MILFORD HAVEN: ENERGY KINGDOM

MH:EK strategic outline case for a smart local energy system

Prospering from the Energy Revolution

March 2022

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Purpose of this report

This report brings together the research and detailed whole energy system modelling delivered by the project partners to support a broader evidence base and start to establish a Strategic Outline Case for a smart local energy system for MH:EK that is replicable, scalable and investable.

The report includes summary information in the format of the Strategic, Economic, Commercial, Financial and Management cases to set out a roadmap to develop a SLES for Milford Haven in 2030 that is in transition towards being fully decarbonised by 2050. 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 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

This report has been prepared by Arup on behalf of Pembrokeshire County Council in connection with the Milford Haven: Energy Kingdom (PfER) project and takes into account their particular instructions and requirements. It is not intended for and should not be relied on by any third party and no responsibility is undertaken to any third party.

In preparing this report we have relied on information provided by others, and we do not accept responsibility for the accuracy of such information.

We emphasise that the forward-looking projections, forecasts, or estimates are based upon interpretations or assessments of available information at the time of writing. The realisation of the prospective financial information is dependent upon the continued validity of the assumptions on which it is based. Actual events frequently do not occur as expected, and the differences may be material. For this reason, we accept no responsibility for the realisation of any projection, forecast, opinion or estimate.

MH:EK strategic outline case for a smart local energy system

Report contents

Net zero by 2050

Navigating this report

How this report is structured

To help you find the information you need and navigate this report we have used a navigation bar across the top and iconography throughout.

Document navigation

The navigation bar helps you navigate to each section

Executive Summary | Overview | Introduction | The Strategic case | The Economic case | The Commercial case | The Financial case | The Management case | Recommendations and next steps

Iconography

Below shows the three propositions

Milford Haven Marina SLES

Pembrokeshire Food Park SLES

Pembroke Schools, Leisure Centre and Dock SLES

Below shows the commercial models that could apply across the propositions

Community owned model

Disaggregated market model

Centralised model

SPV / Partnership model

Links

Underlined text throughout the document will link to further information

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After viewing high-resolution images, click to return to report

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Definitions

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 2040
  - Long-term: 2040 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.*

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

MILFORD HAVEN: ENERGY KINGDOM

Foreword

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Foreword

The Council is proud to lead the Milford Haven: Energy Kingdom project which is positioning the Milford Haven Waterway as a frontrunner for breakthrough renewable energy and hydrogen technologies to provide increased flexibility to the way we consume electricity and gas, as we deliver greater amounts of green, affordable onshore solar, and offshore wind, tidal and wave generation in the Celtic Sea and beyond.

Having already established itself as the UK's Energy Capital, the Milford Haven Waterway is now at the centre of a renewable energy revolution, with huge potential to become the low carbon energy capital of the UK, safeguarding thousands of local jobs and creating thousands more new ones.

The projects heating and transport demonstrators showcase what can be achieved through collaboration with our partners and Pembrokeshire can use these innovations as we work to become a net zero carbon local authority by 2030.

To get to net zero, we must deliver net zero power, transport and heat across a smartly connected whole energy system with progression to regulatory & policy frameworks to support truly multi-vector trading platforms.

We have all the necessary components here on our doorstep in Pembrokeshire to act as a vital cluster of national significance and to provide opportunities in the green energy sector for both current and future generations.

Steve Keating, Project Lead for MH:EK and Pembrokeshire County Council Energy & Sustainability Team Lead

This project, funded by Innovate UK, and delivered by the many project partners has significantly advanced the existing evidence base in support of the route to a net zero energy system.

The study has incorporated the following:
- a review of existing policy and regulation;
- developed thinking around new commercial models and structures looking out to a changing future system;
- detailed whole system energy modelling of three smaller-scale smart local energy systems (SLES) which is a draft view on potential roadmaps out to 2050, bringing together insights on direction of travel from across the existing energy industry in the region (such as RWE's Pembrokeshire Net Zero Centre and the South Wales Industrial Cluster programme);
- consideration of the role of trading platforms within the future system and the enablers and barriers to current implementation; and
- recommendations towards ensuring that Pembrokeshire is aligned with the national Modernising Energy Data Access programme.

Across all these areas, this report intends to summarise the collective work carried out by the project partners and present recommendations and next steps for different actors from the local community, to potential investors, to Ofgem and BEIS in setting future policy and regulation.

If we're to reach our goal of decarbonising the energy system, we need to think of the transition not as one giant leap but as a series of smaller, more achievable steps. These involve establishing individual low-carbon 'clusters' and joining them together to unlock greater benefits.

This project has set out a "series of smaller, more achievable steps" for Milford Haven, and the Pembrokeshire region on the journey to net zero.

Alan Thomson, Arup Global Energy Leader

MILFORD HAVEN: ENERGY KINGDOM

Executive Summary

Executive Summary

The Milford Haven: Energy Kingdom project

The Milford Haven: Energy Kingdom (MH:EK) project is part of the Prospering from the Energy Revolution (PfER) programme funded by Innovate UK (IUK) as part of the UK research and Innovation (UKRI) Industrial Strategy Challenge Fund (ISCF).

MH:EK has reviewed the current energy landscape in the local area, to investigate options for a future Smart Local Energy System (SLES) by identifying proposition (opportunities) that are investable in the short-term and could provide the initial smaller steps towards larger scale decarbonisation and realisation of a Pembrokeshire wide 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. Project non-funded collaborators and supporters include Western Power Distribution (WPD) and RWE; and Welsh Government Energy Service, Simply Blue and Community Energy Pembrokeshire respectively.

Routes to net zero

This research has explored a range of different scenarios, or possible pathways, to net zero across both immediate actions that could be taken now, out to decisions across the period to 2050. The study has drawn on the existing literature base, previous studies, extensive stakeholder engagement and Arup analysis to inform the scenarios considered.

The scenarios are not intended to present a recommended outlook but to enable exploration of a wide spectrum of outlooks that future decisions will influence, to support 'no regrets' decisions in the short-term.

The role for SLES

Smart local energy systems are shown to have significant benefits in terms of costs and carbon emissions.

This is the case where there is strong interplay between the demand energy vectors (heating, cooling, electricity and hydrogen) supporting system balancing and greater flexibility of supply.

The study has highlighted a strong case for a hierarchy of energy usage as the system transitions to net zero. Energy should be used locally where possible and unnecessary transition between vectors should be minimised.

However, SLESs and heat networks are not always the preferred solution, this is dependent on the mix and scale of demand energy vectors.

The role for hydrogen

A national transition from natural gas to hydrogen is increasingly seen as a necessary component of full decarbonisation by 2050.

Large scale hydrogen markets may provide essential cross-vector system balancing and inter-seasonal energy storage for an energy system dominated by the UK's abundant renewables, especially high-capacity factor offshore wind and marine resources.

Electricity is shown to be more cost and carbon effective for power and heating in the SLES propositions modelled, with locally produced hydrogen playing a role in absorbing excess electricity to create green hydrogen for local transport. The case for hydrogen in transport is seen to be most viable in heavy goods vehicles, particularly whilst the market is nascent, as highlighted by other studies *[10]*.

Short-term propositions

This feasibility study has focused on three shortlisted 'propositions' to assess their viability as a SLES and set out recommended 'no regrets' opportunities that if pursued would 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.

The three shortlisted propositions:

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

These are summarised overleaf.

The propositions

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 across the heat, power and transport vectors include the existing and proposed buildings and the commercial vehicle fleet owned by PoMH.

The analysis showed 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.

*Modelling for proposition 1 has been undertaken to a greater level of detail due to additional funding and therefore has only been run for the 2020 scenario at this higher level of detail.**

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 1: 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 cold climate heat pump 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)	MCA Score
24.1	0.003	0.074	3.9

Figure 2: 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 hydrocarbon-based energy 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 as modelled. The outcomes mainly consist of a large capacity of solar PV that predominantly 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 energy vectors.

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

Figure 3: Pembroke Ysgol Harri Tudor School (© https://www.ysgolharritudur.cymru/)

Key messages

The study has highlighted:

- **The need for whole system energy modelling at a wider scale that optimises across supply and demand, and balances between energy vectors. Doing this will enable informed decision making around the level of renewables development required, alongside storage technologies (batteries or hydrogen) so that utilisation of assets remains high and losses within the system are minimised.**
- **Electricity is likely to be the dominant low carbon energy vector, preferred for power, heat and a proportion of transport demand. As new renewable generation assets are developed locally supporting decentralised low carbon electricity options and the UK electricity grid continues to decarbonise, as back-up to decentralised local systems, the emerging hierarchy is to use low carbon electricity first ahead of green hydrogen generation.**
- **Hydrogen will play a role, but the degree to which it does, and to which it presents an efficient, low carbon, cost effective alternative will depend on external factors and policy and regulatory decisions.**
- **Future decisions made around the UK's transmission network will be significant in influencing development of new renewable generation, balancing, flexibility and trading. Regulatory barriers currently present a significant challenge to local trading platforms.**
- **The most significant regulatory risks arise from "Newer Market Entrants", particularly those with an undeveloped regulatory framework (e.g., networked hydrogen, heat networks), market access, and asset co-ownership.**
- **Establishing a robust data ecosystem at a local level, that integrates beyond the local boundary, is key to benefit from and support the national modernising energy data access (MEDA).**
- **The transition to net zero should put the community, stakeholders and wider aims at the centre and ensure a just transition for all. Through continual stakeholder engagement and adopting a theory of change approach, MH:EK should develop a roadmap for everybody to understand their role to get to net zero by 2050.**

Whole energy system infographic

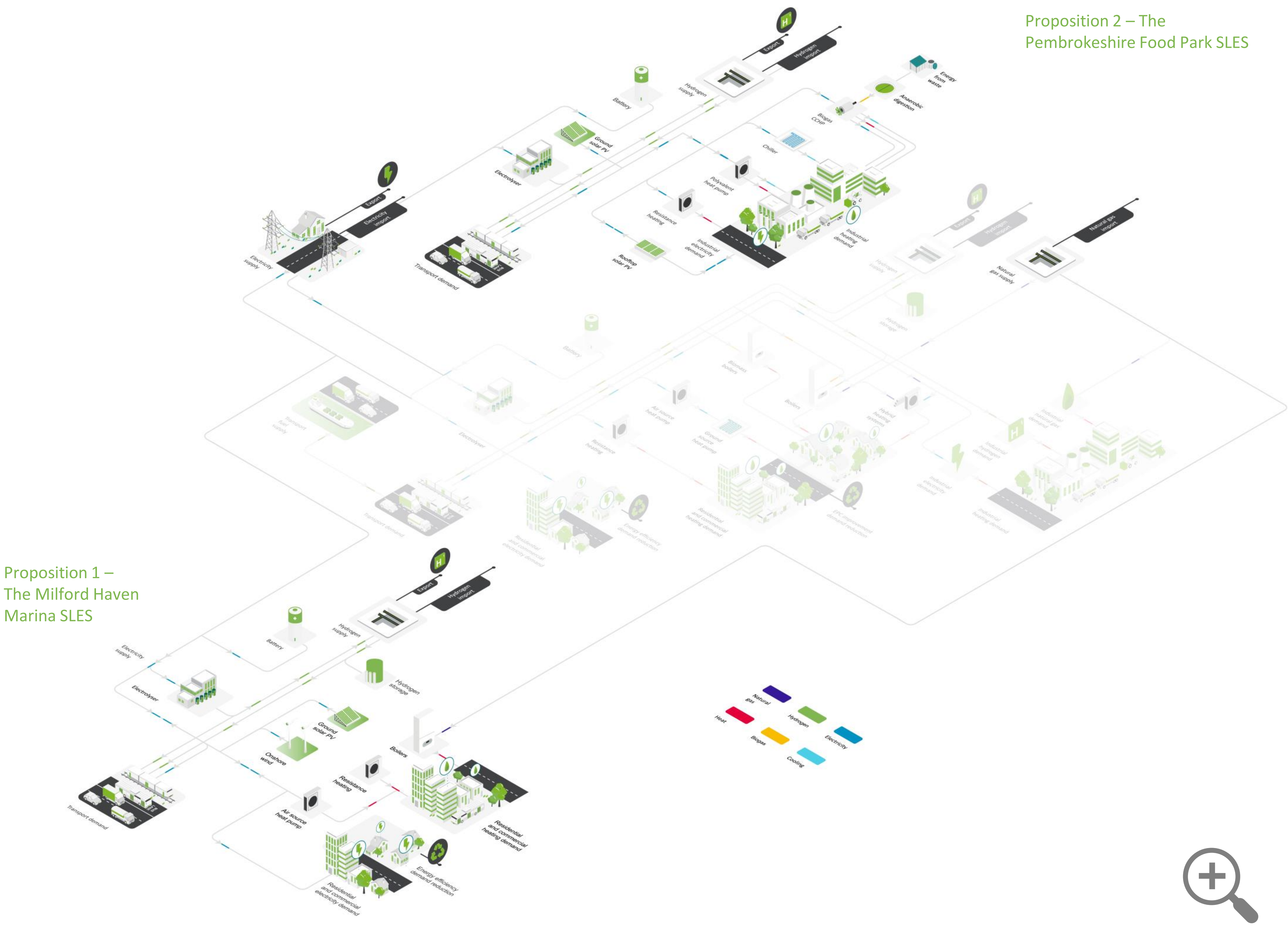

Figure 4: Whole energy system infographic with a focus on proposition 1 and proposition 2

MILFORD HAVEN: ENERGY KINGDOM

Overview

An overview of the case for change, project aims, key findings and recommendations

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The case for change

“Climate change is real, and it is happening all across the world and **impacting on local communities in Pembrokeshire**.

Sir David Attenborough in 2019 called climate change *‘our greatest threat in thousands of years’*, adding, *‘while Earth has survived radical climactic changes and regenerated following mass extinctions, it’s not the destruction of Earth that we are facing, it’s the destruction of our familiar, natural world and our uniquely rich human culture.’*

It is up to us all to change this.”

Cllr Joshua Beynon, Chair of the Net Zero Carbon 2030 Group, Pembrokeshire County Council *[1]*

The Case for Change – net zero by 2050

The UK and Welsh Government net zero targets by 2050 require whole system decarbonisation at scale and at pace.

Everyone has a role to play as individuals, local communities, private organisations, industry, public sector actors and financiers to ensure we reach these targets.

This will require technological adoption and innovation, economic, financial and regulatory innovation, business transformation, and behavioral change.

The fastest and most effective way to deliver against country level decarbonisation targets, is to decarbonise the energy sector as a priority.

Pembrokeshire and more specifically Milford Haven, Pembroke and Pembroke Dock are uniquely positioned to take a leading stance on this decarbonisation journey.

The Port of Milford Haven is the UK’s largest energy port, with associated industrial processes, jobs and skilled workforce, and Pembrokeshire has significant offshore and onshore renewables potential.

The Case for Change – energy sector decarbonisation as a priority

Whole energy sector decarbonisation is establishing behaviours, processes and infrastructure that bring about net zero emissions across all electricity, heat and transport.

The UK Government has set a more ambitious target for the electricity sector of reaching net zero by 2035, in support of whole system decarbonisation by 2050. This will need to be met with significant additional renewables as part of the UK electricity network than exists today, as well as some degree of carbon capture & storage in order to meet:

- Decarbonisation of current electricity demand,
- Increasing electricity demand linked with expected population growth,
- Shifts in locational demand as urban centres grow,
- Increasing electricity demand linked to electrification of heat and transport.

There is a shared commitment across Government and industry to deliver against these targets as evidenced by the presence and contributions of the private sector at COP26 and through many collaborative industry studies that are referenced throughout this report.

“We believe decarbonising energy is possible but also that it will be complex, not least because there are many ways to reach net zero, each with their own trade-offs.” National Grid ESO

Amongst the many ways to reach net zero, Smart Local Energy Systems (SLES) are expected to have a significant role in supporting decentralisation of the energy system, greater local balancing and through enabling a greater number of (new) actors to engage.

“Smart Local Energy Systems can help to achieve these targets. Smaller scale, decentralised energy systems utilising smart technologies can be delivered at a local level to offer a route to net zero, while providing considerable market opportunities associated with the transition.” EnergyREV

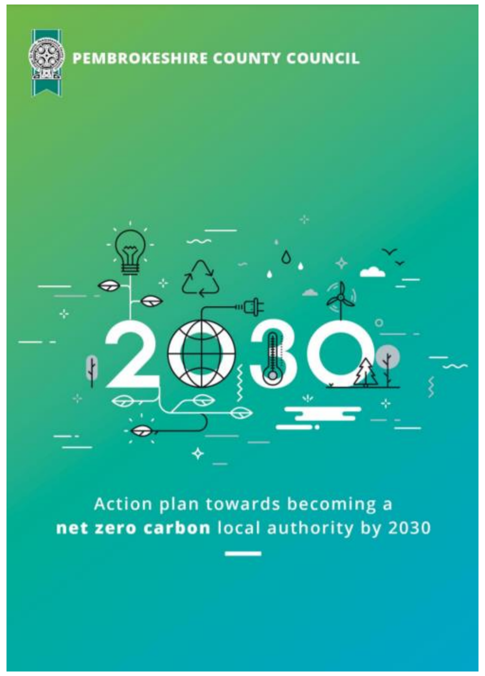

Figure 5: Pembrokeshire County Council Net Zero 2030 action plan *[1]*

Smart local energy systems

"If we're to reach our goal of **decarbonising the energy system**, we need to think of the transition not as one giant leap but as a series of **smaller, more achievable steps**.

These involve establishing **individual low-carbon 'clusters'** and **joining them together** to unlock **greater benefits**."

Alan Thomson, Arup Global Energy Leader

The role for SLES – what this study has shown

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 SLESs are electricity, heating and mobility interaction and being mutually supportive of one another towards net zero goals. This project demonstrates the value of interconnected SLESs and the potential for hydrogen production as an alternative vector where electricity networks are currently constrained.

However, 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 (ASHPs), 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 within a geographic or system boundary. For instance, if the intervention consisted solely of hydrogen derived from grid or local electricity, and the local electricity generation was not used to satisfy the local electricity demand first, this would not be considered a SLES.

The Milford Haven: Energy Kingdom project

The MH:EK project has reviewed the current energy landscape in the local area, to investigate options for a SLES by identifying proposition (opportunities) that are investable in the short-term and could provide the initial smaller steps towards larger scale decarbonisation and realisation of a Pembrokeshire wide SLES.

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.**

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

This is further discussed in the *Introduction to the project* section.

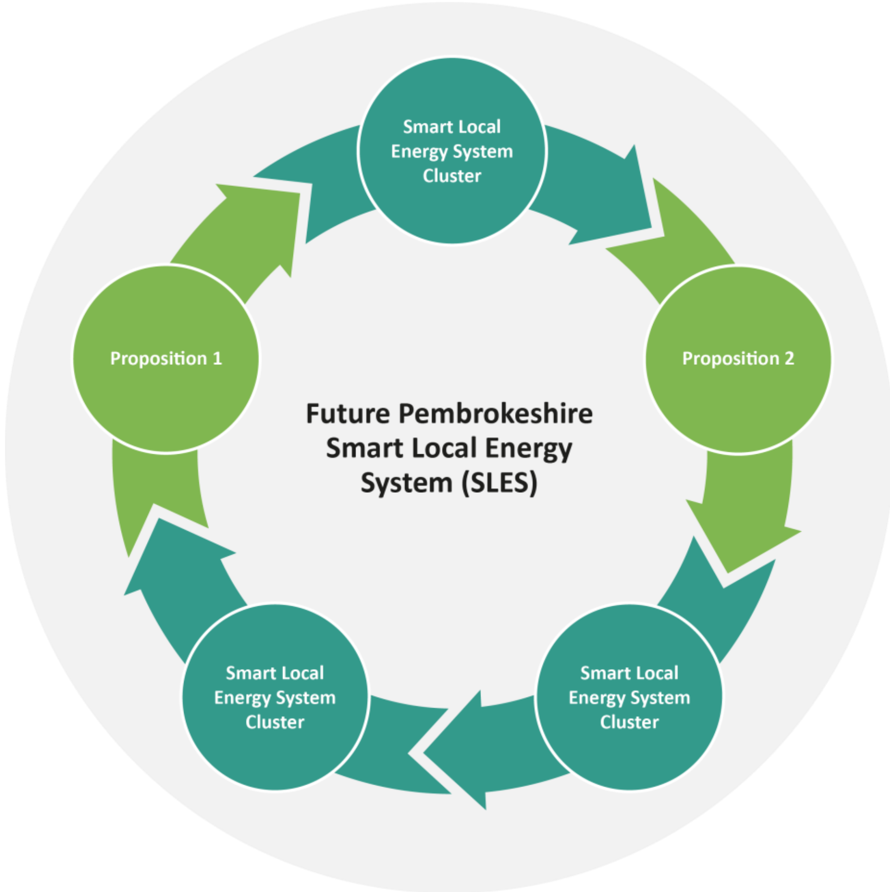

Figure 6: Propositions identified during this study could result in acting as 'stepping stone' projects or catalysts for other SLES clusters developing towards a Future Pembrokeshire Smart SLES

Short-term actions on the roadmap to net zero by 2050

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 modelled, the resulting optimum 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 (using heat pumps) and EV transport.
2. If excess electricity is generated beyond the power and heat demand baseload, this is used to support local electrolysis and green hydrogen production, where there is a local hydrogen transport demand.
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 regional or national grid, in preference to exporting excess electricity 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.

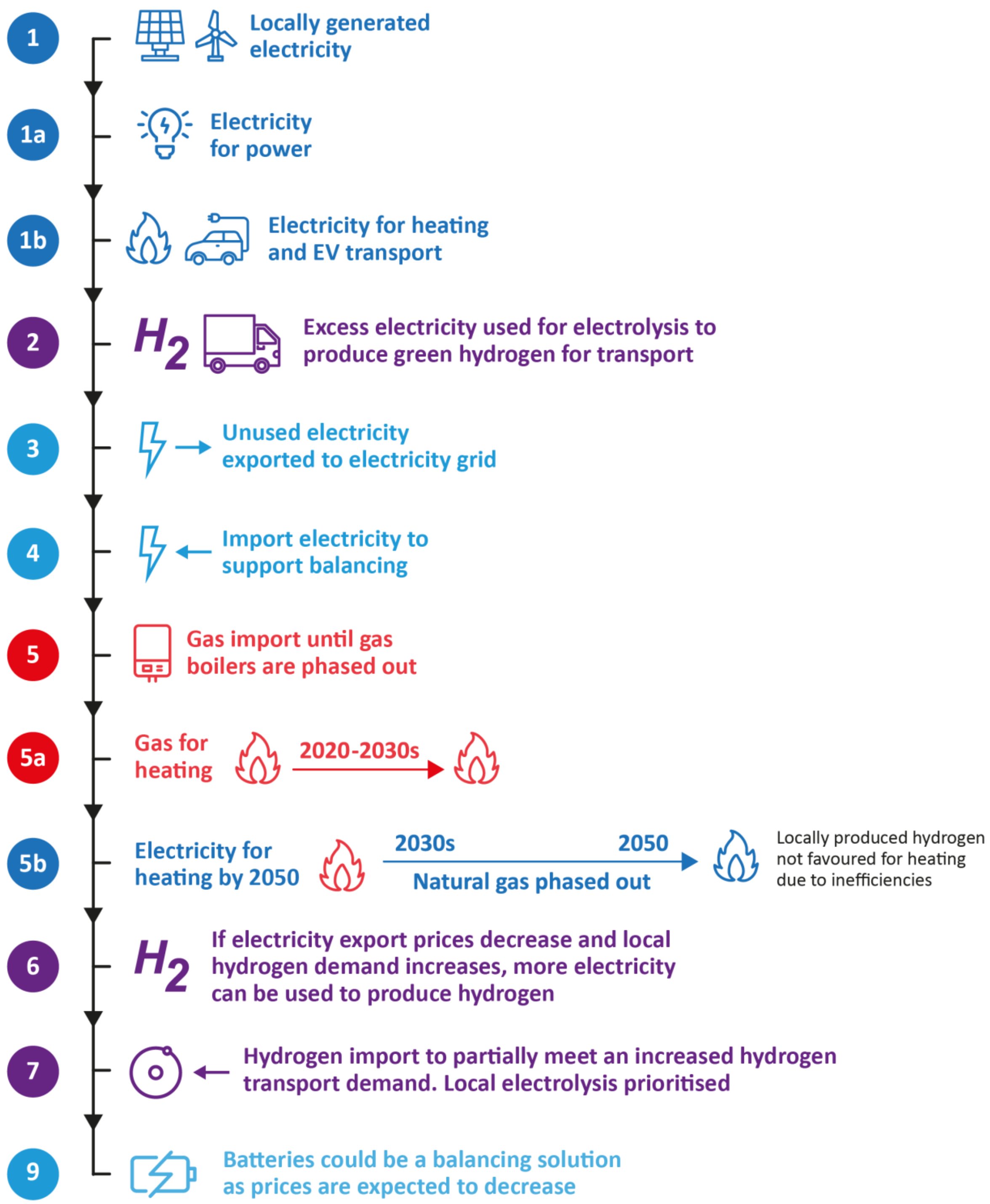

Figure 7: Hierarchy of energy supply-demand relationship based on a 2020 world view and short-term actions to support reaching net zero by 2050

The proposition recommendations

> “Technology and business decisions must now be considered as **one entire approach** to enable a green recovery and thriving **net zero future**, mitigate climate change, **sustain reasonable returns**, and ensure a **fair price for the consumer**.”
>
> Filippo Gaddo, Arup Head of Economics

The propositions

MH:EK SLES project recommendations

- It is recommended that the MH:EK project pursues both Proposition 1 and Proposition 2.
- 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.
- The outcome of Proposition 3 suggests that it is not a strong SLES candidate, so is not recommended to be progressed. It does highlight the commercial opportunity for onshore wind development if network constraints can be reasonably addressed.

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.

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).

Delivering the propositions

Steps for project delivery – the commercial model

The initial findings show that a commercial model made up of several project partners under a special purpose vehicle (SPV) type structure could potentially be viable. Through a multi criteria assessment the SPV/ partnership model scored the highest and delivered best against the criteria assessed.

The SPV model would allow for an efficient allocation of risk as a range of entities would sit within the SPV as project partners, and risks could be allocated to those best able to manage them.

An SPV/Partnership model would be able to reflect the local communities needs and priorities as we would expect that there would be some sort of community representation within the SPV. How the SLES is optimised would need to be decided by the SPV as there would ultimately be trade-offs between where energy is directed to, and which offtakers are prioritised.

As part of a next stage of the study, we would recommend that further work is done to explore the applicability of the SPV / Partnership model. We particularly recommend that specific use cases are worked through, to identify how each of the different stakeholders would interact under the model. This exercise would also further articulate the revenue flows between stakeholders.

We would also recommend that this potential model is started to be tested with the various stakeholders to explore their appetite for such a model, and to better understand what risks or barriers there might be in implementing it.

Finally, we would recommend exploring in more detail how the ESCo model would work in practice, what the relationship would be with other project partners, and the commercial relationship with entities outside of the SPV partnership perimeter.

Regulatory considerations

The second half of the Commercial case identifies, categorises, and contextualises regulatory risks, obstacles, and barriers that could be faced by the three propositions outlined in the techno-economic modelling. The regulatory review covers the following steps:

1. **Existing Regulatory Arrangements:** Key energy market stakeholders, systems, and technologies – and some significant relationships there between – are mapped. These are categorised as "Traditional Market Users", "Newer Market Entrants", "Networks", and "Government / Regulator". Existing regulatory arrangements are introduced, and relevant considerations identified at a high level.
2. **Identification of Regulatory Barriers:** For each of the three propositions, those market stakeholders, systems, and technologies most relevant to bringing the preferred arrangement to market are highlighted. Potential regulatory and related barriers are identified and mapped to the highlighted stakeholders, systems, and technologies. Barriers are rated on a three-colour scale from low to high risk. The most significant risks arise from "Newer Market Entrants", particularly those with an undeveloped regulatory framework (e.g., networked hydrogen, heat networks), market access, and asset co-ownership.
3. **Routes to Market:** Options are put forward to overcome some of the more significant regulatory risks; these include licensing exemptions, off-network hydrogen transportation, engagement with the market regulator, alternative means of selling surplus generation, consideration of commercial model suitability, and demonstrating innovation in the regulatory sandbox.

The role for trading platforms in developing SLESs

Trading platforms facilitate the exchange of goods and services, often across multiple markets. In the context of energy, a trading platform might allow for the exchange of electricity or hydrogen, as well as acting as a local balancer and flexibility provider, optimising the use, and further development of, distributed energy resources, including local hydrogen production and storage.

MH:EK could benefit from a trading platform because export of electricity from Pembrokeshire is constrained. A local trading market could support more renewables development, hydrogen production capacity, and flexibility/storage within the system.

However, there are technical, regulatory and market barriers that must be overcome.

In the electricity sphere, the largest technical barrier to participating in wider flexibility and capacity (electricity) markets is that export is constrained. There also need to be improvements in the network, and forecasting ‘prosumer’ data available from DNOs. Local, peer-to-peer trading could be utilised to overcome the export constraint, but this would need to be done with regulatory relief from Ofgem.

In the hydrogen sphere, the maturity of the market remains a barrier. Market liquidity calls into question the utility of using a trading platform over securing long-term contracts. Fulfilling orders remains difficult without transport infrastructure, and electrolysers participating in the electricity balancing, flexibility and capacity sphere are competing against CHP and battery incumbents. Securing jobs in the region would likely be better served through production assets securing long term contracts with transport, or chemicals firms.

As such, it seems unlikely that establishing a digital trading platform represents the most beneficial approach at this time. Trading platforms do not work in isolation and there needs to be a trading ecosystem that hosts trading collateral, enables administrative actions and counterparty risk management and more. Once a more robust hydrogen market is established, a trading ecosystem that has access to electricity and gas markets is recommended.

Why hydrogen?

"As the UK's largest energy Port, we are responsible for the supply of 25% of UK energy needs. It is becoming increasingly clear that to achieve net zero by 2050, we need renewable electrons and molecules. Gas plays a very significant role in the UK's energy mix and the gas network is able to be used for hydrogen transportation and storage. As a vital component of the energy system, the gas network can support the already-constrained electricity grid when at capacity with renewable energy or when renewable energy is unavailable."

Tam Bardell, Port of Milford Haven

A national transition from natural gas to hydrogen is increasingly seen as a necessary component of full decarbonisation by 2050.

Large scale hydrogen markets may provide essential cross-vector system balancing and inter-seasonal energy storage for an energy system dominated by the UK's abundant renewables, especially high-capacity factor, offshore wind and marine resources.

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 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 (PNZC). 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 interconnector which will support balancing of the GB energy system with Ireland.
3. Hydrogen can be created using excess electricity generated by renewable technologies, and then it acts as a chemical energy store, releasing energy when needed to support electricity grid balancing which will be increasingly important as the energy sector decarbonises and electricity demand increases. What we need to look at is how to make using 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. This is something that the project aims to explore in detail.

Figure 8: MH:EK hydrogen refueller demonstrator at Milford Haven marina

Looking out to 2050

> "RWE is looking to deliver 2GW of hydrogen projects by 2030, including a green hydrogen project in Pembrokeshire. Key to this is the economic viability of projects producing hydrogen for use across a wide variety of sectors such as transport, power and industry. RWE welcomes the work of MH:EK in helping to make the storage, use and distribution of hydrogen cost effective."
>
> Jeremy Smith, RWE

The journey to decarbonisation of the UK energy system by 2050 is uncertain. The National Grid Future Energy Scenarios (FES) *[2]* set scenarios under which the UK energy system could achieve net zero by 2050 - with differing level of societal, sector level and policy changes required. Three of the four FES 2021 *[3]* modelled scenarios meet the net zero target, however immediate action for deployment of new technologies at scale; demand flexibility; trading flexibility; digitalisation and whole energy systems approach is needed.

By applying this UK wide view to a local context, the MH:EK project aims to develop a conceptual proposal for what a 2050 decarbonised Milford Haven energy system could look like and provide a roadmap for short- to mid-term steps to reach net zero by 2050.

The longer-term pathways represent possible future energy systems for High-Electric, Balanced Green Hydrogen and Balanced Blue Hydrogen pathways.

The pathway approach is consistent with industry future energy system pathway development such as National Grid FES *[2]*, the Climate Change Committee 6th Carbon budget *[4]* and the Regen Net Zero South Wales studies *[5]*. The pathways are a qualitative representation of our understanding of the various local and regional decarbonisation plans and show how they can be aligned to accelerate the transition of the Pembrokeshire energy system to net zero by 2050. They are based on information reviewed and received through stakeholder engagement and are based on implementation of the stepping-stone MH:EK SLES propositions and the materialisation of the regional plans such as South Wales Industrial Cluster (SWIC) and the RWE Pembroke Net Zero Centre (PZNC)

The Balanced Green Hydrogen roadmap is shown overleaf, this pathway is well aligned to the CCC 'balanced pathway' demonstrating the potential balance of electric and hydrogen technologies. By transitioning large industrial sites to hydrogen production and storage, there is opportunity to retain jobs through skill shifting supporting a just transition.

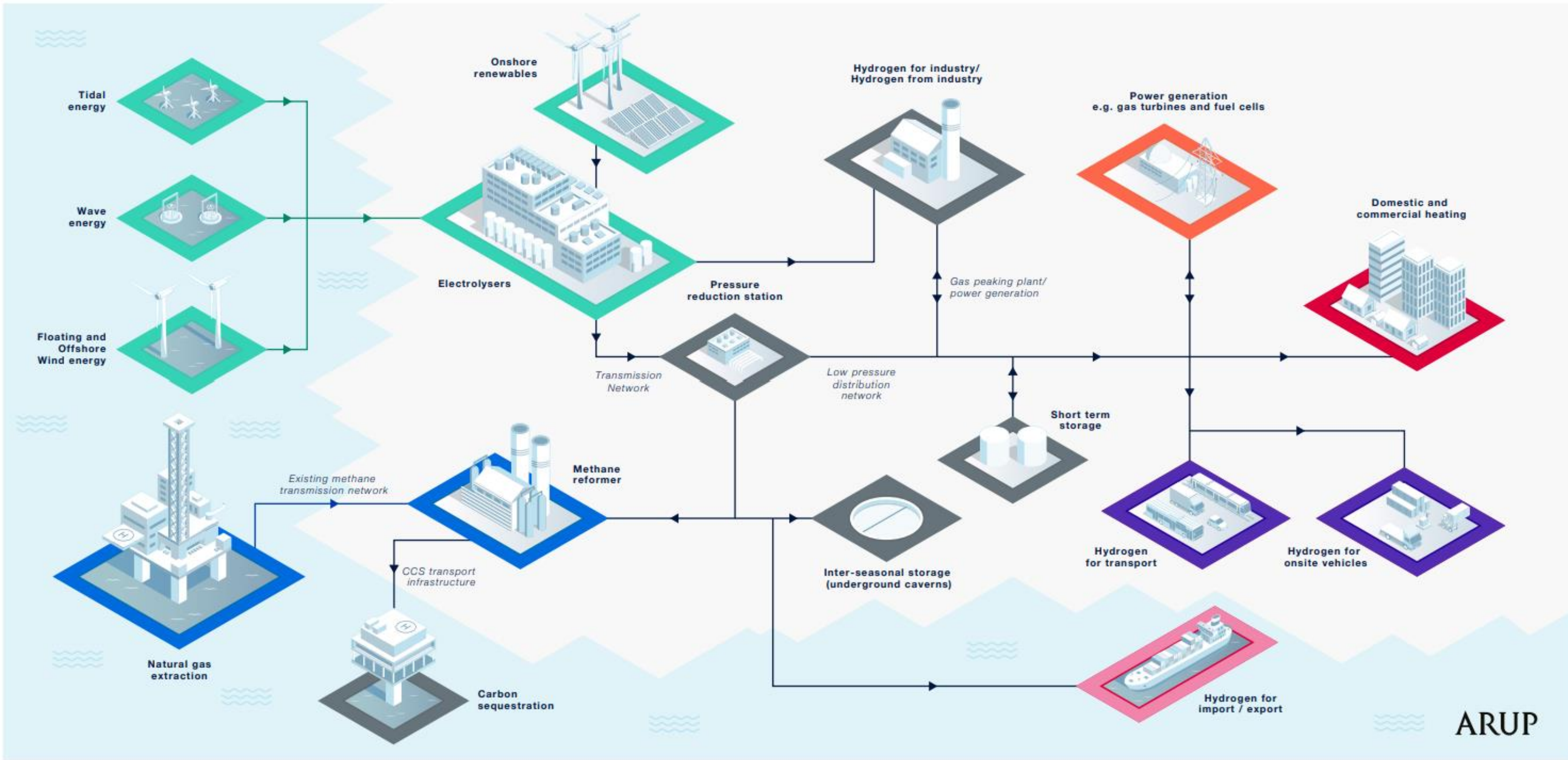

Figure 9: The Arup future energy system view

The MH:EK longer-term pathways: The Green Hydrogen pathway

Figure 10: Timeline of events for the MH:EK Green Hydrogen pathway

What could change the picture?

What could change the picture?

Delivering energy system transformation at the scale and pace needed to reach net zero by 2050 will require balancing multiple complex factors. Our work has consolidated the current evidence base to help build an understanding of the 'no regrets' first steps that could support broader system level change, whilst meeting a broad range of key objectives and critical success factors. We have produced a view of what could be developed and where in a range of future world scenarios.

However, there are still several unknowns, uncertainty and gaps in the evidence base, and different assumptions, or higher quality datasets, could create different outputs.

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- *The impact of hydrogen import prices*

  Our sensitivity analysis showed that current hydrogen prices of 0.135 to 0.18 £/kWh (£4.50 to £6.00/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*

  With no natural gas supply, heat is largely electrified with air-source heat pumps with a small amount from hydrogen boilers. Electrolysis and electricity exports were decreased with renewable electricity for heat being prioritised. This led to very large decreases in carbon emissions, but an inevitable increase in cost. This suggests that electrification of heat is preferable to hydrogen boilers if gas was removed from the system and for any new buildings, air-source heat pumps are likely to be cost competitive.

- *Lower electricity price, higher gas price*

  In this sensitivity analysis, the system started to switch over to electrification of heating via air-source heat pumps resulting in lower national grid exports and higher national grid imports. This result suggests a prioritisation of meeting the heating demand with the local renewable generation rather than only the electrical demand.

- *Lower battery prices*

  With lower battery capital costs, batteries were selected by the WSEM optimisation process to be part of the optimised system in every scenario, but with varying capacities. Higher capacity batteries resulted in less national grid electricity import and export and instead promoted self-consumption. 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.

Key areas as highlighted in the recommendation and next steps section overleaf could be further developed to support greater understanding of the optimal pathway to a net zero energy system.

Recommendations

Recommendations are provided across the short-term and mid-term time horizon in support of reaching net zero by 2050. Longer term recommendations are difficult to set out at this point and should be established over the next decade(s) reflecting on progress to that point and required targets for reaching net zero.

Short-term

Early action through development of the recommended SLES propositions by taking the 'no-regret' steps will jumpstart the journey to decarbonisation.

- It is recommended that the MH:EK project pursues both Proposition 1 and Proposition 2.
- The outcome of Proposition 3 suggests that it is not a strong SLES candidate, so is not recommended to be progressed. It does highlight the commercial opportunity for onshore wind development if network constraints can be reasonably addressed.

Flexibility (supply, demand, trading) is a key part of the future energy system as demonstrated by industry net zero pathways. Regulators should provide regulatory relief to set up demonstrator flexibility platforms by 2030 to support flexible energy trading by 2040.

- Future decisions made around the UK's transmission network will be significant in influencing development of new renewable generation, balancing, flexibility and trading. Regulatory barriers currently present a significant challenge to local trading platforms.
- Engagement with network operators should be coordinated to ensure integration of network capacity and planned upgrades into further whole system energy modelling and the future roadmap.

Monitor and influence developing regulatory frameworks, take advantage of changes and create a Market Access Strategy.

- Uncertain regulatory futures for networked hydrogen (which could affect future hydrogen demand) and heat networks could present a regulatory barrier.
- Mitigation strategies include avoiding networked hydrogen transportation, informal outreach to Ofgem in the short term, and potentially application to use the Regulatory Sandbox - to demonstrate innovation and value to consumers - in the longer term.
- Recent and ongoing regulatory changes have removed some embedded benefits and increased network charges for decentralised generators but have opened up new value streams to smaller market users. A trend of increasing support for local systems is part of Ofgem's ongoing work to increase system flexibility during the energy transition.
- Wholesale market access can be expensive for small generators and a power purchase agreement will likely not be attractive to a third party for exporting surplus generation.
- Using an aggregator, now with access to the balancing mechanism, as an intermediary is a potential route to access flexibility value streams.
- Licencing and asset ownership regulatory constraints should be taken into account when selecting and developing the commercial model.

Establishing a robust data ecosystem at a local level, that integrates beyond the local boundary, is key to benefit from and support the national modernising energy data access (MEDA).

- The main recommendation for the MH:EK project is that it has plans in place to prepare for initiatives such as open data, standards and a focus on the fact that having available and accurate data will be to its advantage when some of the outcomes from the national initiatives become a reality. Throughout the lifecycle of the design, construction and operation of the propositions, the data required from these assets for their maintenance, and for the wider energy sector will be required as part of the delivery.
- The table below lists out the easiest to implement and more impactful project level recommendations to enable and prepare projects like MH:EK and other SLES's ahead of national standards and guidance being implemented. These are recommended to be part of the project management process for the future development stages of the SLES.

#	Recommendation
1	Common Energy Modelled Data Portal
4	Formation of a Milford Haven Energy System data management working group
5	Creation and implementation of an ongoing data management strategy to incorporate system changes into modelling
9	Contribution and adoption of national energy data standards and access protocols

Table 1: The top recommendations for data management for the MH:EK SLES. Refer to the Data Ecosystem report for the full list *[40]*.

Recommendations

Mid-term

A fully integrated and adaptable roadmap including key decision points and determinants for the decarbonisation of the Pembrokeshire energy system should be developed, stemming from the short-term SLES proposition and in close partnership and collaboration with the local and regional projects and network operators.

- We recommend that the next phase of the MH:EK project considers developing a roadmap for the decarbonisation of the Pembrokeshire energy system by 2050. We recommend that the starting point would be the short-term investable propositions for SLESs that is integrated with key projects and regional plans such as South Wales Industrial Cluster (SWIC), RWE Pembroke Net Zero Centre (PNZC) as well as the ERM Dolphyn project as they are further developed.
- As shown on the MH:EK pathways, early action up to 2025 will involve fewer actors and will therefore be less complex to implement. They will however have a catalyst effect to form larger energy clusters and eventually a decarbonised energy system.
- We recommend close partnership and collaboration with the regional plans such as SWIC, RWE PZNC and ERM to develop a roadmap for decarbonisation of the Pembrokeshire energy system by 2050. A fully integrated roadmap will enable the implementation of the short-term no regret steps with a view of integrating those with their plans on the journey to decarbonisation.
- Other upcoming studies such as the Pembokeshire Local Area Energy Planning (LAEP) which will include whole system energy modelling and optimisation of the Pembrokeshire local authority energy system, LAEP delivery pathways and local energy decarbonisation routemap are also key to inform the development of this roadmap.
- The future energy system will be based more around energy supply. Increased flexibility and interaction of multiple vectors and services will be required to flex demand, enable use and storage and trade different commodities. As such, technical, regulatory and market barriers around flexibility trading platforms would need to be overcome and local actors, network operators and regulators all have a role to play to realise these benefits by 2050. Further details on recommendations on how a trading platform could support the decarbonisation of Milford Haven and Pembrokeshire is provided in the *Commercial case.*
- Engagement with network operators should be continuous to integrate the network capacity and planned upgrades into the roadmap.
- The roadmap should be kept under review and adapted as the regional picture evolves, more actors become interested in the transition including investors and energy sector level changes happen for example network upgrades and policy and regulatory changes.

