tech Type | Setting | Value | Units | Notes | Reference | Scenario | Proposition |
|---|---|---|---|---|---|---|---|
| national_grid_import | om_con | 0.1482 | kgCO2e / kWh | grid emissions factor based on average of grid emissions intensity in the 3 net zero compatible scenarios in FES 2020. Assume 0 emissions in 2040 and 2050 as governments have committed to net zero by 2045 in Scotland and 2050 in England. | FES 2020 Data workbook SV.27: Power sector carbon intensity https://www.nationalgrideso.com/future-energy/future-energy-scenarios/fes-2020-documents. Note that this is very different to BEIS - which puts the number at 0.23314 kgCO2e/kWh. | baseline | All |
| national_grid_import | om_con | 0 | kgCO2e / kWh | 2030 grid emissions factor based on average of grid emissions intensity in the 3 net zero compatible scenarios in FES 2020. Assume 0 emissions in 2040 and 2050 as governments have committed to net zero by 2045 in Scotland and 2050 in England. | FES 2020 Data workbook SV.27: Power sector carbon intensity https://www.nationalgrideso.com/future-energy/future-energy-scenarios/fes-2020-documents | high_elec_2050<br>hybrid_2050<br>high_hydrogen_2050 | All |
| national_grid_export | om_con | 0 | kgCO2e / kWh | Export set to zero carbon because export is when there are excess renewables | | baseline | All |
| national_grid_export | om_con | 0 | kgCO2e / kWh | Export set to zero carbon because export is when there are excess renewables | | high_elec_2050<br>hybrid_2050<br>high_hydrogen_2050 | All |
| natural_gas_import | om_con | 0.18387 | kgCO2e / kWh | Natural gas scope 1 emissions factor used. This will not change over the time period, because we are assuming natural gas stays the same, hydrogen and biogas are dealt with as separate carriers and can be blended into the natural gas. | BEIS (2020). Greenhouse gas reporting: conversion factors 2020. https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2020 | baseline | All |
| hydrogen_import | om_con | 0.0072 | kgCO2e / kWh | | Progressive Energy "Expanded notes on LCOH 08102020" | baseline | All |
| hydrogen_import | om_con | 0.0072 | kgCO2e / kWh | | Progressive Energy "Expanded notes on LCOH 08102020" | high_elec_2050<br>hybrid_2050<br>high_hydrogen_2050 | All |
| hydrogen_export | om_con | 0 | kgCO2e / kWh | | | baseline | All |
| sewage_gas | om_con | 0.00021 | kgCO2e / kWh fuel in | Biogas scope 1 emissions factor used | BEIS (2020). Greenhouse gas reporting: conversion factors 2020. https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2020 | baseline | All |
| anaerobic_digestion | om_con | 0.00021 | kgCO2e / kWh fuel in | Biogas scope 1 emissions factor used | BEIS (2020). Greenhouse gas reporting: conversion factors 2020. https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2020 | baseline | All |
| biomethane_supply | om_con | 0.000380664 | kgCO2e / kWh | Biomethane scope 1 emissions factor used. 0.10574 kgCO2e/GJ. | | baseline | All |

# Technologies carbon emissions

| Tech Type | Setting | Value | Units | Notes | Reference | Scenario | Proposition |
|---|---|---|---|---|---|---|---|
| national_grid_import | om_con | 0 | kgCO2e / kWh | | FES 2020 Data workbook SV.27: Power sector carbon intensity https://www.nationalgrideso.com/future-energy/future-energy-scenarios/fes-2020-documents | hy_counterfactual_2050 elec_counterfactual_2050 | All |
| national_grid_export | om_con | 0 | kgCO2e / kWh | Export set to zero carbon because export is when there are excess renewables | | hy_counterfactual_2050 elec_counterfactual_2050 | All |
| hydrogen_import | om_con | 0.0072 | kgCO2e / kWh | | Progressive Energy "Expanded notes on LCOH 08102020" | hy_counterfactual_2050 elec_counterfactual_2050 | All |
| anaerobic_digestion_biogas | om_con | 0.00021 | kgCO2/kWh | | https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2020 | baseline | Proposition 2 |

# Technologies Constraints

| Tech Type | Setting | Value | Units | Notes | Reference | Scenario | Proposition |
|---|---|---|---|---|---|---|---|
| national_grid_import | energy_cap_max_systemwide | 4100 | kW | Steynton substation - demand headroom on 13/05 assuming power factor of 1 | https://www.westernpower.co.uk/our-network/network-capacity-map-application | baseline | All |
| national_grid_import | lifetime | 1 | years | Selected to have no effect | | baseline | All |
| national_grid_export | lifetime | 1 | years | Selected to have no effect | | baseline | All |
| natural_gas_import | lifetime | 1 | years | Selected to have no effect | | baseline | All |
| hydrogen_import | lifetime | 1 | years | Selected to have no effect | | baseline | All |
| hydrogen_export | lifetime | 1 | years | Selected to have no effect | | baseline | All |
| sewage_gas | lifetime | 20 | years | | BEIS (2020) BEIS Electricity Generation Costs (2020). https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020 | baseline | All |
| sewage_gas | energy_cap_max_systemwide | 0 | kW | | | baseline | All |
| onshore_wind | lifetime | 25 | years | | BEIS (2020) BEIS Electricity Generation Costs (2020). https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020 | baseline | All |
| offshore_wind | lifetime | 30 | years | | BEIS (2020) BEIS Electricity Generation Costs (2020). https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020 | baseline | All |
| anaerobic_digestion | lifetime | 20 | years | | BEIS (2020) BEIS Electricity Generation Costs (2020). https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020 | baseline | All |
| anaerobic_digestion | energy_cap_max_systemwide | 0 | kW | | | baseline | All |
| rooftop_pv | lifetime | 30 | years | | BEIS (2020) BEIS Electricity Generation Costs (2020). https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020 | baseline | All |
| ground_pv | lifetime | 35 | years | | BEIS (2020) BEIS Electricity Generation Costs (2020). https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020 | baseline | All |
| hydrogen_storage_tank | lifetime | 30 | years | | https://www.nrel.gov/docs/fy14osti/58564.pdf | baseline | All |
| hydrogen_chp | lifetime | 15 | years | | https://www.energymanagermagazine.co.uk/will-combined-heat-and-power-chp-still-have-a-role-in-the-net-zero-economy/ | baseline | All |

# Technologies Constraints

| Tech Type | Setting | Value | Units | Notes | Reference | Scenario | Proposition |
|---|---|---|---|---|---|---|---|
| hydrogen_boiler_to_heat | lifetime | 15 | years | | Currie & Brown and AECOM for CCC (2019) The costs and benefits of tighter standards for new buildings. https://www.theccc.org.uk/publication/the-costs-and-benefits-of-tighter-standards-for-new-buildings-currie-brown-and-aecom/ | baseline | All |
| electrolysers | lifetime | 25 | years | | ENA (2020) Gas Goes Green: Hydrogen:Cost to customer, May 2020 | baseline | All |
| gas_boiler_to_heat | lifetime | 15 | years | | Currie & Brown and AECOM for CCC (2019) The costs and benefits of tighter standards for new buildings. https://www.theccc.org.uk/publication/the-costs-and-benefits-of-tighter-standards-for-new-buildings-currie-brown-and-aecom/ | baseline | All |
| resistance_heating | lifetime | 20 | years | | | baseline | All |
| air_source_heat_pump | lifetime | 18 | years | | Currie & Brown and AECOM for CCC (2019) The costs and benefits of tighter standards for new buildings. https://www.theccc.org.uk/publication/the-costs-and-benefits-of-tighter-standards-for-new-buildings-currie-brown-and-aecom/ | baseline | All |
| ground_source_heat_pump | lifetime | 20 | years | | Danish Energy Agency (2018) Technology Data for Individual Heating Plants. https://ens.dk/en/our-services/projections-and-models/technology-data/technology-data-individual-heating-plants | baseline | All |
| marine_source_heat_pump | lifetime | 15 | years | | https://glascohvac.com/heating/heat-pumps/long-heat-pump-last/ | baseline | All |
| battery | lifetime | 15 | years | | Mott MacDonald for BEIS (2018) Storage cost and technical assumptions for BEIS. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/910261/storage-costs-technical-assumptions-2018.pdf | baseline | All |
| pumped_storage | lifetime | 41 | years | Assumed Lifetime of pumped storage the same as hydropower | BEIS (2020) BEIS Electricity Generation Costs (2020). https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020 | baseline | All |

# Technologies Constraints

| Tech Type | Setting | Value | Units | Notes | Reference | Scenario | Proposition |
|---|---|---|---|---|---|---|---|
| sewage_gas | energy_eff | 0.46 | fraction | From the BEIS electricity generation costs 2020. This is the load factor, which can be used as an efficiency to ensure the plant does not operate at full capacity all year. | BEIS (2020) BEIS Electricity Generation Costs (2020). https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020 | baseline | All |
| anaerobic_digestion | energy_eff | 0.316 | fraction | From the BEIS electricity generation costs 2020. This is the load factor multiplied by the plant efficiency to account for the fact that the plant cannot operate at full load throughout the year. | BEIS (2020) BEIS Electricity Generation Costs (2020). https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020 | baseline | All |
| hydrogen_storage_tank | energy_eff | 0.94 | fraction | | https://journals.sagepub.com/doi/pdf/10.1260/014459806779367455 | baseline | All |
| hydrogen_chp | energy_eff | 0.42 | fraction | Heating efficiency | https://www.2-g.com/en/hydrogen-chp/ | baseline | All |
| hydrogen_boiler_to_heat | energy_eff | 0.84 | fraction | | HM Government (2013) Part L Domestic Building Services Compliance Guide. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/697525/DBSCG_secure.pdf | baseline | All |
| electrolysers | energy_eff | 0.65 | fraction | | ENA (2020) Gas Goes Green: Hydrogen:Cost to customer, May 2020 | baseline | All |
| electrolysers | energy_eff | 0.8 | fraction | | ENA (2020) Gas Goes Green: Hydrogen:Cost to customer, May 2020 | high_elec_2050 hybrid_2050 high_hydrogen_2050 | All |
| gas_boiler_to_heat | energy_eff | 0.84 | fraction | | HM Government (2013) Part L Domestic Building Services Compliance Guide. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/697525/DBSCG_secure.pdf | baseline | All |
| resistance_heating | energy_eff | 1 | fraction | | | baseline | All |
| air_source_heat_pump | energy_eff | 2.21 | fraction | Can we use a seasonal Coefficient of performance? | https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/502500/DECC_Heat_Pumps_in_District_Heating_-_Final_report.pdf | baseline | All |
| ground_source_heat_pump | energy_eff | 2.77 | fraction | | https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/606818/DECC_RHPP_161214_Final_Report_v1-13.pdf | baseline | All |
| marine_source_heat_pump | energy_eff | 4.15 | fraction | Valliant Flexotherm WSHP at 55deg flow and 19kW. Update to MSHP specific numbers if technology is selected | https://www.vaillant.co.uk/downloads/aproducts/renewables-1/flexotherm/vaillant-flexotherm-tech-brochure-2-6-web-1311272.pdf | baseline | All |

# Technologies Constraints

| Tech Type | Setting | Value | Units | Notes | Reference | Scenario | Proposition |
|---|---|---|---|---|---|---|---|
| battery | energy_eff | 0.92 | fraction | energy_eff = 0.92 this means a round trip efficiency of 0.85 | https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/910261/storage-costs-technical-assumptions-2018.pdf | baseline | All |
| pumped_storage | energy_eff | 0.75 | fraction | "Round Trip Efficiency value used" | Mott MacDonald for BEIS (2018) Storage cost and technical assumptions for BEIS. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/910261/storage-costs-technical-assumptions-2018.pdf 50MW Frequency Management battery | baseline | All |
| electricity_distribution | energy_eff | 1 | fraction | | To account for in demands | baseline | All |
| gas_distribution | energy_eff | 1 | fraction | | To account for in demands | baseline | All |
| hydrogen_distribution | energy_eff | 1 | fraction | | To account for in demands | baseline | All |
| heat_distribution | energy_eff | 1 | fraction | | To account for in demands | baseline | All |
| electricity_distribution | lifetime | 40 | years | | NG2050 - from WWU | baseline | All |
| gas_distribution | lifetime | 40 | years | | NG2050 - from WWU | baseline | All |
| hydrogen_distribution | lifetime | 40 | years | | NG2050 - from WWU | baseline | All |
| heat_distribution | lifetime | 40 | years | | Arup assumption | baseline | All |
| hydrogen_chp | carrier_ratios.carrier_out_2.electricity | 0.95 | fraction | heat to electrical ratio | https://www.2-g.com/en/hydrogen-chp/ | baseline | All |
| existing_solar | lifetime | 35 | | | As solar | baseline | All |
| gas_CHP | lifetime | 15 | years | Same as hydrogen CHP | | baseline | Proposition 3 |
| gas_CHP | energy_eff | 0.42 | fraction | Same as Hydrogen CHP | | baseline | Proposition 3 |
| gas_CHP | carrier_ratios.carrier_out_2.electricity | 0.95 | fraction | Same as Hydrogen CHP | | baseline | Proposition 3 |
| chiller | lifetime | 15 | years | Copied value from Jersey study | | baseline | Proposition 2 |
| chiller | energy_eff | 5.7 | Fraction | SEER value copied from Jersey study | | baseline | Proposition 2 |
| simultaneous_heat_pump | energy_eff | 2.865 | Ratio | This is the cooling EER only | Based on Mitsubishi the EN14511 conditions, cooling with heat recovery, efficiency scaled by 75% to account for real world conditions - https://arup.sharepoint.com/:b:/t/prj-27613600/Eb-7YSrZ9Y5MkGDTKp-ZBQoBwDtTOc6ITMzRu01ulu3BzQ?e=GUcQvv | baseline | Proposition 2 |