The decarbonisation roadmap should have the community, stakeholders and wider sustainable development aims at the centre to ensure a just transition.

- The transition to net zero should put the community, stakeholders and wider aims at the centre and ensure a just transition for all. Through continual stakeholder engagement and adopting a theory of change approach, MH:EK should aim at developing a set of tangible actions and a roadmap for everybody to understand their role to get to net zero by 2050 whilst ensuring societal cohesion.

Next steps

Short-term: development of proposition 1 & 2

- Further work and more detailed analysis of both propositions is required, including:
  - taking the **whole system energy modelling** undertaken to date to the next stage of detail to support a more detailed design;
  - exploration and **use case testing of the SPV / partnership commercial model**;
  - specific **stakeholder engagement** to explore their appetite for such a model, and to better understand what risks or barriers there might be in implementing;
  - exploring in more detail **how the ESCo model would work in practice**, what the relationship would be with other project partners, and the commercial relationship with entities outside of the SPV partnership perimeter;
  - **financial modelling** to further understand the potential pay-back or revenue to different parties; and
  - establishing a **detailed management plan**, including: an implementation programme, data management, risk management and contract management approaches.

Short-term: data ecosystem

- Establish a data working group within the MH:EK organisations to ensure that the various data initiatives recommended in this report, and within the energy sector, are discussed and championed locally in a coordinated way.
- Through the above data working group, engage with key national energy sector initiatives which are underway such as Open Energy *[6]*, Virtual Energy System *[7]* and Future of Gas *[8]* which will enable a much better integration of MH:EK SLES into the wider energy market through better data sharing and standardisation

Mid-term: setting a roadmap

- Identify a project lead to take forward establishing a roadmap in line with the mid-term recommendations.
- Continued stakeholder engagement, in particular with other key regional initiatives such as SWIC and RWE PNZC, alongside increasing community engagement to support all parties in taking a role in the local energy transition.

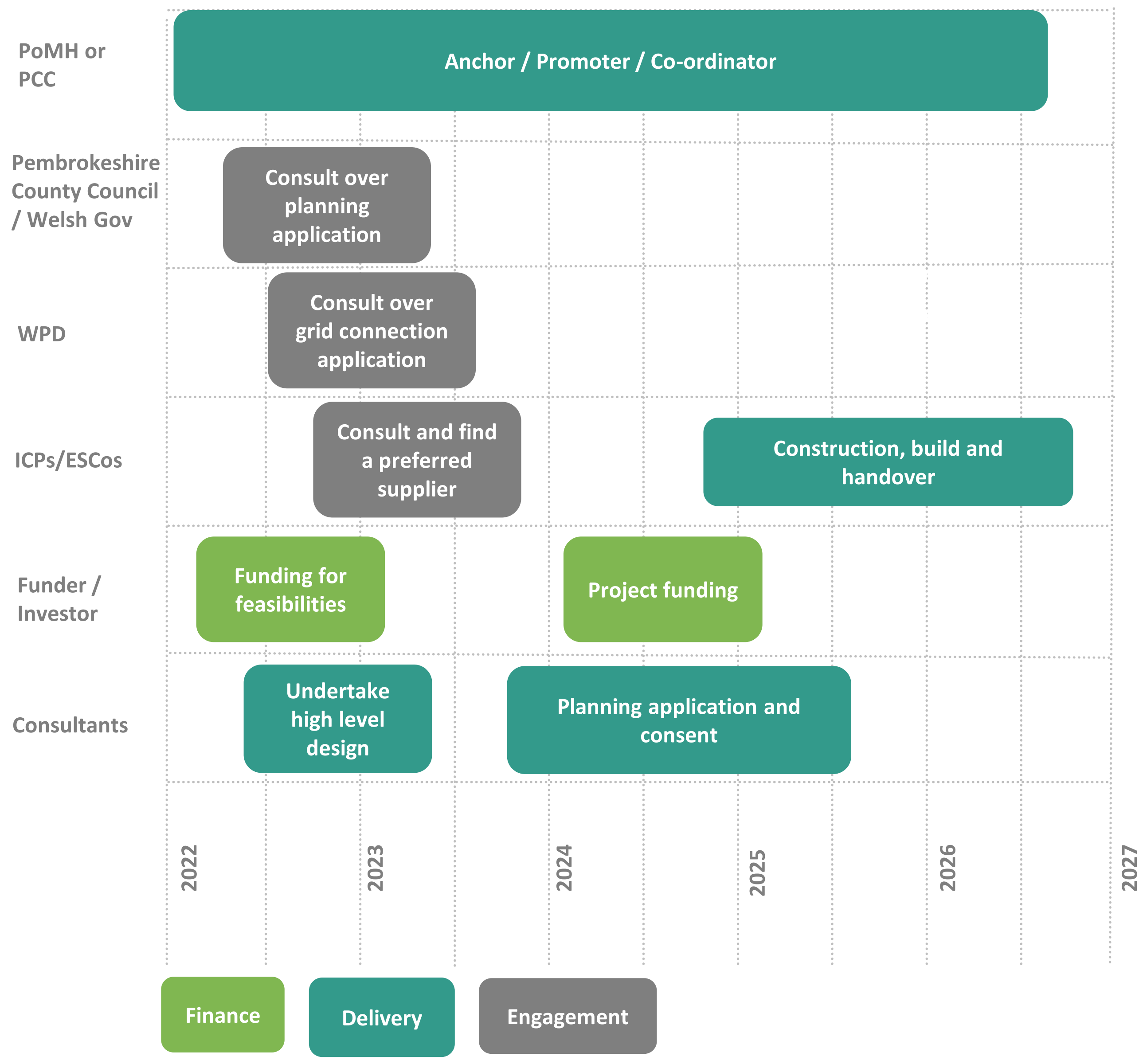

Figure 11:Indicative implementation programme for the recommended SLES

MILFORD HAVEN: ENERGY KINGDOM

Introduction

An InnovateUK Prospering from the Energy Revolution funded project

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.

Introduction to the Milford Haven: Energy Kingdom project

The Milford Haven: Energy Kingdom (MH:EK) project is a £4.5m project within the Prospering from the Energy Revolution (PfER) programme funded by Innovate UK (IUK) as part of their Industrial Strategy Challenge Fund (ISCF).

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.

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. The project 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.

The project team consists of ORE Catapult, Port of Milford Haven, Wales & West Utilities, Riversimple, Energy Systems Catapult, Arup; led by Pembrokeshire County Council. Project non-funded collaborators and supporters include Western Power Distribution (WPD) and RWE; and Welsh Government Energy Service, Simply Blue and Community Energy Pembrokeshire respectively.

Figure 12: MH:EK project partners

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.**

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

This is summarised in Table 2.

Theme	What are we trying to answer?	Objective	Section
Environment	What does a "best" scenario look like for the MH:EK project boundary by 2050 at a strategic level?	To develop a conceptual proposal for what a 2050 decarbonised MH:EK energy system could look like and the short-term investments.	The *Strategic* & *Economic* case
Economy & Policy	How do you create appropriate market pull, using MH:EK as a case study for a local system with a regional South Wales focus, within the national picture?	To understand and map market mechanisms that would create a sustainable demand for a hydrogen energy economy.	The *Commercial* case
Economy & Policy	What policy, regulatory and trading structures are needed to successfully integrate hydrogen trading into the energy market?	Establish a roadmap from the MH:EK perspective of policy change necessary to support an energy system that incorporates hydrogen.	The *Commercial* case
Economy & Policy	How do Government incentives and market signals drive investment in hydrogen?	Establish the potential role of and likely support mechanisms needed to see replicable roll out of a hydrogen energy system.	The *Commercial* case
Environment	What carbon price is needed to make hydrogen a viable energy vector?	To model and understand the Economic case for a decarbonised multi-vector energy system through energy supply-demand modelling.	The *Economic* case
Vectors	How could, and what value of, transportation services be impacted by a switch to hydrogen?	Demonstrate that hydrogen fuel cell electric vehicles are a core part of the whole systems approach - green power, green hydrogen, green heat, green transport. This whole systems approach is key to the Green Recovery.	The *Economic* case
Vectors & Environment	What does a "best" scenario look like for the MH:EK project boundary by 2030 by developing a concept stage design for the local energy system from scenario testing?	To develop a detailed concept design of an energy system for MH:EK in 2030 that is in transition towards being fully decarbonised.	The *Economic* case
Vectors, Education	What are the external demand drivers and outstanding challenges?	To engage investors by demonstrating an economic and sustainable investment case for a decarbonised multi-vector energy system.	The *Financial* case
Community	Is hydrogen good for consumers? (In which contexts e.g. hydrogen fuel cell vehicle range and cost being different drivers)	To assess the feasibility and demonstrate the viability of hybrid hydrogen heating systems to bridge the gap between all electric or fossil fuel heating systems.	The *Economic* case
Education	Are consumers ready to adopt even if the benefit is demonstrated?	To engage stakeholders by explaining the potential environmental, economic, societal, wellbeing, energy security and practicality benefits of a decarbonised multi-vector energy system. The stakeholder engagement will draw strongly on the vehicle and hydrogen heating demonstrations which will support awareness raising and education by demonstrating how hydrogen can be integrated into the local Milford Haven context.	Stakeholder Engagement Plan and Virtual Engagement Room
Education	How will we engage and raise awareness at a local, regional and national level?		

Table 2: The MH:EK key questions and objectives

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 13 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. The boundary was extended northwards to include Haverfordwest, a town and associated airfield that may provide opportunities for future hydrogen use and generation. The boundary includes major generation assets along with areas that have potential for renewable generation in the future.

Key:

- Renewable generation assets
- Future hydrogen generation opportunities
- The MH:EK project boundary

Figure 13: The MH:EK project boundary

MILFORD HAVEN: ENERGY KINGDOM

The Strategic case

Summary of findings

ENERGY KINGDOM
DEYRNAS YNNI

The case for change

The Case for Change – net zero by 2050

The UK and Welsh Government net zero targets by 2050 require whole system decarbonisation at scale and at pace.

Everyone has a role to play as individuals, local communities, private organisations, industry, public sector actors and financiers to ensure we reach these targets.

This will require technological adoption and innovation, economic, financial and regulatory innovation, business transformation, and behavioral change.

The fastest and most effective way to deliver against country level decarbonisation targets, is to decarbonise the energy sector as a priority.

Pembrokeshire and more specifically Milford Haven, Pembroke and Pembroke Dock are uniquely positioned to take a leading stance on this decarbonisation journey.

The Port of Milford Haven is the UK's largest energy port, with associated industrial processes, jobs and skilled workforce, and Pembrokeshire has significant offshore and onshore renewables potential.

The Case for Change – energy sector decarbonisation as a priority

Whole energy sector decarbonisation is establishing behaviours, processes and infrastructure that bring about net zero emissions across all electricity, heat and transport.

The UK Government has set a more ambitious target for the electricity sector of reaching net zero by 2035, in support of whole system decarbonisation by 2050. This will need to be met with significant additional renewables as part of the UK electricity network than exists today, as well as some degree of carbon capture & storage in order to meet:

- Decarbonisation of current electricity demand,
- Increasing electricity demand linked with expected population growth,
- Shifts in locational demand as urban centres grow,
- Increasing electricity demand linked to electrification of heat and transport.

There is a shared commitment across Government and industry to deliver against these targets as evidenced by the presence and contributions of the private sector at COP26 and through many collaborative industry studies that are referenced throughout this report.

"We believe decarbonising energy is possible but also that it will be complex, not least because there are many ways to reach net zero, each with their own trade-offs." National Grid ESO

Amongst the many ways to reach net zero, Smart Local Energy Systems (SLES) are expected to have a significant role in supporting decentralisation of the energy system, greater local balancing and through enabling a greater number of (new) actors to engage.

"Smart Local Energy Systems can help to achieve these targets. Smaller scale, decentralised energy systems utilising smart technologies can be delivered at a local level to offer a route to net zero, while providing considerable market opportunities associated with the transition." EnergyREV

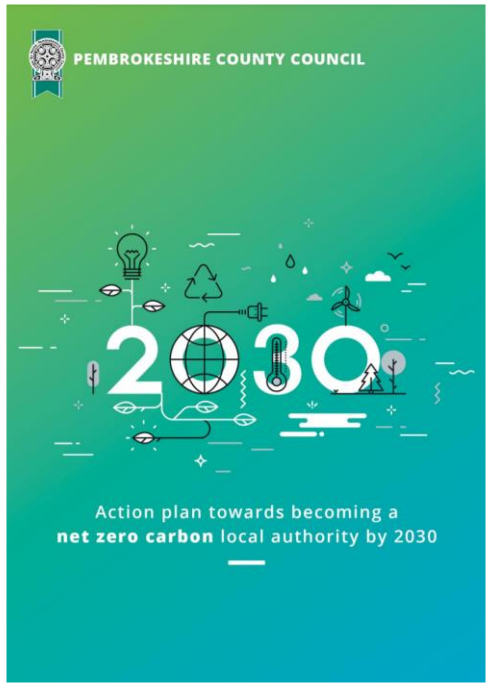

Figure 14: Pembrokeshire County Council Net Zero 2030 action plan *[1]*

The role for SLES – what this study has shown

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 SLESs are electricity, heating and mobility interaction and being mutually supportive of one another towards net zero goals. This project demonstrates the value of interconnected SLESs and the potential for hydrogen production as an alternative vector where electricity networks are currently constrained.

However, 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, 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 within a geographic or system boundary. For instance, if the intervention consisted solely of hydrogen derived from grid or local electricity, and the local electricity generation was not used to satisfy the local electricity demand first, this would not be considered a SLES.

The role of hydrogen

Why hydrogen?

A national transition from natural gas to hydrogen is increasingly seen as a likely, perhaps necessary, component of full decarbonisation by 2050.

Large scale hydrogen markets may provide essential cross-vector system balancing and inter-seasonal energy storage for an energy system dominated by the UK's abundant renewables, especially high-capacity factor, offshore wind and marine resources.

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 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 interconnector which will support balancing of the GB energy system with Ireland.
3. Hydrogen can be created using excess electricity generated by renewable technologies, and then it acts as 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. What we need to look at is how to make using 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. This is something that the project aims to explore in detail.

Figure 15: MH:EK hydrogen refueller demonstrator

The wider context

The local context

The Milford Haven Waterway is at the centre of nationally important energy infrastructure, with major energy related investment underway, targeting efficiency and decarbonisation. Facilities include South Hook LNG terminal, Dragon LNG terminal, RWE's 2.2GW CCGT, and National Grid's NTS pipeline that connects the Milford Haven Waterway with other assets like Grain LNG terminal, in Kent, and St Fergus gas terminal, Aberdeenshire.

This project has focused on developing diverse, local seed markets to support the transition, to hydrogen and renewables, of the cluster of major energy infrastructure along the Milford Haven Waterway.

This transition will occur via a mixture of pathways available locally - meeting heating and transportation needs of local communities, including via fuel cell vehicles; creating transport solutions for Pembrokeshire's 4.2 million annual tourists; hydrogen production from curtailed onshore wind and solar generators; and improving off-take markets for offshore renewables in the South-Western Approaches, including the consented Pembrokeshire Demonstration Zone (PDZ).

The regional context

There are various, and ongoing, regional studies and projects that aim to contribute to the growing evidence base to support not just the case for change in the region, but what change could look like for South Wales and Pembrokeshire.

These are summarised within the *Economic case* and include:

- South Wales ZERO 2050 *[9]*
- Regen Net Zero South Wales [*5]*
- The Future role of gas in transport *[10]*
- South Wales Industrial Cluster (SWIC)
- RWE Pembrokeshire Net Zero Centre *[11*]
- Offshore wind renewable generation – Celtic sea cluster
- ERM Dolphyn project
- Greenlink Interconnector *[12]*

The MH:EK project has looked to draw together this growing evidence base in support of a holistic and whole system roadmap under three future pathways.

We recommend close partnership and collaboration with the regional plans such as SWIC, RWE PZNC and ERM to develop a roadmap for decarbonisation of the Pembrokeshire energy system by 2050. A fully integrated roadmap will enable the implementation of the short-term no regret steps with a view of integrating those with their plans on the journey to decarbonisation.

Other upcoming studies such as the Pembokeshire Local Area Energy planning (LAEP) which will include whole system energy modelling and optimisation of the Pembrokeshire local authority energy system, LAEP delivery pathways and local energy decarbonisation routemap are also key to inform the development of this roadmap.

The South West Wales Regional Energy Strategy is a regional energy strategy aiming at developing a strategic pathway identifying key interventions to deliver on the region's ambitions for decarbonising its energy system. The vision is *"Harnessing the region's low carbon energy potential across its on and offshore locations, to deliver a prosperous and equitable net zero carbon economy which enhances the well-being of future generations and the region's ecosystems, at a pace which delivers against regional and national emissions reduction targets by 2035 and 2050"*

The national context

Whilst the journey to decarbonisation of the UK energy system by 2050 is uncertain, there is a shared commitment across Government and industry to deliver against net zero targets. This was recently evidenced by the presence and contributions of the private sector at COP26 and through many collaborative industry studies that are referenced throughout this report.

The Climate Change Committee (CCC) 'Balanced Pathway' to maintain the 6th Carbon budget *[4]* and achieve net zero by 2050 includes recommendations across varying levels of behavioural change and sector innovation.

The balanced pathway features strong contribution of take-up of low carbon solutions (boilers, transport and carbon capture and storage) and expansion of low-carbon energy supplies (renewables and at scale hydrogen production).

The CCC balanced pathway has assumed key phase out dates for gas boilers by 2033, fossil fuel powered vehicles by 2032 and the switch of HGVs to low carbon transport by 2040 which is in line with our assumptions.

The CCC balanced pathway energy system moves almost entirely to low-carbon energy sources by 2050. Low-carbon electricity becomes the dominant energy vector; a hydrogen economy is formed comparable to the existing electricity by 2050; domestic demand is met by more efficient EVs and heat pumps; a modest growth in bioenergy and waste use; carbon capture and storage is applied to the industrial sector.

The National Grid Future Energy Scenarios (FES) *[2]* set scenarios under which the UK energy system could achieve net zero by 2050 - with differing level of societal, sector level and policy changes required.

Three of the four FES 2021 *[3]* modelled scenarios meet the net zero target. However, to achieve this target, immediate action to enable deployment of new technologies at scale, demand flexibility, trading flexibility, digitalisation whilst taking a whole energy systems approach is needed.

By applying this UK wide view to a local context, the MH:EK project aims to develop a conceptual proposal for what a 2050 decarbonised Milford Haven energy system could look like and provide a roadmap for short- to mid-term steps to reach net zero by 2050.

MILFORD HAVEN: ENERGY KINGDOM

The Economic case

Summary of findings

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The Economic case

Introduction

The aim of the Economic case chapter is to demonstrate the techno-economic viability of the short-term investments within the MH:EK boundary that would kickstart the journey 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 the short-term (up to 2025) that is in transition towards being fully decarbonised by 2050.

To answer the overarching question of **how 'best' to integrate hydrogen into the energy system to decarbonise energy supply?,** 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?

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.

The "Technical Summary Report" *[29]* provides detail on the whole energy system modelling, which itself provides the supporting evidence for the Economic case for the MH:EK smart local energy system.

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 16 overleaf shows the process to get to a preferred option for a scalable, replicable and investable SLES for MH:EK which consisted of:

- **Data gathering and stakeholder engagement** to gain a detailed insight of the physical energy system within the project boundary
- **Infrastructure mapping** to identify opportunities or propositions for investable, replicable and scalable SLESs based on the project objectives and critical success factors to act as stepping-stones to deliver system level change and energy transition.
- A **longlist of 16 propositions** 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 (CSFs).
- **Multi-criteria assessment (MCA)** assessment against project CSFs and **key stakeholder and expert review** against SLES requirements for success using a SLES Decision Tree
- **Shortlist of three propositions** based on the results of the MCA supplemented by the SLES Decision Tree, expert review and stakeholder engagement:
    - Proposition 1: The Milford Haven Marina SLES;
    - Proposition 2: The Pembrokeshire Food Park SLES;
    - Proposition 3: The Pembroke Schools, Leisure Centre and Dock SLES
- 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.

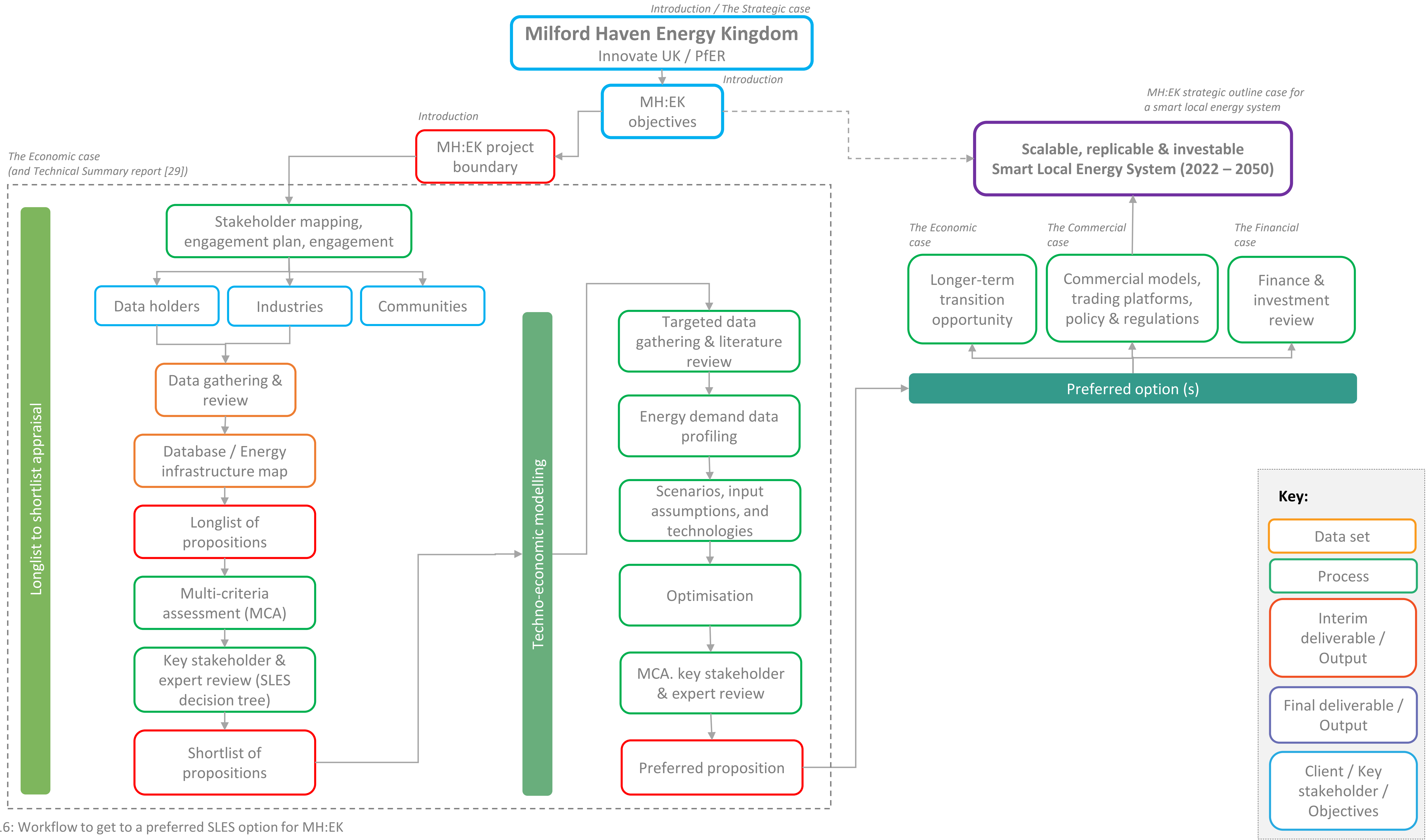

Figure 16: Workflow to get to a preferred SLES option for MH:EK

Data gathering and review

Data gathering and review

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 gathered demand data for key energy demand centres and buildings 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 *[13]* 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.

The Milford Haven energy network infrastructure

We engaged with WPD to gather data on the substations and their capacities within the project boundary. The Milford Haven area is in an active network management (ANM) zone which implies 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", however 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 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.

To build up a better understanding of the longer-term plans for 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 the South Wales Industrial Cluster (SWIC).

Any SLES identified through this project should be able to perform well when placed in the external context of a range of future energy system environments with an uncertain energy mix and energy supply. We reviewed several industry studies, the various driving factors and possible pathways to inform the scenarios taken for analysis in this study.

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 geographic information system (GIS) based geospatial map enables users to view the existing energy supply and demand assets, alongside additional asset information. We used the tool to identify constraints and opportunities for future potential energy generation and 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 is a key step in the development of SLES opportunities that can be replicated and scaled.

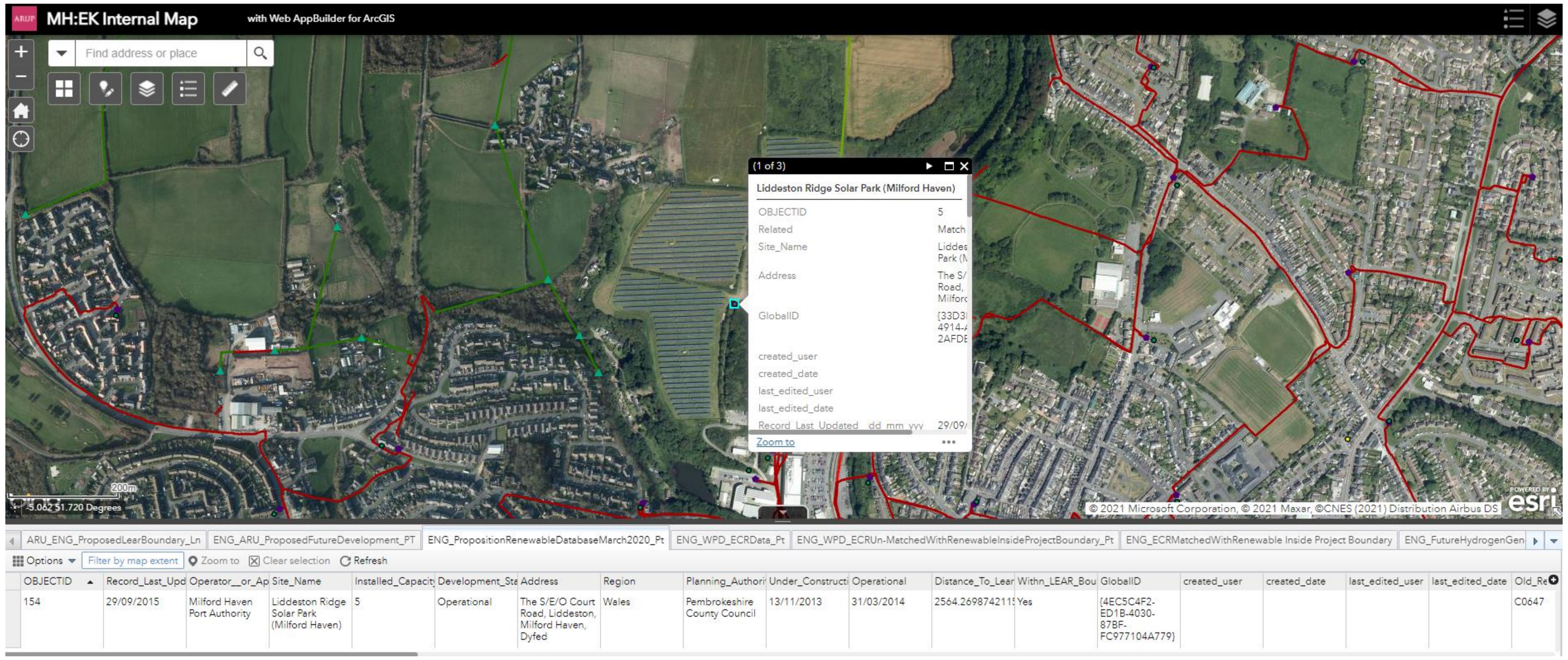

Figure 17: Extract of the energy infrastructure map for energy asset and network mapping with energy asset metadata information that is accessible through a 'pop-up' or full attribute table at the bottom by clicking on the asset icon.

Longlist of propositions

To identify a longlist of opportunities for a SLES, we adopted a bottom-up approach of identifying a longlist of opportunities for SLESs within Milford Haven, Pembroke and Pembroke Dock using the database and infrastructure map. To define the success criteria that will enable the identification of a longlist of opportunities for a SLES, we used a 2-step approach:

1. What makes a successful SLES?

We 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?

2. Critical success factors

The critical success factors (CSFs) are used to assess the longlist of propositions against the project objectives and enable the shortlisting process using a strategic approach and are grouped in three main categories as shown in Table 3.

CSF categories	Criteria	Objective	Criteria icon
Key objectives	Carbon emissions, Catalyst, Jobs & Prosperity Social value, Stakeholder acceptability, Community awareness raising	Directly address the MH:EK objectives and the benefits of developing SLESs	
Other CSFs	Need, Energy resilience, Technical viability, Commercial viability, Investor interest, Development risks, Policy and Regulatory risks	To ensure the solution contributes to energy security & resilience, is technically, economically and commercially viable and addresses other development risks	
Wider benefits	WFGA goals and ways of working, circular economy, education	To ensure contribution to wider regional and global sustainability goals.	

Table 3: Summary of the critical success factors of MH:EK

Using the energy database and map we identified critical or central assets that are either demand or supply assets that have a stronger opportunity to be part of a SLES. We clustered a broader mix of assets around the central or critical asset considering feasible geographical links to form propositions that are broadly in line with the CSFs and SLES key success criteria.

We undertook a high-level demand and supply assessment using the gathered data to determine the overall scale of the proposition and carried out a qualitative 'triage' of the longlist against the CSFs using a RAG assessment to further consolidate the longlist.

After stakeholder review, we established a longlist of 16 propositions that are in line with the CSFs and SLES success criteria. These were identified geographically across the project boundary as well a temporally from short-, mid-, and longer-term time horizon propositions.

The full longlist is shown in Figure 18 and a summary of each proposition is provided on proposition summary cards in appendix C of The Technical Summary report [29]

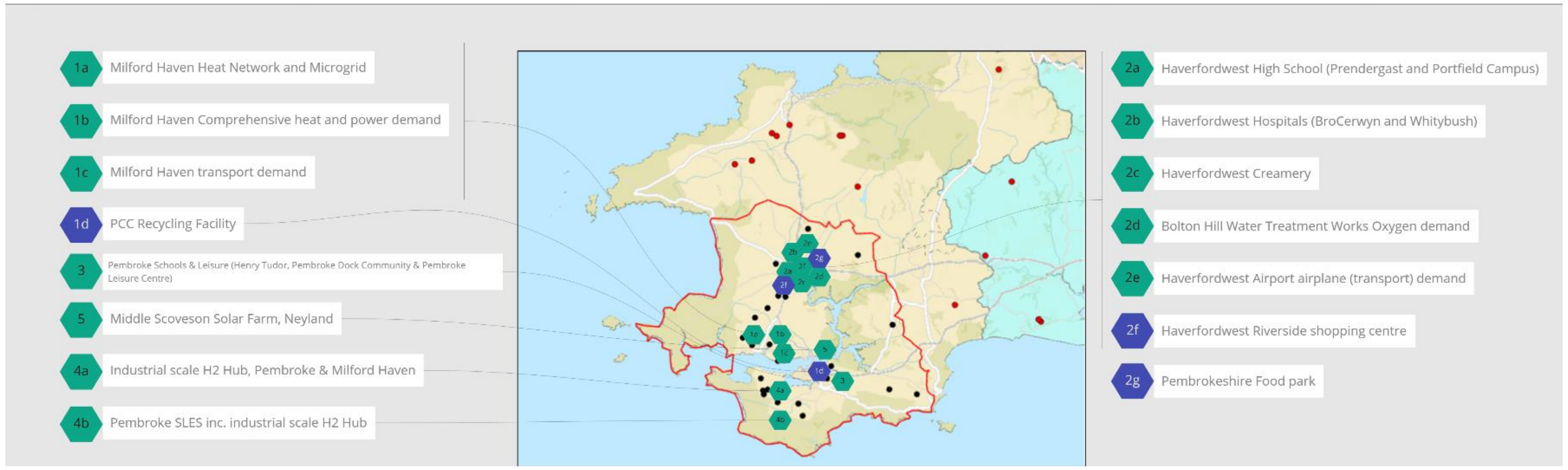

Figure 18: Overview of the longlist proposition within the MH:EK project boundary

The longlist to shortlist appraisal

The shortlist of propositions

To evaluate the longlist of propositions against the project CSFs in a consistent manner, we adopted a multi-criteria assessment (MCA) 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 was 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

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. The 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 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 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 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. The absolute key requirements that the propositions must satisfy prior to being shortlisted, were as follows:

1. Need: Societal / National Contribution towards net zero; System Level Need and 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.

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

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.*(the longer-term pathways)*

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

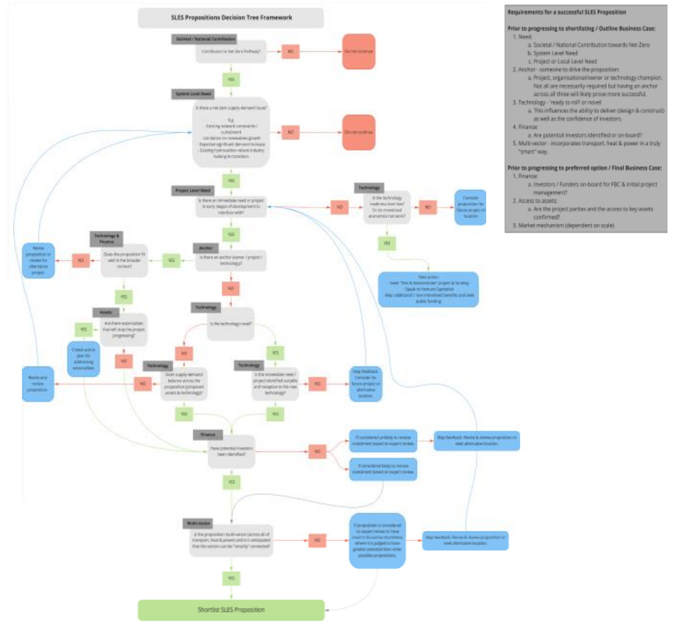

Figure 19: SLES decision tree

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

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 replicable in context and form, and present significant future scaling opportunity. The three shortlisted propositions are summarised in more detail overleaf.

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.

The shortlist of propositions

Figure 20: Map overview of the Milford Haven Marina and Liddeston Ridge site and the proposition boundary.

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 *[14]* making it a strong short term stepping-stone opportunity for a SLES.

Proposition 1 was at a more advanced stage of development when being considered in the longlist; and due to additional funding available, modelling has been undertaken to a greater level of detail compared to propositions 2 and 3.

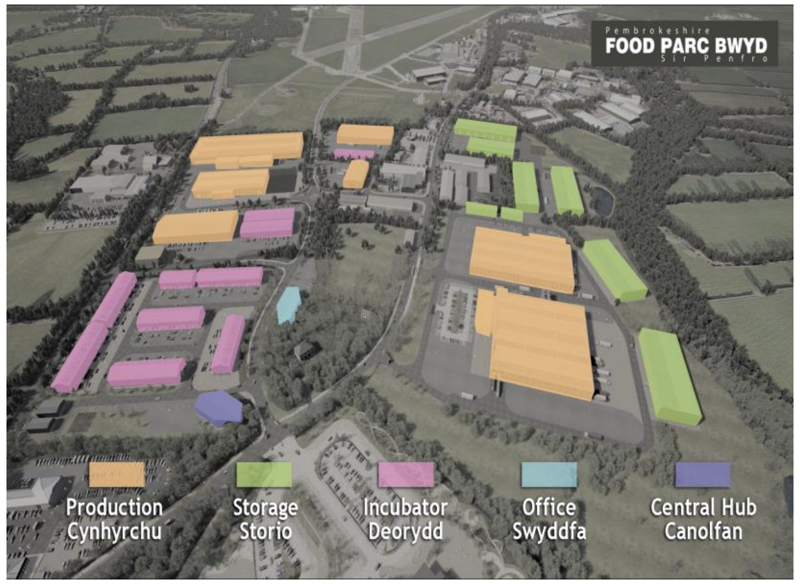

Figure 21: Visualisation of the proposed Pembrokeshire food park (©hacerdevelopments.com)

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. *[15]*

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.

Figure 22: Pembroke Ysgol Harri Tudor School (© ysgolharritudur.cymru)

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.

Techno-economic appraisal

Introduction

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.

We used a targeted approach to gather data specific to each proposition. Where gaps were identified in the gathered project data, we used industry datasets and benchmarks, supported by a series of modelling assumptions.

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

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)

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.

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 23.

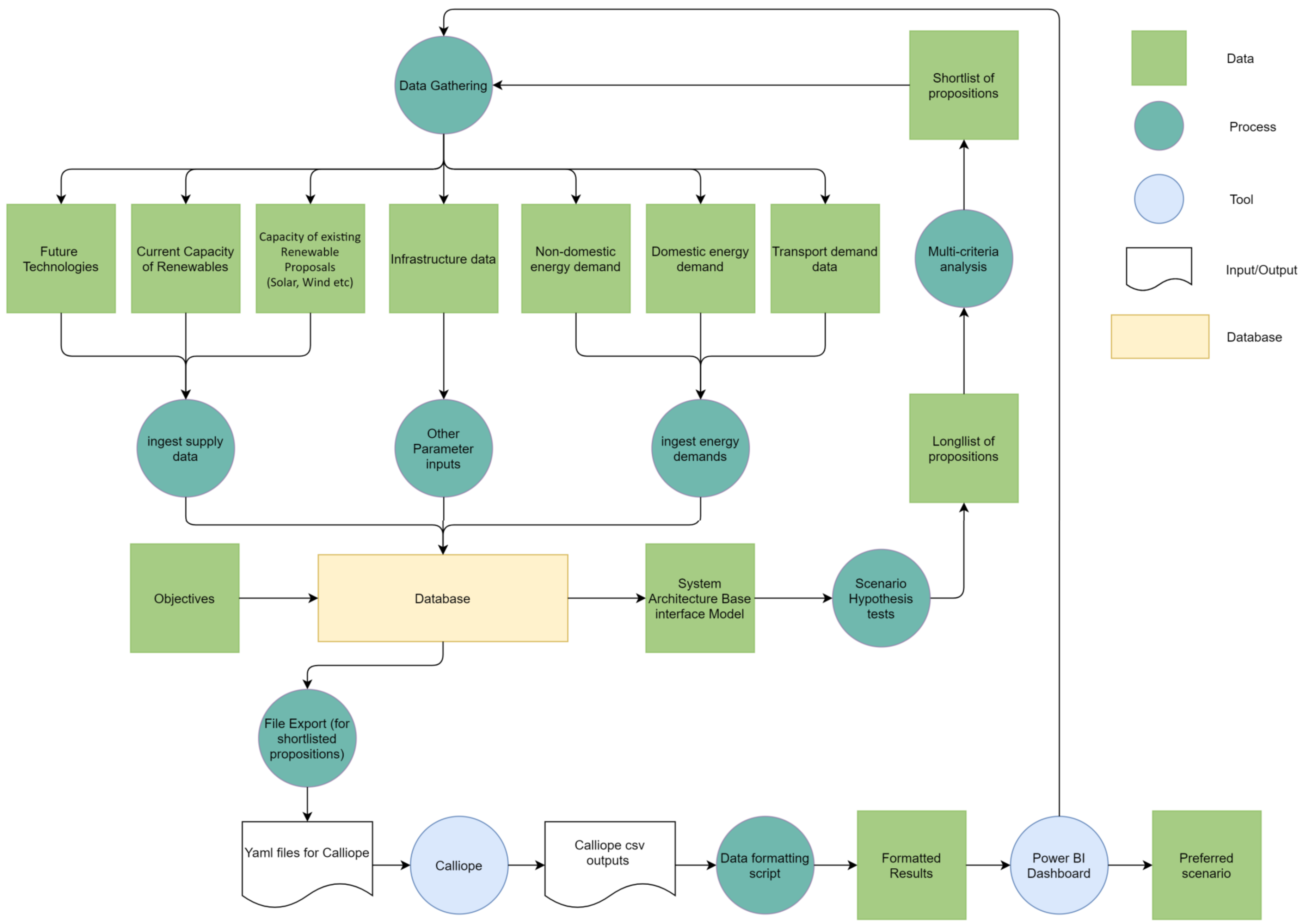

Figure 23: Workflow diagram for the techno-economic modelling process

Techno-economic modelling

The scenarios & world- views

The 'world views' or scenarios form the frame of the modelling and are consistent across all the propositions. Based on our review of industry publications including the National Grid Future Energy Scenarios 2020 (FES) *[2]* and the Regen Net Zero South Wales 2050 *[5]* studies, we selected three **decentralised** 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:

- **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 and existing electric vans were are electric while other vans, buses and HGVs were assumed to be 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.

Demand data

To collect demand data for propositions and to profile the energy demand, we used metered data as a priority and used benchmarks when metered data was not available. The resulting hourly demand profiles for heat, power (electricity and cooling) and transport were used as direct inputs to the optimisation process.

Transport frequency and mileage data from PoMH and PCC for all their car, van, bus and heavy goods vehicle fleet was used to calculate the transport energy demand per hour. This was met by different proportions of electricity or hydrogen based on the scenario. This load formed **the core transport load** that was used as part of the transport demand for the propositions

For **Proposition 1 - the Milford Haven Marina SLES,** metered data provided from PoMH was used to derive monthly and daily profiles supplemented by benchmarked data where unavailable or to estimate the loads for planned developments. Due to unavailability of metered data and the high percentage of proposed buildings within the proposition. The core transport load was doubled to account for public use of charging / refuelling infrastructure as advised by PoMH. Supply side data was also provided by PoMH, including curtailment plans for the Liddeston Ridge assets and the renewable potential from the area considered to be available for future development was estimated based on previous feasibility studies for a range of renewable technologies and land ownership maps.

Demand data for heating, cooling and electricity loads for **Proposition 2 – the Pembrokeshire Food Park SLES** was benchmarked from site layout plans for the proposed food park. In addition to the core transport load, we assumed demands from the food park, the proposed Haverfordwest parking facilities, and the First Milk Ltd Haverfordwest creamery.

The supply data consisted of the rooftop PV supply estimated using the roof area from the site plans and the planned capacity for ground PV at the Haverfordwest airfield.

For **Propositon 3 - the Pembroke Schools, Leisure Centre and Dock SLES,** metered data provided from PCC was used to derive monthly and daily profiles. Transport demand included both the core transport load along with the energy demand for surface transport at Pembroke Dock as provided by PoMH. Supply capacities of existing local renewable was taken from the BEIS Renewable Energy Planning Database *[13] and* adjacent empty spaces were considered as potential sites for additional solar PV.

We conducted research to understand the miles to energy consumption relationship for each vehicle type for both electric and hydrogen vehicles. We used the real time data gathered from the Riversimple Rasa vehicles demonstration to validate the assumptions for hydrogen car efficiency in miles per kilogram.

Our assumptions for the scenarios are set out as follows:

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

Techno-economic modelling (continued)

Technology 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 and considered if the deployment of the technology would be consistent with Pembrokeshire County Council's goal of net zero by 2030 *[1]*.

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 and discounted the technologies with low resource availability.
We used the scenarios definition and assumptions to undertake a further screening of the technologies resulting in a shortlist of technologies to be modelled.

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.

Cost assumptions

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

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. More details on the cost assumptions are provided in the Technical Summary Report *[29]*.

Fuel costs / prices

A similar hierarchical approach to estimating building energy consumption was applied to derive the fuel costs – real cost data where available was applied and otherwise we used industry standard benchmarked figures from parties such as BEIS. We calculated forecast energy prices using an Energy market simulation tool. 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. More details on the fuel costs and prices assumed and sources are provided in the Technical Summary Report *[29]*.

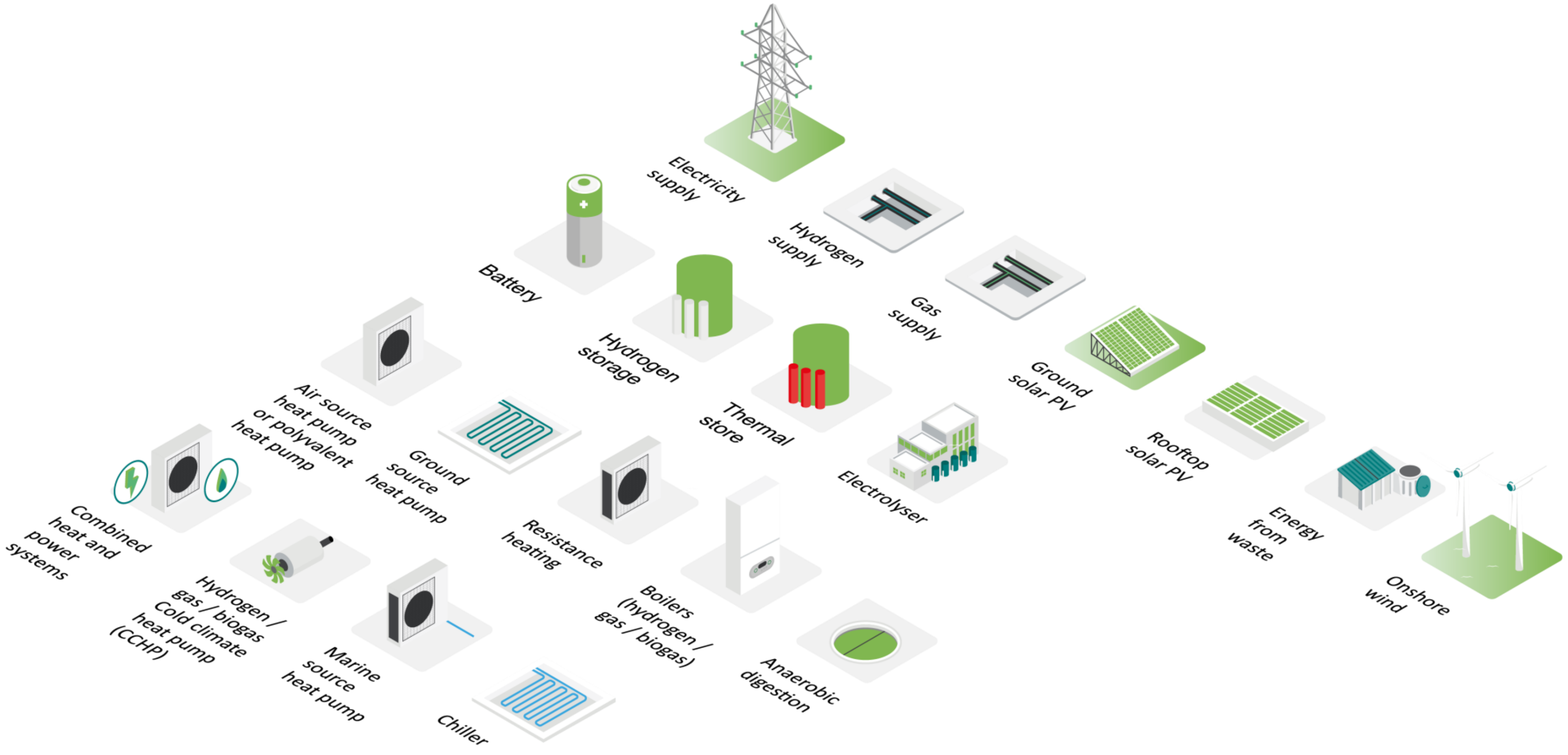

Figure 24: Technology options modelled

Modelling outcomes

Summary of the propositions optimised outcomes

Table 4 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. This is because 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 4 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 – Milford Haven 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 4: 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.

Figures 25, 26, and 27 show a schematic view of the preferred system for each proposition. The core recommended technologies have been highlighted in light green and the supporting or situationally beneficial technologies to watch have been highlighted in grey. Similarly, the preferred distribution option is highlighted in light green and other options in grey.

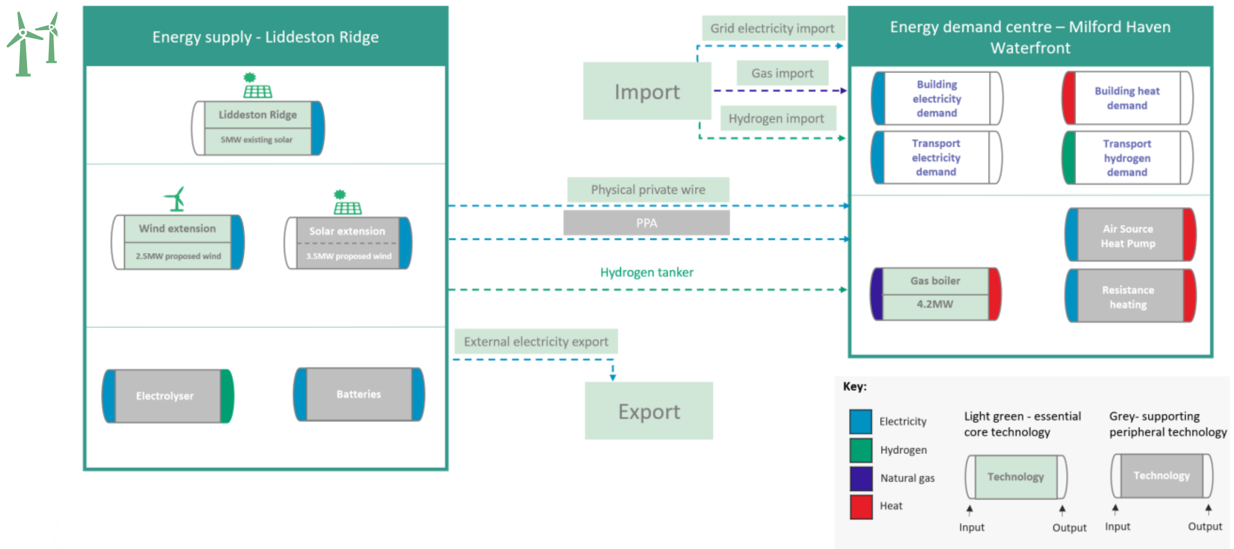

Figure 25: Preferred system for Proposition 1 – Milford Haven Marina SLES

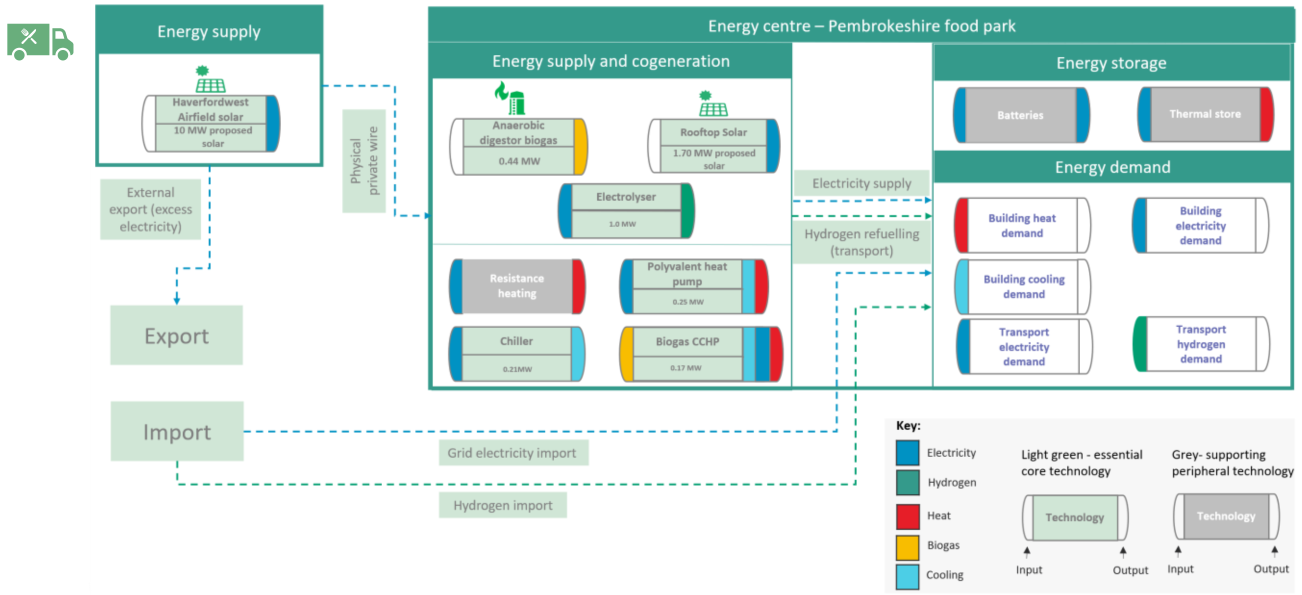

Figure 26: Preferred system for Proposition 2 – Pembrokeshire Food park SLES

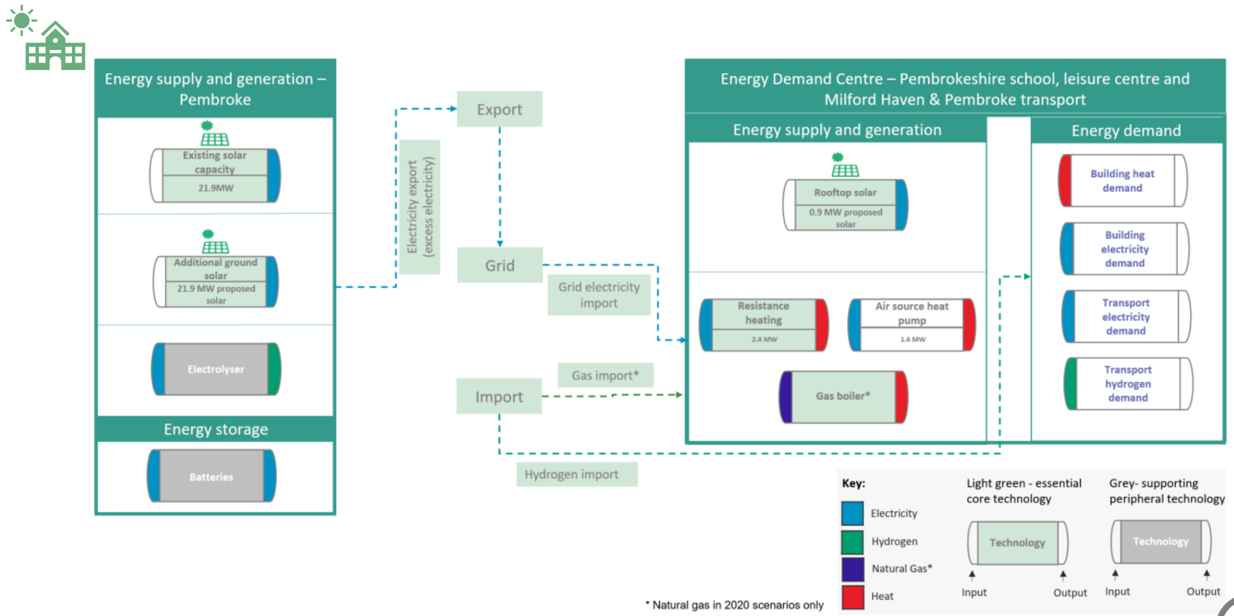

Figure 27: Preferred system for Proposition 3 - Pembroke Schools, Leisure Centre and Dock SLES

Techno-economic conclusions

Sensitivity analysis

Sensitivity analyses were conducted to better understand the impact of key uncertainties in the future energy market as outlined below.

- *The impact of hydrogen import prices*
  This sensitivity suggests current hydrogen prices of 0.135 to 0.18 £/kWh (£4.5 to £6/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*
  With no natural gas supply, heat was largely electrified with air-source heat pumps with a small amount from hydrogen boilers. Electrolysis and electricity exports were decreased with renewable electricity for heat being prioritised. This led to very large decreases in carbon emissions, but an inevitable increase in cost. This suggests that electrification of heat is preferable to hydrogen boilers if gas was removed from the system and for any new buildings, air-source heat pumps are likely to be cost competitive.
- *Lower electricity price, higher gas price*
  In this sensitivity, the system started to switch over to electrification of heating via air-source heat pumps resulting in lower national grid exports and higher national grid imports. This result suggests a prioritisation of meeting the heating demand with the local renewable generation rather than only the electrical demand.
- *Lower battery prices*
  With lower battery capital costs, batteries were selected in every scenario but with varying capacities. Higher capacity batteries resulted in less national grid electricity import and exp[ort and instead promoted self-consumption. These changes produced a very marginal decrease in annualised costs and carbon emissions.

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.

Techno-economic conclusions: short-term actions on the roadmap to net zero by 2050

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 modelled, the resulting optimum 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 (using heat pumps) and EV transport.
2. If excess electricity is generated beyond the power and heat demand baseload, this is used to support local electrolysis and green hydrogen production, where there is a local hydrogen transport demand, 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 regional or 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.

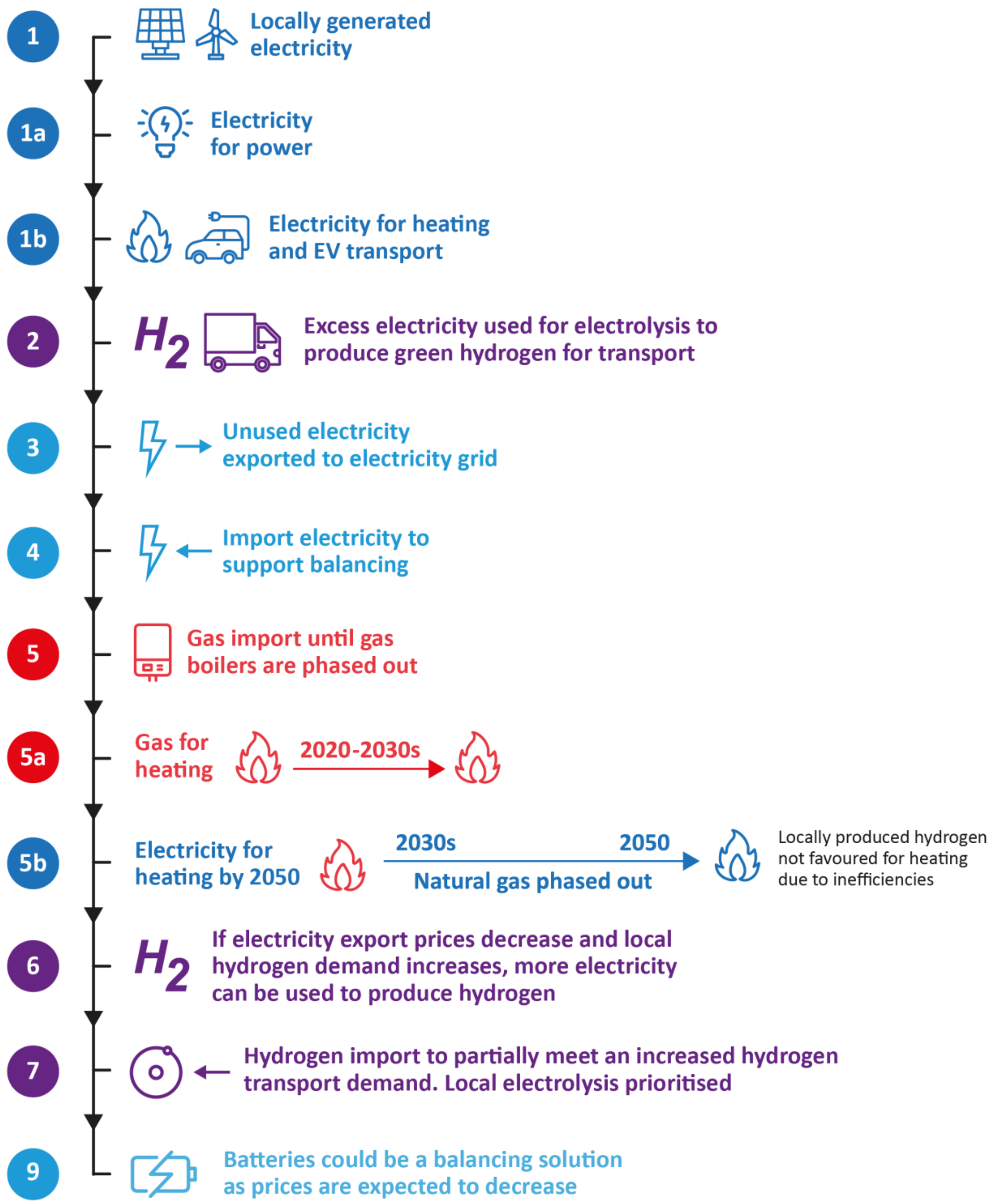

Figure 28: Hierarchy of energy supply-demand relationship based on a 2020 world view and short-term actions to support reaching net zero by 2050

Techno-economic conclusions

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.

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, refer to the *longer-term energy pathways review* for more details of the existing use of hydrogen for industrial processes and transport. 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. *(longer-term energy pathways)*

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.

Qualitative Benefits Appraisal

The techno-economic appraisal methodology is solely based on monetised benefits such as the monetary value of carbon emission savings or revenue from adopting the SLES approach with low carbon technologies. There are other non-monetised benefits that do not form part of the modelling but could have a significant impact on the decision-making process for SLESs. This a gap that is starting to be addressed through other studies and considered within the broader PfER programme. In addition to the quantitative output and modelling conclusions, we revisited how the propositions align with the project objectives and critical success factors, focusing on the wider non-monetised benefits and established an updated MCA score.

	Proposition 1 – Milford Haven Marina SLES	Proposition 2 - Pembrokeshire Food Park SLES	Proposition 3 - Pembroke Schools, Leisure Centre and Dock SLES
Non-monetised Benefits / MCA score	**3.44**	**3.89**	**2.08**
Are the SLESs multi-vector, scalable and replicable; are they stepping-stone projects that contribute to the economy, society and environment?	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. Although it 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. This proposition promotes the generation of renewable energy for use within the system and therefore is least reliant on national grid and hydrogen imports. There is a potential to sell energy to the end user at a lower retail price, thus promoting better energy security and price resilience. 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.	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 There is a significant scaling opportunity around the proposed new development with its proximity to other light industrial sites 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. The proposition 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. This proposition presents a strong opportunity for electrolysis should the hydrogen price be more favourable which will promote energy security and less reliance on the grid.	Proposition 3 is not considered to be a suitable SLES. 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. Proposition 3 was shortlisted on the basis of identifying interconnected demand that then was not realised during more detailed assessment. 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. This proposition has highlighted the fact that’s SLESs and heat networks are not always going to be the answer to transitioning the energy sector to net zero.
How do the SLESs contribute to community awareness raising / education?	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 Liddeston Ridge.	The food park project have energy resilience and sustainable production and use as part of their agenda. There is a 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 for example through a visitor centre.	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.
How do the SLESs contribute to the local economy, jobs and prosperity and promote social value?	The proposition will involve construction, operation and maintenance of new technologies but it doesn't stimulate significant growth. With a lesser opportunity for scaling up, the proposition has a smaller power to create jobs for the community. This proposition still 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 or the use of ULEV or hydrogen vehicles to public vehicles.	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. With a larger opportunity for replication and scaling up for example, the potential formation of a low-emission transport hub for HGVs and broader transport demand. the proposition has the potential to create more jobs and opportunities to upskill for the community and to demonstrate the application of SLESs to food production and other light industrial activities.	This proposition doesn't form a SLES and therefore this system currently doesn't have any scope for replication and scaling. It promotes export of locally generated energy which does not directly benefit the local community and economy and presents no significant opportunity for job creation and upskilling.
How do the SLESs contribute to wider regional and global sustainability goals	This proposition promotes a decentralised energy system with cost savings to PoMH/tenants and greater energy security. Opportunity to replicate to other organisations and potentially residential with associated benefits of long term investment. There would be less waste overall from building retrofits.	The food park development has a strong focus on energy resilience and sustainable food production. Additionally, the SLES proposition promoted the use of renewable energy and circular economy principles are applied through the production of energy from waste.	This proposition doesn’t promote integration of demand assets into a SLES, and therefore doesn’t adequately contribute to sustainable development goals.

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.

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. The analysis, recommendations and next steps are further detailed in the Milford Haven Heat Network: Phase 2 report *[36]*

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.

Longer-term energy pathways

Introduction

In the previous section, we presented three short-term propositions that could act as stepping-stones to a larger Pembrokeshire SLES. Two of the propositions are recommended to be further developed as SLESs:

Proposition 1 - The Milford Haven Marina SLES and

Proposition 2 - The Pembrokeshire Food Park SLES

This section aims to explore how the short-term propositions can be integrated with other local and regional plans including renewable energy generation developments; future energy demands and future network infrastructure plans to form a net zero Pembrokeshire SLES by 2050. Three energy pathways for Pembrokeshire have been framed around the following scenarios: High Electric, Green Hydrogen and Blue Hydrogen. The pathways are heavily underpinned by the development status of the future plans referenced and assumptions made. The pathways are not ultimate roadmaps for decarbonising the Pembrokeshire energy system but represent areas of further research, investigation and collaboration to enable an adaptive roadmap out to 2050.

The journey to decarbonisation of the UK energy system by 2050 is uncertain. The National Grid Future Energy Scenarios *[2]* set the framework or scenarios under which the UK energy system could achieve net zero by 2050 - with differing level of societal, sector level and policy changes required. Three of the four FES 2021 modelled scenarios meet the net zero target, however immediate action for deployment of new technologies at scale; demand flexibility; trading flexibility; digitalisation and whole energy systems approach is required.

By applying this UK wide view to a local context, the MH:EK project aims to develop a conceptual proposal for what a 2050 decarbonised Milford Haven energy system could look like and provide a road map for short- to mid-term steps to reach net zero by 2050.

Summary of future plans and developments

Regional Plans

- South Wales ZERO 2050 *[9]*

The Zero 2050 study considers how net zero greenhouse gas emissions for the whole energy system in South Wales can be achieved. Pembrokeshire was one of the 14 local authorities in South Wales covered by the project with Milford Haven featuring as a major energy use location in South Wales.

The study identifies low regret options that would accelerate the transition to net zero by 2050 including:

- increasing the capacity of onshore wind and solar;
- piloting hydrogen production from both autothermal reformation and electrolysis;
- undertaking network studies to understand feasibility and cost of transitioning networks to hydrogen; and
- investigating options for CCUS and CO_2 export from South Wales (which are of particular relevance to MH:EK).

The study recognises the uncertainties around the route to decarbonisation and recommends to take an adaptive pathway approach by monitoring tipping points that will enable future decision making.

- Regen Net Zero South Wales *[5]*

The Regen Net Zero South Wales project undertook an integrated net zero Distribution Future Energy Scenarios (DFES) analysis in South Wales. Regen along with Wales and West Utilities (WWU) and Western Power Distribution (WPD) explored three scenario pathways for the gas and electricity networks to 2050 to explore what the future could look like in the region and develop a methodology that can be used for future integrated DFES analysis. The DFES approach created bottom-up, stakeholder led, locally relevant decarbonisation pathways for licence areas and regions. The DFES data produced was then used by the distribution networks to plan how the network might need to evolve and where and when network investment or flexibility solutions might be needed.

Three net zero scenario pathways: High Electrification, Core Hydrogen and High Hydrogen were used in this study. These were guided by the FES 2019 data which was the latest available version at the time and early information on FES 2020 structure from National Grid.

The High Electrification, scenario was similar to the FES 2020 Consumer Transformation scenario assuming heat is electrified, and hydrogen is limited to industrial clusters. Renewable electricity generation is maximised with a small amount used for electrolysis.

The Core Hydrogen scenario was similar to the FES 2019 Net Zero sensitivity analysis case which assumes hydrogen for heating is provided by hydrogen boilers and hybrid systems supplemented by bio-methane gas networks. Renewable electricity generation is maximised with a higher proportion used for electrolysis.

The High Hydrogen scenario was similar to the FES 2020 System Transformation scenario which is similar to Core Hydrogen but assumes the majority of the gas network is converted to low-cost hydrogen, delivered predominantly by hydrogen boilers with off-gas customers using electrified heat.

The recommendations from the study are particularly relevant to how to integrate DFES (local & regional distribution pathways) to National Grid FES. The study recommends that a scenario approach is critical to delivering a cross-vector DFES which allows the gas and electricity networks to agree on a set of possible futures. The National grid FES play a key role in setting credible envelopes for the future energy system and provides a consistent framework for regional application which has been emphasised by the production of a combined DFES.

Longer-term energy pathways

- The Future role of gas in transport *[10]*

This study was undertaken by a steering group comprising the UK and Ireland gas network operators to understand the transition from the GB economy today to a decarbonised economy in 2050. The study focusses on the transport vector and most specifically trucks as an early adopter of green gases. The role of blue and green hydrogen as fuels of the future were explored and the study concluded that hydrogen powered trucks represent a substantial opportunity for green gases to accelerate transport decarbonisation.

Pembrokeshire is categorised as a 'Phase 1' region: a region that is well located for large-scale hydrogen production; either that they are close to significant offshore wind generation potential that could be used for green hydrogen production, or that they are close to existing natural gas import terminals and oil and gas fields that could be converted for carbon storage suggesting good sites for blue hydrogen production.

Industrial users of hydrogen can provide an anchor load for blue hydrogen production. Hydrogen production could become available at scale in these industrial clusters which will lead to a step change in the volumes available and prices, helping to drive adoption.

- South Wales Industrial Cluster (SWIC)

SWIC is a partnership between Welsh Industry, energy suppliers, infrastructure providers, academia, legal sector, service providers and public sector organisations, working to map what is needed to support South Wales in becoming a net zero carbon region by 2040. The project is jointly funded by the project partners and UKRI. The project entered its deployment phase in February 2021 and over a period of 26 months aims to create pathways and opportunities to promote Wales as a leading global player in decarbonised industrial and economic growth, with a goal of net zero carbon by 2040.

The project brings together various industries such as energy, oil refining, paper, nickel, chemicals, LNG import, steel and cement to research, investigate and develop solutions and a plan to decarbonise the industrial sector in South Wales. Topics or options being investigated include the development of the circular economy, resource and energy efficiency, blue hydrogen production, Carbon Capture and Utilisation, Carbon Capture and Storage, carbon dioxide transportation and shipping, and mass green hydrogen production.

The MH:EK project has engaged with the SWIC team to form an understanding of their project objectives and plans which fed into the MH:EK longer-term pathways.

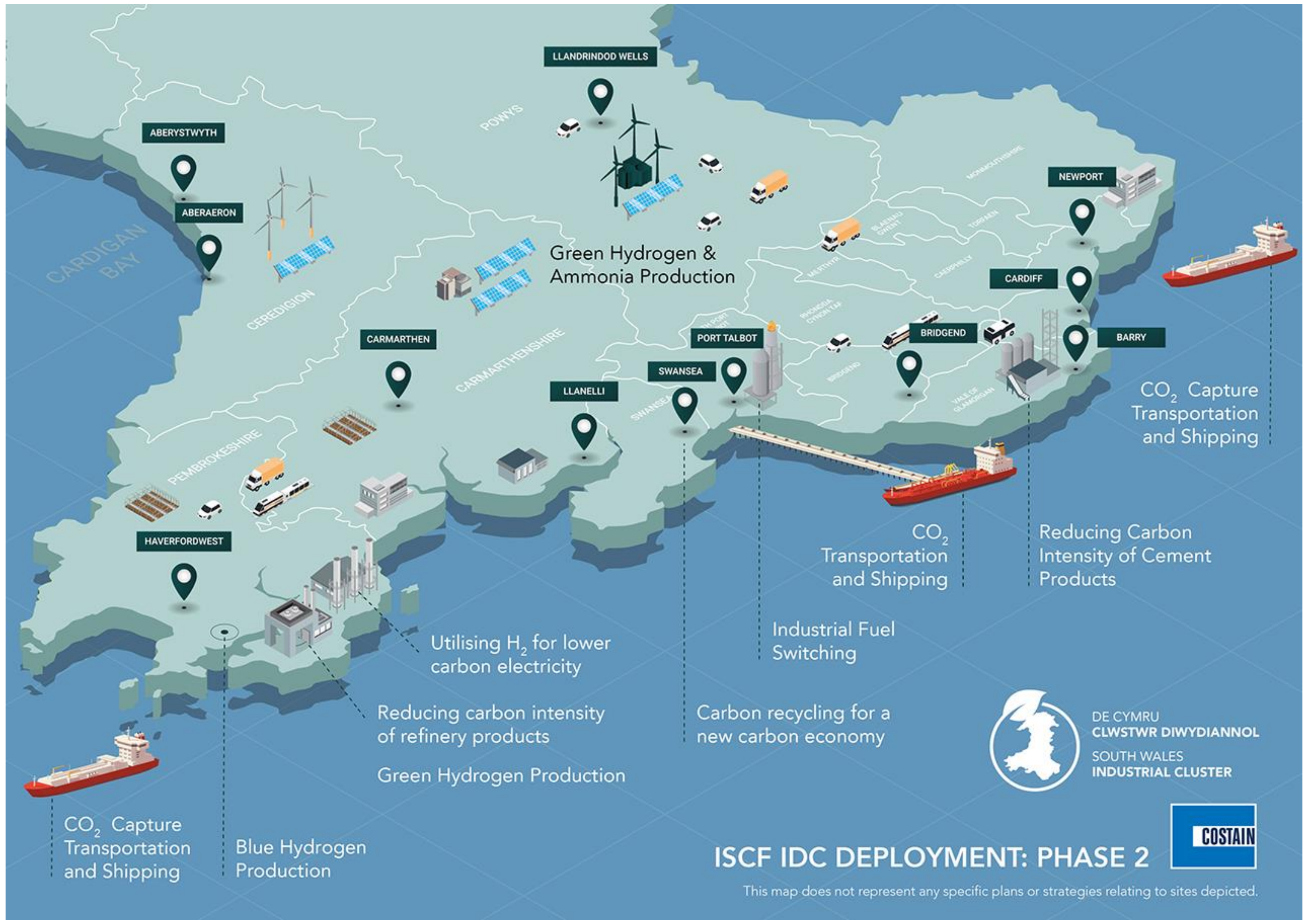

Figure 29: SWIC net zero graphic *(©costain.com)*

Longer-term energy pathways

- RWE Pembrokeshire Net Zero Centre (PNZC) *[11]*

RWE is a key industrial player on the Haven waterway, owning and operating the Pembroke natural gas-fired power station. To transition to carbon neutrality, RWE is looking at wide-scale investment in decarbonisation technologies which includes transforming the Pembroke power station to the Pembrokeshire Net Zero Centre (PNZC) – a decarbonisation hub linking innovative low carbon technologies such as hydrogen production, CCUS and floating offshore wind.

Feasibility studies for the decarbonisation of the Pembroke power station with CCS and hydrogen production have commenced and RWE have now started FEED (Front End Engineering Design) study for a green hydrogen production project using a 100-110 MW electrolyser. RWE has plans to scale hydrogen production to the Gigawatt (GW) scale in the longer term and develop floating offshore wind farms in the Celtic sea.

RWE sees the PNZC as an enabler to unlock the route to net zero in South Wales and is working with the MH:EK project and the SWIC projects to further understand decarbonisation plans and ensure projects and plans are aligned

The construction of a 100-110MW electrolyser at the Pembroke power station site is assumed to be completed by 2025 and scaled up to the GW scale by 2030.

By 2040, the Pembroke Power station is assumed to be fully decarbonised, alongside RWE deploying GW scale floating wind and establishing large-scale hydrogen production.

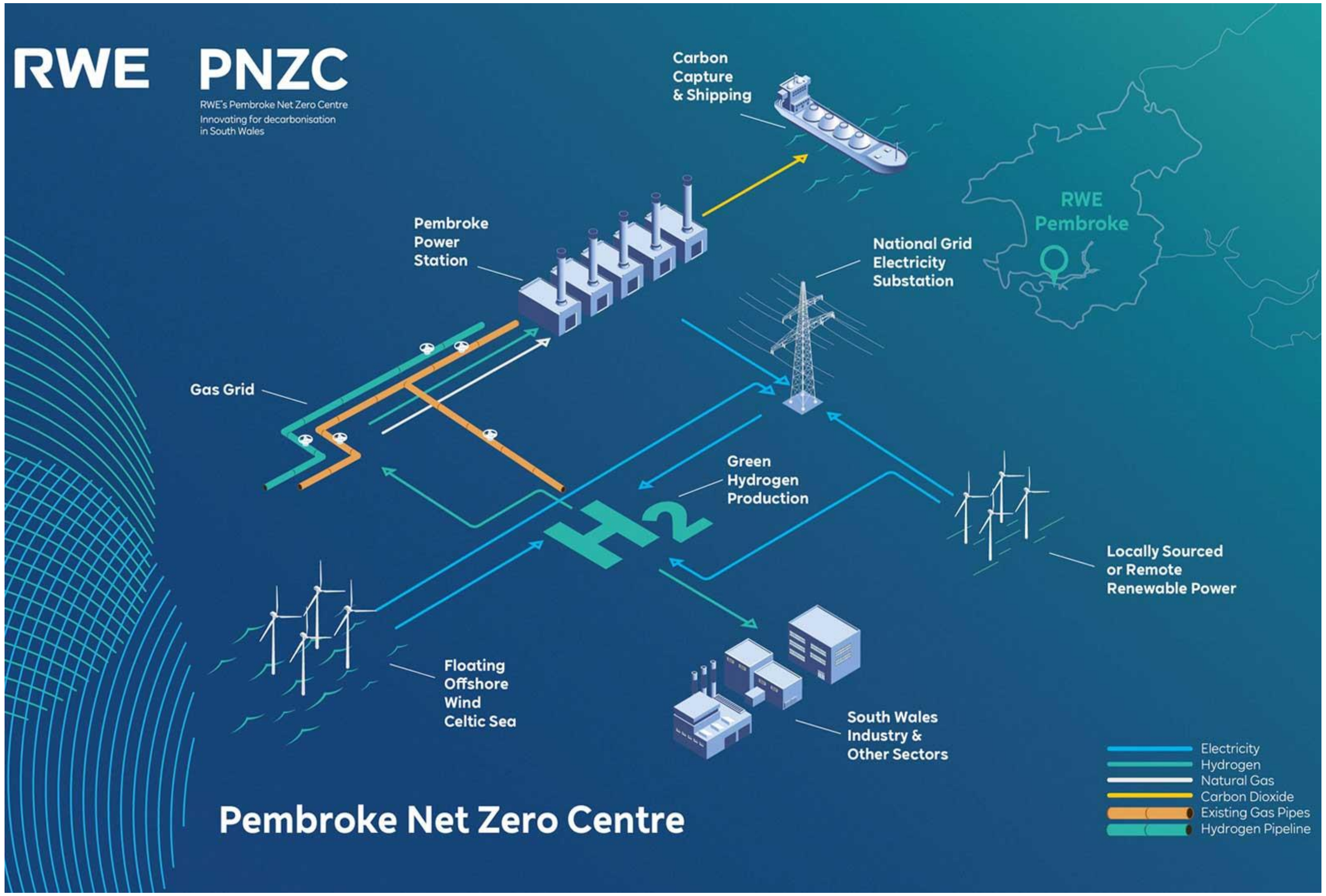

Figure 30: RWE PNZC vision (©rwe.com)

Longer-term energy pathways

- Offshore wind renewable generation – Celtic sea cluster

The Celtic sea represents a strong opportunity for floating wind farms to accelerate the UK Government target of reaching 1GW of floating offshore wind by 2030. The Crown Estate (TCE) have supported multiple demonstrator & test scale projects of up to 400MW including the following projects:

  - 96MW Erebus wind farm to be developed by Blue Gem Wind, planned for 2026-2027 *[16]*
  - The Llŷr 1 and Llŷr 2 projects, two separate 100MW sites to be developed by Floventis Energy and planned for 2025-2026 *[17]*
  - 100MW White cross project, to be developed by Floatation Energy, planned for 2026-2027 *[18]*

TCE have announced an upcoming leasing round to unlock up to 4GW of floating offshore wind capacity. The leasing application round is planned for mid-2023, with agreements for leases awarded by end of 2023 to support development of full-commercial scale projects from 2030 into the next decade. [19] The Celtic Sea floating wind opportunity has the potential to create 3,000 jobs and £682m in supply chain opportunities for Wales and Cornwall by 2030 and will be a strong contributor to achieving the UK Government's commitment to reach 40 GW of operational offshore wind by 2030.

- Blue Gem Wind

Blue Gem Wind is a partnership between Simply Blue Energy and TotalEnergies to develop floating wind projects in the Celtic Sea. Their 'Erebus' 96MW project is currently the only project with an agreed Crown Estate lease. Blue Gem Wind will initially focus on the Erebus demonstration project which is 45 km offshore. Delivering the Celtic Sea's first offshore floating wind project will provide green energy to 90,000 homes per year and will utilise Principle Power's Windfloat technology as the foundation. Blue Gem Wind also plan the development of the commercial scale 300MW Valorous project, which will be sited 50km off the south-west coast of Pembrokeshire by 2029 [16]

DP Energy and EDF Renewables are scoping floating offshore wind and Green H2 opportunities in Pembrokeshire and the Celtic Sea. DP Energy is using its 30-year project development expertise across wind, solar and ocean energy worldwide and have partnered with EDF to deliver up to 1 GW floating wind farm in the Celtic Sea.

Other projects announcing planned installation dates by 2030 include SimplyBlue / Shell project Emerald and other developers, like RWE, looking to develop large scale floating offshore wind sites by 2040.

- ERM Dolphyn project

The ERM Dolphyn project is a planned 100-300MW commercial project for a hydrogen wind farm in the Celtic sea using the ERM Dolphyn technology.

The ERM technology comprises of an offshore electrolyser sited on a floating offshore wind substructure, producing green hydrogen from generated electricity and desalinated sea water. The deployment phase is set to have a 2MW prototype facility by 2024 followed by 10MW full scale pre-commercial project by 2027.

The Celtic sea 100-300MW project plans to have a single hydrogen pipeline to Pembroke / Milford Haven, where there are options to supply green hydrogen at scale for industrial use to industries around the Haven waterway, for port marine operations, storage or to other future hydrogen off-takers. The project is planned to be in operation by 2030 with plans to expand to the GW scale by mid 2030s.

- Greenlink Interconnector *[12]*

The Greenlink Interconnector *[12]* is a proposed 500MW subsea and underground electricity interconnector cable that will provide a new grid connection between then EirGrid's Great Island substation in County Wexford, Ireland and the National Grid's Pembroke substation in Pembrokeshire in Wales. The interconnector will provide additional grid capacity and therefore deliver increased energy security, increased opportunities for low carbon renewable energy generation and regional investment. Greenlink is planned to be commissioned in 2023.

In the MH:EK context, the interconnector represents an opportunity for renewable electricity export should grid capacity or network improvement costs be a hindrance to large scale renewable energy production in the shorter term (up to 2030).

- Local vision and plans

It is PCC's and PoMH's vision for Pembrokeshire to be the green energy capital & green hydrogen hub of the UK, supported by Offshore Renewable Energy Catapult (OREC). The 'Future Haven Waterway Clean Energy Cluster Group' established to position Pembrokeshire as the UKs clean energy and hydrogen hub. Representation includes but is not limited to: PoMH, PCC, Stephen Crabb MP, Blue Gem Wind, Industry Wales, SWIC, Valero, South Hook LNG, OREC, RWE, Prosperity Energy, ERM, Marine Energy Wales, Cambrian Offshore, Dragon LNG.

In addition to the large-scale hydrogen production plans by SWIC and RWE, there are local plans to develop sites for large scale hydrogen production. The upcoming North Pembrokeshire hydrogen project part of the Haven Waterway Enterprise zone which will aim to help decarbonise the Pembrokeshire region, in particular transport applications has been considered. We assumed that it is to be developed to include a 50MW solar farm with battery storage and 15 MW electrolysed green hydrogen production for road and rail transport by 2025.

The MH:EK longer-term energy pathways

The MH:EK pathways set three distinct scenarios that represent a spectrum of possible future decarbonised energy systems. This study compares and takes into account the scenarios set out in FES 2020 *[2]* and the Regen Net Zero South Wales study *[5]*.

A longlist of scenarios was considered in this study, shown in Figure 31, with the scenarios taken forwards in this study:

1. High Electric
2. Balanced Electric: Green Hydrogen
3. Balanced Electric: Blue Hydrogen

It is anticipated that in future world views, the cost of electricity and hydrogen will continue to fall but hydrogen is unlikely to completely replace electricity across all energy vectors. On that basis, a high hydrogen pathway has not been further considered for MH:EK.

Figure 31 summarises assumptions around how the demand from each energy vector is met.

The following sections provide a qualitative assessment of a possible roadmap for each pathway, showing the actions and developments that could be integrated with wider policy context and direction of travel for the energy system decarbonisation.

The actions or developments are categorised under the following intervention areas:

- **Enabling actions**
- **SLES development**
- **Oncoming national infrastructure / asset**
- **Haven waterway industrial sites / SWIC**
- **RWE PZNC**
- **Local / regional energy or hydrogen generation**
- **Network infrastructure upgrades**
- **Flexible energy trading**

A high-level view of the current energy system in Milford Haven

The Haven waterway is home to some of the largest industries contributing to the current UK energy mix. The South Hook LNG and Dragon LNG terminals and the RWE Pembroke Power station are key contributors to the current UK energy system.

RWE's Pembroke Power Station is a 2200 MW Combined Cycle Gas Turbine (CCGT) power station which officially opened in 2012. Pembroke Power Station currently burns natural gas and is capable of meeting the electricity demands of 3.5 million homes via its five 440 MW CCGTs. The Pembroke Power Station is the UK's third largest single point emitter at 1% of total UK total carbon emissions (4.3 million tonnes CO_2 in 2019). Tata Steel in Port Talbot is the UK's highest single point emitter at 6.4 million tonnes CO_2 equivalent to 1.5% of the UK's total carbon emissions *[27]*

Valero's Pembroke refinery is one of Europe's largest and most complex refineries, with a total capacity of 270,000 barrels per day. The refinery is responsible for 10% of Wales GDP, works in a strong export market and supports many local jobs. Valero is one the UK's top 15 largest single point emitters at 0.5% of total UK emissions (2.2million tonnes CO_2 in 2019*) [27].* The Valero Pembroke refinery has an existing hydrogen demand which is currently being self-supplied by grey hydrogen production i.e steam methane reformation with carbon emissions. PoMH manage the fuel import and vessel operations at Pembroke Dock.

South Hook LNG terminal is an LNG regasification terminal near Milford Haven and is the largest LNG terminal in Europe. Together with the smaller Dragon LNG terminal it can handle up to 25% of the UK's gas requirement. During the Covid-19 pandemic and lockdown, these terminal supplied 80% of the UK gas. Construction of the LNG terminals unlocked access into the gas network via the extension of the national transmission system (NTS) into Pembrokeshire.

There are multiple solar farms within the project boundary including Liddeston Ridge (LR) 5MW solar farm owned by PoMH, who sell generated electricity to the grid. The electricy grid is active network managed by WPD.

Milford Haven, Pembroke and Haverfordwest towns include residential, commercial and light industrial assets where power demand is met by the grid, heating is predominantly provided by the gas network and transport is predominantly diesel/petrol-based vehicles with some electric vehicles. In terms of hydrogen fleet, there are currently circa 300 hydrogen vehicles in the UK.