# Technologies Constraints

| Tech Type | Setting | Value | Units | Notes | Reference | Scenario | Proposition |
|---|---|---|---|---|---|---|---|
| simultaneous_heat_pump | carrier_ratios.carrier_out_2.heat | 1.25 | Fraction of primary output | Ratio of the cooling output - giving a effective heating COP of 3.82*1.25 = 4.76 | Based on the EN14511 conditions, cooling with heat recovery - https://arup.sharepoint.com/:b:/t/prj-27613600/Eb-7YSrZ9Y5MkGDTKp-ZBQoBwDtTOc6ITMzRu01ulu3BzQ?e=GUcQvv | baseline | Proposition 2 |
| simultaneous_heat_pump | lifetime | 18 | years | | Assumed same as ASHP | baseline | Proposition 2 |
| cooling_distribution | energy_eff | 1 | fraction | Same as heat distribution | | baseline | Proposition 2 |
| cooling_distribution | lifetime | 40 | years | Same as heating distribution | | baseline | Proposition 2 |
| absorption_chiller | lifetime | 15 | years | | | baseline | Proposition 2 |
| absorption_chiller | energy_eff | 0.74 | Fraction | | US DOE https://www.energy.gov/sites/prod/files/2017/06/f35/CHP-Absorption%20Chiller-compliant.pdf | baseline | Proposition 2 |
| anaerobic_digestion_biogas | energy_cap_max | 437 | kW | | Based on roughly 10000 tonnes of food waste per day - https://arup.sharepoint.com/:x:/r/teams/prj-27613600/_layouts/15/Doc.aspx?sourcedoc=%7B1bf28e64-e82b-4f9c-b4ba-737dbb53444b%7D&action=edit&wdSkeletonState=%7B%22IsEnabled%22%3Atrue%2C%22Options%22%3A1090%7D&wdlor=c150BB16A-E0B4-4311-AB01-C0734B52 | baseline | Proposition 2 |
| anaerobic_digestion_biogas | lifetime | 20 | years | | | baseline | Proposition 2 |
| biogas_boiler | energy_eff | 0.84 | fraction | Same as gas boiler | | baseline | Proposition 2 |
| biogas_boiler | lifetime | 15 | years | Same as gas boiler | | baseline | Proposition 2 |
| biogas_chp | lifetime | 15 | years | Same as gas CHP | | baseline | Proposition 2 |
| biogas_chp | energy_eff | 0.42 | fraction | Same as gas CHP. Heating efficiency. | | baseline | Proposition 2 |
| biogas_chp | carrier_ratios.carrier_out_2.electricity | 0.95 | fraction of primary output | Same as gas CHP. Electrical / Heat ratio. | | baseline | Proposition 2 |
| biogas_cchp | energy_eff | 0.4 | fraction | Same as gas CHP. Electrical efficiency. | | baseline | Proposition 2 |
| biogas_cchp | lifetime | 15 | years | Same as gas CHP | | baseline | Proposition 2 |
| biogas_cchp | carrier_ratios.carrier_out_2 | {heat: 1.05, cooling: 0.77} | fraction of primary output | Same as gas CHP and absorption chiller respectively | | baseline | Proposition 2 |
| hydrogen_cchp | energy_eff | 0.4 | fraction | Same as gas CHP. Electrical efficiency. | | baseline | Proposition 2 |
| hydrogen_cchp | lifetime | 15 | years | Same as gas CHP | | baseline | Proposition 2 |
| hydrogen_cchp | carrier_ratios.carrier_out_2 | {heat: 1.05, cooling: 0.77} | fraction of primary output | Same as gas CHP and absorption chiller respectively | | baseline | Proposition 2 |
| thermal_store | storage_loss | 0.018164 | kWh loss/hour | | Used in Prop 1 - unknown source | baseline | All |