A view of possible future energy scenarios

	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 and 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	Personal vehicles are EV, public are a mix of EV and hydrogen and freight vehicles are hydrogen fuelled	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 blue hydrogen via SMR with CCUS and industrial sites have a hydrogen demand	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
		The High Electric pathway		**The Green Hydrogen pathway**	**The Blue Hydrogen pathway**			
	"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 31: Analysis of possible future energy scenarios

The High Electric pathway

Timeline of events

Now to 2025:

By 2025, we have assumed the recommendations for Milford Haven Marina SLES are implemented and a SLES including expansion of Liddeston ridge with a wind turbine that supplies electricity directly to the Milford Haven demand centre through a private wire or PPA is formed. The heat demand continues to be met by gas until 2030 but new gas boilers are unavailable by 2025. Power and transport demand are met by renewable electricity from LR supported by National Grid imports.

Similarly, the recommendations from the Pembrokeshire food park SLES are implemented and another SLES at Haverfordwest including the airfield 10MW solar supplying electricity to the food park via a private wire. The power, heating and cooling demands as well as electric transport demands from the food park, the creamery and PCC fleet are met by renewable electricity from the SLES supported by National Grid imports.

The Greenlink 500MW interconnector is also installed and is assumed to act as a balancing asset for high voltage electricity import and export to Pembrokeshire.

Green hydrogen production at RWE PZNC and the North Pembrokeshire Hydrogen project will progress but are not considered as part of this pathway.

2025 to 2030:

By 2030, the Pembrokeshire Food Park SLES (proposition 2) is expanded to a larger EV transport hub and includes further commercial and light industrial demand centres.

The challenge around decarbonisation of residential heating will remain. Based on stakeholder engagement with WWU, it is assumed that natural gas for heating is phased out by 2040, with a potential for Milford Haven to be a demonstrator town which is off-gas by early 2030s. This is in line with the assumptions made in the propositions' techno-economic modelling. For off-gas consumers, the UK government / BEIS *[20]* plan to install 600,000 heat pumps per year by 2028 and on that basis, non-gas users will have heat pumps by 2030. By 2030, fossil fuel powered cars are no longer available, all new vehicles are EVs by 2030.

The power demand and electric vehicles transport demand is met by local renewable generation through PPAs and private wires.

Future onshore wind and solar renewables will come online. They could export to National Grid but there would likely be network constraints. Network upgrades as well as policy & regulatory updates would be required to support investment in renewable generation. Future renewable projects could form SLESs, replicated from Propositions 1 & 2 but learning from proposition 3 which did not meet the requirements of a SLES.

In terms of the larger industrial transition, we have assumed that the Dragon LNG, South Hook LNG and the Valero refinery industrial demand is met by renewable electricity through private wires and PPAs with local renewable generators and that the Puma site is used for large scale battery storage.

By 2030, we have assumed that the Celtic sea will have up to 400MW offshore wind capacity that is exported to the national grid. This assumes that electricity network upgrades are commissioned to align with the UK's target of 40GW of offshore wind by 2030. To alleviate network constraints, we have also assumed that demonstrator style trading platforms are in operation to help peer-to-peer trading of electricity. Provided the electricity can be transmitted at an appropriate voltage, part of the electricity generated can also be locally stored in batteries at the Puma site for local use.

We have assumed that RWE PZNC green hydrogen production will scale up to GWs and ERM Dolphyn green hydrogen production project will progress, but they do not form part of this pathway.

2030 to 2040:

By 2040, we have assumed that the MH:EK SLESs have expanded even further and more SLESs are formed.

We have assumed that domestic heating is fully provided by air source heat pumps by 2040 and the power demand and electric vehicles transport demand is met by local renewable generation through PPAs and private wires. This is supported by batteries for balancing that is expected to be lower cost by 2040.

The Celtic sea offshore wind capacity is increased to 4GW to support a decarbonised electric system. As shown in the techno-economic modelling, the decarbonisation of the electricity grid will give rise to electric technologies.

RWE is also expected to develop offshore wind farms in the Celtic sea and therefore it is expected that another level of investment for electricity network upgrade is commissioned to support the additional generation and avoid constraints.

We have assumed that by 2040, multi-vector and flexible trading platforms are operational to support demand shifting, balancing and flexible trading.

2040 to 2050:

By 2050, we have assumed that multiple SLESs are clustered to form the Pembrokeshire SLES, where the local power and EV transport demand is met by local renewable electricity supported by batteries for balancing and National Grid imports. Heat is fully electrified and met by heat pumps. Any excess electricity generated can be exported to National Grid or traded using flexibility platforms.

We have not considered hydrogen production at the RWE PZNC, ERM Dolphyn and the North Pembrokeshire hydrogen project as part of the High Electric pathway but they are developments that are likely to progress.

This pathway assumes net zero is achieved across the whole system by 2050 through the no- regrets steps that continue to be made across 2022-2050.

The High Electric pathway

Timeline of events

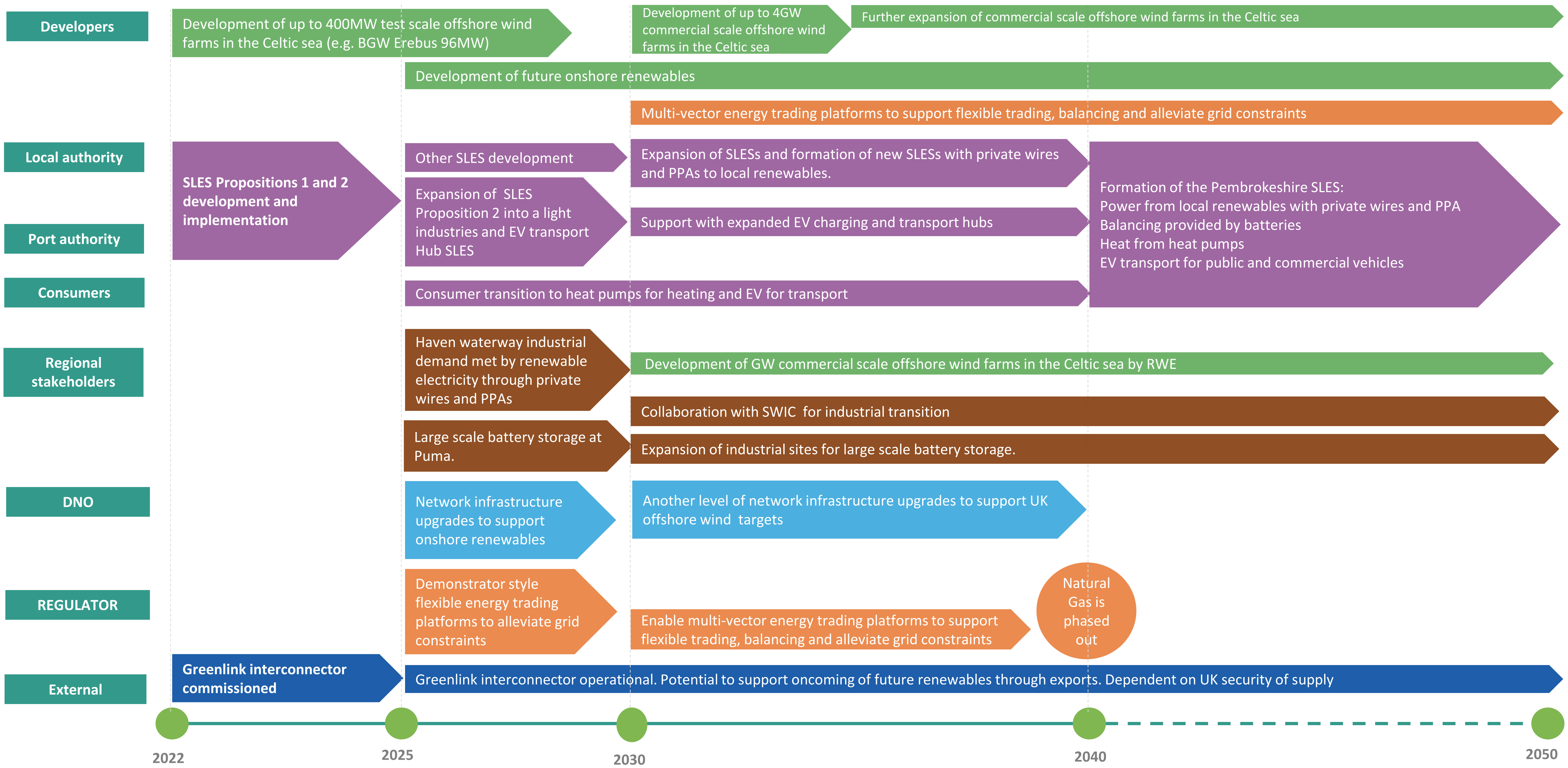

Figure 32: Timeline of events for the MH:EK High Electric pathway

The Green Hydrogen pathway

Timeline of events

Now to 2025:

As with the High electric pathway, we have assumed that the recommendations of Proposition 1 and 2 are implemented and the Milford Haven Marina SLES and the Pembrokeshore food park SLESs are formed. However, in this pathway, we have assumed that both propositions have a hydrogen transport demand as set out in the preferred systems of each proposition (*preferred system schematics*). We have assumed that this hydrogen demand is fulfilled by green hydrogen.

The North Pembrokeshire hydrogen project is developed with a 50MW solar farm and electrolyser that produces green hydrogen for road and rail transportation. It is assumed that only HGVs are an off-taker of this hydrogen as the most likely user of hydrogen as highlighted in The Future role of gas in transport study *[10]*.

RWE have developed their PNZC with a 100-250MW electrolyser that produces green hydrogen. The green hydrogen can be stored on the PNZC site and sold to off-takers regionally or nationally. It is also assumed that the green hydrogen is also used to power the Pembroke power station to produce electricity that is sold to National Grid.

2025 to 2030:

As with the High Electric pathway, we have assumed that the Pembrokeshire Food Park SLES (proposition 2) has expanded to a larger EV and hydrogen transport hub with on site green hydrogen production.

For decarbonisation of domestic heating, based on engagement with WWU, we have assumed up to 20% hydrogen will be blended into the gas grid to supply domestic heat to consumers that are on-gas whilst transitioning to hybrid systems by 2030. However, this assumption is to kept under review in line with the UK Hydrogen Strategy where strategic decisions for hydrogen for heating will be made by 2026. For off-gas consumers, the UK government / BEIS *[20]* have plans to install 600,000 heat pumps per year by 2028 and on that basis, we have assumed that all non-gas users would have heat pumps by 2030. By 2030, fossil fuel powered cars are no longer available, so we have assumed that all public vehicles are Evs, and HGVs and commercial vehicles are hydrogen powered.

Assuming that the PoMH's decarbonisation strategy includes decarbonisation of their estate and business operations, we have assumed that the Porth of Milford Haven has been developed as a point of import and export of hydrogen such that they can remain the UK's largest energy port. In doing so, supporting the national energy transition and maintaining jobs and promoting local upskilling. However, the UK's ability to export hydrogen is dependent on security of supply.

In terms of the larger industrial transition, we have assumed that the Dragon LNG and South Hook LNG sites are redeveloped as green hydrogen production sites with storage capacity. The energy for electrolysis comes from local renewable generators or potentially from the Celtic sea offshore wind generators, through private wires and PPAs provided they can be transmitted at an appropriae voltage . We have assumed that green hydrogen is also produced at the Valero site to fulfil their own industrial hydrogen demand.

By 2030, we have assumed that green hydrogen production at the RWE PNZC has scaled up to GWs and that the green hydrogen can be stored and sold to off-takers regionally or nationally or used to power the Pembroke power station to produce electricity that is sold to National Grid .

By 2030, we have assumed that the ERM Dolphyn project producing up to 300MW green hydrogen is commissioned with a pipeline to Milford Haven. We have assumed that this hydrogen is stored at the industrial sites (South Hook, Dragon and Valero) and the off-takers include the industrial and local HGV and light commercial vehicles transport demand.

2030 to 2040:

As with the High Electric pathway, we have assumed that the MH:EK SLESs have expanded even further and more SLESs are formed.

We have assumed that gas is phased by 2040 and domestic heating is supplied by heat pumps for consumers that are off-gas and hybrid systems for consumers that are on-gas. This is to be reviewed post the Hydrogen Strategy decision on hydrogen for heating by 2026.

RWE will develop offshore wind farms in the Celtic sea and we have assumed part of the electricity is used to produce green hydrogen. We have also assumed that green hydrogen production continues at the industrial sites who can have private wires and PPAs to onshore local renewable generators or offshore wind farms.

Furthermore, it is assumed that ERM have scaled up the offshore wind and hydrogen production which is stored at the industrial sites. The locally produced hydrogen is used to meet the local hydrogen demand for heating and transport. It is unlikely that excess hydrogen could be exported outside of the UK as international mega-scale hydrogen production would be more commercially favourable and there would be shipping constraints. The UK's ability to export will be down to security of supply. Therefore, it is assumed that any excess hydrogen is traded regionally or nationally.

As with the High Electric pathway, by 2040, multi-vector and flexible trading platforms will become operational to support demand shifting, balancing and flexible trading of multiple commodities and services.

2040 to 2050:

By 2050, we have assumed that multiple SLESs are clustered to form the Pembrokeshire SLES, where the local power demand is met by local renewable electricity supported by batteries for balancing and National Grid imports. Heat is supplied by heat pumps and hybrid systems. The hydrogen demand for heat and transport is met by locally produced and traded hydrogen. Any excess electricity generated can be exported to National Grid or traded using flexibility platforms.

This pathway assumes net zero is achieved across the whole system by 2050 through the no-regrets steps that continue to be made across 2022-2050.

The Green Hydrogen pathway

Timeline of events

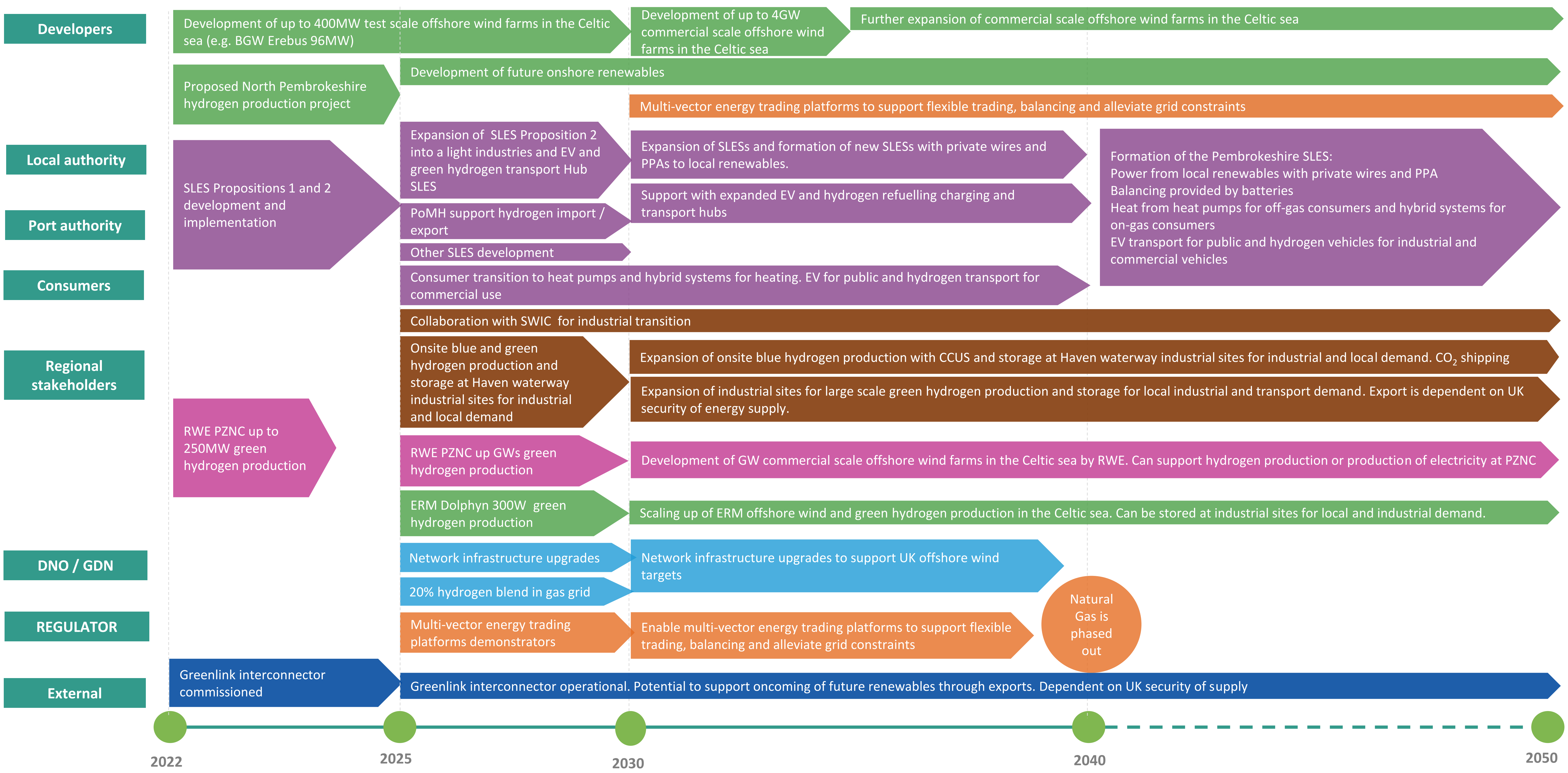

Figure 33: Timeline of events for the MH:EK Green Hydrogen pathway

The Blue Hydrogen pathway

Timeline of events

Now to 2025:

As with the Green Hydrogen pathway, it is assumed that the recommendations of Proposition 1 and 2 are implemented and the preferred system of Milford Haven Marina SLES and the Pembrokeshore food park SLESs are formed, however the hydrogen demand is met by blue hydrogen.

It is also assumed that by mid 2024, SWIC would have developed a roadmap for the South Wales Industrial decarbonisation, including the Haven waterway. It is expected that projects for CCUS, blue hydrogen production, carbon export and shipping etc would have reached feasibility stages and be in development to support the production of blue hydrogen.

2025 to 2030:

The Blue Hydrogen pathway would be no different to the Green Hydrogen pathway except for the larger industrial transition. We have assumed that the CCUS projects would be implemented as part of the SWIC project roadmap, and the Dragon LNG and South Hook LNG sites are redeveloped as blue hydrogen production sites with CCUS technologies. The sites have hydrogen storage capacity and the CO_2 captured is used for industrial purposes. We have assumed that blue hydrogen is also produced at the Valero site to fulfil their own industrial hydrogen demand.

The Porth of Milford Haven has been developed a point of import and export for both hydrogen and CO_2. although highly dependent on the UK security of energy supply.

ERM and RWE will be producing green hydrogen as per the Green Hydrogen pathway. The local hydrogen demand can be met by a combination of green and blue hydrogen from the industrial sites and RWE.

Decarbonisation of heating assumptions are as per the Green Hydrogen pathway except that the gas grid could be blended with 20% hydrogen from blue and green sources by 2030.

2030 to 2040:

By 2040, the Blue Hydrogen pathway would be no different to the Green Hydrogen pathway except for the larger industrial transition that will scale up the production of blue hydrogen. CO_2 captured is locally used for industrial processes or exported.

The local hydrogen demand is met by a combination of green and blue hydrogen as more domestic heating transitions to hybrid systems and all public vehicles are EVs whilst light commercial and industrial vehicles are hydrogen powered.

2040 to 2050:

By 2050, we have assumed that multiple SLESs are clustered to form the Pembrokeshire SLES, where the local power deamand is met by local renewable electricity supported by batteries for balancing and National Grid imports. Heat is supplied by heat pumps and hybrid systems. The hydrogen demand for heat and transport is met by locally produced and traded blue and green hydrogen. Any excess electricity generated can be exported to National Grid or traded using flexibility platforms. CO_2 captured is locally used for industrial processes, traded or exported.

This pathway assumes net zero is achieved across the whole system by 2050 through the no-regrets steps that continue to be made across 2022-2050.

The Blue Hydrogen pathway

Timeline of events

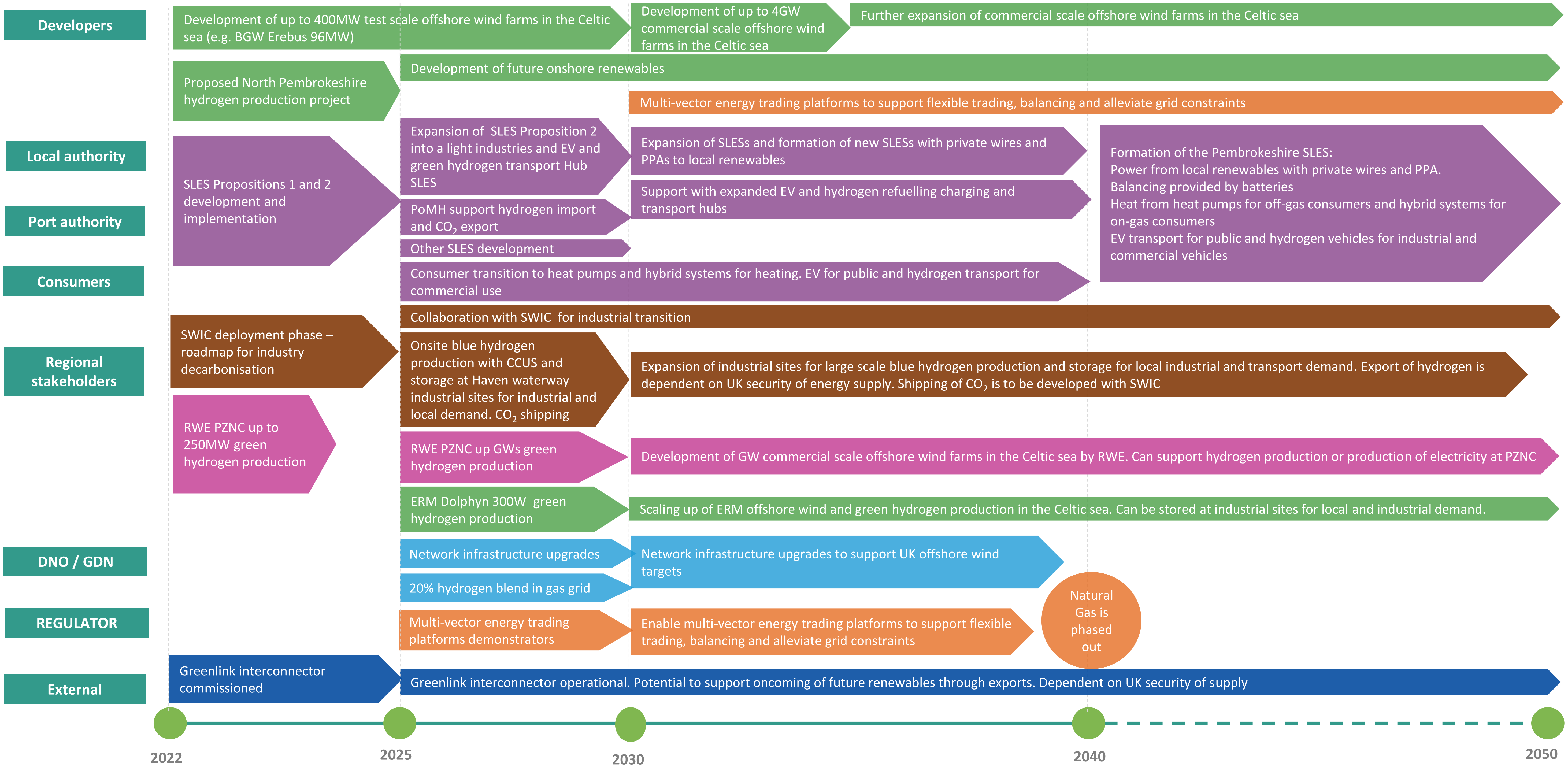

Figure 34: Timeline of events for the MH:EK Blue Hydrogen pathway

Review of the longer-term pathways

Alignment of the pathways to industry future energy system models.

The Climate Change Committee (CCC) 'Balanced Pathway' to maintain the 6th Carbon budget *[4]* and achieve net zero by 2050 includes recommendations across varying levels of behavioural change and sector innovation.

The balanced pathway features strong contribution of take-up of low carbon solutions (boilers, transport and carbon capture and storage) and expansion of low-carbon energy supplies (renewables and at scale hydrogen production).

Figure 35 shows that measures involving low carbon solutions around electrification will have the highest contribution to reduction of carbon emissions, followed by the production of low carbon energy. This is in line with our assumption that electrical technologies and production of renewable electricity will likely be an integral part of the pathway to decarbonisation.

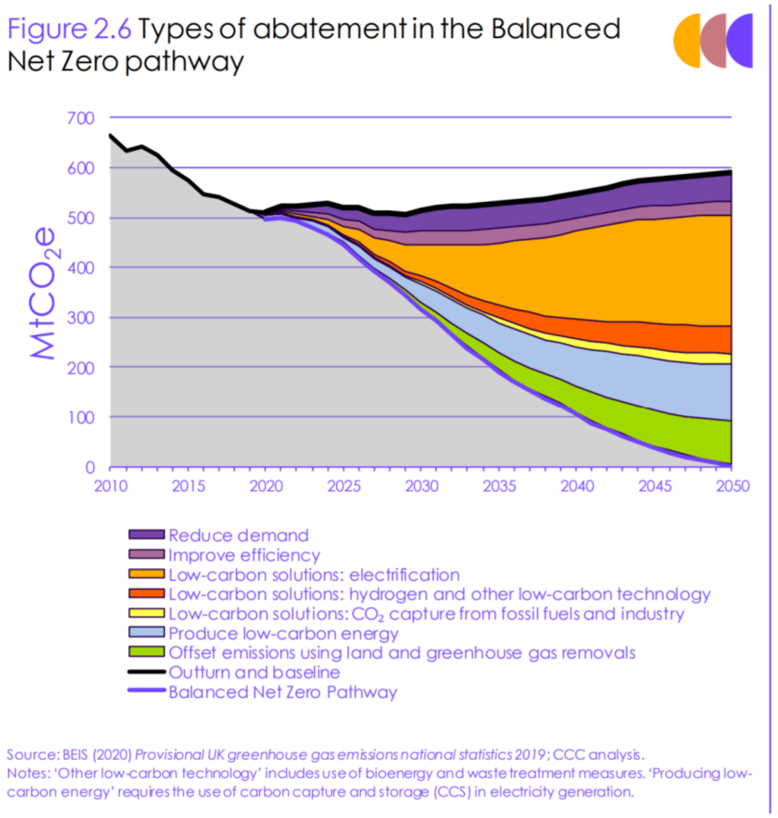

Figure 35: Contribution of different measures to the Balanced Pathway *[4]*

The CCC balanced pathway has assumed key phase out dates for natural gas boilers by 2033, fossil fuel powered vehicles by 2032 and the switch of HGVs to low carbon transport by 2040 which is in line with our assumptions.

The CCC balanced pathway energy system moves almost entirely to low-carbon energy sources by 2050. Low-carbon electricity becomes the dominant energy vector; a hydrogen economy is formed comparable to the existing electricity by 2050; domestic demand is met by more efficient EVs and heat pumps; a modest growth in bioenergy and waste use; carbon capture and storage is applied to the industrial sector. These are largely in line with the assumptions made in the MH:EK pathways.

Figure 36 shows the predicted contribution of electricity and hydrogen to meet the future energy demand by sector in 2050, showing that electricity will likely be predominantly used to fulfil building/residential demands, surface transport will be met by a combination of electricity and hydrogen and hydrogen will be predominantly used in manufacturing and construction (industrial demand).

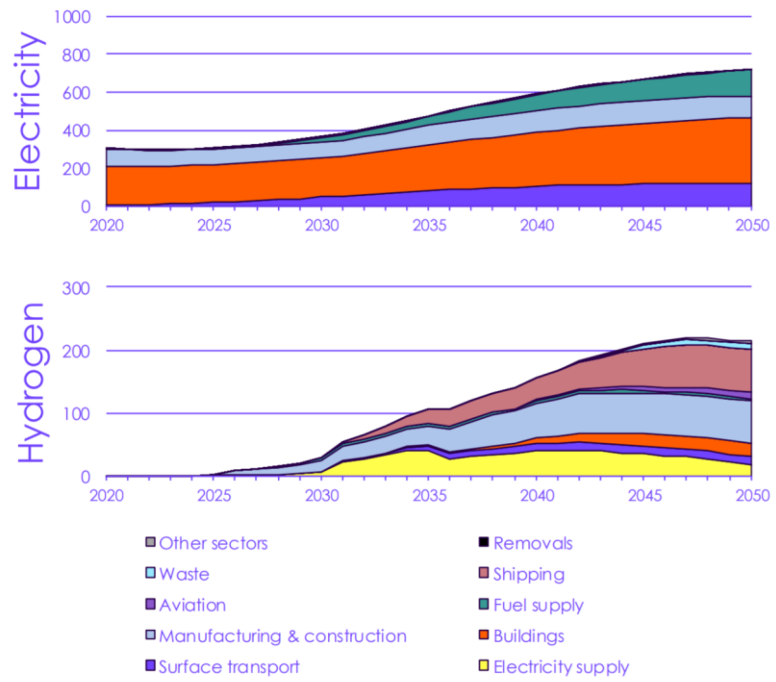

Figure 36: Energy demand in TWh by sector or the predicted electricity and hydrogen contribution (in TWh) to the 2050 energy system *[4]*

National Grid Future Energy Scenarios (2021) *[3]*

As with FES 2020, net zero is achieved by 2050 in the 'Leading the Way', 'System Transformation' and 'Consumer Transformation' scenarios. The scenarios in the 2021 FES model reach lower emissions faster due to increased government support by recent policies and the more challenging CCC 6th carbon budget *[4]*.

- The **System Transformation** scenario models a world where there is least consumer engagement and residential level upgrades / investment. The system therefore has the highest proportion of hydrogen for heating, industry and HGVs. The hydrogen is predominantly blue hydrogen requiring CCUS with hydrogen storage.
- The **Consumer Transformation** scenario models a world with the highest level of consumer behavioral change and investment to low carbon heating (heat pumps and hybrid systems) and transport. Hydrogen is produced through electrolysis for heating, transport, industrial and shipping and aviation transport.
- The **leading the Way (LW)** scenario models a more balanced level of change from consumers and the system / policies resulting is a combination of hydrogen and electricity being used for heating and industry. Natural gas is not used for hydrogen production (blue hydrogen) and this is the only scenario that includes non-networked electricity and hydrogen production.

The MH:EK balanced hydrogen pathways align best with the 'Leading the Way' scenario – where there is strong engagement and investment from consumers to improve home efficiency, transition to heat pumps and hybrid systems and EV vehicles. Hydrogen is produced by electrolysis and still better utilised in HGV transport and industrial demand. The LW scenario doesn't feature blue hydrogen with CCUS.

FES 2021 highlights that demand reduction (increased efficiency), electrification and low carbon technologies including hydrogen and flexibility (smart systems, batteries, hybrids and demand flexibility/shifting) will be key to decarbonisation which are aligned with the basis of the MH:EK pathways.

Regional boundary modelling

Regional boundary modelling – Wales and West Utilities [30]

Wales and West Utilities (WWU) undertook further modelling of the future energy system using their 2050 Energy Pathfinder model *[21].* The aim of the modelling was to assess the feasibility of different energy mixes through a series of future energy scenarios and show and any shortfall / surplus in heat and power supply and ensure there would be no blackouts. In addition to the short-term propositions and optimised preferred systems shown *in the economic case*, this work aimed to provide quantitative analysis to support the long-term MH:EK 2050 pathways**.**

The modelling work has been based upon the physical boundary of Pembrokeshire County Council. Building on a present day 'baseline' scenario, three further scenarios were modelled:

- Green hydrogen
- Blue hydrogen
- Electrified

Each scenario was based on Pembrokeshire's 'fair share' of national assets being available for energy import and export. These Great Britain-wide capacities were influenced by a combination of National Grid ESO's Future Energy Scenarios [2] and previous work undertaken as part of the Energy Networks Association's Gas Goes Green Programme [22], in turn drawing on Guidehouse's Pathways to Net Zero report. [23]. The model was then iterated to:

a) reduce CO_2 emissions as far as reasonably practicable, and

b) balance supply and demand to ensure resilience through the mitigation of network blackouts.

The 2050 Energy Pathfinder model
[21] is an hourly imbalance model, which uses human iteration to calculate whether to use storage, interconnection or flexibility. Scenarios were based on FES scenarios, which are not necessarily optimal, and the outcome is that greater renewable generation capacity is required by the model in order to limit network blackouts that could be balanced through more efficient use of renewables alongside storage.

The modelling approach taken for the propositions used Arup's WSEM optimisation models, which optimises the whole energy system on an hourly basis, incorporating battery and hydrogen storage technologies to find the least cost and carbon solution.

Two high-level assumptions were made across all scenarios:

1. 20% demand reduction due to increases in technology efficiency
2. Additional 18% demand reduction for transport due to a decrease in car ownership, and an increase in active travel and use of public transport

Green Hydrogen scenario

The demand input assumptions for both hydrogen scenarios were based on stakeholder information from MH:EK project partners and the Guidehouse's report *[23].* Green hydrogen made up 80% of the built capacity but 63% of the annual supply due to the lower capacity factor of electrolysis.

Generation was scaled up to support electrolysis. However, this is a limitation of the study as this is not based on an optimised energy system. Further iterations or an optimisation approach would be required to determine a more efficient solution.

For domestic heating, the study assumed the majority of on-gas customers remained on boilers with 15% shifting to hybrids. 50% of off-gas customers switch to heat pumps.

Blue Hydrogen

The assumptions were the same as the green hydrogen scenario except that the green hydrogen was reduced by 80% and replaced by blue hydrogen being produced at industrial sites along the Haven waterway.

Electrified

The demand input assumptions were based on the Regen and WPD's DFES outlook for 2050 [5]. Some deviations were made to reflect the local infrastructure. Solar capacity was adjusted to match the seasonal heat demands and offshore wind capacity was increased to account for the Celtic sea floating offshore wind opportunity.

For the transport demand, it was assumed that two-thirds of BEVs and one-third of FCEV due to the more likely applicability of hydrogen for transport to buses and heavy transport in line with the Regen study.

Summary of model output

Green hydrogen – 121MW green hydrogen (dedicated production 45MW and curtailed electricity 76MW) + 30MW blue hydrogen to ensure resilience. Total 151MW of hydrogen to be supported by 17,000MWh storage capacity – assumed to be a national storage system.

Blue hydrogen – 67MW of hydrogen with 23MW green hydrogen – lower due to higher capacity factor for Blue H. Storage capacity also lower at 13,750MWh.

Electrified - 96% increase in peak electricity demand in this scenario, requiring 7 times more generation than current capacity. Significant network capacity upgrades to accommodate this scenario. 186MWh of storage for 425MW of combined wind and solar generation capacity, noting that this is not optimised. This would mean significant deployment of heat pumps and district heating networks.

Limitations and risks

Supply and storage capacities were only adjusted to the point that no blackouts were modelled to balance the supply and demand every hour. Further iterations to optimise the generation and storage were not undertaken. Further work will be required to optimise the ratio of generation (hydrogen and electricity) to storage capacities.

The modelling showed a reduction in carbon emissions from the baseline value of 558,070tCO_2e to less than 5000tCO_2e, however negative emissions technologies like BECCS, biohydrogen or DACC which would likely be required to reach net zero have not been modelled.

Future work

Whole systems energy modelling for Pembrokeshire and optimisation of the energy system for lowest cost and lowest carbon for a spectrum of future energy scenarios. This should include:

- The optimum electricity and hydrogen production to storage capacities
- Incorporating negative emissions technologies
- Refinement of vehicle to grid storage capacities
- Explore the uptake and availability of smart vehicle charging
- Explore sensitivities around seasonal local demand variations
- Review cost assumptions and provide costs of each scenario

Future low carbon technologies demonstrations

Demonstration of future low carbon technologies to help shape the decarbonisation roadmap

The MH:EK project supported two demonstrations of low carbon technologies applied to local settings:

- Hydrogen hybrid heating system demonstration
- Fuel cell vehicle, Rasa and hydrogen refueller demonstration.

The design, installation and operation of these demonstrators has enabled key learning on the future deployment of these low-carbon technologies at scale within the local context. The demonstrators have also been a first introduction of these technologies to the communities, making them visible to the public and raising awareness on how these technologies could form a key part of their future lives and energy system.

The findings and learnings are valuable to understand how these technologies could fit in the longer term decarbonisation roadmap for Pembrokeshire and the partnerships formed should continue to support the development of the roadmap.

Hydrogen hybrid heating system demonstration *[31]*

The MH:EK Hydrogen hybrid heating system trial is a world first demonstration of a smart hydrogen hybrid heating system comprising of a natural gas boiler and air source heat pump, and then for short term trials converted to a smart hybrid heating system comprising a hydrogen boiler and heat pump. The system used smart controls to coordinate operation for the decarbonisation of heat. The advantages of the hybrid system is to balance the electricity network with hydrogen for heat during high demand times.

The demonstrator consisted of a heat pump with smart controls provided by Passiv UK which was deployed in an office building within the PoMH complex at Milford Haven in 2021. A Samsung heat pump and a Worcester-Bosch boiler, initially operating on natural gas provided heating to the building during the winter of 2021-2022. During two weekends in January 2022 when the office building was unoccupied, the boiler operated on:

a) a 20% hydrogen mix (the same boiler with gas supply replaed with bottled mixed gas), and

b) 100% hydrogen (the boiler was replaced with a pure hydrogen boiler)

This was to simulate the scenario of the gas grid is blended with 20% hydrogen in the medium term and then a gas network completely converted to 100% hydrogen.

The trials were run successfully. The heat pump provided 60-80% of the building's heat demand. For the hybrid heat pump and gas trial period, the heat pump provided the 'baseload' and the boiler (natural gas) was only used to top-up the heat when the thermostat temperature was increased. For the hybrid heat pump and the 20% and 100% hydrogen trials, network constraints were simulated by setting a peak electricity tariff signal on the smart controls, which triggered the heat pump to switch off and be replaced by the hydrogen boiler.

This provided a real life example of how a hydrogen hybrid system could be used with most of the heat being provided by a heat pump powered by renewable electricity, backed up by hydrogen which can be stored and used when really needed. The smart controls were key to enable the system to prioritise heat pumps as much as possible switching to hydrogen supply when the electricity supply is under strain to ensure the building demand is always met.

The hybrid heat pump system showed a 50-65% carbon reduction compared to the business as usual scenario of providing heating by natural gas. This could increase to up to 90% if the hydrogen boiler runs on green hydrogen. In a future where heat pumps only run on renewable electricity and green hydrogen is available, this system has the potential to become zero carbon. The details of the trials can be found in the Milford Haven Energy Kingdom Hydrogen Hybrid Field trial report *[31]*

This demonstration showed the potential for hybrid heat pump and hydrogen systems to be part of the decarbonisation of heat for on-gas consumers. The upcoming UK Hydrogen Strategy due 2026 will make strategic decisions for hydrogen for heating and will help inform the future role of hydrogen hybrid systems. Consumer adoption and investment in insulation and home upgrades will also be key.

Furthermore, as part of the Welsh Government HyBRID Hydrogen fund, the following projects are further investigating feasibility of hydrogen for heating *[28]:*

- HyProspect project builds on the Milford Haven Energy Kingdom (MH:EK) project to design and develop the tools needed for a new micro-grid service operator (MSO) functionality. This innovative service proposition will balance localised generation of power and hydrogen by optimising heat demands from buildings in the same area.
- HyMaker Heat builds on a successful field trial in the Milford Haven: Energy Kingdom (MH:EK) project which deployed a smart hydrogen hybrid heating system in single domestic scale building. HyMaker Heat will develop a new system for delivering heat to multi-occupancy scale buildings using intelligent controls paired with a hydrogen boiler and an air-source-heat pump. This will be at Pier House Pembroke Dock.

Future low carbon technologies demonstrations

Demonstration of future low carbon technologies to help shape the decarbonisation roadmap (continued)

Hydrogen Fuel cell vehicles, Rasa and hydrogen refueller demonstration

The Hydrogen fuel cell vehicle demonstration in Milford Haven includes two Riversimple Rasa vehicles, operating on routes mimicking journeys of the PoMH, PCC and NHS fleet and collecting driving data such as H_2 consumption, journey distance/duration, driving style, topography. The vehicles are refuelled by a demonstrator hydrogen refueller.

At the time of writing this report the vehicle trials are ongoing. The demonstration will provide real world data in terms of driving patterns and actual hydrogen use which will enable an assessment of the actual hydrogen demand for light duty vehicle. The driving patterns will also allow an assessment of hydrogen demand for other hydrogen passenger vehicles and vans. In addition, the incremental demand associated with other transport sectors such as medium and heavy duty trucks, buses, construction and agriculture will be assessed in the Promoting hydrogen mobility report *[32]* .

Figure 37: Riversimple Rasa vehicle and hydrogen refueller demonstation

The hydrogen refueller and all associated works including the AEM electrolysers by Enapter, compressors, water treatment units, dryer units necessary to electrolyse, store and dispense hydrogen has been successfully installed by Fuel Cells systems. Through the design and installation, the project learnt valuable lessons around the technical requirements, environmental legislation and planning requirements of installing hydrogen refuellers. The visibility of the Rasa vehicles being refuelled by the hydrogen refueller is proving to be very effective for community awareness raising.

The Promoting hydrogen mobility report *[32]* will assess the degree of alignment between the potential demand for hydrogen in the Milford Haven area, and the investment required to meet that demand. If a commercial gap exists, recommendations will be made regarding potential solutions to close the gap such that a sustainable business case can be developed. The report will explore potential locations for hydrogen refuellers (a broad view) considering the real-world journey data that has been gathered from the trial. The Promoting hydrogen mobility report *[32]* will be published in May 2022.

The MH:EK project has developed a set of Key Stage (KS) 2 primary and KS 3 secondary curriculum resources based around the MH:EK H2 refueller, electrolyser, fuel cell vehicles and hybrid hydrogen ready heating applications. The resources are being used during and post visits to schools to stimulate interest in young minds regards the existing MH:EK project, our energy history and the future whole energy system. They are designed to engage young people in the conversation around climate change and their contribution to the journey net zero as well as the prospects for employment that are emerging in the future hydrogen and renewable energy economy. It paves the way for further engagement with schools including visits to the MH:EK demonstrators and ultimately we aim for the resources set to be shared beyond the project throughout the education system. *[41]*

Figure 38: Extract from the MH:EK reducational resources *[41]*

Future work to help shape the longer term decarbonisation roadmap

Longer Time-Horizon Energy Generation Development

The MH:EK project is also further investigating the role of hydrogen in longer time-horizon offshore wind energy generation and the technical/technology challenges that lie ahead and how they can be addressed through a separate work package. At the time of writing this report, this work is still ongoing and the Longer Time-Horizon Energy Generation Development report *[33]* will be published in May 2022.

The overarching aim of the study is to realise enabling activity for multi-GWs of offshore wind producing green hydrogen in nearby offshore locations, e.g. the Celtic Sea, connected to established and/or repurposed regional onshore infrastructure, e.g. Milford Haven/South Wales Industrial Cluster.

This work will be organised under four themes of activity:

1. Technology Development

   Definition of a research and development programme to identify enabling actions focused technology development in three key areas: efficiency, reliability and flexible operation.

2. SLES Roadmap / Scenario Review

   Further development of the SLES roadmap including how they align with the overarching goal and further investigations around the development timelines, energy demands and supporting infrastructure.

3. Development of larger demonstration proposals

   Development of larger demonstration proposals to support the overarching goal integrating with other UK and EU projects such as the Concepts, Planning, Demonstration and Replication of Local User-friendly Energy Communities (CLUE) project and H100 Fife. Areas under consideration include hydrogen for marine refuelling and maritime vessel use for offshore wind farms operational and maintenance activities.

4. Milord Haven in a global green hydrogen generation context.

   Investigate the role of Milford Haven in a global green hydrogen offshore wind generation market through a review of global activity and gathering insight through stakeholder engagement. Example stakeholder groups include EU and international research groups, the relevant stakeholders within the Celtic sea offshore wind development opportunity and other ports.

This work aims to highlight how best to integrate the local industrial cluster and how to interact with the upcoming national offshore wind generation assets which are geographically close to Milford Haven. It is recommended that this work feeds directly and support the next stage of development of a longer term roadmap for the decarbonisation of the Pembrokeshire energy system by 2050.

Gathering early insights on consumer transition

Recognising the challenges around decarbonisation of heat and the significant contribution and buy-in needed from consumers, the MH:EK project undertook the ‘co-designing a switch to hydrogen with customers study’ aiming to engage consumers into the journey of decarbonisation of heat, focusing on the repurposing of the gas grid with hydrogen.

In-depth interviews were used to gather insights on the consumers’ concerns and how to build a public support network to address practical challenges they may face. The self-selecting consumer sample represented a cross-section of gas users in and around Milford Haven, from large families to elderly couples and single households.

The qualitative domestic consumer research explored:

- the issues they might face during a switchover to hydrogen,
- the extent to which those issues represent a barrier for consumers,
- the solutions they feel could reduce those barriers

Exploration of the challenges and potential solutions provided the basis for the following key insights:

- **Increasing awareness of the link between home heating and climate change could help consumers understand and accept a switch to hydrogen.** Consumers showed a lack of understanding of the link between home heating and climate change but through the interviews understood the need to stop using natural gas for heating and were more accepting of hydrogen. They were not so concerned about the safety aspect and trusted that the risks would be managed; they’ve also seen the Rasa vehicle demonstrations using hydrogen as a fuel and believe that there is potential to establish Milford Haven as being at the “cutting edge” of decarbonisation.
- **Consumers wanted relevant, tangible information about the impact of a hydrogen switchover on their own home and household.** Consumers raised concerns of being uncertain of the real impact of the switchover; in particular, they wanted to know what costs would be involved in the switchover process itself as well as ongoing costs.
- **Consumers were generally accepting of the need for disruption in their homes, though some challenges represented greater barriers than others.** Consumers felt that using hydrogen to heat their homes would mean minimal (if any) behaviour change. Some felt that while they were generally accepting of the concept of short-term disruption in their home, they would want to understand what exactly that disruption might entail and what would be done to ensure a smooth and satisfactory experience for them.

The research focused on a switchover to hydrogen and the process – and disruption – that this might entail in homes. Further research could explore reactions to hydrogen, including the switchover process, within a wider context, considering other low-carbon heating options that might be available and the disruption that a hydrogen transition might involve outside the home.

The research findings are delivered in a clear report with consumer testimonials and align with other publicly available studies that support the switch to hydrogen for heating *[34]*. This work will support the development of the longer-term roadmap in terms of understanding the barriers to switching on-gas consumers to hydrogen for heat. However, the roadmap should also consider the upcoming UK Hydrogen Strategy where strategic decisions for hydrogen for heating will be made by 2026.

Longer-term energy pathways recommendations

Conclusion

The longer-term pathways represent possible future energy systems for high-electric, balanced green and balanced blue hydrogen pathways. The scenario approach is consistent with various industry future energy system pathway development such as National Grid Future Energy Scenarios (FES), the Climate Change Committee 6th Carbon budget and the Regen Net Zero South Wales studies.

The Climate Change Committee (CCC) 6th Carbon budget developed a range of scenarios to achieve Net Zero by 2050 and used these scenarios to identify a 'balanced pathway' that is illustrative of what a sensible path based on assumptions could look like.

The pathways are a qualitative representation of our understanding of the various local and regional future decarbonisation plans and the pathways show how they can be aligned to accelerate the transition of the Pembrokeshire energy system to net zero by 2050. They are based on information reviewed and received through stakeholder engagement. They are heavily hinged on the implementation of the stepping-stones MH:EK SLES propositions and the materialisation of the regional plans such as SWIC and RWE PZNC.

The pathways and roadmaps should be seen as a set of possible short-term steps that will accelerate the journey to decarbonisation. The decarbonisation roadmap for Pembrokeshire will be affected by the local and regional context but in line with the CCC balanced pathway, it will likely be a balance of electric and hydrogen technologies. By transitioning the large industrial sites to hydrogen production and storage, there is a strong opportunity to retain thousands of jobs but also skill shifting that will support a just transition.

The MH:EK pathways highlight future areas of further research, investigation and collaboration to enable the development of an integrated and adaptable decarbonisation roadmap.

Recommendations

- We recommend that the next phase of the MH:EK project considers developing a roadmap for the decarbonisation of the Pembrokeshire energy system by 2050. We recommend that the starting point would be the short-term investable propositions for SLESs that is integrated with key projects and regional plans such as SWIC, RWE PZNC and ERM as they are further developed.
- As shown on the MH:EK pathways, early action up to 2025 will involve fewer actors and will therefore be less complex to implement. They should have a catalytic effect to form larger energy clusters and eventually a decarbonised energy system.
- We recommend close partnership and collaboration with the regional plans such as SWIC, RWE PZNC and ERM to develop a roadmap for decarbonisation of the Pembrokeshire energy system by 2050. A fully integrated roadmap will enable the implementation of the short-term no regret steps with a view of integrating those with their plans on the journey to decarbonisation.
- Other upcoming studies such as the Pembokeshire Local Area Energy planning (LAEP) which will include whole system energy modelling and optimisation of the the Pembrokeshire local authority regional area energy system, LAEP delivery pathways and local energy decarbonisation routemap are also key to inform the development of this roadmap.
- The future energy system will be based more around energy supply. Increased flexibility and interaction of multiple vectors and services will be required to flex demand, enable use and storage and trade different commodities. As such, technical, regulatory and market barriers around flexibility trading platforms would need to be overcome and local actors, network operators and regulators all have a role to play to realise these benefits by 2050. Further details on recommendations on how a trading platform could support the decarbonisation of Milford Haven and Pembrokeshire is provided in the Commercial case.
- Engagement with network operators should be continuous to integrate the network capacity and planned upgrades into the roadmap.
- The roadmap should be kept under review and adapted as the regional picture evolves, more actors become interested in the transition including investors and energy sector level changes happen for example network upgrades and policy and regulatory changes.
- The transition to net zero should put the community, stakeholders and wider aims at the centre and ensure a just transition for all. Through continual stakeholder engagement and adopting a theory of change approach, MH:EK should aim at developing a set of tangible actions and a roadmap for everybody to understand their role to get to net zero by 2050 whilst ensuring societal cohesion.

Early action through development of the recommended SLES propositions by taking the 'no-regret' steps will jumpstart the journey to decarbonisation.

In parallel, a fully integrated and adaptable roadmap including key decision points and determinants for the decarbonisation of the Pembrokeshire energy system should be developed, stemming from the short-term SLES proposition and in close partnership and collaboration with the local and regional projects and network operators.

Flexibility (supply, demand, trading) is a key part of the future energy system as demonstrated by industry net zero pathways. Regulators should provide regulatory relief to set up demonstrator flexibility platforms by 2030 to support flexible energy trading by 2040.

The decarbonisation roadmap should have the community, stakeholders and wider sustainable development aims at the centre to ensure a just transition.

MILFORD HAVEN: ENERGY KINGDOM

The Commercial case

Summary of findings

ENERGY KINGDOM
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The Commercial case

Introduction

This chapter of the study looks to build on the Economic case and presents the Commercial case for MH:EK. While the propositions identified have been found to be techno-economically viable, demonstrating commercial viability is a central part of the overall process.

Establishing the Commercial case will identify potential commercial models, roles and responsibilities across the propositions, revenue streams and the route to market for the various stakeholders, and the procurement strategy.

Commercial Models

In this section, we present a number of potential commercial models that could be applied to the various propositions identified through the techno-economic modelling. We explore the potential market arrangements and revenue streams that could apply under the commercial models, and how risks are best allocated across stakeholders.

Regulatory and Policy Constraints

This section outlines, at a high level, the existing regulatory framework governing the UK energy market. Key market users, systems, and technologies are identified, and their regulatory arrangements summarised. Next, these market users, systems, and technologies most relevant to the proposed SLES models and their potential business cases are highlighted, and potential regulatory obstacles outlined. Finally, routes to market – options to circumvent or avoid some regulatory obstacles, as well as policy recommendations – are proposed.

Trading Platform

In the context of energy, a trading platform might allow for the exchange of resources such as electricity or hydrogen, as well as acting as a local balancer and flexibility provider. They have the potential to unlock benefits to the network, consumers, and to support local objectives.

MH:EK could benefit from a trading platform because export of electricity from Pembrokeshire is constrained. Some benefits have been demonstrated through the Smart Energy Cluster trial. A local trading market could support more renewables development, hydrogen production capacity, and flexibility/storage within the system.

However, there are technical, regulatory and market barriers that must be overcome.

In the electricity sphere, the largest technical barrier to participating in wider flexibility and capacity (electricity) markets is that export is constrained. There also need to be improvements in the network, and forecasting ‘prosumer’ data available from DNOs. Local, peer-to-peer trading could be utilised to overcome the export constraint, but this would need to be done with regulatory relief from Ofgem.

In the hydrogen sphere, the maturity of the market remains a barrier. Market liquidity calls into question the utility of using a trading platform over securing long-term contracts. Fulfilling orders remains difficult without transport infrastructure, and electrolysers participating in the electricity balancing, flexibility and capacity sphere are competing against CHP and battery incumbents. Securing jobs in the region would likely be better served through production assets securing long term contracts with transport, or chemicals firms.

As such, it seems unlikely that establishing a digital trading platform represents the most beneficial approach at this time. Once a more robust hydrogen market is established, a platform that also has access to electricity and gas markets is recommended.

This is further discussed on page *97 to 99*.

The Commercial case

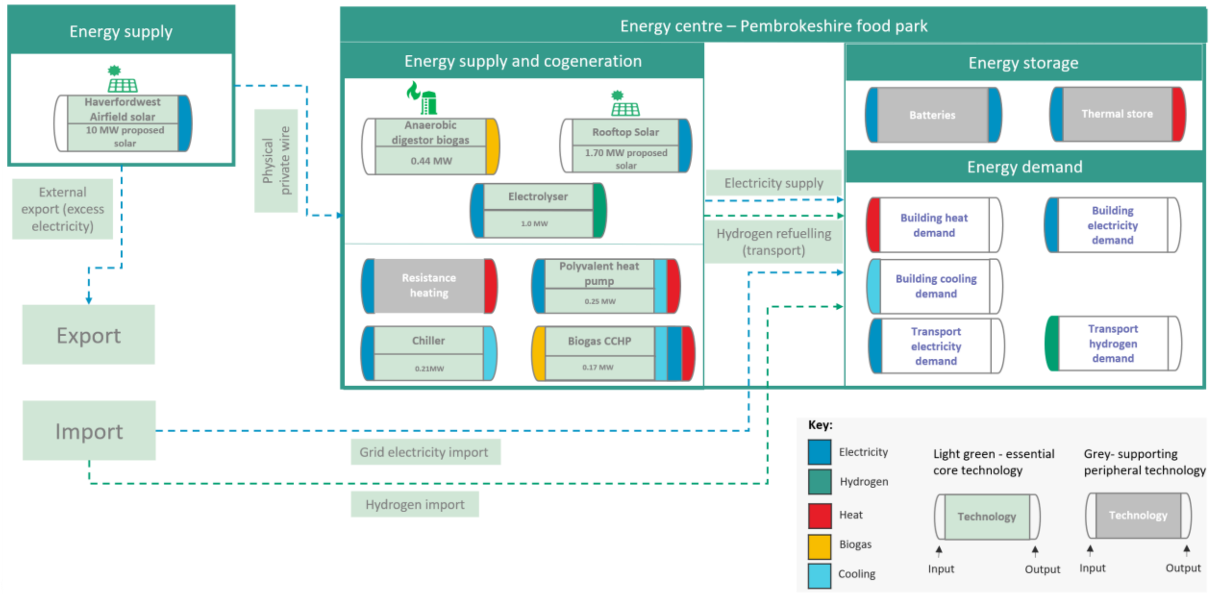
Overview of propositions considered

In developing the potential commercial models that can be applied to the MH:EK SLES, it is important to consider the different propositions put forward (as discussed in *the Economic case)*, and the different assets/technologies that fall under those propositions (as outlined in *the Economic case* and in Figure 39).

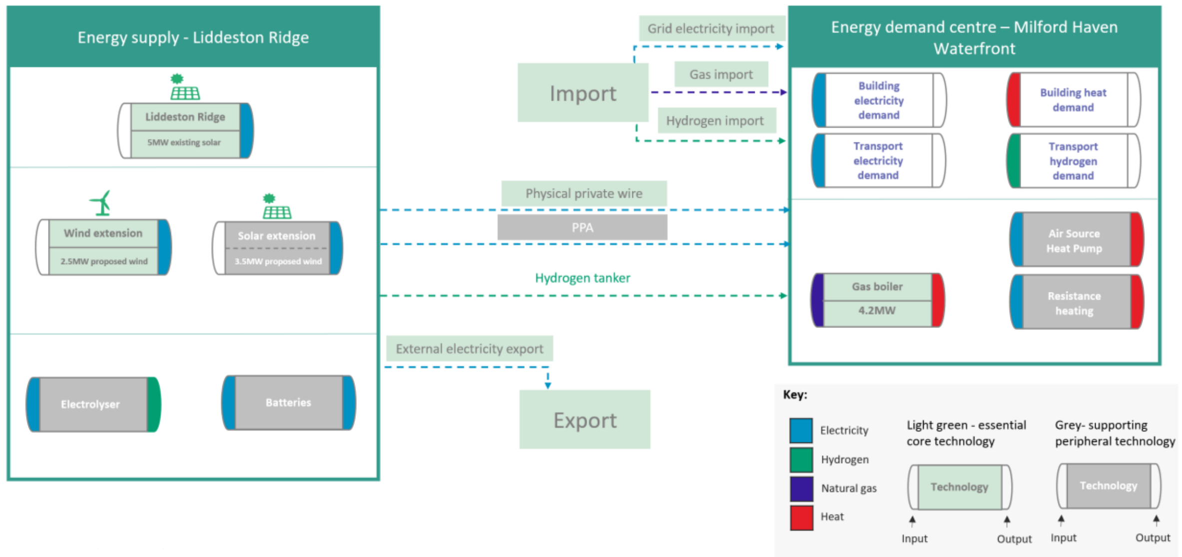
Under the Economic case, a longlist of different propositions was assessed against several different criteria to determine a shortlist of three propositions, which were modelled against different energy scenarios. These were then further assessed to result in a 'preferred system' for each proposition, setting out the techno-economic no-regrets options and recommendations.

We have used these preferred systems as the basis for the commercial model assessment. An overview of the propositions and preferred system are provided Figure 39.

Proposition 2 – Pembrokeshire Food Park SLES



Proposition 1 - The Milford Haven Marina SLES



Proposition 3 - Pembroke Schools, Leisure Centre and Dock SLES

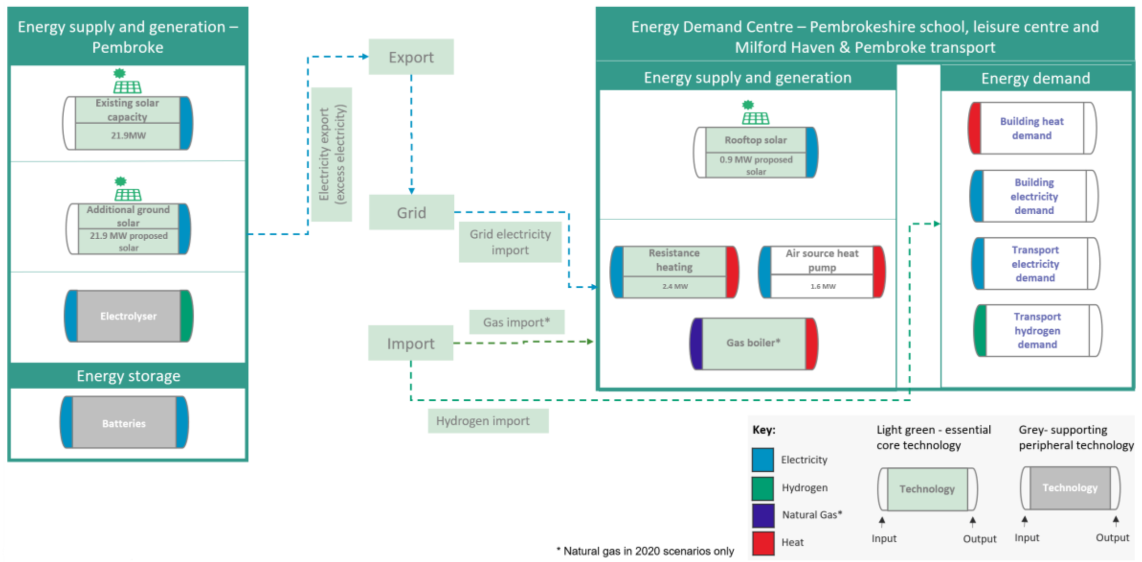


Figure 39: Propositions optimised system schematics

Commercial roles and responsibilities

In developing the commercial models, it is important to consider the different roles and responsibilities that need allocating across the different stakeholders under each proposition. In some cases, the same party will hold the same roles and responsibilities across propositions, and in other cases they will differ.

The appetite for involvement from each stakeholder will inform the final commercial model for the project as explored throughout the following pages.

An overview of the key roles and responsibilities is presented on this page.

1. Customer

The customer in this case is the off-taker or end user of energy, be that either a domestic or commercial/ I&C (Industrial & Commercial) customer. The customer will contract either directly with the generator/ producer or an intermediary to procure its energy.

2. Funder

The project funder provides or arranges finance for the project and will usually take the form of a strategic partner/ developer, or a third-party investor. Funders or investors will often require a certain level of return determined by the 'hurdle rate' and may require security against the funding provided depending on whether the funding is provided on a debt or equity basis.

3. Asset owner

The asset owner legally owns the physical assets. Ownership could be split for different classes of assets for example, demand reduction, generation assets, primary network and secondary networks. Ownership of assets may vary over the life of the project. This is normally a long-term function and survives completion of installation and repayment of finance. Asset owners are responsible for ensuring the assets are maintained and replaced.

4. Landowner

The role of the landowner, in this context, is to grant leases and easements for the siting of network assets and provide rights of access for the installation, operation and maintenance of plant and equipment. This arrangement may arise where a third party with no other interest in the scheme lets land for an energy centre or pipe route, or where an operator or supplier of energy installs plant and equipment on a client's site.

5. Installers

The installer designs and installs the energy scheme. This might include energy centres, renewable energy technologies, pipework or cabling. Independent Connection Providers (ICPs) are accredited companies that are entitled to build electricity networks to the specification and quality required for them to be owned by a Distribution Network Operator (DNO) or independent DNO (IDNO) and are generally contracted by the Developers of Property.

6. Network Operator

The network operator is responsible for operating and maintaining the distribution assets (pipes/ cables) that transport energy from the generation/production to the end user. In the UK, these roles are provided by a small number of large natural monopolies, namely GDNs and DNOs, who are regulated by Ofgem. Physical private wires, however, may be operated independently. With respect to heat networks specifically, there are several emerging Operators of various sizes that offer their services to operate heat networks.

7. System Operator

The Transmission System Operator (TSO) – operates and maintains the transmission systems for both electricity and gas. The TSO must ensure the stable and secure operation of the networks/system and is regulated by Ofgem. In 2019, Ofgem split the system operator function out from the network operator function, and this now operates independently.

8. Supplier

Suppliers are distinct from the generators and producers of energy in that they are responsible for procuring electricity, heat, natural gas or hydrogen either in the wholesale market, or from generators/ shippers directly, and sell it on to their customers. Suppliers are responsible for duties like billing and metering, collecting revenues, and managing customer debt and default.

9. Regulators

Policy, regulation, and legislation in the energy market is largely the remit of the Department for Business, Energy and Industrial Strategy **(**BEIS) and Ofgem. BEIS monitors, and set policy for, business an industrial users, set climate change policy, as well as promoting innovation within the energy industry. Ofgem oversees the network price controls (RIIO), for the electricity and gas distribution and transmission companies. Ofgem also regulate the network operators at transmission and distribution (ESO and future DSO). The heat and hydrogen markets are currently unregulated. The Heat Trust offers opt-in heat regulation for suppliers, and it is expected that hydrogen will eventually be regulated under Ofgem's gas regulation. In the meantime, operating within unregulated markets offers reduced energy security and protection for customers.

10. Governance

The Governance role includes setting objectives, prescribing policies and rules of conduct and overseeing performance. These objectives, rules and policies will need to be prescribed by the contract(s) under which the scheme is operated.

11. Supplier of last resort

Where the energy provision is not regulated currently (heat / hydrogen), it is best practice to make alternative provision for a "supplier of last resort".

This role involves providing heat/hydrogen to the customers if the scheme's provider is unable to do so (e.g. because of insolvency or because a Concession Period ends and there is no replacement of the responsible party). Supplier of last resort should also be considered when connecting to a private wire style electricity arrangement.

Commercial models longlist

Options overview

As demonstrated on *proposition overview section*, the three propositions differ both in the assets included within the proposition perimeter, and the stakeholders relevant to those propositions. The commercial models therefore differ across the different propositions, in order to reflect their attributes.

Table 5 to the right presents an overview of the different commercial models that could apply across the propositions.

Community owned model	• The community owned model is one where local community group or groups has overall responsibility for owning and operating assets • The priorities of the local community are likely better reflected through a community ownership model, however risk allocation will need careful delineation between project partners. • While the financial returns of the various propositions are unlikely to be a key driver under this model, project funders and financiers will still require some remuneration for the deployment of capital. • Some elements are unlikely to be able to fall under community ownership – and would have to be retained by public sector/private sector ownership model. Clear delineation of roles and responsibilities would be needed under each proposition.
Disaggregated market model	• The disaggregated market model opens up the various propositions to competitive market forces and dynamics. Under this model, a range of stakeholders interact to deliver the SLES, responding to market signals to deliver investment. • Ownership of assets varies across technologies, and investors require returns commensurate with the wider market. • Under the disaggregated market model, risk is allocated to those best placed to manage it, resulting in an efficient operating model. However, there is the potential risk of investment not materialising if there is insufficient demand – and vice versa – known as the chicken and the egg dilemma.
Centralised model	• Under the centralised model, the various propositions would be driven by a single entity. Decisions are centralised, and benefits can be optimised through the community how the 'leader' sees fit. • This entity could potentially make use of sub-contractors to deliver specific elements of the proposition, but ultimate responsibility for the delivery of the programme would sit with the leading entity, either the Port of Milford or Pembrokeshire County Council in the context of the propositions. • The leading entity will assume overall responsibility for organizing the funding of the propositions and is likely to be the owner of many of the assets under consideration. Where specific risks are better managed by other parties, this is where the leading entity could look to subcontract certain responsibilities out. • Under this model, the leading entity , as centralised decision maker, has the power to make decisions almost unilaterally, and can enact change in ways in which market dynamics might not be able to.
SPV / Partnership model	• Under an SPV / Partnership model, a consortium of key project partners would come together to form a special purpose vehicle entity, under which the project would be run, and propositions developed and operated. • This would likely include generation asset owners, IDNOs and private wire owners/operators, and local authority/landowners. This will enable the pooling of expertise, and the appropriate allocation of risk across SPV entities. • This type of model, a partnership arrangement between developers, local authorities and other relevant bodies would also help to facilitate investment in the propositions.

Table 5: Summary of Commercial Model Options

The community owned model

Option 1: Community owned model

Option 1 envisages a community owned model where local community group or groups has overall responsibility for owning and operating assets

The priorities of the local community are likely better reflected through a community ownership model; however, risk allocation will need careful delineation between project partners.

While the financial returns of the various propositions are unlikely to be a key driver under this model, project funders and financiers will still require some for of remuneration for the deployment of capital.

Some elements unlikely to be able to fall under community ownership – and would have to be retained by public sector/private sector ownership model. Would need to be clear delineation of roles and responsibilities under each proposition.

Ownership

- Community ownership of generation assets and most of the various technologies (batteries, electrolysers, heat pumps and boilers etc) – potentially through the establishment of a community Energy Supply Company (ESCo).
- Owned through financing of a green/community bank/ Welsh Gov funding, or leased assets.
- Distribution assets unlikely to be transferred across to community ownership and may need to be owned through IDNO/IGT entity.

Funding

- Community ownership could be funded through a financing and leasing arrangement with an ethical bank such as the Green Investment Bank for example.
- Alternatively, grant funding / subsidies could be secured through Welsh Government funding over a trial period.
- Some assets likely to be funded through conventional avenues, for example distribution assets funded through iDNO/IGT framework.

Revenue

- Revenues recovered from local off-takers for the supply of energy (either building heat and electricity, or transport demand) – with internal hurdle rate (break even and reduce customer bills).
- Some revenue would need to be passed through to investors/funders, in the form of debt repayments.
- Surplus energy sold back to the grid with associated revenue distributed through community/offset against community bills.

Risks

- Certain stranded asset risk, especially around some more nascent technologies like hydrogen transport demand in this case. Risk of return not being realised on assets like electrolyser if demand doesn't materialise. Peripheral technology status should help mitigate this risk, only being enabled when demand increases.
- Revenue risk for distribution assets/ private wire, with operators potential seeking underwriting.
- Would likely have to be some form of public underwriting to provide commercial viability.

Impact on net zero

- Community owned model, would be able to set its own priorities and objectives. Conceivable that reducing carbon impact could be a local priority, but could have detrimental impact if local community prioritises impact on bills (for example) over net zero.

Difference between propositions

- Similarity across propositions means community ownership model theoretically applicable across the three propositions.
- Risk under Propositions 2 and 3 potentially higher with electrolyser identified as core technology with transport hydrogen demand as an off-taker. The propositions would need sufficient demand to make it commercially viable.
- Community element potentially less applicable to Propositions 2 and particularly Proposition 3 as it doesn't actually satisfy all requirements of a SLES and wouldn't be well placed for community ownership because of the nature of the elements included.

The community owned model

Roles and responsibilities

Below are the key roles and responsibilities identified at the beginning of the section and how these are met under the community owned model. In some cases, the entity that assumes a role is consistent across models, but these are highlighted on a case-by-case basis.

1. Customer

Under all the different potential models, the customers in each proposition will likely remain the same. The difference between the models however is both the entity that it is buying the energy from, and the commercial relationship between the customer and that entity.

2. Funder

Under this model, it is anticipated that the local community, through the leading entity will own and fund the SLES. Funding would most likely be originated through a green bank or lender, and there is the potential that certain assets could be leased rather than owned. Some level of grant funding may also be available to community energy projects.

3. Asset owner

Under this model there would be community ownership of generation assets and most of the various technologies (batteries, electrolysers, heat pumps and boilers etc) – potentially through the establishment of a community Energy Supply Company (ESCo).

Assets would likely be owned through financing of a green/community bank/ Welsh Gov funding or leased.

Distribution assets unlikely to be transferred across to community ownership and may need to be owned through IDNO/IGT entity.

4. Landowner

Landowners likely to be consistent across models but differ between propositions. Some form of easements likely necessary for some assets, for example generation assets if situated on third party land.

5. Installers

Community owner would potentially subcontract installation/ construction of assets through an Engineering, Procurement and Construction (EPC) contract, with ownership handed over on completion.

Installation of private wire/ independent network could be done by ICP and then adopted by an IDNO, or just done by an IDNO who would then go on to operate the networks.

6. Network Operator

Community groups unlikely to have the necessary technical capability to operate networks so likely to subcontract this out to an independent network entity, e.g. iDNO.

A similar arrangement would potentially be implemented for any hydrogen transportation.

7. System Operator

National Grid as TSO. A local trading platform as local balancer/ flexibility provider who would probably optimise for local communities' priorities, rather than responding simply to pricing signals.

8. Supplier

Supplier as the ESCo potentially but could also have a standard retail supplier. This would be the intermediary between the generation and off-takers.

9. Regulators

Likely to be consistent across all models, and similar to current regulatory landscape, for example, Ofgem, BEIS, Health and Safety Executive (HSE), Elexon etc.

10. Governance

Community groups may appoint a board to monitor the project and hold different stakeholders to account.

11. Supplier of last resort

The supplier of last resort will depend on the proposition in question. This may be the Council or back-up generators.

The disaggregated market model

Option 2: Disaggregated market model

The disaggregated market model opens up the various propositions to competitive market forces and dynamics. Under this model, a range of stakeholders interact to deliver the SLES, responding to market signals to deliver investment.

Ownership of assets varies across technologies, and investors require returns commensurate with the wider market.

Under the disaggregated market model, risk is allocated to those best placed to manage it, resulting in an efficient operating model. However, there is the potential risk of investment not materialising if there is insufficient demand – and vice versa – known as the chicken and the egg dilemma.

Ownership

- Ownership under the disaggregated market model will differ across asset classes and technologies, and is likely to reflect similar ownership structures as the wider energy market.
- Generation assets like embedded solar and wind are likely to be owned by traditional developers, physical private wires could be owned by off-takers or adopted by private iDNOs.
- Storage technologies could feasibly be owned by generation developers or shared across off-takers (e.g. Pembrokeshire food Park).

Funding

- Under this model, funding would be determined through traditional routes, with private capital (debt or equity). An expectation around future returns will drive private sector capital into the different technology and asset classes.
- Network owners (e.g. iDNOs, and IGTs) are likely to be funded through existing mechanisms, i.e. network charging.
- On site technologies like heat pumps, boilers, chillers etc expected to be funded by the off-taker/ demand, but could potentially tap into public sources of funding. Otherwise funding would be driven by commercial view of optimal solution (e.g. payback period, cost competitiveness with existing technologies).

Revenue

- Network operators revenue recovered through traditional network charging mechanisms.
- Generation assets remunerated through sale of energy to off-takers, or exported to the grid (whichever higher).

Risks

- A model that looks to replicate wider market arrangements is likely to allocate risk across participants most effectively.
- Given the lack of a dedicated 'Project leader' or sponsor, there is a risk that investment may not materialise if the market signals aren't there. For example, through the chicken and egg dilemma of investment vs demand.
- While the risks may be better allocated under a disaggregated market model, there is a real risk that the lack of an organising sponsor may inhibit the formation of an optimal solution. Across the scenarios, there a range of stakeholders, with complex market arrangements at play. A model such as this may struggle to form organically, without some sort of leadership/sponsor.
- Driven by market forces so if generators can recover more money from selling directly to the grid, they will be incentivised to do so, without other arrangements in place.

Impact on net zero

- SLES participants will respond to market signals. In order for this model to further the net zero goal, market mechanisms would need to be in place to incentivise this, for example subsidies. The model in itself wouldn't further net zero without the financial incentive.

Difference between propositions

- Not significant difference expected between the propositions under the disaggregated market model. Certain market participants will differ based on the different technologies in each proposition but interaction between participants would be broadly consistent.

The disaggregated market model

Roles and responsibilities

Below are the key roles and responsibilities identified at the beginning of the section and how these are met under the disaggregated market model. In some cases, the entity that assumes a role is consistent across models, but these are highlighted on a case-by-case basis.

1. Customer

Under all the different potential models, the customers in each proposition will likely remain the same. The difference between the models however is both the entity that it is buying the energy from, and the commercial relationship between the customer and that entity. For example, under this model, relationships will be on a commercial basis.

2. Funder

Funding through a range of sources depending on market participants, developers and iDNOs from own funds. Different entities are likely to tap into external capital as well.

There is potentially some scope for funding from grants, for example the local authority if it owns any of the assets.

3. Asset owner

Different market participants will own different assets, for example developers will own generation assets, iDNOs will own the local distribution network, and the local authority could own heating technologies.

4. Landowner

Landowners likely to be consistent across models but differ between propositions. Some form of easements likely necessary for some assets, for example generation assets if situated on third party land.

5. Installers

Installation of network assets, carried out by ICP or iDNO, determined through the market if it sees enough potential demand and associated revenue through network charging.

Installation of generation assets led by developers, with other technologies installed potentially by off-takers.

6. Network Operator

Network operator expected to be iDNO or another independent network operator. Likely that another entity would need to commission these services.

7. System Operator

National Grid as the TSO as under existing arrangements. Local trading platform as local balancer/ flexibility provider. Under the disaggregated market model, local balancing/trading platform would be expected to optimise based on price maximisation, so local community could be deprioritised if wider market is offering higher price for example.

8. Supplier

Traditional supplier likely to come forward. However, also feasible to envisage the need for some sort of ESCo 'lite' that just carries out basic supplier responsibilities. Not clear how that develops without an organising party under this commercial model.

9. Regulators

Likely to be consistent across all models, and similar to current regulatory landscape, for example, Ofgem, BEIS, HSE, Elexon etc.

10. Governance

Could be a private ESCo, or contractor via contract with developers and promoters.

11. Supplier of last resort

Most likely to be the estate's management company, for instance PCC or the PoMH's facilities teams.

The centralised model

Option 3: Centralised model

Under the centralised model, the various propositions would be driven by a single entity. Decisions are centralised, and benefits can be optimised through the community how the 'leader' sees fit.

This entity could potentially make use of sub-contractors to deliver specific elements of the proposition, but ultimate responsibility for the delivery of the programme would sit with the Milford Haven Port Authority or Pembrokeshire County Council.

The leading entity will assume overall responsibility for organizing the funding of the propositions and is likely to be the owner of many of the assets under consideration. Where specific risks are better managed by other parties, this is where the leading entity could look to subcontract certain responsibilities out.

Under this model, the Port Authority or PCC, as centralised decision maker, has the power to make decisions almost unilaterally, and can enact change in ways in which market dynamics might not be able to.

Ownership

- Asset ownership likely to be centralised under PoMH or PCC, although ownership of some assets may be better placed with other stakeholders.
- It is conceivable to foresee a world in which the PoMH leases generation assets from a Low Carbon Technology (LCT) asset provider, while also owning other assets like ASHPs, chillers and boilers etc.
- Ownership (and potentially operation) of any private wire assets are likely to be sub-contracted out to an independent network operator.

Funding

- The majority of funding under the centralised model would be provided by theleading entity, e.g. PCC or PoMH in its capacity as project sponsor, and could obtain funding through either borrowing (raised on capital markets), or through public sector grants.
- If remaining independent, independent networks would continue to be funded through network charging like under the existing framework.

Revenue

- Majority of revenue accrued from sale of energy, either to off-takers within the proposition boundary, transport demand, or through export to the grid.
- Network owner/operators revenue recovered through network charging, with any other subcontractors revenue through a service level agreement or equivalent.
- The hydrogen production facility would continue to receive revenue for hydrogen produced and sold, and there remains some demand side risk from the demand not materialising.

Risks

- Generally speaking, risks under this model are likely to be less well allocated to those best placed to manage them as many of the risks will sit with the leading entity. As mentioned, in some instances, some responsibilities and their risks could be subcontracted out for particularly complex tasks, like for example network operation.
- Despite this, the centralised model would be able to prioritise the needs of offtakers/ local community, if these were at odds to maximising revenue, for example determining that energy met local demand, even if a higher price could be obtained from selling to the grid.
- Risk of hydrogen demand not materialising as early as expected and not payback period for production facility being extended.

Impact on net zero

- Centralised model should be able to set its own priorities and objectives.
- Should the project anchor decide that net zero ambitions are important – this model should help to further that objective.

Difference between propositions

- Proposition 3 is not a good example of a SLES and the project lead or 'anchor' as discussed in the Economic case is unclear.
- However, a wider stakeholder could assume programme leader that covers all three propositions.

The centralised model

Roles and responsibilities

Below are the key roles and responsibilities identified at the beginning of the section and how these are met under the Centralised model. In some cases, the entity that assumes a role is consistent across models, but these are highlighted on a case-by-case basis.

1. Customer

Under all the different potential models, the customers in each proposition will likely remain the same. The difference between the models however is both the entity that it is buying the energy from, and the commercial relationship between the customer and that entity.

2. Funder

Funding organised through the central entity (Port Authority or equivalent), potentially secured through external borrowing or public sector grant funding.

3. Asset owner

Assets largely owned by centralised entity, although there remains the potential for leasing of LCT assets. Furthermore, independent network assets likely owned by a separate entity as it is expected that they would be operated independently.

4. Landowner

Landowners likely to be consistent across models but differ between propositions. Some form of easements likely necessary for some assets, for example generation assets if situated on third party land.

5. Installers

Centralised entity likely to commission out the installation of various assets through something like an EPC contract and then assume ownership of many of the assets. Installation of independent network more likely to be carried out by and iDNO or ICP with ownership retained by iDNO.

6. Network Operator

The network operator responsibility is likely overly complex for the centralised entity to undertake. We envisage that this role is outsourced to an iDNO or equivalent independent network operator.

7. System Operator

National Grid as TSO as under exiting arrangements. Local trading platform as local balancer/ flexibility provider. Centralised entity would be able to set local policy/ determine how the SLES should be best managed/ which assets to prioritise. For example, providing electricity to the local off-takers, rather than exporting to the grid, or diverting renewably sourced electricity to produce hydrogen through the electrolyser rather than supplying local off-takers.

8. Supplier

Centralised party expected to commission a supplier, potentially through a specific ESCo role.

9. Regulators

Likely to be consistent across all models, and similar to current regulatory landscape, for example, Ofgem, BEIS, HSE, Elexon etc.

10. Governance

Responsibility for governance would be with the centralised party.

11. Supplier of last resort

Would be the centralised party.

The SPV / partnership model

Option 4: SPV / Partnership model

Under an SPV / Partnership model, a consortium of key project partners would come together to form a special purpose vehicle entity, under which the project would be run, and propositions developed and operated.

This would likely include generation asset owners, IDNOS and private wire owners/operators, and local authority/landowners. This will enable the pooling of expertise, and the appropriate allocation of risk across SPV entities.

This type of model, a partnership arrangement between developers, local authorities and other relevant bodies would also help to facilitate investment in the propositions.

Ownership

- Ownership of assets under the SPV model would likely be spread across the various project partners, and there would need to be an exercise to determine the most efficient allocation of ownership and consequently risk.
- It is conceivable to envisage an ESCo could be established to own and operate generation assets, and potentially boilers, ASHPs etc.
- An independent network operator would likely own and operate any private wires/ distribution assets, while the Port Authority/local authority could coordinate priorities within and across the propositions.

Funding

- Under the SPV model, funding would be pooled between project partners, who would either put forward their own capital, or capital could be raised through borrowing.
- Further, it is likely that local authority representation could be secured through the provision of grant funding.

Revenue

- Revenue under this model would be collected by the various project partners. The IDNO/ private wire operator/owner would collect revenue through network charging.
- The owner of the generation assets would receive a revenue for the sale of energy, either to the demand within the proposition boundary, or through export to grid.
- Revenues would either be optimised through market dynamics, or by community need, depending on how the SPV is structured. Operating under an SPV model would allow for the cross-subsidisation of technologies, if for example certain technologies are not as profitable when delivering customer benefit.

Risks

- The SPV would be made up of a small number of projects partners, specialised in their field. Therefore, under this model, risks are likely to be best allocated to those able to manage and mitigate them.
- There is a risk that the objectives and priorities of different SPV partners conflict, and so terms of references and propositions would need to be clearly articulated.

Impact on net zero

- SPV/ Partnership model should be able to set its own priorities and objectives, acknowledging there may be different priorities between the project partners.
- Should the SPV decide that net zero ambitions are important – this model should help to further that objective.

Difference between propositions

- If the SPV was established at the proposition level, it is likely that the entities within each SPV will differ to reflect the specificities of that proposition. For example, under proposition 3, there is no private wire assumed, and so there is unlikely to be a need for an iDNO or other independent network operator.

The SPV / partnership model

Roles and responsibilities

Below are the key roles and responsibilities identified at the beginning of the section and how these are met under the SPV model. In some cases, the entity that assumes a role is consistent across models, but these are highlighted on a case-by-case basis.

1. Customer

Under all the different potential models, the customers in each proposition will likely remain the same. The difference between the models however is both the entity that it is buying the energy from, and the commercial relationship between the customer and that entity. For example, under the SPV model, off-takers like the building demand would hold a supply contract directly with the SPV.

2. Funder

Under the SPV model funding would be expected to be provided by a range of public and private sources. Some stakeholders, like developers and iDNOs would provide their own capital or borrow through the markets, whereas others like local authorities or the wider consortium may be able to access public sector grant funding.

3. Asset owner

Most assets would be owned by the SPV itself, or in some cases, by partners within the SPV. There would need to be an exercise to determine the most efficient allocation of ownership and consequently risk.

4. Landowner

Landowners likely to be consistent across models but differ between propositions. Some form of easements likely necessary for some assets, for example generation assets if situated on third party land.

5. Installers

Installers would either be a part of the SPV (renewable generation developers) or would be subcontracted directly by the SPV with ownership of assets handed over at completion.

6. Network Operator

An independent network operator would likely be a partner in the SPV and would own and operate any private wires/ distribution assets. A similar arrangement would potentially be implemented for any hydrogen transportation.

7. System Operator

National Grid as TSO like under existing arrangements. Local trading platform as local balancer/ flexibility provider. SPV would be able to set local policy/ determine how the SLES should be best managed/ which assets to prioritise in the stack. This would likely be set out in some sort of terms of reference or MoU between SPV partners.

8. Supplier

We would expect that an ESCo was set up and formed one of the project partners under the SPV. This ESCo would take on the supplier duties including metering and billing.

9. Regulators

Likely to be consistent across all models, and similar to current regulatory landscape, for example, Ofgem, BEIS, HSE, Elexon etc.

10. Governance

Likely to be undertaken by the SPV especially if the SPV is local authority led.

11. Supplier of last resort

Having a grid connection would be the last resort for electricity. For heat and hydrogen this is currently likely to be the local authority for its tenants and the Port for its tenants.

Commercial model appraisal

Options appraisal and assessment approach

In refining the options, we have assessed each proposed commercial model against an assessment criteria. An overview of the criteria, alongside the scoring approach is presented below.

#	Criteria	Method of assessment	Scoring methodology
1	**Meets local community needs & priorities**	To what extent will the local communities/ stakeholders needs and priorities be met through the commercial model?	*H – Aims and objectives of the commercial model closely aligned with the local community/stakeholders.* *M – Some of local community/stakeholders interests aligned with commercial model but not all.* *L – Significant differences between objectives of commercial model and local community/stakeholders.*
2	**Allocates risk efficiently**	To what extent are risks efficiently allocated, i.e. are they borne by those best placed to manage them?	*H – Risks are allocated to those best able to manage them* *M – Most risks efficiently allocated but model structure means some are unable to be.* *L – Inefficient allocation of risk.*
3	**Incentivises private investment**	To what extent will the proposed commercial model encourage and incentivise private or 3rd party investment?	*H- Significant opportunities for private investment with clear revenue streams available* *M - Some opportunities for private investment with some revenue streams available to developers* *L - Limited opportunities for private investment with no existing revenue streams available*
4	**Achievable within existing regulatory framework**	To what extent can the proposed commercial model be implemented within the existing policy and regulatory framework?	*H - No changes required under existing regulatory arrangements and framework.* *M - Some changes required to existing framework, e.g. licence and/ or code modifications.* *L - Significant changes to regulatory model required, e.g. primary legislation.*
5	**Replicable at scale**	To what extent can the proposed model be implemented in other geographies, where another SLES has different characteristics?	*H - Easily replicable at scale, and to other geographies, without significant change to model.* *M - Applicable in some cases, but changes in framework required to enable national roll out.* *L - Commercial model only applicable in Milford Haven area little potential for national roll out.*
6	**Applicable to propositions**	To what extent can the proposed model be applied to the SLES propositions?	*H – Applicable to all three of the propositions will clear allocation of roles and responsibilities.* *M – Applicable to one or two of the propositions but not all.* *L – Not applicable to any of the propositions identified.*
Models will be assessed against the six criteria and awarded points based on their results. Points will be summed to allow for a comparison across the different models. H = 3 points, M = 2 points, L = 1 point.			