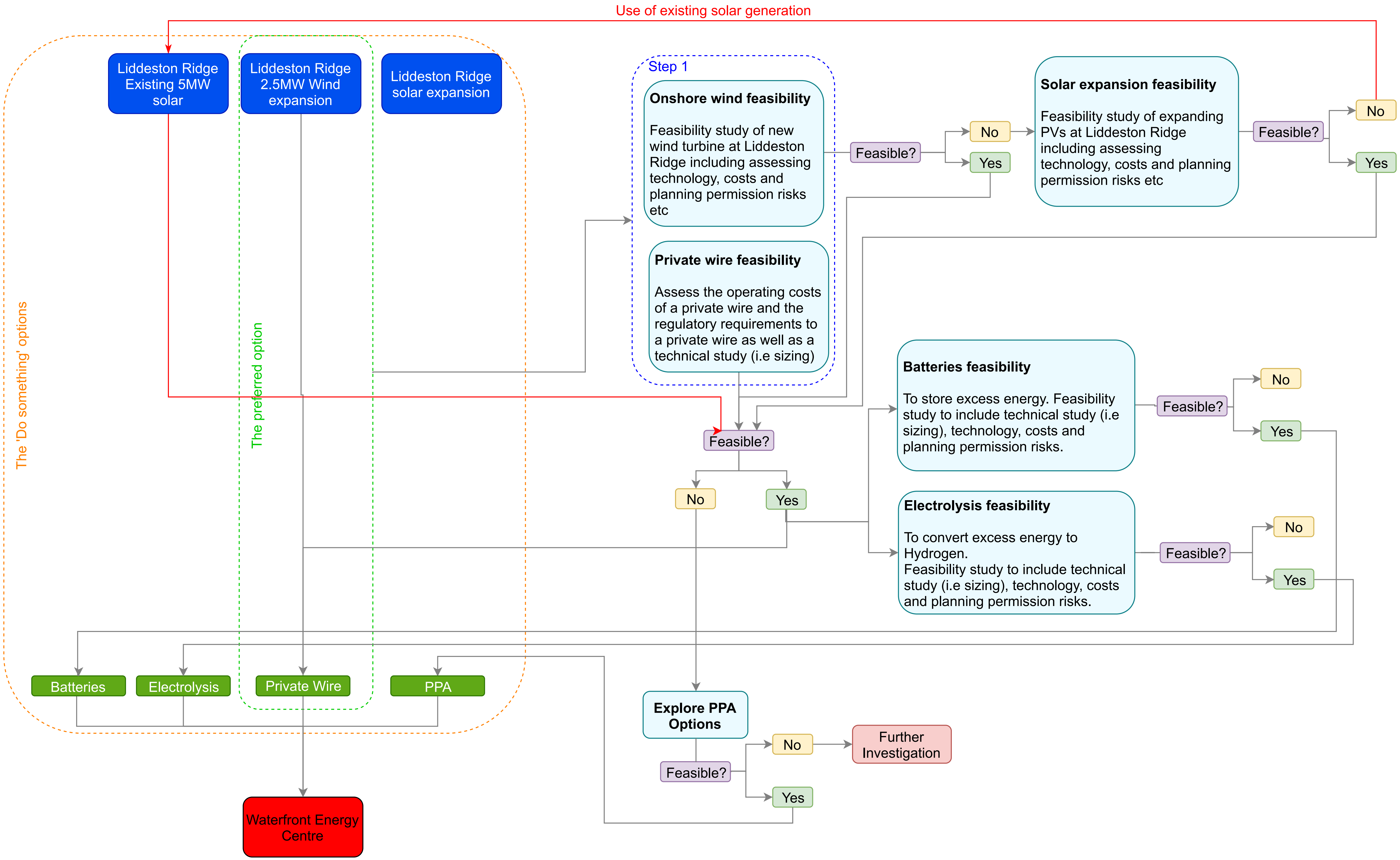
# Technologies Constraints

| Tech Type | Setting | Value | Units | Notes | Reference | Scenario | Proposition |
|---|---|---|---|---|---|---|---|
| thermal_store | storage_cap_max | 16700 | kWh | Peak daily heat demand | | baseline | Proposition 2 |
| thermal_store | lifetime | 30 | years | | | baseline | All |
| battery | energy_cap_per_storage_cap_equals | 1 | kW/kWh | | Data based on 50MW peak and 50MWh capacity - https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/910261/storage-costs-technical-assumptions-2018.pdf | baseline | All |
| battery | storage_cap_max | 36800 | kWh | Peak daily electrical demand | | baseline | Proposition 2 |
| national_grid_export | export_carrier | export_electricity | | Line required to allow export | | baseline | All |
| hydrogen_export | export_carrier | hydrogen_export | | Line required to allow export | | baseline | All |

# Appendix E - Decision making flowchart for Proposition 1

The recommended next steps for Proposition 1

ENERGY KINGDOM
DEYRNAS YNNI



Use of existing solar generation
Liddeston Ridge Existing 5MW solar
Liddeston Ridge 2.5MW Wind expansion
Liddeston Ridge solar expansion
The 'Do something' options
The preferred option
Step 1
Onshore wind feasibility
Feasibility study of new wind turbine at Liddeston Ridge including assessing technology, costs and planning permission risks etc
Private wire feasibility
Assess the operating costs of a private wire and the regulatory requirements to a private wire as well as a technical study (i.e sizing)
Feasible?
No
Yes
Solar expansion feasibility
Feasibility study of expanding PVs at Liddeston Ridge including assessing technology, costs and planning permission risks etc
Feasible?
No
Yes
Feasible?
No
Yes
Batteries feasibility
To store excess energy. Feasibility study to include technical study (i.e sizing), technology, costs and planning permission risks.
Feasible?
No
Yes
Electrolysis feasibility
To convert excess energy to Hydrogen.
Feasibility study to include technical study (i.e sizing), technology, costs and planning permission risks.
Feasible?
No
Yes
Batteries
Electrolysis
Private Wire
PPA
Explore PPA Options
Feasible?
No
Yes
Further Investigation
Waterfront Energy Centre

MILFORD HAVEN: ENERGY KINGDOM

# Appendix F - Updated MCA report for the propositions

## Updated MCA scoring report post techno-economic modelling

ENERGY KINGDOM
DEYRNAS YNNI

# Review Proposition Multi Criteria Scoring

| Multi Criteria Scoring Proposition Name | Weighting (Copied from MCA) | Proposition 1 - MH Marina SLES | Proposition 2 - Pembrokeshire Food Park SLES | Proposition3 - Pembroke Schools, Leisure centre and dock SLES |
|---|---|---|---|---|
| Achieves emissions reductions | 0.04 | 3 | 4 | 2 |
| Catalyst | 0.05 | 4 | 5 | 1 |
| Jobs & Prosperity | 0.03 | 2 | 3 | 1 |
| Social Value | 0.03 | 2 | 4 | 2 |
| Stakeholder acceptability | 0.04 | 3 | 4 | 3 |
| Design | 0.02 | 4 | 4 | 3 |
| Construction | 0.02 | 4 | 4 | 2 |
| Operation | 0.01 | 4 | 4 | 3 |
| Decommissioning | 0.02 | 2 | 4 | 2 |
| Impact | 0.02 | 3 | 3 | 2 |
| Mitigation | 0.02 | 4 | 5 | 2 |
| Water Bodies | 0.04 | 3 | 2 | 2 |
| Biodiversity | 0.02 | 2 | 3 | 2 |
| Commercial Opportunity | 0.03 | 4 | 5 | 2 |
| Capital Cost (CAPEX) | 0.03 | 3 | 1 | 2 |
| Maintenance Cost (OPEX) | 0.02 | 2 | 4 | 3 |
| Price Resilience | 0.03 | 4 | 3 | 2 |
| Levelised Cost of Energy | 0.03 | 5 | 4 | 2 |
| Supply chain | 0.03 | 4 | 5 | 3 |
| Investor Interest / Funding Streams | 0.03 | 3 | 4 | 4 |
| Immediate Need / | 0.02 | 4 | 5 | 1 |
| Complexity of asset ownership | 0.03 | 3 | 4 | 1 |
| Policy & Regulatory Considerations | 0.03 | 3 | 2 | 2 |
| Development Risk | 0.03 | 2 | 3 | 1 |
| Scheme Constraints | 0.03 | 2 | 3 | 1 |
| Future Expansion | 0.03 | 4 | 5 | 1 |
| Visual Impact | 0.03 | 2 | 3 | 3 |
| Low-Carbon Technologies | 0.03 | 4 | 5 | 3 |
| Energy Resilience | 0.03 | 4 | 3 | 2 |
| Innovation | 0.03 | 4 | 4 | 1 |
| WFGA Goals | 0.04 | 5 | 5 | 2 |
| WFGA Ways of Working | 0.03 | 4 | 5 | 2 |
| Waste Reduction / Circular Economy | 0.03 | 4 | 5 | 3 |
| Air Quality | 0.03 | 5 | 5 | 4 |
| Education | 0.02 | 5 | 4 | 2 |
| Total weighted score | 1 | 3.44 | 3.89 | 2.08 |

Final Proposition MCA

# Review Proposition Multi Criteria Scoring

| Multi Criteria Scoring Proposition Name | Proposition 1 - MH Marina SLES | Proposition 2 - Pembrokeshire Food Park SLES | Proposition3 - Pembroke Schools, Leisure centre and dock SLES | Scoring guide |
|---|---|---|---|---|
| Criteria 1 Criteria Name | **Achieves emissions reductions** | **Achieves emissions reductions** | **Achieves emissions reductions** | |
| Achieves emissions reductions | 3 | 4 | 2 | [1 - Neutral, 5 - positive contribution] |
| Criteria 1 Comment | The proposition achieves near zero annual CO2 emissions in 2050 compared to the counterfactual scenarios in 2020.<br>However, this is a small and local scale system and therefore the impact on the overall UK Net-Zero pathway is small.<br>This proposition includes existing buildings with retrofits with fewer immediate (new build) opportunities for growth as well as less export which means the opportunity for scaling up is limited without growing the supply. Therefore a score of 3 is given due to lesser opportunity for scaling and a smaller impact on Net-zero targets. | The proposition achieves near zero annual CO2 emissions in 2050 compared to the counterfactual scenarios in 2020.<br>Although, this proposition is still at a small and local scale, it involves proposed developments with a strong focus on sustainable energy usage and therefore a greater opportunity to be incorporated into a SLES and more opportunities for growth. The system also has a larger proportion of electricity export creating more opportunities to expand the demand centre into a larger SLES.<br>With more local industries located in the same geographical areas and the small town Crundale, this proposition is more promising to be scaled to a larger SLES and therefore have a bigger contribution to achieving Net-Zero by 2050. | The proposition achieves near zero annual CO2 emissions in 2050 compared to the counterfactual scenarios in 2020.<br>However, this is a small and local scale system with existing buildings that are already in the process of being retrofitted. The impact on the UK Net-Zero pathway is negligible and the opportunity for growth is very slim and dependent on many unknown factors. | |
| Criteria 2 Criteria Name | **Catalyst** | **Catalyst** | **Catalyst** | |
| Catalyst | 4 | 5 | 1 | [1 - Neutral, 5 - positive contribution] |
| Criteria 2 Comment | This proposition provides a roadmap on how existing buildings can be retrofitted to be integrated as part of a SLES and makes the case for increasing the local energy generation supply. However, within the bounds of the known energy supply opportunities there is a lesser opportunity to scale up. | The proposition provides a roadmap to establish a SLES involving light industrial businesses, EV and Hydrogen transport which can be replicated to other similar sized proposed light industrial development.<br>It also has stronger opportunities for growth and scaling evidenced by the larger proposition of export and nearby industrial and retail buildings and presents opportunities to expand into residential energy shift. | The modelling has proven that this proposition doesn't form a SLES due to various reasons and therefore this system currently doesn't have any scope for replication and scaling. There are opportunities to expand local generation assets however what demand centres would benefit or what conversion methods would be most viable is not known. | |
| Criteria 3 Criteria Name | **Jobs & Prosperity** | **Jobs & Prosperity** | **Jobs & Prosperity** | |
| Jobs & Prosperity | 2 | 3 | 1 | [1 - Neutral, 5 - positive contribution] |
| Criteria 3 Comment | The proposition will involve construction, operation and maintenance of new technologies but it doesn't stimulate significant growth.<br>With a lesser opportunity for scaling up, the proposition has a smaller power to create jobs for the community. | The proposition will involve construction, operation and maintenance of new technologies as well as operation of a smart system. New skills would likely be required.<br>With a larger opportunity for replication and scaling up, the proposition has the potential to create more jobs and opportunities to upskill for the community.<br>With the potential formation of a low-emission transport hub for HGVs and broader transport demand, this could create a focal point for new jobs in the area. | The modelling has proven that this proposition doesn't form a SLES due to various reasons and therefore this system currently doesn't have any scope for replication and scaling and presents no significant opportunity for job creation and upskilling. | |
| Criteria 4 Criteria Name | **Social Value** | **Social Value** | **Social Value** | |
| Social Value | 4 | 4 | 2 | [1 - negative, 3- neutral, 5- positive] |

# Review Proposition Multi Criteria Scoring

| Multi Criteria Scoring Proposition Name | Proposition 1 - MH Marina SLES | Proposition 2 - Pembrokeshire Food Park SLES | Proposition3 - Pembroke Schools, Leisure centre and dock SLES | Scoring guide |
|---|---|---|---|---|
| Criteria 4 Comment | This proposition has the highest opportunity to showcase the non-quantifiable benefits of a SLES to the community for example retrofitting commercial properties with low carbon energy technologies can be applied to residential settings with the associated whole life cost and carbon savings or the use of ULEV or Hydrogen vehicles from light commercial vehicles to public vehicles. This proposition has a lower LCOE but higher CO2 emissions (2450t/year) than P2. | This proposition demonstrate the application of SLES to food production or other light industrial activities. This proposition gives rise to the adoption of new technologies and low carbon transport in Haverfordwest with a strong opportunity to expand. This proposition has a higher LCOE but significantly lower CO2 emissions (42.3te/year) than P1. | The modelling has demonstrated that this proposition doesn't really form a well-integrated SLES. As such, the biggest part of the proposition is to develop large PV farms and export the energy which does not directly benefit the local community and economy. Carbon emissions 11.5t/year | |
| Criteria 5 Criteria Name | Stakeholder acceptability | Stakeholder acceptability | Stakeholder acceptability | |
| Stakeholder acceptability | 3 | 4 | 3 | [1 - negative, 3- neutral, 5- positive] |
| Criteria 5 Comment | Key stakeholders include PoMH, the tenants and users of the developments at the Marina and the community. This project gives the opportunity to demonstrate a SLES to the community including the use of multiple low carbon technologies in the buildings at the marina and expansion of the Liddeston Ridge asset. However, there is a planning risk with a new wind turbine at Liddeston Ridge including visual and noise impact. There would also need to be careful management and a beneficial pricing arrangement to persuade end consumers to transition to this model and away from centralised grid provision. | Key stakeholders include PCC, food park developers and the airfield; with PCC as the project anchor this project could be developed with strong engagement from the stakeholders. The food park project have energy resilience and sustainable production and use as part of their agenda. This project can also be used to engage the community to demonstrate the application of a SLES at light industrial level and how it can be scaled to include public use. | The project doesn't present much opportunity to demonstrate the application of SLES to the public/community with most of the energy generated being exported. The impact on the energy usage of the public buildings is minimal. | |
| Criteria 6 Criteria Name | Design | Design | Design | |
| Design | 4 | 4 | 3 | [1 - negative, 3- neutral, 5- positive] |
| Criteria 6 Comment | The technologies chosen are well developed. The design and use of electrolysers to produce H for transport has been demonstrated on this project. However, battery technology is still in development, especially at this scale.<br>Further work has been undertaken to investigate the most appropriate energy distribution infrastructure, but further work is required to further define the operating costs and planning risks. There is a better energy demand-supply balance.<br>Private wire and PPA arrangements could be difficult to establish with multiple parties, and the necessary infrastructure requirements for a private wire. | The technologies chosen are novel but the food park design team can be engaged early on to integrate the results of the MHEK project into the design process. The design and use of electrolysers to produce H for transport has been demonstrated on this project.<br>However, battery technology is still in development, especially at this scale.<br>Further work is required to establish the energy distribution infrastructure. There is also a large proportion of electricity export that requires further work on the market mechanism. | The technologies chosen are well developed, but presents a degree of challenge to install in a retrofit environment. The supply-demand balance cannot be achieved and the majority of the energy generated is to be exported. Further work is required to establish the energy distribution infrastructure and market mechanism. | |
| Criteria 7 Criteria Name | Construction | Construction | Construction | |
| Construction | 4 | 4 | 2 | [1 - negative, 3- neutral, 5- positive] |