Table 6: Commercial models option assessment summary

Commercial model appraisal

Options assessment

Figure 40 below presents the results of the multi criteria assessment – this assessment shows that the SPV/Partnership model scored the highest.

Criteria / Model	Meets local community needs & priorities	Allocates risk efficiently	Incentivises private investment	Achievable within existing regulatory framework	Replicable at scale	Applicable to propositions	Score
Community owned model	H - Community owned so can set own direction/ objectives	L - Majority of risks sit with community owned entity with limited outsourcing	L - Prioritisation of community benefit over project returns likely to inhibit investment	M - Potential issues around ownership of network and generation assets	L - Would be very specific to Milford Haven stakeholders and difficult to replicate	M – Would not be applicable to proposition 3	10
Disaggregated market model	L - Market dynamics/revenue optimisation at expense of community need	H – Market to determine most efficient allocation of risk	M - revenues in place but demand risk may deter investment in certain assets	H - Fully implementable within existing framework	H - at conceptual level should be simple to replicate nationwide	H – could be applied to all 3 of the propositions	15
Centralised model	H - Central entity determines SLES objectives and needs	M - Most risk sits with central entity but some subcontracted out	M - Revenue streams in place but may not be prioritised under SLES objectives	M - Potential issues around ownership of network and generation assets	M - Potentially replicable but would need to reflect new stakeholders	M – Would not be applicable to proposition 3	13
SPV / Partnership model	M - Compromise of aims across SPV partners. Although community to have representation	H - Risk to be allocated across SPV partners and subcontracted where necessary	H - Clear revenue streams for all project partners	H - Fully implementable within existing framework	H - at conceptual level should be simple to replicate nationwide	H – could be applied to all 3 of the propositions	17

Figure 40: Results of the commercial models assessment

The recommended commercial model

Example Use case: SPV / Partnership model

Developing and articulating a use case can help to demonstrate how the Commercial case might operate in practice. A use case provides a set of interactions between users in an environment, and in this case, the relationships between stakeholders in the Milford Haven propositions.

Figure 41 presents a potential use case for the SPV/ Partnership commercial model under Proposition 1: Milford Haven Heat Network and Microgrid SLES. The SPV commercial model has been chosen as the highest scoring through the multi criteria options assessment.

Key:

1. Solar/wind farm generates and dispatches. Trading platform/ SPV determines if energy flows to storage, electrolyser, local electricity demand, or exported to grid based on a criteria.
2. Heat demand met through electricity or gas based on optimisation from the trading platform.
3. Electricity demand met either direct from embedded generation, battery storage or imported from the grid.
4. Electrolyser sells hydrogen to local hydrogen transport demand, or exports.
5. Supplier/ ESCo acts as intermediary and organises payment and billing between off-takers, generators, and network operators.

- Energy flows
- Money flows
- SPV Perimeter
- Offtakers
- Technologies
- SPV Partners
- Network operators

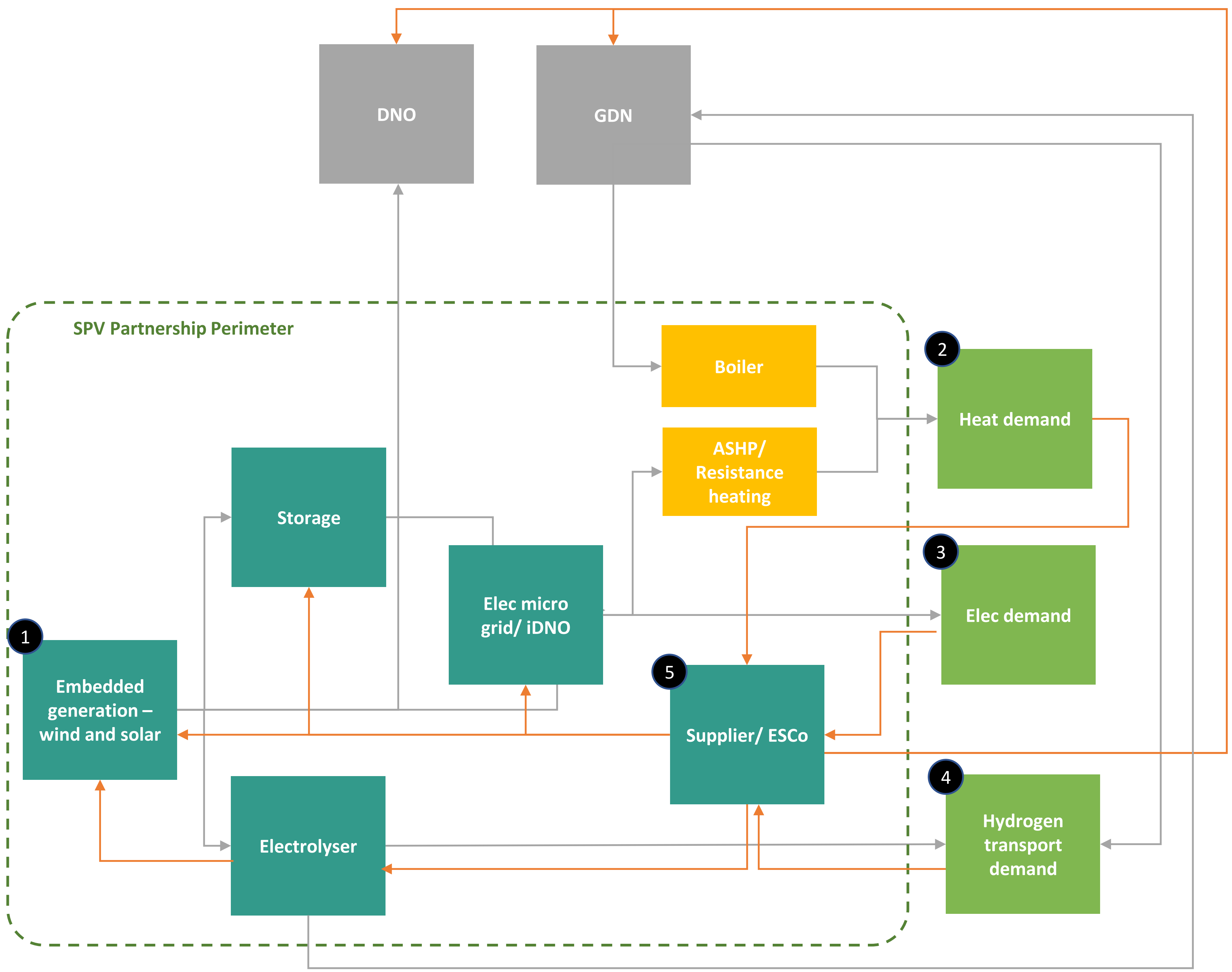


Figure 41: SPV Partnership model

The recommended commercial model

SPV Model: Summary impact across propositions

The SPV model has been identified through the assessment as the highest scoring commercial model in the longlist.

In determining that, the following looks to consider the SPV model in further detail, highlighting the applicability to the different propositions, and how the risks, challenges and potential actions under the SPV model differ between the propositions.

SPV / Partnership model

Proposition 1 - The Milford Haven Marina SLES

Best fit
- Despite small differences between the three propositions, we consider the SPV model to be the best fit across all three.

Challenges/ issues
- Potentially conflicting commercial interests given number of stakeholders involved in the SLES.
- Potentially complex interfaces will require more sophisticated optimisation of the trading platform.
- Prioritisation of SLES will need identifying, e.g. which party to prioritise.

Actions
- Undertake more detailed mapping of revenue flows, SPV partners, and commercial relationship between parties.

Key regulatory risks
- Identified in the following section

Proposition 2 - The Pembrokeshire Food Park SLES

Best fit
- Despite small differences between the three propositions, we consider the SPV model to be the best fit across all three.

Challenges/ issues
- Commercialisation and revenue streams for hydrogen transportation less clear.
- Potentially complex interfaces will require more sophisticated optimisation of the trading platform.
- Prioritisation of SLES will need identifying, e.g. which party to prioritise.

Actions
- Undertake more detailed mapping of revenue flows, SPV partners, and commercial relationship between parties.

Key regulatory risks
- Identified in the following section

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

Best fit
- Despite small differences between the three propositions, we consider the SPV model to be the best fit across all three.

Challenges/ issues
- Proposition 3 is not a good example of a SLES and the project lead or 'anchor' is unclear. Delineation of roles may be more difficult under this proposition.

Actions
- Identification of potential SPV partners.
- Undertake more detailed mapping of revenue flows, SPV partners, and commercial relationship between parties.

Key regulatory risks
- Identified in the following section

Commercial models recommendations

Findings

This section has sought to explore some of the commercial considerations of the various propositions, and what the potential commercial model could look like to make the propositions commercially viable.

In doing so, we have identified the various roles and responsibilities that would need allocating across the stakeholders in each of the MH:EK propositions.

We have developed and articulated at a high level four potential commercial models: Community owned model; Disaggregated market model; Centralised model; and an SPV / Partnership model.

For each model we have set out:

- Who would own assets;
- How the SLES would be funded,
- The revenues available to SLES participants;
- How risks and allocated; and,
- How these might differ across the propositions.

Through a multi criteria assessment we found that the SPV/ partnership model scored the highest and delivered best against the criteria assessed.

An SPV/Partnership model would be able to reflect the local communities needs and priorities as we would expect that there would be some sort of community representation within the SPV. How the SLES is optimised would need to be decided by the SPV as there would ultimately be trade-offs between where energy is directed to, and which offtakers are prioritised.

We understand through previous conversations that the PoMH would seek the support of other organisations to drive and promote a SLES rather than leading it themselves. We would need to explore with PoMH and PCC if they would be comfortable as an SPV partner.

The SPV model would allow for an efficient allocation of risk as a range of entities would sit within the SPV as project partners, and risks could be allocated to those best able to manage them. Further, we see clear revenue streams available to SPV partners, which we consider would incentivise private investment, either from project partners themselves, or through external funding, likely in the form of borrowing.

The SPV model appears broadly achievable within the existing regulatory framework, although more consideration is given to this is the following section. We also consider the SPV model to be replicable at scale. Project partners would inevitably differ, but we consider the general structure to be transferable.

Recommendations

The work carried out represents a high-level review into some of the factors that would help to improve the commercial viability of the different SLES propositions, and an exploration of potential commercial models that could be applied.

The initial findings show that a commercial model made up of several project partners under an SPV type structure could potentially be viable, and applicable to the various propositions considered. With respect to Proposition 1 in particular, this aligns with the PoMH's preference to not lead a SLES, but rather act as a project partner.

As part of a next stage of the study, we would recommend that further work is done to explore the applicability of the SPV / Partnership model. We particularly recommend that a number of specific use cases are worked through, to identify how each of the different stakeholders would interact under the model. This exercise would also further articulate the revenue flows between stakeholders.

We would also recommend that this potential model is started to be tested with the various stakeholders to explore their appetite for such a model, and to better understand what risks or barriers there might be in implementing it.

Finally, we would recommend exploring in more detail how the ESCo model would work in practice, what the relationship would be with other project partners, and the commercial relationship with entities outside of the SPV partnership perimeter.

Policy and regulations

Section Overview

High Level Overview of Regulatory Environment

- The UK energy sector operates under a complex regulatory system: sector bodies face differing degrees of market freedom and must follow distinct sets of codes, licensing arrangements, and legal requirements.
- Energy policy in the UK is set by the government Department for Business, Energy, and Industrial strategy (BEIS).
- BEIS mandates the industry regulator, Ofgem, to protect consumers in market segments operating under regional or national monopolies.
- Ofgem is governed by GEMA, the Gas and Electricity Markets Authority. Interactions between key market bodies are illustrated in the following slide.

System Decentralisation

- As part of the energy transition, significant market transformation is underway. This is marked by system decentralisation, digitalisation, and flexibility.
- In a centralised system, market users perform distinct roles in the energy supply chain: a generator might own a generation plant, sell power to a separate supplier, and export it onto an energy network operated by a separate DNO, who then distributes the energy to a separate user.
- Decentralised, distributed systems can create overlap between these roles – in some systems, generation, supply, and distribution could be performed by one user.

Regulatory Challenges

- Although some technologies or market users feature more prominently between the three proposed SLES models, they face similar regulatory barriers. Some recent and expected regulatory changes affect the systems and technologies featured in the propositions.
- The three SLES propositions must be compliant with existing regulatory and legal requirements. Business model selection and development should consider regulatory barriers and opportunities for mitigation.

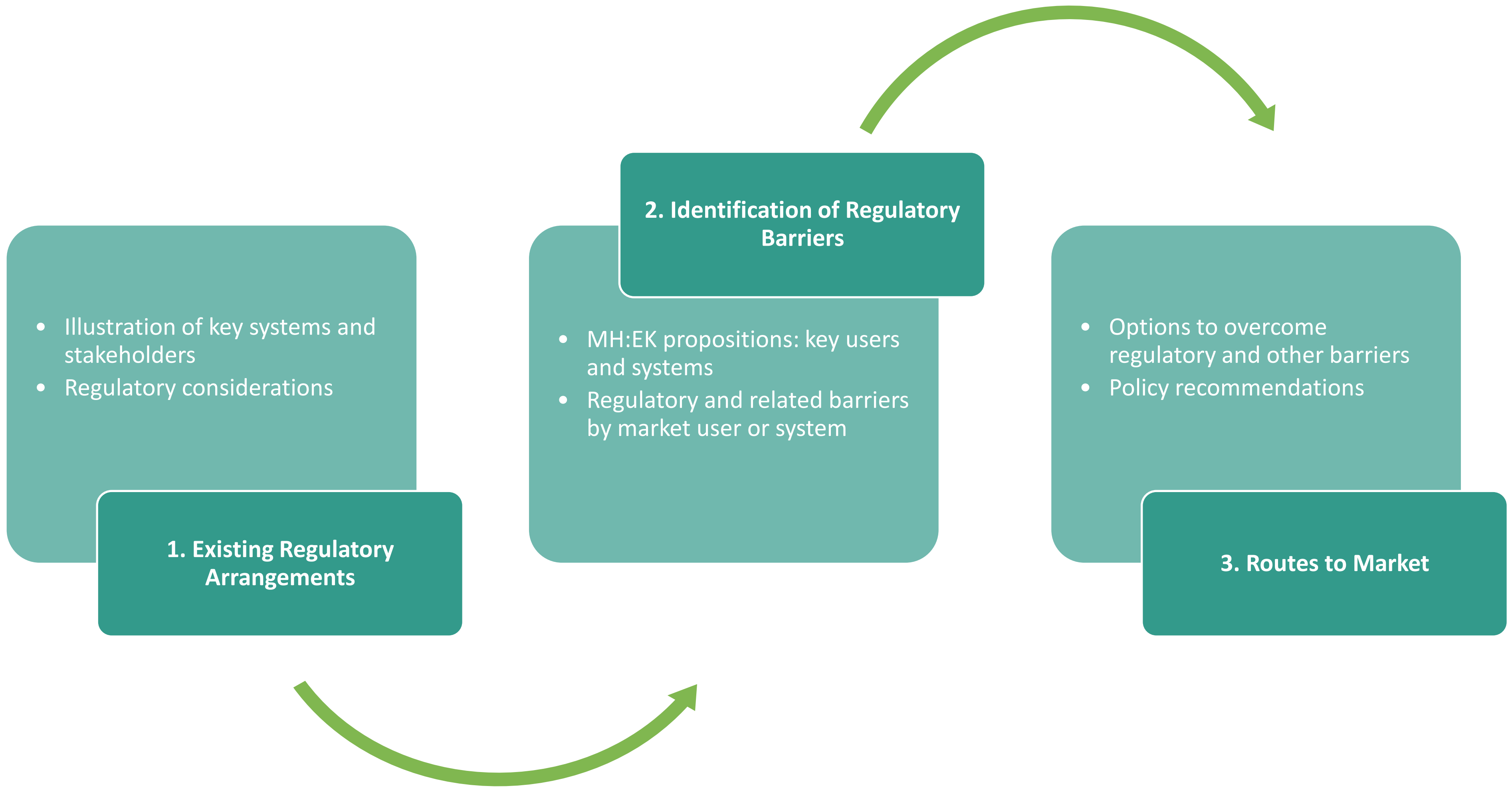


Figure 42: Overview of the policy and regulatory review

Policy and regulations

Stakeholder mapping under existing regulatory framework

The energy market map on Figure 43 illustrates, at a high level, the existing relationships between some of the market users, systems, and technologies most relevant to the regulatory environment.

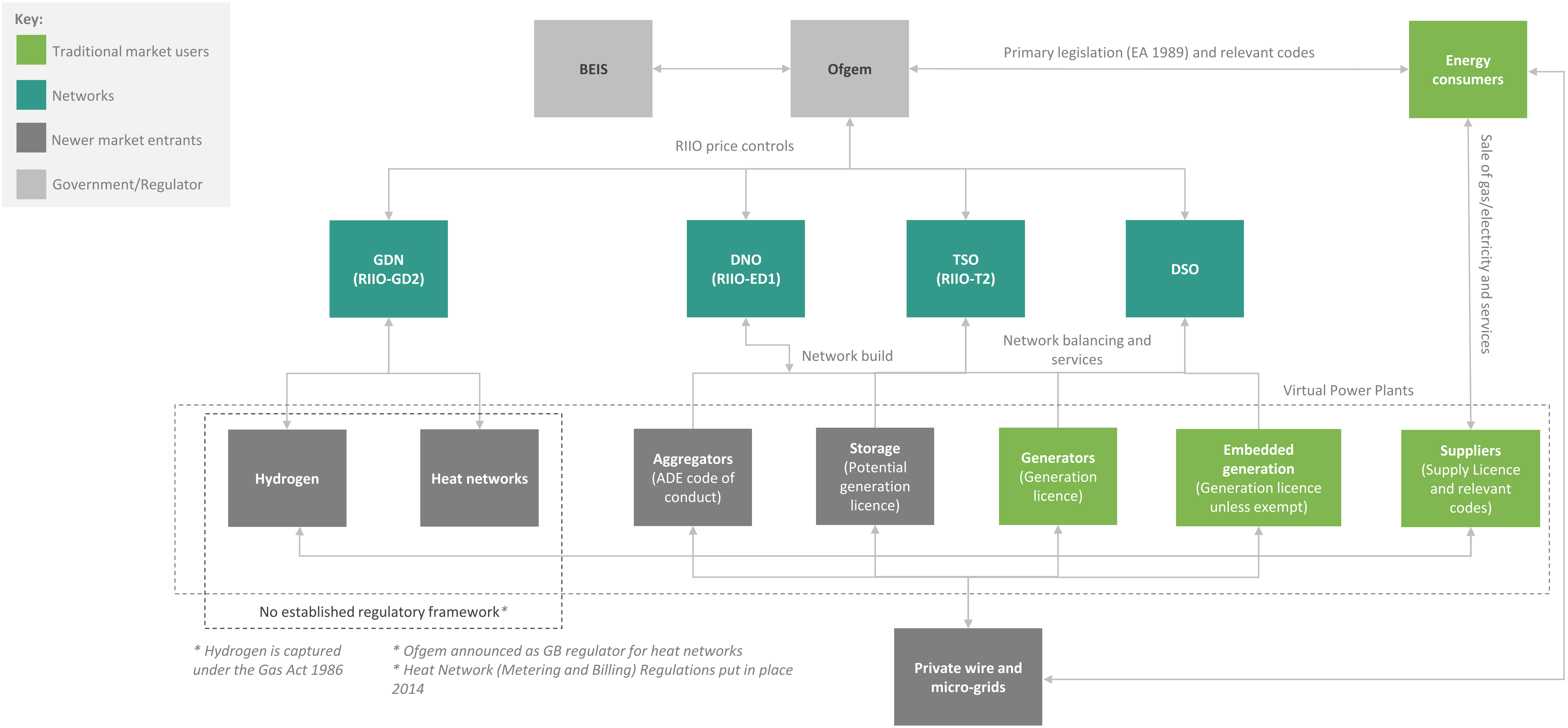


Figure 43: Summary of stakeholder mapping under existing regulatory framework

Policy and regulations

Key:
Traditional market users
Newer market entrants
Networks
Government/Regulator

Existing Regulatory Arrangements (1/2)

Table 7 outlines some of the existing regulatory arrangements most relevant to the market users, systems, and technologies identified in the market map on Figure 43.

BEIS (Business, Energy, and Industrial Strategy)	Ofgem	DNO / GDN / DSO	TSO / ESO (electricity and gas)
• BEIS (the UK Government Department for Business, Energy, and Industrial Strategy) help develop industrial strategy and deliver competitive markets. • BEIS does not actively regulate companies. • BEIS monitors progress on climate targets, including the UK's commitment to achieving net zero climate emissions by 2050. • The Secretary of State for BEIS can provide regulatory exemptions to some small generators (see embedded generation on the following slide).	• Ofgem is the industry body that regulates networks and oversees price controls • Ofgem holds direct regulatory power over some market bodies (mainly national or regional monopolies like networks), with indirect dealings (including licencing and code reviews) with unregulated markets (e.g., the retail energy market). • Ofgem approves funding for energy market innovation (e.g., in Hydrogen projects associated with networks). • Ofgem runs a regulatory sandbox for pilots and demonstrations in energy industry and alleviates regulatory barriers to innovation.	• DNOs and GDNs operate and maintain regional electricity and gas distribution networks, respectively. • Great Britain has eight gas GDNs and 14 electricity DNOs (owned by six DNO groups), plus smaller independent "IDNOs". • IDNOs do not have regional monopolies and licensing as an IDNO presents a lower regulatory hurdle; 15 are licensed in GB. • DNOs and GDNs are regulated by Ofgem under price controls. Current price controls: power distribution RIIO-ED1 (2015-2023), gas distribution RIIO-GD2 (2021-2026). • DSOs are a newer entity that perform distribution system operation and interact more closely with the transmission network.	• The TSO operates and maintains gas and electricity transmission systems / networks. • National Grid Electrical Transmission (NGET) owns the English and Welsh electricity transmission networks, and both Scottish Power and Scottish and Southern Electricity Networks own parts of the Scottish. • NGESO, a separate legal entity, operates the entire GB electricity transmission system. • National Grid plc owns and operates the GB gas National Transmission System (NTS). • Northern Ireland maintains a transmission system with the Republic of Ireland. • Regulated by Ofgem under the current price control: RIIO-T2 (2021-2026).
Elexon and the BSC	**Energy Suppliers**	**Energy Consumers**	**Generators**
• Elexon is the body administrating the Balancing and Settlement Code (BSC). • Elexon monitors predicted or stated vs actual electricity production and consumption values, and settles imbalances. • The BSC contains the governing rules for the market's Balancing Mechanism (BM). • Licenced generators, transmission owners, distribution operators, interconnectors, and suppliers must sign up to the BSC. • In 2021, Ofgem approved a modification to the BSC allowing meters behind the connection point to be used in settlement and affording smaller asset owners, like storage providers and embedded generators, opportunities to provide balancing services.	• Energy suppliers ("retail" suppliers) purchase energy and sell it to the consumer. • The retail energy market is a competitive one and not directly regulated by Ofgem; however, there are licence requirements and codes of conduct. Ofgem appoints a "Supplier of Last Resort" to step in when retail suppliers fail. • Supplier codes and agreements with other market users include: BSC, SEC, CUSC, DCUSA, MRA, SPAA, DCODE, UNC (see glossary). • Suppliers can be responsible for renewable scheme obligations. • Suppliers can be unlicenced in some cases, including when supplying to a limited number of consumers.	• Energy consumers are the end-users of gas, electricity, hydrogen, and heat. • Energy consumers' interests are safeguarded by Ofgem, as the regulator's primary responsibility. • BEIS monitors consumer and public interests, e.g., fuel poverty, and creates policy. • Security of supply to the consumer is maintained under SoLR (see left) by Ofgem. • Energy consumers are protected under the Electricity Act (1980). • Energy consumers include users from the domestic, industrial, transport, commercial, agriculture sectors.	• Larger generators produce electricity and transmit it onto the transmission network. Smaller generators might export directly onto the distribution network. • Generators operate in a competitive market and are not directly regulated by Ofgem; they compete to sell energy on the wholesale market and BM, or directly to a consumer via a Power Purchase Agreement (PPA). • Generator codes and agreements include DCODE, DCUSA, CUSC, Grid Code, and BSC. • Larger (>100 MW) generators must hold a licence and pay both transmission and distribution charges, while smaller generators might be unlicenced and pay only distribution charges (or use a private wire).

Table 7: Summary of existing regulatory arrangements relevant to stakeholders on the market map

Policy and regulations

Key:
- Traditional market users
- Newer market entrants
- Networks
- Government/Regulator

Existing Regulatory Arrangements (2/2)

This table outlines some of the existing regulatory arrangements most relevant to the market users, systems, and technologies identified in the market map on Figure 43.

Embedded / Distributed Generation	Aggregators	Storage Owners	Hydrogen Networks
• Embedded or distributed generators are smaller (<100MW) and transmit electricity directly onto the distribution network or to the user via a private wire connection. • BEIS can exempt licence requirement, but a licence (or a licenced proxy) is required to operate in the balancing mechanism (BM). • Embedded benefits were reduced in 2018 and again in 2021. Ofgem's 2020 TCR set TGR to zero, removing disadvantage to smaller generators. However, the TCR also removed the BSUoS embedded benefit from 2021; a subsequent Task Force determined BSUoS charges should be levied on final demand.	• Aggregators act as intermediaries between energy suppliers and groups of domestic end users, providing balancing services via the coordination of demand-side response. • Aggregators have a growing role in the integration of distributed energy resource (DER) into the market and flexibility services. • Aggregators are not directly regulated by Ofgem, but follow an industry conduct code; access to the BM was granted by Ofgem for all aggregators. • BEIS is currently consulting the results of a call to evidence concerning "Third-party intermediaries in the retail energy market".	• Provide energy storage, e.g., for balancing and flexibility. With the energy transition, this has a growing role in the market. • Storage owners are not regulated by Ofgem directly, but there are barriers to market entry (e.g., limitations against DNOs). • Changes to the BSC allow smaller storage owners access to the BM and the use of "asset metering" (behind the connection boundary) in BM settlement. • Electricity storage development falls under the Infrastructure Planning (Electricity Storage Facilities) Order 2020. Pumped hydro storage falls under the NSIP regime.	• Under GSMR, hydrogen is permitted to enter the gas network only up to levels of 0.1%. • Technical and economic regulation must be developed if a case is made for the use of hydrogen (for heat, transport, etc.) in ongoing demonstrations and studies. • ENA *[22]* announced that the British gas grid is set to be ready to deliver gas blended with 20% hydrogen by 2023. BEIS is to make a decision on hydrogen for domestic heating in 2026. • The current gas distribution price control, RIIO-GD2, includes uncertainty mechanisms to fund network innovation (e.g. £12m to Cadent for hydrogen development in industrial clusters).
Heat Networks	**Private Wire**	**Micro-Grids & Closed Distribution Systems**	**Virtual Power Plants (VPPs)**
• In December 2021, Ofgem was officially appointed as the regulator for heat networks in Great Britain. • There is no existing regulatory framework for heat networks in GB; however, after Ofgem's appointment as regulator, it was announced that Ofgem will be working with the Government to design such a framework. • This regulatory framework is likely to cover all heat networks regardless of size. In an open consultation, Ofgem proposed a cost recovery scheme that shares regulatory fees across gas, electricity, and heat networks. • The CIBSE code of practice applies to heat network operators and the Heat Trust protects consumers.	• Typically, a private wire is a direct generator-to-user connection. Private wire connections are not directly regulated by Ofgem and tend not to require supply licence (if they are serving a sufficiently small number of users). • Private wire connections are typically privately funded, with a PPA arrangement for energy payment to the generator. • Ofgem's 2020 TCR amended distribution network "residual charges" from a variable charge, based on energy consumption, to a fixed charge for all users. This increases the residual charge for connected users generating (or using energy generated) "behind the meter" (connection boundary) that were previously avoiding these charges.	• Micro grids are small distribution systems containing DER, storage, and users. • Micro-grids can be connected to the main energy grid and are not directly regulated by Ofgem; however, users may require licences. • Micro-grids were under the scope of Ofgem's 2020 TCR, which removed the benefit of residual charge avoidance. • Closed distribution systems are generally small, licence-exempt distribution networks that serve a limited number of end users. • Tariffs and charging methodologies in closed systems do not require Ofgem approval.	• Care a combination of DER with smart grid technology, software, and IoT-enabled assets. • VPPs can remotely control and optimise DER, aggregating the distributed assets into a coordinated power plant. • VPPS are able to participate in energy trading as an intermediary between aggregated DER and the wholesale market. • VPPs can provide ancillary services for balancing and can access the BM. • System operation or coordination is a service that VPPs can provide for energy hubs or smart local energy systems (SLES).

Table 7 (continued): Summary of existing regulatory arrangements relevant to stakeholders on the market map

Regulatory barriers

Key:
- Traditional market users
- Newer market entrants
- Networks
- Government/Regulator

Identification of Regulatory Obstacles (1/3)

This section outlines three propositions for Smart Local Energy Systems in Milford Haven. For each proposition, the key stakeholders, systems, and users are highlighted: this will help to identify where there are regulatory barriers.

Proposition 1: The Milford Haven Marina SLES

- A potential microgrid for the Milford Haven marina by forming a SLES incorporating the demand and supply assets owned by PoMH.
- The preferred system includes embedded renewable generation at Liddeston Ridge and a physical private wire to Milford Haven Waterfront. Energy is additionally imported from and exported to the broader network. Little hydrogen is produced within the SLES; hydrogen is mainly imported and used to meet transport demand.

Proposition. 2: The Pembrokeshire Food Park SLES

- Using electricity from the nearby airfield PV to power the proposed Pembrokeshire Food Park operations as well as freight and other transport demand.
- The preferred system includes renewable generation at Haverfordwest Airfield with a physical private wire to Pembrokeshire Food Park. Energy is imported into and exported out of the system. More hydrogen is produced than in P1, and is stored within the system. Biogas is produced and used in the system for heat and cooling.

Proposition. 3: The Pembroke Schools, Leisure Centre, and Dock SLES

- 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.
- The preferred system includes embedded renewable generation in Pembroke, with energy to be exported to (the grid / a micro-grid) to serve the demand centre. The preferred system produces little hydrogen, but imports it as well. Electrical and gas heat conversion is used initially, but natural gas is phased out.

Relevant market users: Milford Haven Marina SLES

TSO	DSO	DNO	GDN
Generators	Embedded Generators	Suppliers	Energy Users
Networked H2	Embedded H2	Heat Networks	Aggregators
Storage / V2G	Private Wire	Micro-Grids / SLES	VPPs

Relevant market users: Pembrokeshire Food Park SLES

TSO	DSO	DNO	GDN
Generators	Embedded Generators	Suppliers	Energy Users
Networked H2	Embedded H2	Heat Networks	Aggregators
Storage / V2G	Private Wire	Micro-Grids / SLES	VPPs

Relevant market users: Pembroke Schools, Leisure Centre and Dock SLES

TSO	DSO	DNO	GDN
Generators	Embedded Generators	Suppliers	Energy Users
Networked H2	Embedded H2	Heat Networks	Aggregators
Storage / V2G	Private Wire	Micro-Grids / SLES	VPPs

Regulatory barriers

Key:
- Traditional market users
- Networks
- Newer market entrants
- Government/ Regulator
- Low risk / disruption
- Medium risk / disruption
- High risk / disruption

Identification of Regulatory Obstacles (2/3)

This section outlines some key regulatory obstacles, uncertainties, and changes that face the market users, systems, and technologies highlighted for each SLES proposition in the previous slide. These obstacles are rated from "low risk" to "high risk".

Transmission System Operator (TSO)

Established regulatory arrangements with low risk. Proposition interactions with TSO relate to the import / export of energy into / out of the system via networks.

Distribution System Operators (DSOs)

Established regulatory framework including licencing and price control. The proposed SLES models could contribute to the DSO's system balancing role by providing flexibility services to the grid in the form of storage and demand response (contracted flexibility).

Power Distribution Network Operators (DNOs)

Established regulatory arrangements with low risk. Proposition interactions with DNOs relate to the import and export of electricity into and out of the system via distribution networks. If the SLES is connected to the distribution network, it must pay residual charges independent of energy used. More flexible network access options have been proposed by Ofgem in an ongoing Strategic Charge Review awaiting decision. Proposed private wire operation could be exempt from distribution licence requirements under limitations.

Gas Distribution Network Operators (GDNs)

Established regulatory arrangements with low risk (for natural gas). Proposition interactions with GDNs relate to the import and export of gas into and out of the system via distribution networks. GDNs could also operate networked hydrogen in the future, facilitating hydrogen imports into the system (area of higher risk).

Embedded Generation

Established regulatory arrangements with some risk. Proposed local generation plans must receive planning consent, which introduces risk into the development of the local generation proposed under the SLES models.

BSUoS embedded benefits were removed in Ofgem's 2020 TCR decision to avoid market distortion.

Where there is a network connection, the DNO must be informed of any planned generation installations. Ofgem is developing policy around generation assets connected to the distribution system as part of the regulator's full-chain flexibility vision.

Energy Suppliers

Established regulatory arrangements with some risk. Dependent on the commercial model, the proposed SLES regime could engage with existing retail suppliers, that operate under market conditions and are licenced by Ofgem. Regulatory complications, including licensing requirements, when the generator acts directly as the distributer and supplier. Supply can be made without a licence in limited circumstances: <= 5MW with <=2.5MW domestic, or <=100MW with <=1MW domestic from on-site generation to users in a private network.

Energy Users

The Smart Systems and Flexibility Plan 2021 reiterates Ofgem's obligation to consumer protection and specifies that this will continue in smart local systems. Innovative energy models, like SLES, require investment that can risk customer over-payment.

Networked Hydrogen

No existing regulatory framework or regime, although as a gas, hydrogen falls under the Gas Act 1986. BEIS is to make a network decision on Hydrogen in 2026. Risk of stranded assets if selected proposition relies on networked hydrogen. Under current regulations, hydrogen is not permitted to enter the existing gas network above levels of 0.1%.

Embedded Hydrogen

Planning for smaller scale projects can be approved under the Town and Country Planning Act (1990) and the Planning Act (2008). Hydrogen production must follow the Dangerous Substances and Explosive Atmosphere Regulations (2002). If hydrogen is to be transported, this must take place in tanks that follow Pressure Equipment Safety Regulations (2016).

Storage / V2G

DNO ownership and operation of storage is limited under current regulations; third-party ownership is under no such limitations.

In 2022, Ofgem will develop policy around the use of V2G for system flexibility, including a call for evidence.

Hydrogen storage has higher regulatory barriers and may require an Environmental Impact Assessment under the Town and Country Planning Regulations (2017). Hydrogen storage is regulated under the Control of Major Accident Hazards Regulations (2015) and Dangerous Substances and Explosive Atmosphere Regulations (2002).

Regulatory barriers

Key:
- Traditional market users
- Networks
- Newer market entrants
- Government/ Regulator
- Low risk / disruption
- Medium risk / disruption
- High risk / disruption

Identification of Regulatory Obstacles (3/3)

This section outlines some key regulatory obstacles, uncertainties, and changes that face the market users, systems, and technologies highlighted for each SLES proposition two slides previous. These obstacles are rated from "low risk" to "high risk".

Private Wire

Using a private wire connection in combination with plans to import and export electricity from and onto the grid introduces regulatory complexity and risk. If there is a connection to the grid, the user must still pay fixed and capacity-based (but not volumetric) distribution charges regardless of volumetric consumption.

Depending on the offtake arrangements, only surplus energy (that not supplied to the energy demand centre) may be exported to the grid, the energy demand centre might also be prevented from importing energy from the grid unless there is an energy deficit from that produced by the generator.

Responsibility must be determined as to the capital costs of connection installation and infrastructure, as well as operational costs of connection maintenance. The end user can be the owner of both the generator and the private wire and would then be responsible for the costs of the private wire. The generator and the private wire can also be owned by a third party from which the end user would purchase the energy via a PPA.

Aggregators

The Smart Systems and Flexibility Plan 2021 announced that BEIS will consult on "a regulatory approach for flexibility service providers and other organisations controlling load". Ofgem has reiterated that it will protect consumers in SLES regimes, which could include interventions with third-party intermediaries like aggregators.

Micro-Grid / SLES

SLES, by virtue of their size, can have lower regulatory barriers than those faced by larger networks. However, as systems rather than bodies, regulatory navigation becomes more complex; i.e., each component of the system must be compliant with its own legal or regulatory requirements.

Likewise, because SLES solutions are not uniform in their structure or delivery – and are therefore not replicable between systems, they can introduce inefficiencies (e.g., into the design and impact assessment phase). Risk factors include timing of delivery, local demand, and level of reactivity vs proactivity (futureproofing). If left unmitigated, these can increase costs to the user.

SLES receive government support under the Industrial Strategy Challenge Fund, Prospering from the Energy Revolution programme, and Local Energy Programme.

Heat Networks

No established regulatory framework – Ofgem have announced that it will be working with BEIS to design such a framework. This framework is likely to cover all heat networks, regardless of size, down to small communal networks serving one building.

Virtual Power Plants (VPPs)

VPPs, like other third party users, are not directly regulated. Regulatory barriers would include ownership of the assets within the VPP – if a licenced generator owns these assets, they could provide supply but not distribution unless in a closed system.

Other, risks, obstacles, and barriers that were not highlighted but are relevant to the propositions are outlined below:

Access to Trading Platforms

While permitted under regulations, market entry to trading platforms can be challenging for small generators, who can face substantial up-front and operational costs (e.g., setting up traders, subscriptions to trading platforms, establishing a trading strategy).

Access to the Main Grid

The proposed SLES models include a connection of the local system to the main grid. This incurs distribution charges and requires that the main grid have visibility of the SLES system, including generation and storage.

Co-Ownership of Assets

Generation, distribution, and supply can be performed by a single entity under certain limitations relating to the amount of energy being distributed, the end users of the energy, the location of the generator and the user, and the type of network (e.g., private wire). Licensed DNOs cannot own storage assets.

Hydrogen Demand

The extent of hydrogen use in a decarbonised energy system remains uncertain. Hydrogen is used to meet refuelling and transportation demand in proposed models. There is a stranded asset risk associated with this demand not materialising with low uptake for hydrogen-fuelled transportation modes.

Overcoming regulatory barriers

Key:
- Traditional market users
- Networks
- Newer market entrants
- Government/ Regulator
- Low risk / disruption
- Medium risk / disruption
- High risk / disruption

Options to Overcome Regulatory Barriers

This section presents options to avoid or overcome some of the most relevant regulatory barriers. Regulatory barrier risk is rated from "low risk": little, or easily overcome disruption – to "high risk": high uncertainty or difficult to circumvent.

Licencing Requirement Exemptions

The embedded energy generator can act directly as the distributer and supplier in a private wire system. In such a system, generation and network assets can be owned by a single body. As per the Electricity (Class Exemptions from the Requirement for a Licence) Order 2001:

Generators can be exempt from licencing requirements if they are "small" (their capacity is limited at 100MW and they provide 50MW of power or less at any one time), or, serve a single (or qualifying group) customer that consumes or distributes that power *on site*.

Distributers can be exempt from licencing requirements if they are "small" (power distribution is limited to 2.5MW to domestic users), they are "on-site" (system limited to 1MW for distribution to domestic users), or, all power is distributed from an embedded generator, or, no distributed power is used by domestic consumers).

Suppliers can be exempt from licencing **requirements** if they are "small" (energy supply is limited to 5MW of generated energy with 2.5MW to domestic users), or, they are "on-site" (supply is limited to 100MW to be consumed on site, with 1MW to domestic consumers).

Licence Lite and Innovation Derogations

Another option to ease the regulatory barriers posed by supplier licencing requirements, in a commercial model where a licenced supplier is required, would be partnering with a third-party licensed supplier and applying for standard license condition exemption under Ofgem's **Licence Lite**. If this is applicable to the selected SLES proposition and commercial model, application to Licence Lite should be delayed until the proposition is further developed. In the interim, **informal engagement with Ofgem** could be undertaken.

Access to Markets

Wholesale Market

Access to trading platforms was identified as risk in the previous slide because of high market entry barriers. Surplus energy can be sold directly to offtakers in the wholesale market, but access to wholesale trading platforms is expensive for small-scale generators.

Alternatively, small (<=5MW) low-carbon generators can contract directly with licenced suppliers via the **Smart Export Guarantee (SEG)** to offtake surplus energy. Generators are not guaranteed a fixed price, and face some certification requirements.

Embedded generators can contract directly with offtakers in a **PPA**. This would require competition with other generators in the market and negotiating the PPA contract. Potential offtakes will likely not find a PPA with the proposed SLES models attractive because of small generation capacity and low dispatchability (sale of surplus energy rather than dispatchable supply) – many PPA contracts stipulate that 100% of the generated energy is sold to the offtaker.

Balancing and Flexibility

Generators require a licence to access the balancing mechanism; however, they can contract through a licenced body. **Aggregators** can act as intermediaries between embedded generators and the System Operator, allowing access to balancing and flexibility services revenue that might otherwise be inaccessible to smaller generators.

Significant changes are expected that could provide greater access to flexibility revenue streams – the **Smart Systems and Flexibility Plan** will consult on "a regulatory approach for flexibility service providers and other organisations controlling load".

Hydrogen Networking

Hydrogen is not permitted in networks over a minimal limit. **Demonstration projects** are currently underway as part of RIIO-GD2, including from: Cadent, SGN, and Wales & West Utilities *[22]*. One option is to await BEIS's 2026 decision regarding networked hydrogen and engage with Ofgem in the interim; this still risks stranded assets.

In another option, models that transport hydrogen via **networks would be avoided,** and hydrogen would be imported into and exported out of the network via ship or road transport. (See right for additional H2 options).

Heat Network Regulation

It is likely that all heat networks will be included under Ofgem's developing heat network regulation framework. **Engagement with Ofgem** and participation in Ofgem's **Regulatory Sandbox** to demonstrate innovation and consumer benefit, are risk-mitigating actions that could be taken as this framework is developed. Milford Haven should delay application to the Regulatory Sandbox until a SLES proposition is selected and fully developed.

Asset Co-Ownership and Operation

In Ofgem's list of licensed companies, six generators are also licensed to supply energy, but none to distribute it – some generators, e.g., Vattenfall, have **separate legal entities licensed** to carry out generation, distribution, and trading. If, due to licensing requirements, the local authority is prohibited from owning both, or from operating both, generation (including storage) and distribution assets, a **multi-owner model** should be used. These include the Disaggregated Market Model and the SPV Partnership model. These models could also be used to circumvent the generation owner from facing supplier licencing barriers (see leftmost column).

Recommendations

Key Findings and Policy Recommendations

Figure 44 outlines the key findings from the regulatory risk identification process, summarises market trends and changes, and defines some high-level policy recommendations to navigate the regulatory considerations relevant to the proposed SLES models.

Developing Frameworks

- Uncertain regulatory futures for networked hydrogen (which could affect future hydrogen demand) and heat networks could present a regulatory barrier.
- Mitigation strategies include avoiding networked hydrogen transportation, informal outreach to Ofgem in the short term, and potentially application to use the Regulatory Sandbox - to demonstrate innovation and value to consumers - in the longer term.

Regulation Changes

- Recent and ongoing regulatory changes have removed some embedded benefits and increased network charges for decentralised generators, but have opened up new value streams to smaller market users.
- A trend of increasing support for local systems is part of Ofgem's ongoing work to increase system flexibility during the energy transition.

Commercial Ownership Models

- Licencing and asset ownership regulatory constraints should be taken into account when selecting and developing the commercial model.
- Smaller, private wire generators and distributors can be licence-exempt. Allowing them to own these assets simultaneously.