# Review Proposition Multi Criteria Scoring

| Multi Criteria Scoring Proposition Name | Proposition 1 - MH Marina SLES | Proposition 2 - Pembrokeshire Food Park SLES | Proposition3 - Pembroke Schools, Leisure centre and dock SLES | Scoring guide |
|---|---|---|---|---|
| Criteria 7 Comment | The expansion of LR into solar is considered to be fairly low risk due to the existing solar farm. The construction of the new wind turbine is considered to be an uncertainty, however there are onshore wind turbines in the locality.<br>The build of an electrolyser has been demonstrated on the project, but for other technologies to be constructed within existing buildings may be complex. There are limited supply chain skills and local supply of materials.<br>The roll out of EV charging points is increasingly becoming more popular across the UK.<br>The site is on the waterway, hence construction risks related to weather and ground are considered to be medium.<br>Lowest annualised CAPEX | The food park is a proposed development for a new facility and therefore there is less risk of interfaces with existing assets.<br>The build of an electrolyser has been demonstrated on the project, but for other technologies which are quite novel there is limited supply chain skills and local supply of materials.<br>The roll out of EV charging points is increasingly becoming more popular across the UK.<br>The site is inland and in the vicinity of similar sized industrial facilities, hence construction risks related to weather and ground are considered to be low.<br>2nd highest annualised CAPEX | Interface with existing buildings especially schools increases complexity of construction planning. Highest annualised CAPEX | |

# Review Proposition Multi Criteria Scoring

| Multi Criteria Scoring Proposition Name | Proposition 1 - MH Marina SLES | Proposition 2 - Pembrokeshire Food Park SLES | Proposition3 - Pembroke Schools, Leisure centre and dock SLES | Scoring guide |
|---|---|---|---|---|
| Criteria 8 Criteria Name | **Operation** | **Operation** | **Operation** | |
| Operation | 4 | 4 | 3 | [1 - negative, 3- neutral, 5- positive] |
| Criteria 8 Comment | O&M of LR solar assets are well understood, however the operating costs of the distribution infrastructure i.e. private wire is to be investigated. Highest OPEX | New development, single asset owner with PCC and stronger opportunity to influence O&M costs and complexities during the design process.<br>Energy distribution mechanism and associated O&M requirements/costs are unknown. 2nd highest OPEX | As the modelling results in most of the generated electricity being exported at a high price, the OPEX is not a realistic figure and cannot be used for comparison.<br>Interface with existing buildings especially schools increases complexity of operation & maintenance. Age and asset condition of the building are unknown and therefore the extent of the maintenance or replacement requirements are also unknown.<br>Operating costs of the distribution network is unknown. | |
| Criteria 9 Criteria Name | **Decommissioning** | **Decommissioning** | **Decommissioning** | |
| Decommissioning | 2 | 4 | 2 | [1 - negative, 3- neutral, 5- positive] |
| Criteria 9 Comment | Interface with existing buildings increases complexity of decommissioning the technologies. Age and asset condition of the buildings are unknown and therefore when will replacement be required or could the building be decommissioned before the 2050 target? | New development, single asset owner with PCC - potential to increase asset life beyond 2050. | Interface with existing buildings especially schools increases complexity of decommissioning the technologies. Age and asset condition of the buildings are unknown and therefore when will replacement be required or could the building be decommissioned before the 2050 target? | |
| Criteria 10 Criteria Name | **Impact** | **Impact** | **Impact** | |
| Impact | 3 | 3 | 2 | [1 - negative impact, 5 - positive impact] |
| Criteria 10 Comment | The project includes expanding the solar farm and building a new wind turbine but the site is owned by PoMH and is not a designated site. | The project combines two developing projects: Pembrokeshire food park and the airfield ground pv expansion and avoids the need to use additional land. | Proposition includes construction of new ground pv and therefore has a higher land use with no current plans for mitigation/compensation. | |
| Criteria 11 Criteria Name | **Mitigation** | **Mitigation** | **Mitigation** | |
| Mitigation | 4 | 5 | 2 | [1 -cannot mitigate, 5 - highest positive impact] |
| Criteria 11 Comment | Mitigation of environmental risks can be done through the design process but some buildings are existing and therefore may limit some mitigations | There is a bigger opportunity to mitigate environmental risks through the design process | The mitigation to the use of land to construct ground PV is not considered | |
| Criteria 12 Criteria Name | **Water Bodies** | **Water Bodies** | **Water Bodies** | |
| Water Bodies | 3 | 2 | 2 | [1 - negative impact, 5 - positive impact] |
| Criteria 12 Comment | For this proposition, the system prioritises exporting electricity rather than converting to hydrogen and therefore the use of electrolysers and additional water demand is low | Electrolysers require water to produce Hydrogen and this proposition has the highest capacity requirements for electrolysers. This increases the water demand for the food park. | Electrolysers require water to produce Hydrogen and this proposition has lower capacity requirements for electrolysers. This increases the water demand but not significantly | |
| Criteria 13 Criteria Name | **Biodiversity** | **Biodiversity** | **Biodiversity** | |

# Review Proposition Multi Criteria Scoring

| Multi Criteria Scoring Proposition Name | Proposition 1 - MH Marina SLES | Proposition 2 - Pembrokeshire Food Park SLES | Proposition3 - Pembroke Schools, Leisure centre and dock SLES | Scoring guide |
|---|---|---|---|---|
| Biodiversity | 2 | 3 | 2 | [1 - negative impact, 5 - positive impact] |
| Criteria 13 Comment | This proposition includes the construction of a wind turbine at LR. Further work is required to mitigate environmental risks e.g. birds. Currently no mitigation plans to ensure biodiversity net gain | The food park and airfield PV expansion are developing projects. This proposition is to integrate them in a SLES, as a result this project has no direct impact on biodiversity | This proposition is likely to require land clearance to build the ground PV and has currently no mitigation plans to ensure biodiversity net gain | |

# Review Proposition Multi Criteria Scoring

| Multi Criteria Scoring Proposition Name | Proposition 1 - MH Marina SLES | Proposition 2 - Pembrokeshire Food Park SLES | Proposition3 - Pembroke Schools, Leisure centre and dock SLES | Scoring guide |
|---|---|---|---|---|
| Criteria 14 Criteria Name | **Commercial Opportunity** | **Commercial Opportunity** | **Commercial Opportunity** | |
| Commercial Opportunity | 4 | 5 | 2 | [1 - negative / constraint, 5 - strongest opportunity ] |
| Criteria 14 Comment | LCOE £0.061/kwh and assuming a local electricity sale price of £0.18/kWh, annual revenue from this sale and external export would be approximately £1.8m with a payback of around 3 years | LCOE £0.074/kwh and payback period of 5-8 years. Larger opportunity for scaling up and greater revenue potential | LCOE £0.03/kwh and £1.1m revenue estimated from the export of electricity but this proposition doesn't form a SLES | |
| Criteria 15 Criteria Name | **Capital Cost (CAPEX)** | **Capital Cost (CAPEX)** | **Capital Cost (CAPEX)** | |
| Capital Cost (CAPEX) | 3 | 1 | 2 | [1 - negative impact, 5 - positive impact] |
| Criteria 15 Comment | 0.286£m/year (Wind+PW) - £8m 2020 | £0.543m/year (Hybrid_2050) - £16m Hybrid 2020 | £0.547m/year (Hybrid_2050) - £14m Hybird 2020 | |
| Criteria 16 Criteria Name | **Maintenance Cost (OPEX)** | **Maintenance Cost (OPEX)** | **Maintenance Cost (OPEX)** | |
| Maintenance Cost (OPEX) | 2 | 4 | 3 | [1 - negative impact, 5 - positive impact] |
| Criteria 16 Comment | £1.704m/year<br>Highest OPEX | £0.705m/year<br>Lowest OPEX | £-0.236m/year* - unrealistic OPEX due to the limitations of this proposition and that it does not represent a SLES. Most of the energy produced is exported at a high price. | |
| Criteria 17 Criteria Name | **Price Resilience** | **Price Resilience** | **Price Resilience** | |
| Price Resilience | 4 | 3 | 2 | [1 - highest risk, 5 - opportunity ] |
| Criteria 17 Comment | This proposition is least reliant on NG and Hydrogen imports and therefore has better energy security as a result of supplying energy directly from the LR asset. | This proposition has a small amount of NG import and a larger proportion of Hydrogen import to fulfil the H transport demand. Hence if the H import price increases, it would be preferable to use more electrolysis with is not accounted for in the system. | This proposition has the highest proportion of electricity produced being exported, hence is very dependent on the export prices. If the electricity export price increases, there may be less electricity to satisfy the demand of the system. | |
| Criteria 18 Criteria Name | **Levelised Cost of Energy (LCOE)** | **Levelised Cost of Energy (LCOE)** | **Levelised Cost of Energy (LCOE)** | |
| Levelised Cost of Energy (LCOE) | 5 | 4 | 2 | [1 - negative impact, 5 - positive impact] |
| Criteria 18 Comment | 0.061£/kwh - Lowest LCOE | £0.074/kwh - highest LCOE | £0.03/kwh* - unrealistic OPEX due to the limitations of this proposition and that it does not represent a SLES. Most of the energy produced is exported at a high price. | |
| Criteria 19 Criteria Name | **Supply chain** | **Supply chain** | **Supply chain** | |
| Supply chain | 4 | 5 | 3 | [1 - negative / constraint, 5 - strongest opportunity ] |
| Criteria 19 Comment | Includes a less diverse pool of new technologies across multiple vectors and smaller opportunity for scaling up | Includes a diverse pool of new technologies across multiple vectors and the highest opportunity for scaling up | As the modelling has proven that this system doesn't represent a SLES, there is less use of the conversion technologies in the system and more electricity export. The opportunity for scaling up is also not significant. | |

# Review Proposition Multi Criteria Scoring

| Multi Criteria Scoring Proposition Name | Proposition 1 - MH Marina SLES | Proposition 2 - Pembrokeshire Food Park SLES | Proposition3 - Pembroke Schools, Leisure centre and dock SLES | Scoring guide |
|---|---|---|---|---|
| Criteria 20 Criteria Name | **Investor Interest / Funding Streams** | **Investor Interest / Funding Streams** | **Investor Interest / Funding Streams** | |
| **Investor Interest / Funding Streams** | 3 | 4 | 4 | [1 - highest risk, 5 - opportunity ] |
| Criteria 20 Comment | With the PoMH as the project anchor, there could be potential funding from PoMH themselves dependent on the Port's delivery capacity to take the proposition forward.<br><br>Also an opportunity for further funding through the Welsh Gov, Smart Living Demonstration fund. | With PCC as the project anchor, the council's environmental agenda could catalyse potential funding streams.<br>The food park developers may have interest in integrating their project into this SLES. | This proposition demonstrates the investment opportunity associated with independent solar PV farms exporting to the electricity network. However, there may be significant network connection costs based on our understanding of the Pembrokeshire network and likely constraints / upgrade requirements.<br>Alternative revenue streams could include green H production for local sales, provided the business case was shown to be viable at this scale (likely for satisfying local transport demand). | |

# Review Proposition Multi Criteria Scoring

| Multi Criteria Scoring Proposition Name | Proposition 1 - MH Marina SLES | Proposition 2 - Pembrokeshire Food Park SLES | Proposition3 - Pembroke Schools, Leisure centre and dock SLES | Scoring guide |
|---|---|---|---|---|
| Criteria 21 Criteria Name | Immediate Need / Opportunity Readiness | Immediate Need / Opportunity Readiness | Immediate Need / Opportunity Readiness | |
| Immediate Need / | 4 | 5 | 1 | |
| Criteria 21 Comment | The proposition has shown that expansion of LR is no regrets and the transmission using PW is recommended. But the Port have currently shown potentialy constrained internal resources, so it would be recommended that an ESCO is brought on to support project development. There is also a risk of interfacing with the existing buildings and tenants. | The food park development and the airfield ground PV are both in progress. With PCC as the project anchor, there is a strong link and opportunity to integrate the projects into a SLES. | As the modelling has proven that this system doesn't represent a SLES, there is less of a case to invest in this proposition. | |
| Criteria 22 Criteria Name | Complexity of asset ownership | Complexity of asset ownership | Complexity of asset ownership | |
| Complexity of asset ownership | 3 | 4 | 1 | [1 - highest risk, 5 - opportunity ] |
| Criteria 22 Comment | Liddeston Ridge / generation assets owned by the PoMH, similarly the buildings in the energy centre. Changes to the building technologies will include the tenants as additional stakeholders which may bring complexities. | PCC is an important stakeholder in the food park and airfield PV developments and project anchor. Strong opportunity to engage in the project development which is still at early stages. | Existing PV have multiple owners with existing export arrangements.<br>Buildings owned by PCC but as shown by modelling are not really integrated into the SLES.<br>Asset ownership of proposed PV unknown and dependent on investment and development strategy. | |
| Criteria 23 Criteria Name | Policy & Regulatory Considerations | Policy & Regulatory Considerations | Policy & Regulatory Considerations | |
| Policy & Regulatory Considerations | 3 | 2 | 2 | [1 - negative / constraint, 5 - strongest opportunity ] |
| Criteria 23 Comment | Limited hydrogen is featured, policies around other vectors are better understood | Policy changes for hydrogen required | Policy changes for hydrogen required | |
| Criteria 24 Criteria Name | Development Risk | Development Risk | Development Risk | |
| Development Risk | 2 | 3 | 1 | [1 - highest risk, 5 - opportunity ] |
| Criteria 24 Comment | Planning risk associated with wind turbine at Liddeston Ridge and expansion of solar PV | Planning risk associated with Airport PV and food park but not as high as a wind turbine | Planning risk associated with proposed ground PV, large areas of land required etc | |
| Criteria 25 Criteria Name | Scheme Constraints | Scheme Constraints | Scheme Constraints | |
| Scheme Constraints | 2 | 3 | 1 | [1 - highest risk, 5 - opportunity ] |
| Criteria 25 Comment | Planning risk, particularly in case of proposed wind turbine at Liddestone Ridge.<br>Large number of tenant stakeholders to engage.<br>Private wire / PPA complexities, but considered worth pursuing at this stage based on the demonstrated opportunities. | Planning risk.<br>Large number of stakeholders to engage and align. | Planning risk.<br>Network connection fee, associated with highly constrained network.<br>Private wire / PPA arrangements potentially complex as alternative to grid export. | |
| Criteria 26 Criteria Name | Future Expansion | Future Expansion | Future Expansion | |
| Future Expansion | 4 | 5 | 1 | [1 - lowest opportunity, 5 - highest opportunity ] |