Market Access

- Wholesale market access can be expensive for small generators and a PPA will likely not be attractive to a third party for exporting surplus generation.
- Using an aggregator, now with access to the balancing mechanism, as an intermediary is a potential route to access flexibility value streams. Aggregators in energy trading are discussed in the following slides.

Figure 44: key findings from the regulatory risk identification process

Trading platform

What is a trading platform?

Trading platforms facilitate the exchange of goods and services, often across multiple markets. In the context of energy, a trading platform might allow for the exchange of resources such as electricity or hydrogen, as well as acting as a local balancer and flexibility provider.

They have the potential to unlock benefits to:

- **the network** (reduced energy losses, manage constraints and deferring/delaying investment),
- **the consumers/community** (improved hedging opportunities, supports local social objectives), and
- **society** (increased renewables, demand side flexibility).

Our work to date shows that MH:EK could benefit from a trading platform because export of electricity from Pembrokeshire is constrained. A local trading market could support more renewables development, hydrogen development and flexibility/storage within the system.

A local trading platform can be designed to meet local needs and exploit the benefits that local energy offers. The anticipated components of a trading platform ecosystem are shown in Figure 45. An initial specification for potential energy trading platforms has been developed by ESC in line with the systems architecture study *[39]*.

In this section, we present recommendations for changes required technically, and in regulation and policy so that a trading platform might support a SLES in the optimal use of energy across multiple vectors.

Literature review

We reviewed a wide suite of trading platforms operating in the energy space. Minimum passing criteria for a platform to be considered in our more detailed review are presented in the Figure 45 (in the grey boxes).

In addition, we scored the reviewed trading platforms against key criteria deemed necessary for the trading platform to be a success in the MH:EK context (in the light green boxes).

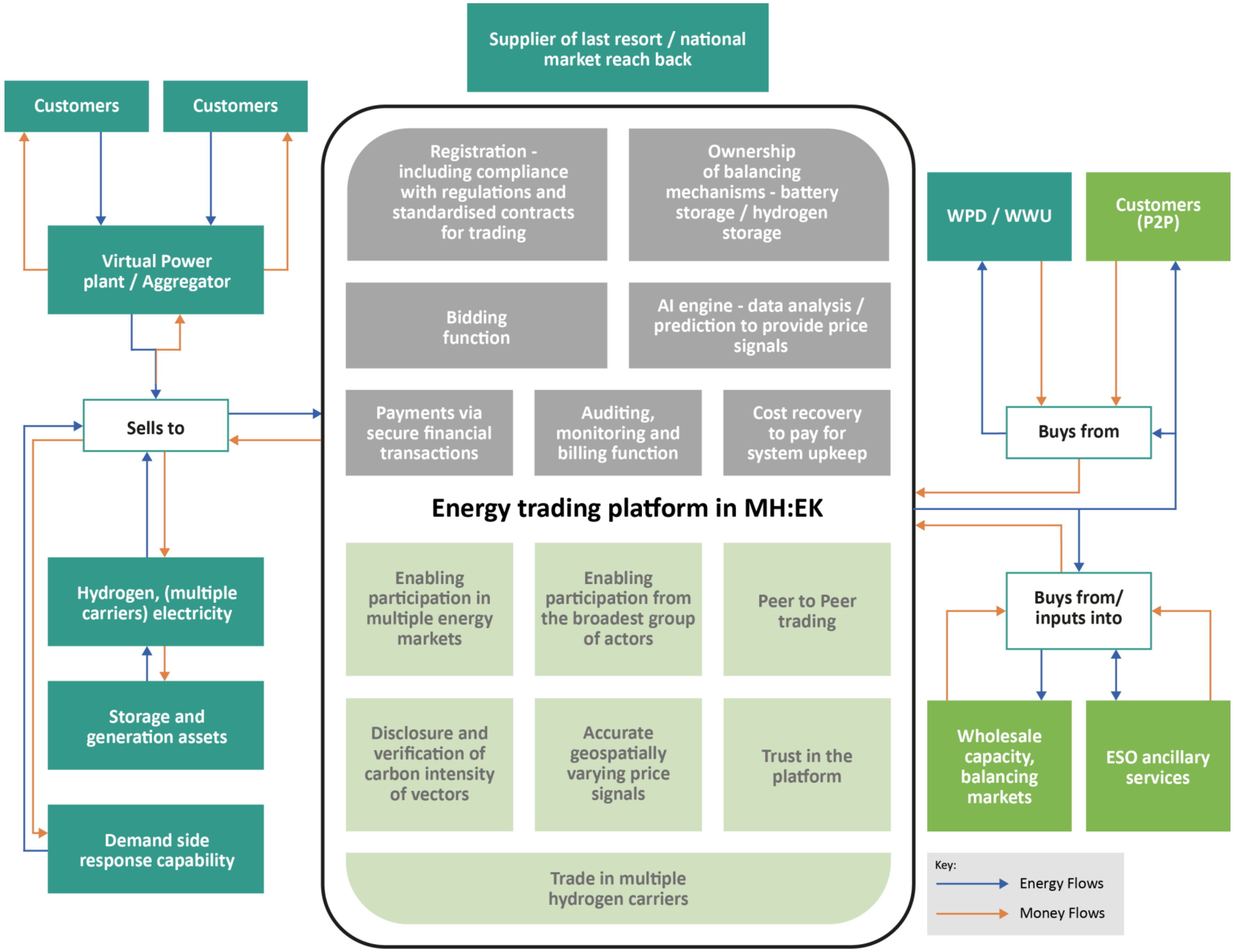


Figure 45: Components of a trading platform ecosystem

Review of existing trading platforms

Introduction to different trading platforms

The Piclo Flex platform operates in the flexibility market. Whilst the scope of the platform may evolve over time to include generation, the current remit is to enable DNOs to signpost their future flexibility requirements, and for providers to register on the platform in order to notify the DNO of their availability – by technology type; location on the network and price. The platform therefore acts as the marketplace for signalling these tender opportunities and for providers, including aggregators, to submit offers.

Piclo Flex acts as a bulletin board, where DSOs post their customised and localised needs for flexibility (essentially a volume, a location, an up/down direction and a period plus some technical characteristics). Asset owners then respond to such “tenders” and submit their best availability and utilisation prices for a given volume (possibly with some limitations, such as maximum utilisation time). Granted offers consequently are made available to the DSO for congestion management at a later stage.

In 2020, EEX kicked off its first-ever Hydrogen Working Group. The objective was to reflect on designing a sustainable wholesale trading market for hydrogen, together with all market players.

In parallel to commodity trading, they planned to certify the origin of hydrogen through hydrogen Guarantees of Origins (GOs). With Grexel, EEX Group supported the creation of the first ever unified European market for hydrogen through Guarantees of Origin: CertifHy.

Origami Energy offers its clients a range of trading and automation solutions, supporting power production, planning and forecasting and energy trading.

Its range of services further includes battery revenue optimisation to derive maximum value from standalone or co-located (with renewable energy assets) batteries, participating in capacity, flexibility and balancing markets, as well as for other flexible assets.

Its forecasting and forecast management services supports clients in making informed trading decisions, utilising real time physical and market data.

The Cornwall Local Energy Market project was a three year trial from 2017 to 2020, funded through the EU Regional Development Fund and Centrica. It created a trial market for flexible demand, generation and storage.

The project trialled several propositions. It allowed the DNO and TSO to both procure flexibility from distributed renewable energy assets, allowing supply and demand side providers to participate in the market, optimising capacity on the network.

Further, it enabled peer to peer trading alongside demand-generation coupling solutions, ran a locational pricing trial, and provided routes for Distributed Energy Resources (DERs) to market.

Funded through the Prospering From the Energy Revolution (PfER) programme, the Liverpool Multi-vector Energy Exchange (LMEX) project will produce a detailed design of a city-wide energy marketplace for the trade of energy services across power, transport and heating/cooling.

The platform will comprise of a Smart Network Controller (SNC), a Flexibility Exchange Platform (FXP) and sensors installed in premises/homes of potential end-users. It therefore allows participants to act in both wholesale and flexibility markets.

The Community Urban Neighbourhoods Internal Trading of Energy (CommUNITY) was a collaborative project between EDF, UKPN, Repowering London and the Bartlett Institute at UCL.

Solar panels were installed on a block of flats in Brixton, South London. Residents were able to trade excess electricity with each other using an app. Ofgem granted regulatory relief to the project to enable peer to peer trading.

A battery was also installed onsite to sell excess solar generation back to the National Grid.

Trading platforms assessment

Matrix of trading platforms reviewed against key criteria

Key Criteria for Trading Platform Success*	*Liverpool Multi Vector Energy Exchange*	*Piclo Platform*	*CommUNITY*	*Origami Energy*	*European Energy Exchange - hydrogen working group*	*Cornwall Local Energy Market*
Enabling participation from the broadest group of actors that could add to or use the service (through aggregation and lowering barriers to entry)	Green	Green	Yellow	Green	Red	Green
Disclosing and verifying the carbon intensity of the energy vectors being traded on the platform, in real time.	Grey	Grey	Yellow	Grey	Green	Red
Trade in multiple hydrogen carriers.	Grey	Red	Red	Grey	Green	Red
Accurately convey geospatially varying price signals for different vectors.	Grey	Red	Yellow	Grey	Yellow	Yellow
Enabling participation in multiple energy markets (capacity mechanisms, balancing services, network constraint services etc) which would facilitate revenue stacking for participants, and optimal use of Distributed Energy Resources (DERs).	Green	Red	Red	Green	Grey	Green
Peer to Peer trading without the necessary involvement of a licensed supplier	Green	Red	Green	Grey	Red	Red
Trust in the Platform by participants and owners of DERs.	Grey	Grey	Green	Green	Green	Green

Key:

- Green: Surpasses expectations
- Yellow: Satisfactory
- Red: Does not meet criteria
- Grey: Unknown - information not available

*Criteria that are specific to **energy** trading platforms are the focus. More general requirements for markets/trading platforms to function, such as sufficient market liquidity, sufficient participants, a facility to cover costs, auditable, secure etc. are assumed a priority.

Table 8 Trading platforms reviewed against key criteria deemed necessary for the trading platform to be a success in the MH:EK context

Challenges and recommendations

Barriers for MH:EK

The following technical, regulatory and market barriers to the development and rolling-out of an energy trading platform for MH:EK have been identified through literature review, stakeholder engagement and analysis.

Technical barriers

- Trading onto a constrained grid
- Enough capacity to store hydrogen for long periods until the price is right and how does hydrogen move around the system?
- Current limit of only a 20% hydrogen blend into the gas network.
- Connection to internet in rural locations
- Multiple energy vectors in a platform could mean that more changes are needed, for instance propane addition would be required for adding hydrogen to the grid under current Gas Safety (management) Regulations (GS(M)R)
- Data – interoperable, consistent, timely

Regulatory barriers

- Peer to peer energy trading without transacting through a licensed energy supplier
- Common understanding of the definition of Low Carbon Hydrogen.
- Lack of being able to participate in multiple energy markets at once (Wholesale, Capacity, Balancing)
- Lack of a coordinated approach

Market functioning barriers

- Participant trust in platform
- High costs and risks associated with trading the wholesale market
- Sufficient liquidity

What needs to happen to enable an energy trading platform to realise the full suite of benefits for MH:EK?

Overcoming technical barriers

To be able to trade, the grid still needs to have capacity for the renewable generation to export to, so the trading platform needs to works alongside balancing mechanisms in the area. There needs to be significant improvement in the data available from DNOs, particularly relating to congestion, forecasting of constraints, the flow of power between grid nodes and the mapping of customers and prosumers (an individual who is a producer and consumer) on the network. This will support the understanding of how the trading platform can iron out the constraints, because grid overload could be a possibility if too much energy entered the grid, that wasn't absorbed in the local area.

For the SLES propositions, we have assumed hydrogen would be transported via tanker, and stored until the price was right to be able to sell it. In future, hydrogen could be sold into a localised (or the national) gas grid, however the hydrogen would then have to meet certain specifications, this could mean bolstering with propane (at additional capex and opex) and meeting certain purity requirements as set out in the GS(M)R to meet the quality needed for the national gas grid.

There needs to be internet connectivity to send signals back and forth to state when to sell and store electricity / hydrogen.

Overcoming regulatory barriers

There needs to be roll out of certification schemes for hydrogen. The Low Carbon Hydrogen Standard consultation which is currently being analysed will lead to an emissions standard that defines "Low Carbon Hydrogen" for the UK. This will support market mechanisms to drive forward hydrogen innovation and funding programmes. In addition, CertifHy has developed hydrogen certification schemes in Europe, establishing Guarantees of Origin certificates.

There is precedent for pilot energy markets to be granted derogations from current regulations, such that these platforms can work outside current regulatory frameworks and engage for example in peer to peer trading, such as the CommUNITY project.

Recently, it has become possible for assets to participate in both capacity markets and balancing services at the same time. This sets a precedent for DERs to further integrate across markets. Ofgem has a role to ensure that National Grid's products for suppling ancillary services are detailed and transparent, enable revenue stacking, and create a technology agnostic marketplace.

There are programmes being progressed or recently concluded, such as Open Networks, Charging Futures, the Review of the supplier hub model, and the HHS and smart meter roll out. The outcomes of these programmes need to complement each other.

GS(M)R boundaries could be adjusted to allow a wider range of Wobbe numbers for hydrogen injection, this is limited based on very little data, and there is potential for the regulations to be widened.

Overcoming market barriers

The high costs associated for owners of distributed energy resources to enter the wholesale trading market, and indeed the capacity and balancing market can be addressed through platforms that offer aggregating services or through Virtual Power Plants (VPPs).

Ensuring sufficient liquidity in the trading platform could be an issue if the platform wishes to facilitate the local exchange of hydrogen, given the current level of production in Milford Haven still being at pilot phase. This could be addressed by linking producers on the platform with producers and consumers outside the Milford Haven area, to enable trading on a wider, more liquid wholesale market, both in GB and further afield .

Challenges and recommendations

Trust in the platform is key for effective functioning. Voluntary code of conducts have appeared which platform operators can sign up to. To foster wider trust and uptake, there may be a role for Ofgem to regulate digital energy platforms, and for voluntary code of practices to become mandatory. Key to this is safeguarding participant data, security against cyber-threats, transparency, and ensuring provisions for participants to switch and/or leave the platform. However, Ofgem has to strike a balance between enabling such platforms to emerge, whilst also protection consumer interests.

What could happen tomorrow within current technical, regulatory and market contexts?

Energy trading platforms operating in electricity markets are more mature at present. There is scope for a network of electrolysers, perhaps through aggregators to sell balancing, capacity and ancillary services, and to stack revenue by participating in multiple markets simultaneously.

There is precedent for Ofgem to grant regulatory relief to enable peer to peer trading, although this has only been trialled with electricity.

The potential benefits of energy trading platform for Milford Haven are dependent on several conditions

Energy trading platforms' potential benefits have been well documented in the case studies presented. They have the potential to unlock benefits to the network, in the form of reduced energy losses, managing constraints and deferring or delaying expensive network upgrades. It could unlock benefits to the consumer through improved hedging opportunities and supporting local objectives through increasing the share of low carbon energy.

However, there are several technical barriers that need to be considered before a trading platform for multiple energy vectors or services in multiple markets could become operational in the Milford Haven context.

The maturity of the hydrogen market at present is the main technical barrier to unlocking some of the benefits afforded through a trading platform. The size of the market has implications for:

- Market liquidity - sufficient hydrogen production capacity, ideally with Guarantee of Origin Certificates needs to be brought online to ensure that the market remains liquid and price discovery occurs, and that forecasting becomes more reliable.
- Fulfilling orders - once an order has been filled and verified, there must exist the physical infrastructure to safely transport the hydrogen from producer to consumer, either through traditional freight, blended into the gas network, or through a repurposed network capable of transporting pure hydrogen.

As new entrants, electrolysers have the potential to profit from participating in the electricity balancing, flexibility and capacity markets. A trading platform could help the asset fulfil an optimal use strategy, and revenue stack through participating in multiple markets. However, these assets would be competing against incumbent technologies in this space, such as CHP and batteries.

The relative immaturity of the hydrogen market at present suggests that electrolysers, perhaps aggregated, would be the most appropriate hydrogen generating assets to be integrated into a trading platform, and would do so acting in the electricity capacity, flexibility and balancing markets.

Considering the non-monetised benefits that stakeholders wish to flow from the establishment of a potential hydrogen industry in Milford Haven, it is not clear that establishing a trading platform would enable this.

A cloud-based trading platform would unlikely bring new or secure current jobs in the region. Acting in the markets that are mature at the moment would likely present a more uncertain and volatile revenue stream for hydrogen production assets, and potential investors would prefer longer term contracts with more certainty of return. Whilst a strengthened sense of community would undoubtedly be fostered by a platform that enables peer to peer trading, this is currently a regulatory barrier, and there is a lack of infrastructure at present to enable trades to be physically fulfilled.

As such, we deem it unlikely that establishing a digital trading platform represents the correct choice right now. Actions that do more to stimulate a mature hydrogen market and supply chain, such as establishing long term contracts with consistent demand hubs, such as transport firms, chemicals factories etc appear to keep benefits more local.

Once a more robust hydrogen market is established, integrating generation and demand assets into a platform with access to the electricity and gas markets is recommended, to further unlock the network, consumer and local benefits, as well as to provide visibility to shortages and surplus, distributed generation assets and infrastructure.

Smart Energy Cluster Trial

The MH:EK Smart Energy Cluster Trial *[35]* is small scale energy cluster that has been set up and continues to be run by Energy Local aiming to model the potential for an energy cluster or club at Milford Haven and Pembrokeshire Port.

An initial cluster was set up with commercial buildings owned by PoMH and a generation asset (rooftop solar) also owned by PoMH to test how much of the half-hourly demand can be met by the cluster generator. The consumers (buildings) consumptions were timed to coincide with the local generation, and the electricity consumed at the same time that it is produced was referred to as 'Matched power'. The generator is then able to sell that electricity at a 'Match tariff agreed between the consumers and generator of the cluster. The match tariff is typically halfway between the electricity export / sale price to grid and the electricity purchase price for the consumers. Since, only the PoMH's assets formed part of the cluster, any benefits were directly translated as cost savings for the Port. The cluster also includes a licensed supplier to supply the matched power through the match tariff as well as to import power or purchase excess generation from the cluster.

The initial cluster showed that 84% of the power generated was produced in the same half hour as the equivalent power consumed by the buildings. This was equivalent to 12% of the total electricity demand met by matched power.

The financial benefits of the cluster are largely dependent on the supplier's tariff for import of electricity to the cluster. Due to the small scale of the trial, the supplier decided not to apply any additional tariff for this service, so maximum benefit could be achieved. A few scenarios were modelled by Energy Local to assess this uncertainty and the study showed that the Port could achieve a savings on bills between 1-9% compared with having no cluster (Business as usual).

Further to the initial trial, the cluster was expanded to include more PoMH sites / commercial buildings around Milford Haven port and Pembroke Port into the cluster. This involved installing smart monitoring devices at the building sites and collecting half-hourly consumption and generation data over several months. At the time of writing this report, this data collection was still in progress. Therefore, a full picture of the yearly consumption and generation data is not available.

From the monitoring data and historic data, the model showed a potential cost saving for PoMH of approximately 9% at Milford Haven Port and 17% at Pembroke Port. However, due to limited data availability, these are just estimates and with more data from the monitoring, the study can be extended to refine the model but also to enable demand shifting.

The smart energy cluster trial is a small-scale example of the Centralised commercial model applied. The leading entity, PoMH also took the role of the asset owner, funder, landowner and customer. PoMH contracted a licensed supplier or ESCo to fulfil the role of the supplier. PoMh also sub-contracted Energy Local to manage and deliver the project and an installer, Enica to install the monitoring devices.

This model which is at an even smaller scale than the SLES proposition has demonstrated cost benefits to the PoMH as well as some degree of energy security and less reliance on National Grid. However, the cluster have highlighted several challenges that were faced:

- Developing a commercial / business model with a supplier – the experience on this project showed that the supply industry is conservative and not responsive to innovation. The supplier struggled to implement changes and set up contracts with business / commercial customers.
- Smart meters – there is a shortage of smart meters in commercial buildings as well as qualified installers.
- Billing - The supplier billing system was incompatible with this commercial model and was inflexible to develop new ways of working.
- Price volatility – The cluster trial has highlighted the impact of high electricity import / purchase price volatility to the system financial model.

The smart energy cluster trial has highlighted potential cost benefits for both generators and consumers whilst showing that taking a decentralised approach to energy supply promotes energy and price security. It has highlighted the need for demand shaping / shifting to maximise the 'internal' use of energy generation. However, the barriers faced was around the current actors not being open to new ways of working, lack of data and whilst this trial did not interact with network operators and regulators, price volatility is an effect of regulatory barriers. The challenges faced on this trial have also been highlighted as barriers to the SLESs. The cluster also considered a single vector: electricity.

Taking a SLES approach would take this energy cluster to the next level to a multi-vector system and with more actors / stakeholders.

Refer to Energy Local Potential benefits of an Energy Local Cluster at Milford Haven Port report *[35]* for more details.

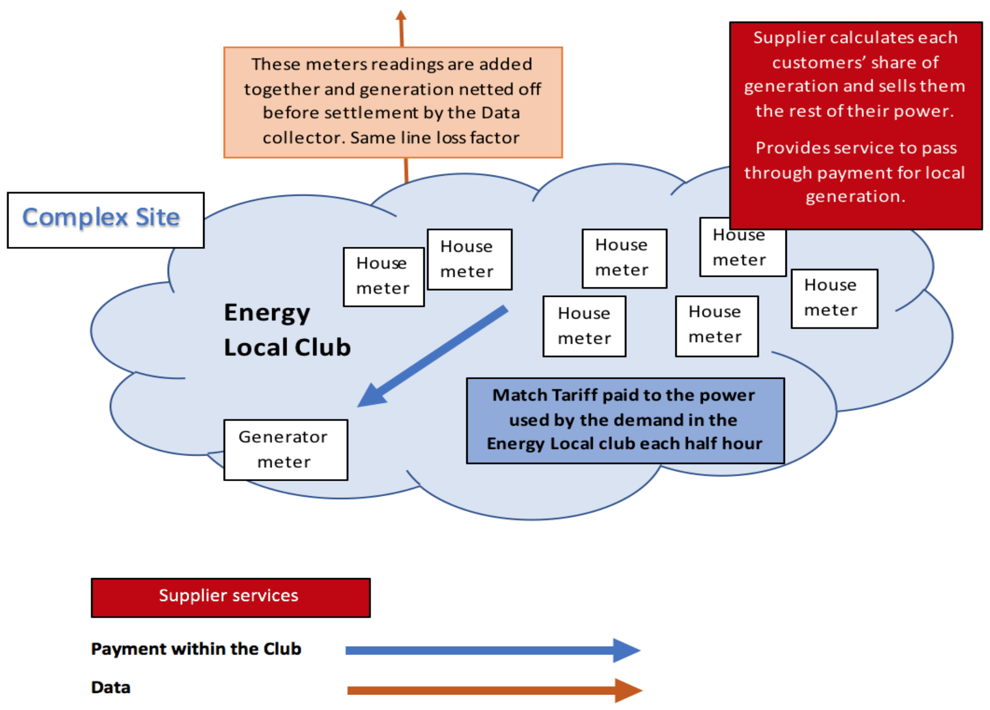


Figure 46: Energy cluster graphic representation *[35]*

Trading platform recommendations

Our recommendations to stakeholders in the MH:EK project

MH:EK project team

We deem it unlikely that establishing a digital trading platform represents the correct choice right now, given the immaturity of the hydrogen market. However, there remains scope for stakeholder action to enable local trading platforms to become operable in the future, integrating hydrogen and electricity markets.

WPD

- Milford Haven does not sit in a Constraint Managed Zone, and WPD is therefore not looking to procure flexibility here. However, DERs in the area still experience non routine curtailment, indicating constraints on the network. WPD could consider extending their Constraint Managed Zone to include Milford Haven to allow for flexible power trading.
- New DERs currently have limited options to connect to the distribution network on a firm basis in Milford Haven due to it being in an Active Network Management zone where WPD can curtail distributed generation assets.
- WPD could act as a keystone by supporting opportunities for local flexibility and energy trading, through using flexibility to provide capacity for new connections before traditional reinforcements need to be made.
- WPD should continue and double down on the steps needed to support its transition to DSO, in keeping with the Energy Data Taskforce *[24]* recommendations.
- Urgently update their existing IT platform currently used to assess the requirements for flexibility, manage dispatch and make payments for the flexibility provided.

WWU

- WWU should consider how peer to peer trading in gas markets could be operationalised, enabling learnings from natural gas trading to apply to hydrogen when it becomes more widespread.
- Continue the gas mains replacement program to enable hydrogen to be transported through the network and be transparent about the cost of other upgrades needed for a hydrogen transition so that these costs can be accounted for.
- WWU could undertake pilots of network conversion to get clarity on further costs for upgrading the system to hydrogen, the cost of decommissioning natural gas and sharing the outputs of these studies widely and openly.

Port of Milford Haven Authority

- Coordinated asset registration in line with the recommendations from the Strategy for a Modern Digitalised Energy System. *[25]*
- All energy infrastructure assets should be or become digitally enabled in the near future with access to internet connections.
- Expanding the energy cluster will likely be hindered by bigger technical and regulatory barriers to peer-to-peer trading. Continuous stakeholder engagement with tenants and consideration to form a community scheme will help assess the interest for a bigger energy cluster with the Port and engagement with WPD will help address the technical constraints. Further details on next steps and recommendations for PoMH are detailed in the Milford Haven Heat Network: Phase 2 report *[36]*

Local authority

- Co-locate energy storage assets, such as batteries or electrolysers with distribution level renewable energy, to minimise the risk of curtailment.
- The local authority may have an important role in developing trust in trading platforms as they emerge, through promoting their use, registering their assets on the platform and acting as partners to their launch.

Ofgem

- Ofgem needs to actively monitor the results, risks, and benefits of the energy trading platform innovations, such as the Cornwall local energy market, and CommUNITY. A key challenge will be to allow for the development of new services, such as digital energy trading platforms that improve consumer service, whilst mitigating the potential for these to result in negative consequences for consumers who might choose not to participate. It will need to be receptive to evidence of digital energy platform trials as part of the PfER programme, to inform more agile regulation.
- Ofgem should continue to urge DNOs to transition to DSO status.
- Ofgem should work with emerging industry codes and standards to appropriately regulate emerging trading platforms, particularly those which act across markets.

Government

- Needs to provide a strategic direction for the evolution of the energy system. Several programmes, such as the supplier hub review model, the Open Networks Project, Charging Futures, and Smart Meter Rollout, have progressed without being coordinated under a strategic umbrella.
- Coordinate the structure, operations and functionality of a national asset register and digital systems map.
- Coordinate definitive standards around data quality, format, granularity and update schedules.

MILFORD HAVEN: ENERGY KINGDOM

The Financial case

Summary of findings

ENERGY KINGDOM
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The Financial case

Introduction

The Financial case seeks to establish whether the recommended propositions are affordable and how the cash cost can be funded.

The cost of the Investable Proposition(s)

As outlined in the *Economic case*, it is recommended that the MH:EK project pursues both Proposition 1, the Milford Haven Marina SLES and Proposition 2, the Pembrokeshire food park SLES to be developed as SLESs. 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. Further work and more detailed analysis of both propositions is required, as these propositions progress along their development journeys.

The upfront capital cost (CAPEX) for the recommended system for each proposition is provided in Table 9. In line with the HM Treasury Green book guidance, an upper bound optimism bias (OB) 66% has been applied. This total CAPEX represents the upfront budget for each proposition.

Proposition		1 – Milford Haven Marina SLES		2 – Pembrokeshire Food Park SLES	
Scenario		Onshore wind expansion with private wire	Onshore wind expansion with private wire and no gas*	Hybrid	Hybrid
		2020	2050*	2020	2050
KPI	CAPEX (£million)	8.12	9.87*	15.6	14.5
	CAPEX with 66% OB (£million)	13.5	16.4*	25.9	24.1
	OPEX (£m/year)	1.704	2.204*	0.765	0.705
	CO_2 emissions (kg/kWh)	0.076	0.002*	0.01	0.003
	LCOE (£/kWh)	0.061	0.081*	0.079	0.074

Table 9: Summary of the CAPEX, OPEX, LCoE and carbon emissions for propositions 1 and 2 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

Revenues

A key component of project funding will be revenues from the sale of electricity generated – either through savings by using the energy within the system or exports to the national grid.

For proposition 1, the Milford Haven Marina SLES, 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 for PoMH. 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.

A core aspect of Proposition 2, the Pembrokeshire food park SLES, 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). 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 but range between 5 and 8 years.

The above summary represents potential funding and revenue streams for the project anchor; however, these propositions present wider investment opportunities for a broad range of investors which should be reviewed in detail by interested parties.

The Financial case

Investment

The MH:EK Investor facing output report (to be completed in May 2022) *[38]* will provide further details on the investment opportunities and returns from the recommended propositions, technology acceleration as well as the potential longer-term opportunities that would stem from the longer-term energy transition vision of the region.

The report will provide a summary of notable local and international near-term funding mechanisms and their applicability to the MH:EK investable propositions. The summary will be presented in a PESTLE analysis and will provide details on the local and national political support for the vision and other investments that could impact the medium-long term vision for Milford Haven.

The report will provide the context for potential investors and funding streams and a custom investor pack for the MH:EK project team to seek investment.

MILFORD HAVEN: ENERGY KINGDOM

The Management case

Summary of findings

The Management case

Introduction

The purpose of the Management case is to demonstrate how the propositions or SLESs should be delivered. Drawing on experience from a combination of building projects and energy system transition projects, it sets out a pragmatic approach to project planning, governance, risk management, data and information management, communications and stakeholder management. This should be developed further during the future stages of development.

Project Management

A project management methodology could be adopted as part of the project management arrangements. The project management arrangements should reflect the key principles of project management systems as follows:

- Definition of roles & responsibilities
- Definition of programme, stages and milestones
- A live risk and opportunities register
- Application of lessons learnt and best practice from other projects to approaches, risks and opportunities
- Review and update of the business case in line with the design, planning and procurement stages
- Collaborative methods of working to be followed
- Data, knowledge and information management
- Change management to be defined in contracts and an agreed management system to be put in place.

Project structure and governance

A suggested project structure, with roles, responsibilities, and governance routes is outlined in the organograms on Figure 47.

This represents a more general project structure and governance for the future development of the SLESs to the implementation stage. The specific commercial roles and responsibilities tailored to different commercial models are discussed in the *Commercial case*.

As part of the MH:EK project, ESC have developed a system architecture *[39]* to define designs of future energy system architectures, combining; technology, the interconnectivity between them and data; with markets, trading platforms and policies; with business models and defined organisational governance. The study provided possible system arrangements which could emerge in the future and details about technical, governance and market considerations that underpin the delivery of such arrangements. The study adds another perspective to the management and commercial structures through which SLESs could be delivered and is summarised in the *systems architecture section*

Suggested project structure

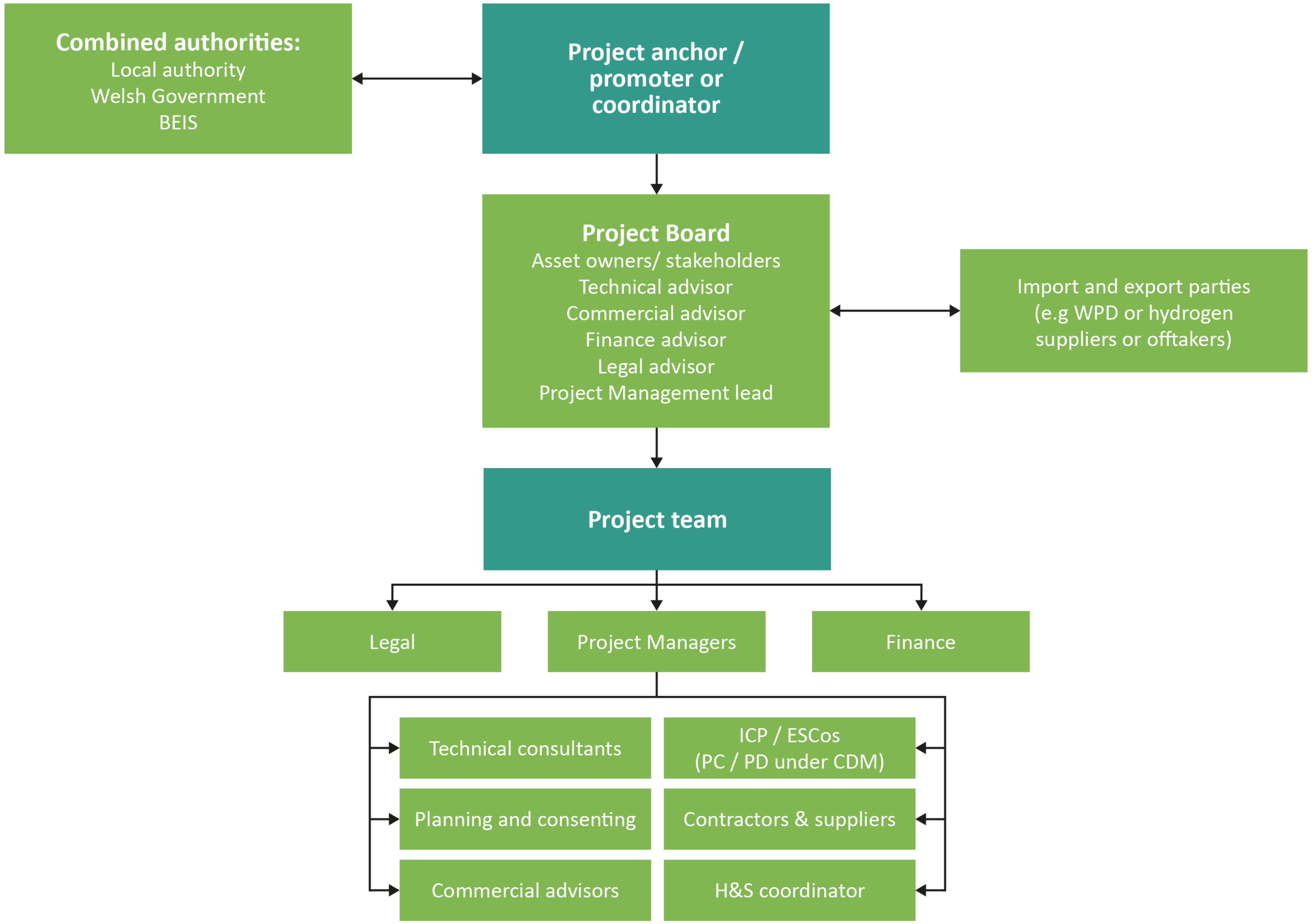

Figure 47: Suggested project structure

Project management recommendations

Implementation programme

A high-level implementation programme is provided in Figure 48, assuming a commencement of the development phase in 2022. The programme identifies broad timescales for activities related to funding and delivery of the project.

Stakeholder engagement

Stakeholder engagement is a key component of the project delivery and key activities are also identified on the programme (Figure 48). A Stakeholder Management Plan, a live document capturing the project context, communication with stakeholders and stakeholder engagement analysis should be prepared and updated throughout the project delivery.

Data Management

Collaboration, transparency, and timely exchange of information will be critical to ensuring the right culture, behaviours and ways of working are developed. Information and data management approaches in line with the MH:EK data ecosystem report (*summarised overleaf*) should be adopted to ensure effective decision making and progress towards a Modern Digitalised Energy System.

Risk management

A risk management strategy should be adopted to assist all parties to understand the risks associated with the development, delivery, operation and decommissioning of the project. A risk register should be developed and be kept live throughout the lifecycle of the project.

Health, Safety , Environmental and Quality management systems should be in place in line with the relevant management standards and the Construction Design and Management Regulations.

Contract Management

It is likely that the project anchor would be contracting other entities to deliver the project as discussed in the Commercial case. Contracts should be managed under a recognised and relevant contract suite, based upon an industry standard and with a demonstrable track record of bankability.

Contingency Plans

Contingency plans should be put in place at the start of the project in line with the project risk assessment, to mitigate and manage significant risks and opportunities with regards to project cost and programme.

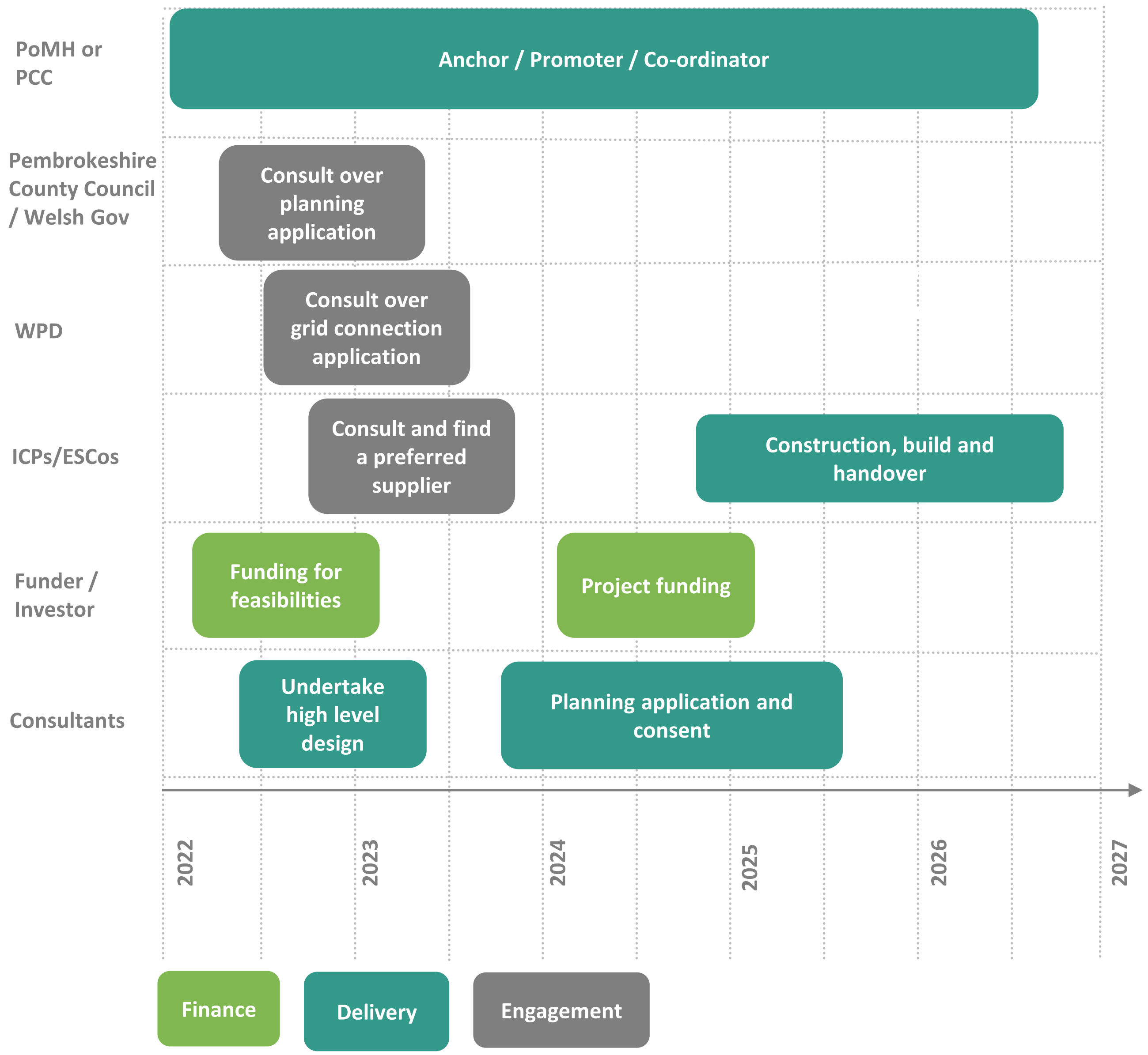

Figure 48:Indicative implementation programme for the recommended SLES

Data ecosystem

The energy sector is currently embarking on a journey of 'A Modern, Digitalised Energy System', and has set a series of steps to achieve this. This system is key to decarbonise the energy sector, and data management is one of the main enablers that will assist the sector in reaching its goals.

A data ecosystem has been developed for MH:EK which is required to ensure the existence of the data lasts beyond the initial 2-year project.

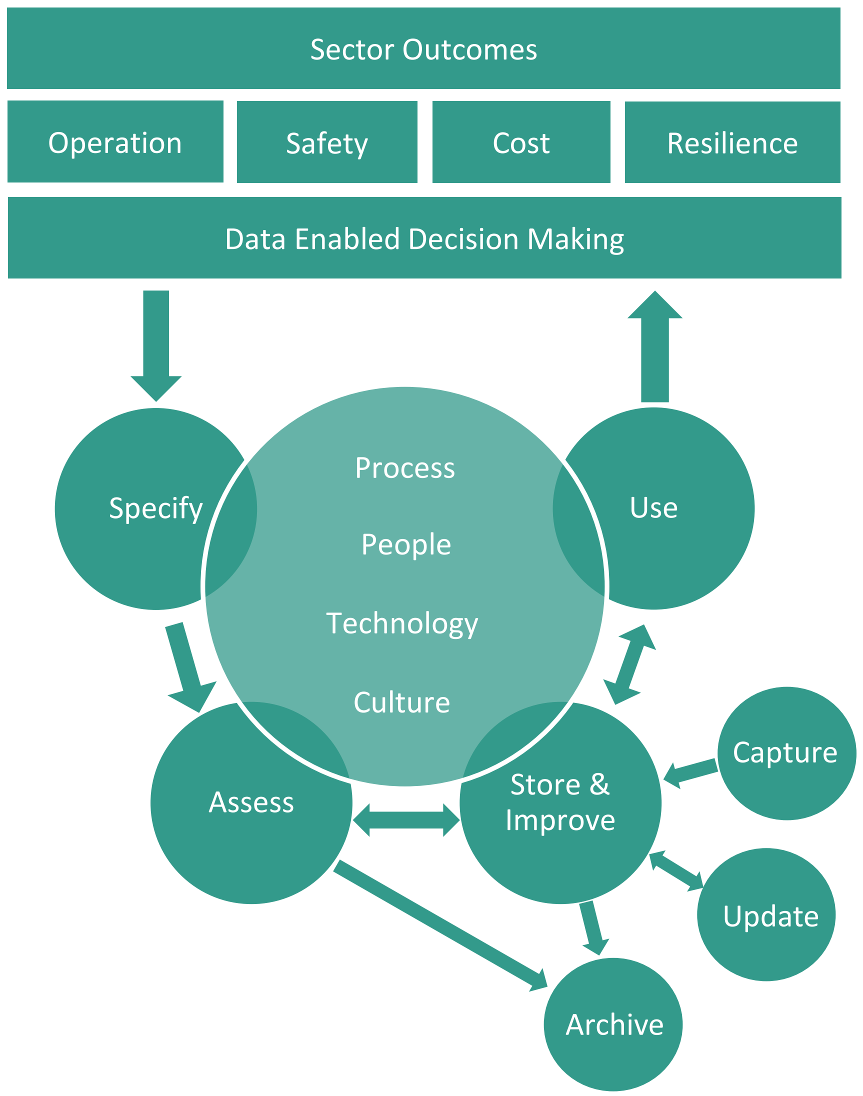

Figure 49: Energy data lifecycle

A data ecosystem should contain all project information and data throughout the lifecycle from design through to operation and ultimately the demolition of assets within the energy system.

A robust data management process is required as part of the proposed data ecosystem. This enables data driven decision making whilst considering the project drivers, which results in the delivery of the outcomes of the sector.