# Review Proposition Multi Criteria Scoring

| Multi Criteria Scoring Proposition Name | Proposition 1 - MH Marina SLES | Proposition 2 - Pembrokeshire Food Park SLES | Proposition3 - Pembroke Schools, Leisure centre and dock SLES | Scoring guide |
|---|---|---|---|---|
| Criteria 26 Comment | This proposition includes existing buildings with retrofits with fewer opportunities for growth as well as less export which means the opportunity for scaling up is limited without growing the supply. | With more local industries located in the same geographical areas, a retail park and the small town Crundale, this proposition is more promising to be scaled to a larger SLES and therefore have a bigger contribution to achieving Net-Zero by 2050.<br><br>This proposition presents the greatest opportunity for immediate scaling of both integrated supply and demand. | Opportunity to integrate new buildings in vicinity to the proposed ground PV but opportunities are unknown at this stage. | |
| Criteria 27 Criteria Name | Visual Impact | Visual Impact | Visual Impact | |
| Visual Impact | 2 | 3 | 3 | [1 - negative, 3- neutral, 5- positive] |
| Criteria 27 Comment | Potential negative visual impact from wind turbine at LR | No change as most technologies proposed are to be located internally within the food park development. Airfield solar PV considered to have no significant visual impact. | No change. Proposed solar PV considered to have no significant visual impact. | |
| Criteria 28 Criteria Name | Low-Carbon Technologies | Low-Carbon Technologies | Low-Carbon Technologies | |
| Low-Carbon Technologies | 4 | 5 | 3 | [1 - negative, 3- neutral, 5- positive] |
| Criteria 28 Comment | Diverse technologies proposed and expansion of LR to include onshore wind but due to electricity export prices less hydrogen is produced on site and therefore less scope for electrolysers and batteries. | More diverse technologiess including AD digestor to produce biogas from waste, a polyvalent heat pump and electrolyser to produce H. | Doesn't promote low-carbon technologies as much as most electricity produced is exported. | |
| Criteria 29 Criteria Name | Energy Resilience | Energy Resilience | Energy Resilience | |
| Energy Resilience | 4 | 3 | 2 | [1 - negative, 3- neutral, 5- positive] |
| Criteria 29 Comment | This proposition is least reliant on NG and Hydrogen imports and therefore could result in better energy security as a result of supplying energy directly from the LR asset. | This proposition has a small amount of NG import and a larger proportion of Hydrogen import to fulfil the H transport demand. Hence if the H import price increases, it would be preferable to use more electrolysis which is not accounted for in the system. | This proposition has the highest proportion of electricity produced being exported, hence is very dependent on the export prices. If the electricity export price increases, there may be less electricity to satisfy the demand of the system. | |
| Criteria 30 Criteria Name | Innovation | Innovation | Innovation | |
| Innovation | 4 | 4 | 1 | [1 - negative, 3- neutral, 5- positive] |
| Criteria 30 Comment | This proposition is a strong example of how SLESs can be formed with existing buildings retrofitted with low carbon energy conversion technologies fed by local renewables. | This proposition is a strong example of how SLESs can be formed with light industrial developments that are short-term and that can be multi-vector. The biggest uncertainty is commercial arrangements. | This proposition is an example of what is NOT a SLES, where the demand centres are largely disconnected from the supply assets and most of the energy generated is exported. | |
| Criteria Name 31 | WFGA Goals | WFGA Goals | WFGA Goals | |
| WFGA Goals | 5 | 5 | 2 | [1 - negative, 3- neutral, 5- positive] |
| Criteria 31 Comment | Promotes a decentralised energy system with cost savings to PoMH/tenants and greater energy security. Opportunity to replicate to other organisations and potentially residential and thus contributing to the WFGA goals. | Promotes a new type of a resilient energy system and technologies and thus promotes job creation and skills development. Strong opportunity to scale up and replicate to other similar sized industrial settings. | Doesn't promote integration of demand assets into a SLES. | |
| Criteria 32 Criteria Name | WFGA Ways of Working | WFGA Ways of Working | WFGA Ways of Working | |

# Review Proposition Multi Criteria Scoring

| Multi Criteria Scoring Proposition Name | Proposition 1 - MH Marina SLES | Proposition 2 - Pembrokeshire Food Park SLES | Proposition3 - Pembroke Schools, Leisure centre and dock SLES | Scoring guide |
|---|---|---|---|---|
| WFGA Ways of Working | 4 | 5 | 2 | [1 - negative, 3- neutral, 5- positive] |
| Criteria 32 Comment | Promotes long term investment and benefits but only involves one organisation (PoMH). | Promotes collaboration and integration between multiple parties and projects forming a SLES. Promotes long term investment and benefits. | Doesn't promote integration of assets into a SLES. | |
| Criteria 33 Criteria Name | Waste Reduction / Circular Economy | Waste Reduction / Circular Economy | Waste Reduction / Circular Economy | |
| Waste Reduction / Circular Economy | 4 | 5 | 3 | [1 - negative, 3- neutral, 5- positive] |
| Criteria 33 Comment | Less waste overall by retrofitting buildings with technologies rather than building new. | AD makes use of food waste to produce biogas, and could lead the way to a circular economy example in the food sector. | This impact is considered to be minimal. | |
| Criteria 34 Criteria Name | Air Quality | Air Quality | Air Quality | |
| Air Quality | 5 | 5 | 4 | [1 - negative, 3- neutral, 5- positive] |
| Criteria 34 Comment | Near-zero emissions are reached within the proposition by 2050 (0.002kg/kWh). | Near-zero emissions are reached within the proposition by 2050 (0.003kg/kWh). | Near-zero emissions are reached within the proposition by 2050 (0.001kg/kWh), although noting that this proposition isn't truly multi-vector and includes a significant proportion of renewable electricity export to the grid. | |
| Criteria 35 Criteria Name | Education | Education | Education | |
| Education | 5 | 4 | 2 | [1 - negative, 3- neutral, 5- positive] |
| Criteria 35 Comment | Higher opportunity for public awareness raising & education as the site is more accessible. Opportunity to create education centres. | Opportunity to create a visitor centre or allow public access to showcase the SLES. | This proposition doesn't represent a SLES | |