Figure 49 shows the energy data lifecycle that was used to assess and analyse the data that has been collected and implemented and the energy modelling on the MH:EK project. The full study is provided in The MH:EK Data Ecosystem report *[40]*

The challenges

A series of sector-wide issues and challenges have been highlighted in the data ecosystem report combining those identified in the Energy Systems Catapults (ESC) 'Energy Data Taskforce Report' *[24], the* ESC Energy Revolution Integration Service Insight Paper titled 'Enabling Smart Local Energy Systems: The value of digitalisation and data best practice' *[26]* which included existing challenges of SLES's across the UK including MH:EK and the ones faced on MH:EK.

- Data gaps - data quality is often poor. leading to it being inaccurate, imprecise or missing. Reasons can be data existing in non-digital formats, data being collected but not stored, and data just not being collected. The MH:EK project encountered similar issues, particularly the lack of consistency in data received, requiring additional manipulation before using. This could be largely down to the data provider collecting data for internal reasons and requirements, and not collecting with a view of sharing it and implementing it into energy modelling exercises.
- Extracting value - organisations collecting and controlling energy systems data not being able to extract its full value due to highly restricted access, poor data discoverability, strict terms and conditions, and low quality/consistency of data. The same difficulties were found on MH:EK limiting the project from having open data between all partners.
- Fragmentation - It was challenging to collect, manipulate and utilise accurate data on MH:EK when information surrounding costs and benefits are distributed unevenly across many organisations, and there is not one open data source for the sector to use.
- Power Imbalance - The MH:EK project and the SLES approach is pushing for innovation within the energy sector. The data providers on the project generally collected data for the benefit of the organisation and not necessarily for the 'innovators' to produce energy modelling.
- Culture – Contrary to the MH:EK project where all partners were in support of innovation, decarbonisation and digitalisation, the wider industry suffers from risk aversion/policy from data providers, restricting the usage and ability to share the data rather than supporting collaborative, data driven solutions.
- Skills - MH:EK found data management skills on the project to be challenging but important. The project team identified a requirement for a data specialist on the team, who worked to ensure data storage and management systems were implemented effectively. In the data collection process, the data providers generally did not always have local data management roles coordinating the collection and storage of data. This complicated the data collection process.

Data ecosystem

The recommendations

This study compared the project with the recommendations of the Energy Data Taskforce and found that in general a similar picture was found at this more localised level. The key actions which the MH:EK SLES group could make were largely limited to improved documentation of the modelling outputs, techniques and publication of any manipulated datasets where data agreements allow.

There are a few key national energy sector initiatives which are underway such as Open Energy *[6]*, Virtual Energy System *[7]* and Future of Gas *[8]* which will enable a much better integration of MH:EK SLES into the wider energy market through better data sharing and standardisation. These initiatives however require the representation of local systems such as MH:EK to ensure that their needs and capacity are considered. Therefore, it is recommended that where possible representation in these advisory groups be sought.

The main recommendation for the MH:EK project is that it has plans in place to prepare for initiatives such as open data, standards and a focus on the fact that having available and accurate data will be to its advantage when some of the outcomes from the national initiatives become a reality. Throughout the lifecycle of the design, construction and operation of the propositions, the data required from these assets for their maintenance, and for the wider energy sector will be required as part of the delivery.

It is recommended that a data working group be established within the MH:EK organisations in future to ensure that the various data initiatives recommended in this report, and within the energy sector, are discussed and championed locally in a coordinated way.

The table below lists out the easiest to implement and more impactful project level recommendations to enable and prepare projects like MH:EK and other SLES's ahead of national standards and guidance being implemented. These are recommended to be part of the project management process for the future development stages of the SLES.

#	Recommendation
1	Common Energy Modelled Data Portal
4	Formation of a Milford Haven Energy System data management working group
5	Creation and implementation of an ongoing data management strategy to incorporate system changes into modelling
9	Contribution and adoption of national energy data standards and access protocols

Table 10: The top recommendations for data management for the MH:EK SLES. Refer to the Data Ecosytem report for the full list *[40]*.

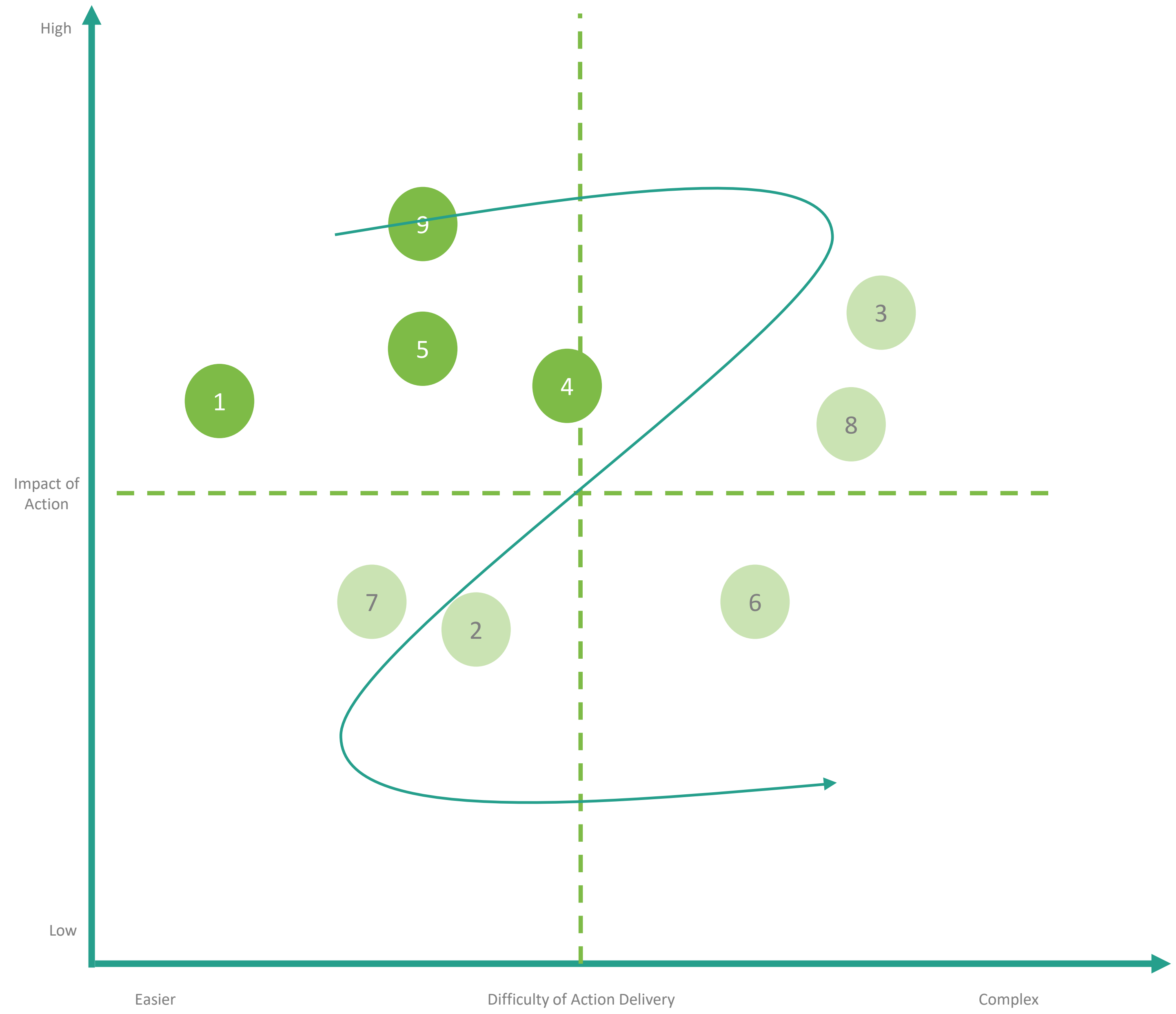

Figure 50: Roadmap of implementation of data management recommendations, with the easiest and most impactful ones highlighted. Refer to Appendix X for the full report including all recommendations

Systems architecture

System Architecture - management and commercial structures

The MH:EK System Architecture Report by ESC [39] describes the outcomes of the effort to define designs of future energy system architectures, combining; technology, the interconnectivity between them and data; with markets, trading platforms and policies; with business models and defined organisational governance.

The key objectives of the system architecture work were:

- To provide a common understanding of the range of possibilities of a future local energy system in Milford Haven and surrounding areas and to drive for choices and/or decisions to be made.
- To provide innovators and investors with a greater understanding of the scale of opportunities and risks in a future hydrogen economy, and key decisions which can impact on outcomes.
- To highlight gaps in existing businesses roles and responsibilities to inform on future growth opportunities and set new requirements for new activities.
- To Illustrate challenges in the integration of a local energy system and the key interfaces with regional / national entities and to further identify the negotiations for change that may be required.

The core findings of this study were as follows:

- Smart Local Energy Systems (SLES) are dominated by a huge number of complex interrelationships.
- Although net zero might be driven locally there are key enablers which are currently in the hands of central government.
- Actions, identified in the report, are required at varying levels (central government, future discussions, immediate actions and local decisions) to create a hydrogen economy and SLES.

The MH:EK systems architecture was primarily hydrogen focused, however the future implementation was intended to be an integrated multi-vector smart energy system. As such, the work complemented the SLES propositions commercial analysis undertaken in the *Commercial case* as well as the deliverability assessment in the *Management case*.

The report provides an overview of a whole energy system architecture with numerous recommendations for the MH:EK area. One example of the key insights is the structures for "potential system arrangements" (PSA) which could emerge in the future, for how a hydrogen physical system and associated commercial arrangements could play out. It provides detail on technical, governance, market considerations, the transition between each PSA and a set of trading platform requirements to underpin the delivery of such arrangements.

PSAs 1 and 2 to a certain extent, already exist now with private organisations producing and trading hydrogen privately. **PSA 3** is the first stage in developing a blended hydrogen system requiring market development at the retail end, progressing to **PSA 4** with the establishment of a proper trading market to facilitate end-to-end trading. **PSA 5** is the first stage in a dedicated local hydrogen system.

PSA 2, Private contracts has the most alignment to how short-term investable propositions could be commercially set up and is also in line with the SPV partnership model discussed in the *Commercial case.* This PSA assumes hydrogen is imported into the local system through pipelines or tankers irrespective of the location of production and commercial arrangements could include purchase orders/ invoices between parties. The market and trading arrangements would include a private bilateral contract, the structure of which dictates the terms and conditions of trade, such as purity, volume, price, and risk allocation.

A risk is that parts of a business could operate under different PSAs which would pose significant challenges for organisations such as system operators and regulators who would need to be able to support multiple approaches simultaneously.

To scale up or transition from **PSA2 to PSA5**, initially the system would need more production than initial sales and flexibility in contracts to support growth (PSA2). Then consider collocating generation and network injection points and allow hydrogen blend in a region and monitoring process to be set up (PSA3). Eventually, more flexible contracts to move from direct trading to market transactions would be required with hydrogen purity sufficiently high to allow connection.

PSA5 to PSA7 represents a transition to national hydrogen flexibility trading, which requires an understanding of data requirements to be able to move between different systems which is covered in the trading platform section. More details on the system architecture design and PSAs are provided in the MH:EK System Architecture report [39].

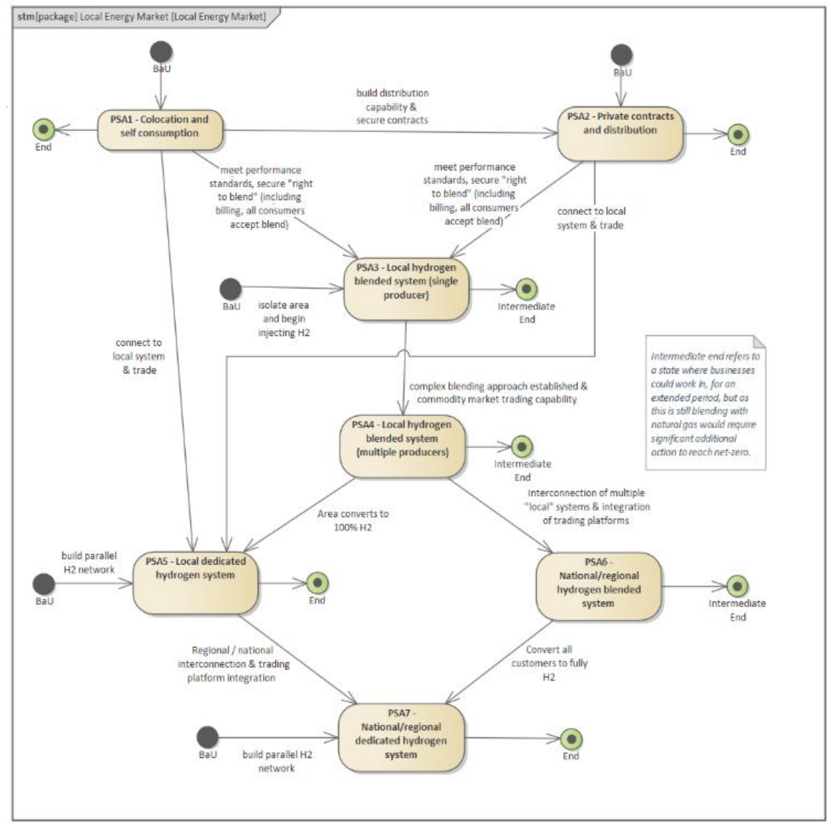

Figure 51: State transition diagram to show how to move between PSAs *[39]*

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Recommendations and next steps

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Recommendations

Recommendations are provided across the short-term and mid-term time horizon in support of reaching net zero by 2050. Longer term recommendations are difficult to set out at this point and should be established over the next decade(s) reflecting on progress to that point and required targets for reaching net zero.

Short-term recommendations

Early action through development of the recommended SLES propositions by taking the 'no-regret' steps will jumpstart the journey to decarbonisation.

- It is recommended that the MH:EK project pursues both Proposition 1 and Proposition 2.
- The outcome of Proposition 3 suggests that it is not a strong SLES candidate, so is not recommended to be progressed. It does highlight the commercial opportunity for onshore renewables development if network constraints can be reasonably addressed.

Flexibility (supply, demand, trading) is a key part of the future energy system as demonstrated by industry net zero pathways. Regulators should provide regulatory relief to set up demonstrator flexibility platforms by 2030 to support flexible energy trading by 2040.

- Future decisions made around the UK's transmission network will be significant in influencing development of new renewable generation, balancing, flexibility and trading. Regulatory barriers currently present a significant challenge to local trading platforms.
- Engagement with network operators should be continuous to integrate the network capacity and planned upgrades into further whole system energy modelling and the future roadmap.

Monitor and influence developing regulatory frameworks, take advantage of changes and create a Market Access Strategy.

- Uncertain regulatory futures for networked hydrogen (which could affect future hydrogen demand) and heat networks could present a regulatory barrier.
- Mitigation strategies include avoiding networked hydrogen transportation, informal outreach to Ofgem in the short term, and potentially application to use the Regulatory Sandbox - to demonstrate innovation and value to consumers - in the longer term.
- Recent and ongoing regulatory changes have removed some embedded benefits and increased network charges for decentralised generators but have opened up new value streams to smaller market users. A trend of increasing support for local systems is part of Ofgem's ongoing work to increase system flexibility during the energy transition.
- Wholesale market access can be expensive for small generators and a PPA will likely not be attractive to a third party for exporting surplus generation.
- Using an aggregator, now with access to the balancing mechanism, as an intermediary is a potential route to access flexibility value streams.
- Licencing and asset ownership regulatory constraints should be taken into account when selecting and developing the commercial model.

Establishing a robust data ecosystem at a local level, that integrates beyond the local boundary, is key to benefit from and support the national modernising energy data access (MEDA).

- The main recommendation for the MH:EK project is that it has plans in place to prepare for initiatives such as open data, standards and a focus on the fact that having available and accurate data will be to its advantage when some of the outcomes from the national initiatives become a reality. Throughout the lifecycle of the design, construction and operation of the propositions, the data required from these assets for their maintenance, and for the wider energy sector will be required as part of the delivery.
- The table below lists out the easiest to implement and more impactful project level recommendations to enable and prepare projects like MH:EK and other SLES's ahead of national standards and guidance being implemented. These are recommended to be part of the project management process for the future development stages of the SLES.

#	Recommendation
1	Common Energy Modelled Data Portal
4	Formation of a Milford Haven Energy System data management working group
5	Creation and implementation of an ongoing data management strategy to incorporate system changes into modelling
9	Contribution and adoption of national energy data standards and access protocols

Table 11: The top recommendations for data management for the MH:EK SLES. Refer to the Data Ecosytem report for the full list *[40]*.

Recommendations

Mid-term recommendations

A fully integrated and adaptable roadmap including key decision points and determinants for the decarbonisation of the Pembrokeshire energy system should be developed, stemming from the short-term SLES proposition and in close partnership and collaboration with the local and regional projects and network operators.

- We recommend that the next phase of the MH:EK project considers developing a roadmap for the decarbonisation of the Pembrokeshire energy system by 2050. We recommend that the starting point would be the short-term investable propositions for SLESs that is integrated with key projects and regional plans such as South Wales Industrial Cluster (SWIC), RWE Pembroke Net Zero Centre (PNZC) as well as the ERM Dolphyn project as they are further developed.
- As shown on the MH:EK pathways, early action up to 2025 will involve fewer actors and will therefore be less complex to implement. They will however have a catalyst effect to form larger energy clusters and eventually a decarbonised energy system.
- We recommend close partnership and collaboration with the regional plans such as SWIC, RWE PZNC and ERM to develop a roadmap for decarbonisation of the Pembrokeshire energy system by 2050. A fully integrated roadmap will enable the implementation of the short-term no regret steps with a view of integrating those with their plans on the journey to decarbonisation.
- Other upcoming studies such as the Pembokeshire Local Area Energy Planning (LAEP) which will include whole system energy modelling and optimisation of the Pembrokeshire local authority energy system, LAEP delivery pathways and local energy decarbonisation routemap are also key to inform the development of this roadmap.
- The future energy system will be based more around energy supply. Increased flexibility and interaction of multiple vectors and services will be required to flex demand, enable use and storage and trade different commodities. As such, technical, regulatory and market barriers around flexibility trading platforms would need to be overcome and local actors, network operators and regulators all have a role to play to realise these benefits by 2050. Further details on recommendations on how a trading platform could support the decarbonisation of Milford Haven and Pembrokeshire is provided in the Commercial case.
- Engagement with network operators should be continuous to integrate the network capacity and planned upgrades into the roadmap.
- The roadmap should be kept under review and adapted as the regional picture evolves, more actors become interested in the transition including investors and energy sector level changes happen for example network upgrades and policy and regulatory changes.

The decarbonisation roadmap should have the community, stakeholders and wider sustainable development aims at the centre to ensure a just transition.

- The transition to net zero should put the community, stakeholders and wider aims at the centre and ensure a just transition for all. Through continual stakeholder engagement and adopting a theory of change approach, MH:EK should aim at developing a set of tangible actions and a roadmap for everybody to understand their role to get to net zero by 2050 whilst ensuring societal cohesion.

Net zero by 2050

Next steps

Short-term: development of proposition 1 & 2

- Further work and more detailed analysis of both propositions is required, including:
  - taking the **whole system energy modelling** undertaken to date to the next stage of detail to support a more detailed design;
  - exploration and **use case testing of the SPV / partnership commercial model**;
  - specific **stakeholder engagement** to explore their appetite for such a model, and to better understand what risks or barriers there might be in implementing;
  - exploring in more detail **how the ESCo model would work in practice**, what the relationship would be with other project partners, and the commercial relationship with entities outside of the SPV partnership perimeter;
  - **financial modelling** to further understand the potential pay-back or revenue to different parties; and
  - establishing a **detailed management plan**, including: an implementation programme, data management, risk management and contract management approaches.

Short-term: data ecosystem

- Establish a data working group within the MH:EK organisations to ensure that the various data initiatives recommended in this report, and within the energy sector, are discussed and championed locally in a coordinated way.
- Through the above data working group, engage with key national energy sector initiatives which are underway such as Open Energy *[6],* Virtual Energy System *[7]* and Future of Gas *[8]* which will enable a much better integration of MH:EK SLES into the wider energy market through better data sharing and standardization

Mid-term: setting a roadmap

- Identify a project lead to take forward establishing a roadmap in line with the mid-term recommendations.
- Continued stakeholder engagement, in particular with other key regional initiatives such as SWIC and RWE PNZC, alongside increasing community engagement to support all parties in taking a role in the local energy transition.

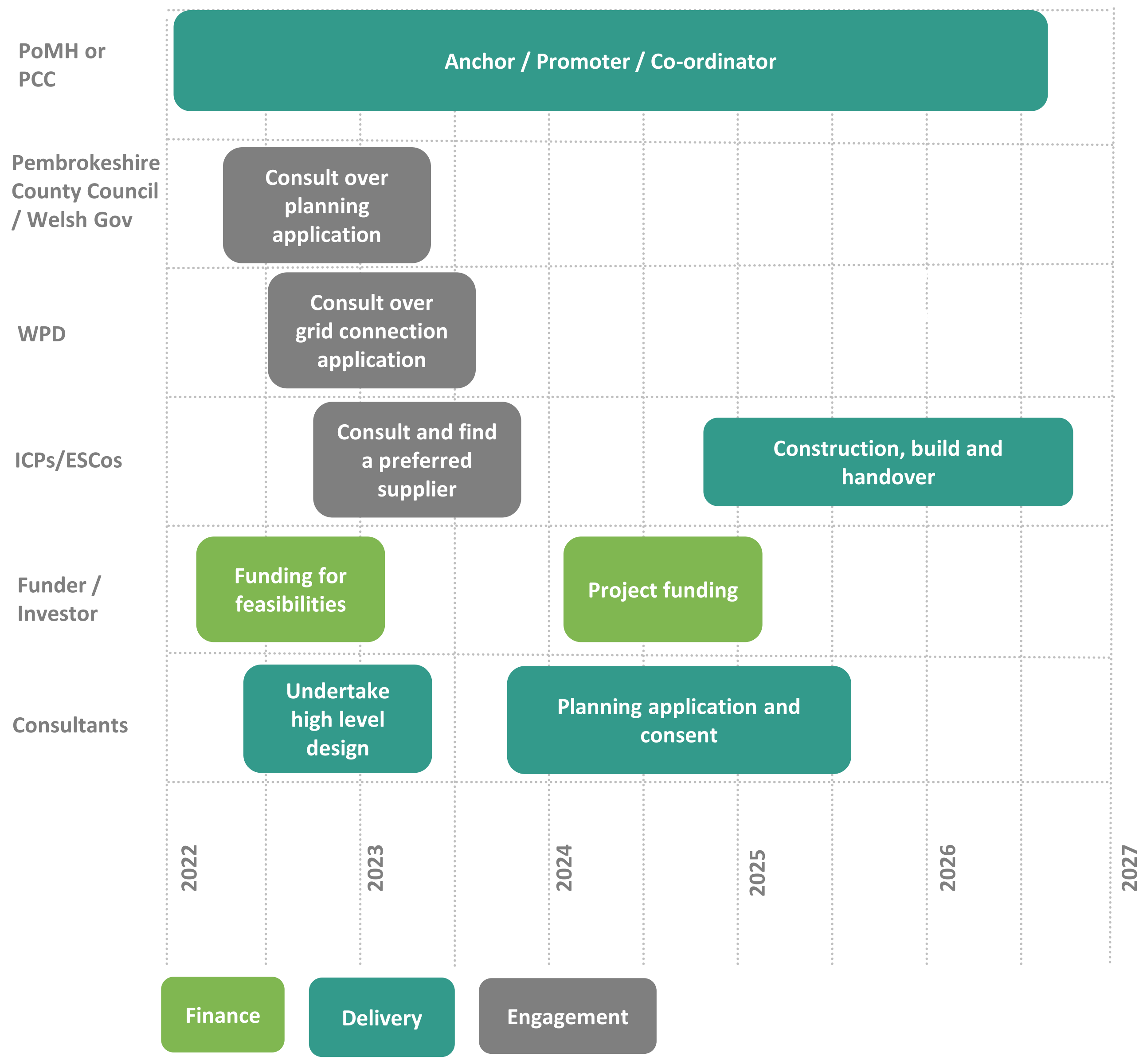

Figure 52: Indicative implementation programme for the recommended SLES

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Appendix A – High-resolution images

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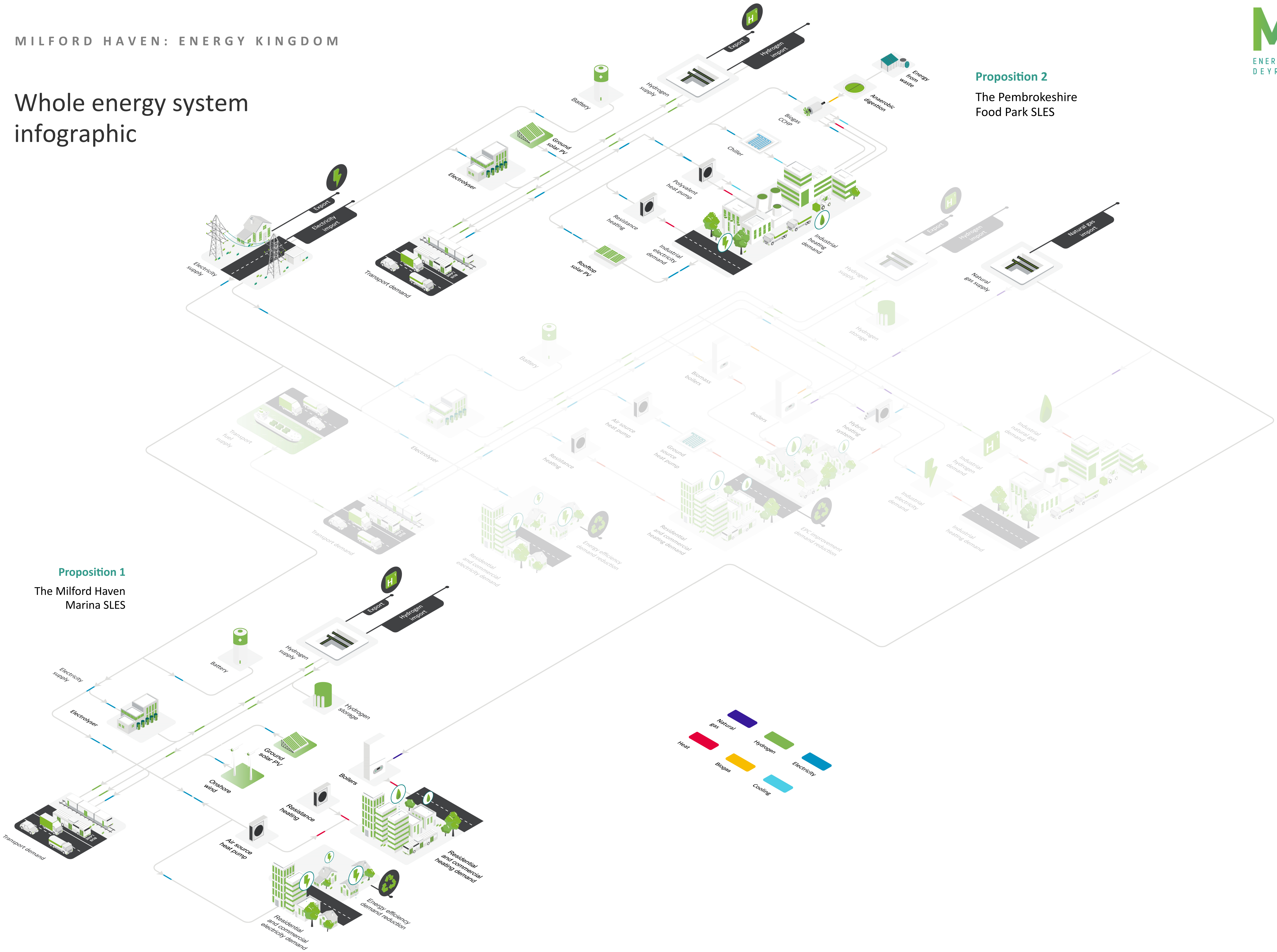
Whole energy system infographic

Proposition 2

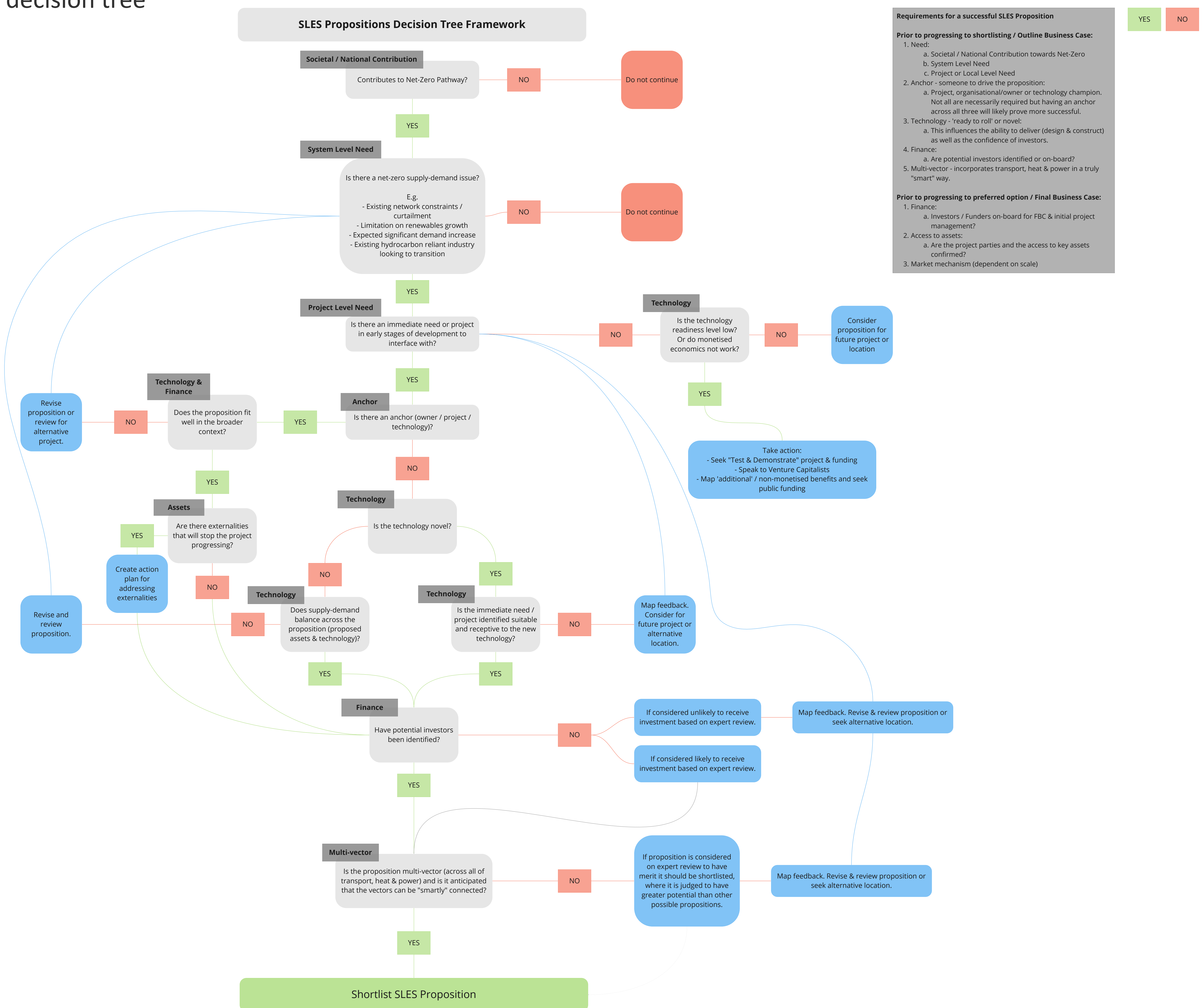
The Pembrokeshire Food Park SLES

Proposition 1

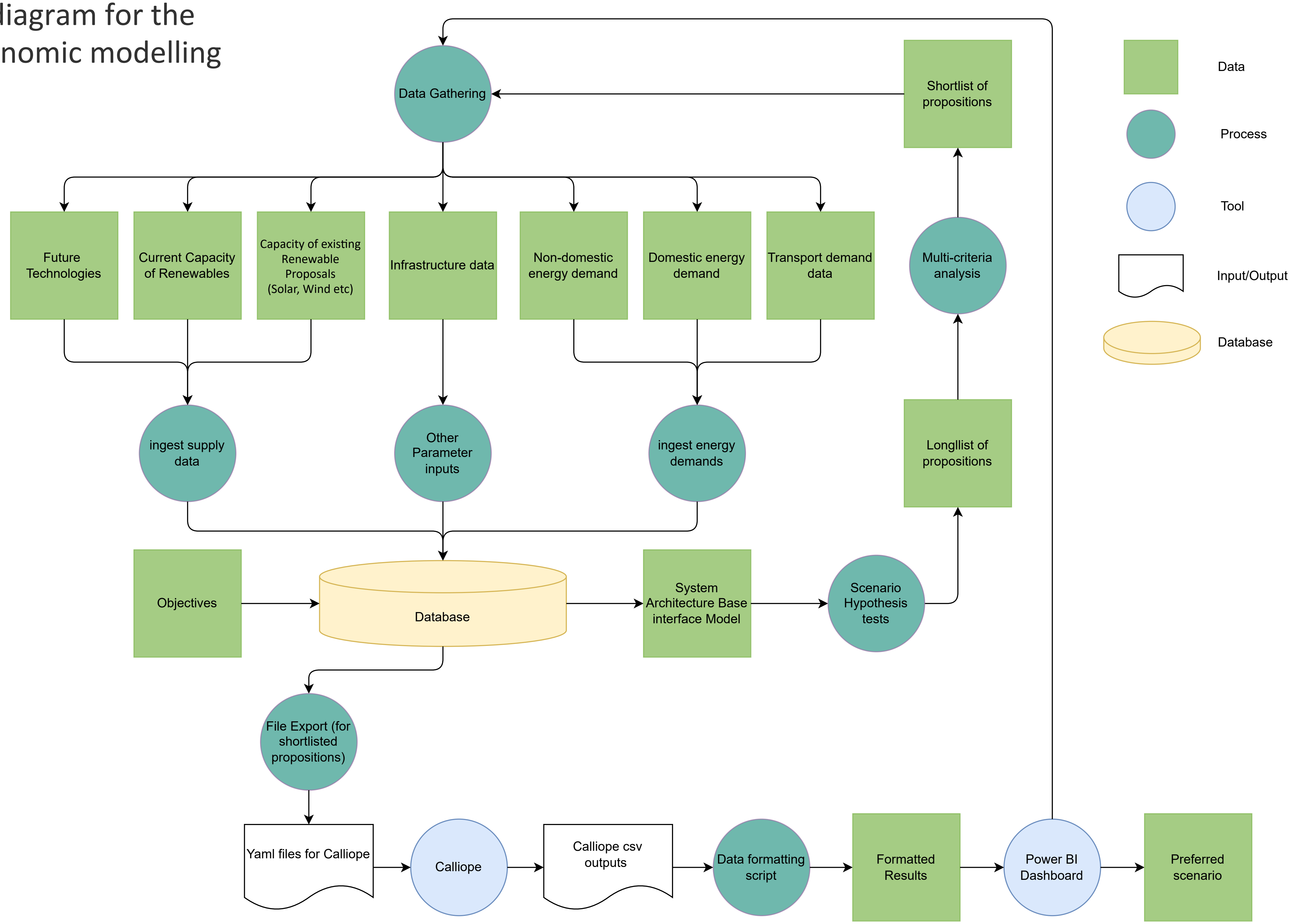
The Milford Haven Marina SLES



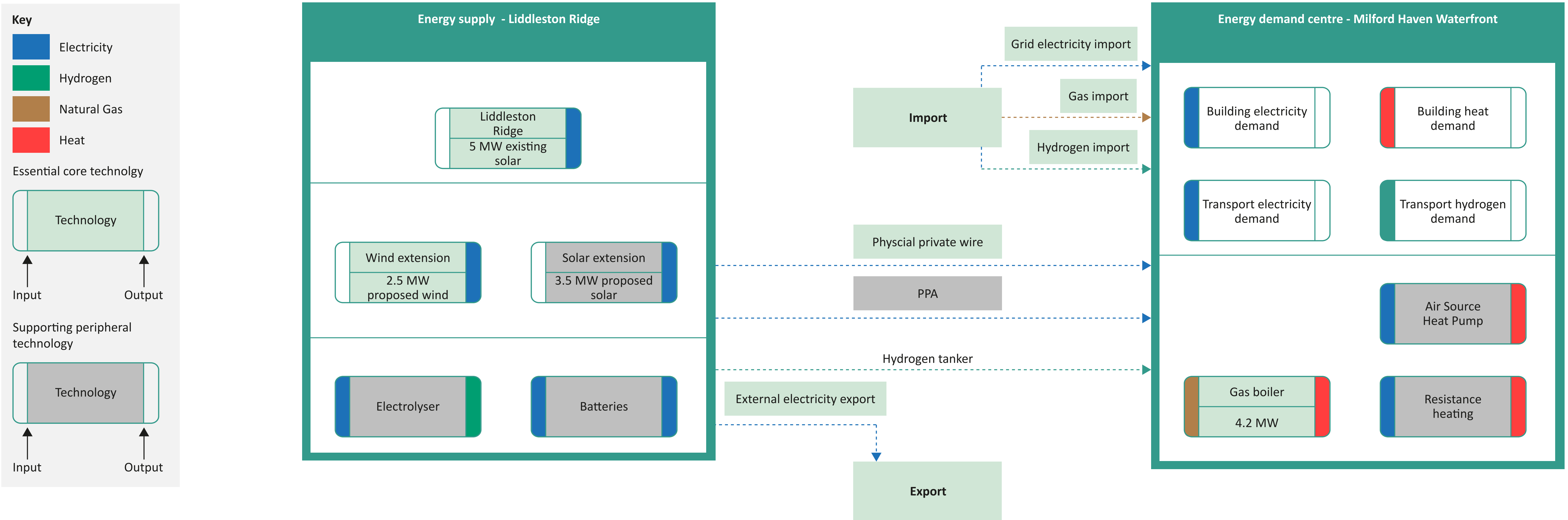
SLES decision tree



Workflow diagram for the techno-economic modelling process



Preferred system for Proposition 1 – Milford Haven Marina SLES



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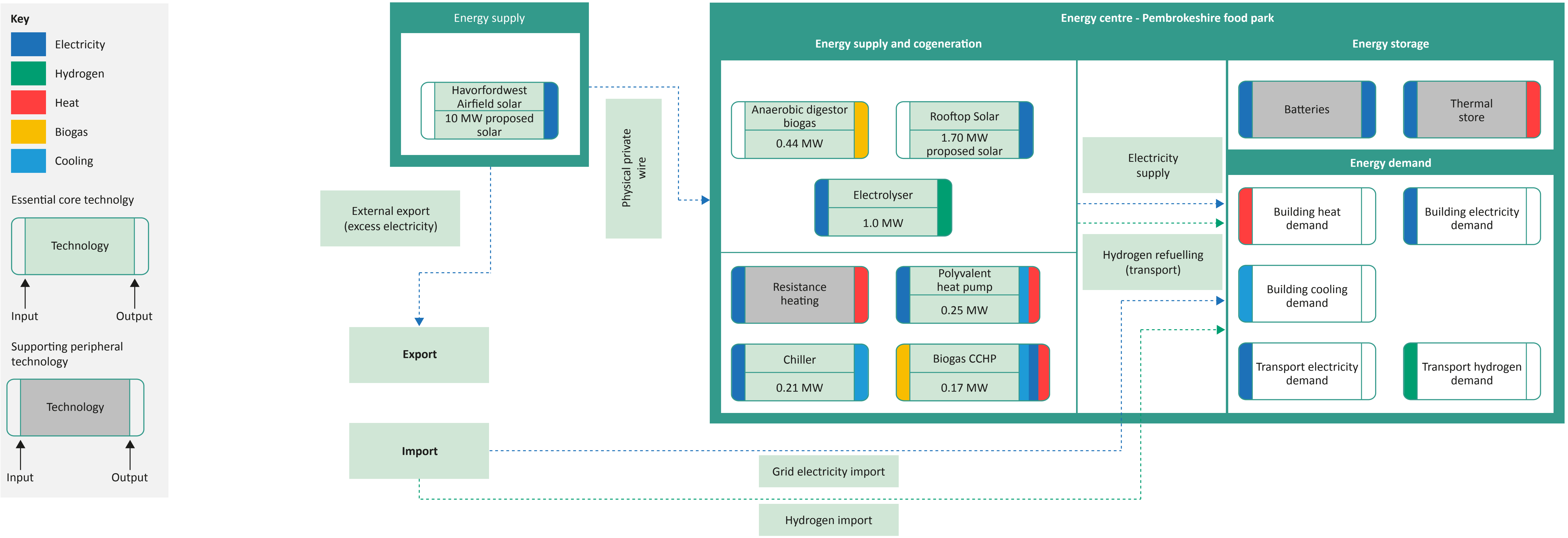
Preferred system for Proposition 2 – Pembrokeshire Food park SLES



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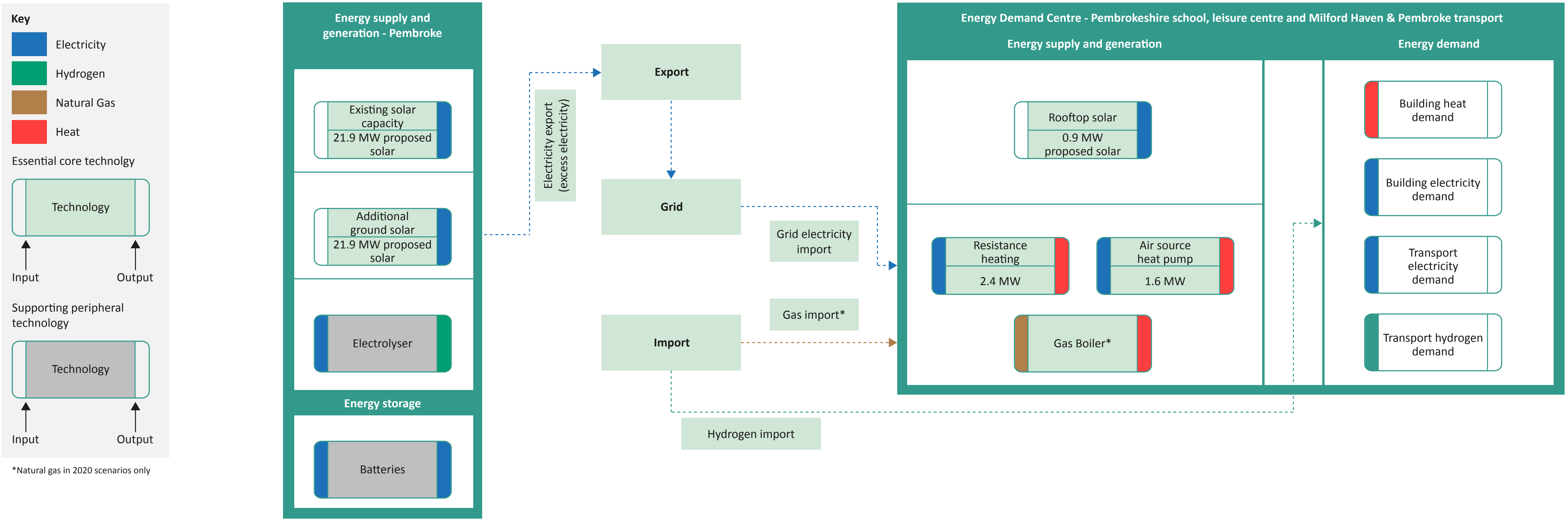
Preferred system for Proposition 3 - Pembroke Schools, Leisure Centre and Dock SLES



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