Hydrogen Handling and Logistics

Challenges and Opportunities in a Remote Archipelago

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1.0	26/08/2022	Version 1	Richard Waine	Grant Tuff, Nick Eraut	Bunmi Adefajo

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Executive Summary

The "Integrating Tidal Energy into the European Grid" (ITEG) project is developing an integrated tidal energy and hydrogen production solution for clean energy generation, and is demonstrating it on Orkney. This report complements Deliverable LT.4.2 "Whole Energy System Analysis: Long Term Impacts on the Orkney Energy System" by providing a discussion of the challenges and opportunities associated with movement of hydrogen across a remote archipelago.

Framed by tools from the disciplines of Systems Engineering and Asset Management, discussion is focused on the high-level specification of a hydrogen distribution system for two scenarios to identify technical challenges. The scenarios have been selected to represent the extremes of both high and low volumes of hydrogen movement across the archipelago from system entry to exit. As an enabler to the process a set of assumptions were developed, including a set of representative stakeholder requirements. These provided the basis of five value drivers for the hydrogen distribution system and enabled the definition of performance requirements. This provided a basic structure to investigation of challenges, ensuring relevance through direct alignment to representative stakeholder requirements.

Consideration of both value drivers and hydrogen quantities enabled identification of key challenges for both a 'small-scale' and 'large-scale' system. Challenge themes were found to be driven primarily by the inherent geography of an archipelago. This requires a combination of road, fixed, and maritime assets, operating in challenging onshore, coastal, and offshore domains, adding significant complexity. This includes an increased, unavoidable, level of regulatory and technical challenges rarely found in a geographical area of comparable size. Key challenges identified were management of multiple regulatory regimes, optimal selection of maritime transport between islands, development of system-wide security of supply for a remote location, and realisation of efficient cost performance.

By viewing the challenges at a system level, common opportunities have been identified to optimise mitigation across the life cycle of a hydrogen distribution system serving an archipelago environment. These have been developed with the intention to realise optimum asset value from the hydrogen distribution system and include:

- the use of common standards
- asset standardisation
- strategies for security of supply
- strategies for maritime hydrogen transportation
- involvement of stakeholders in the development of value drivers and management of the system, to ensure delivery against these drivers and thus real local benefit.

Additionally, recommendations are made for further detailed studies; development of design, decision and procurement tools; and creation of new regulatory and standardisation leadership approaches; to facilitate hydrogen deployment in remote archipelago environments, including:

- a further, detailed review of legislation and regulation domains, including the identification of key legislative instruments that drive other requirements and inter-dependencies
- further social acceptance research of hydrogen on remote archipelagos

- a specific hydrogen distribution system strategic plan, ideally developed as part of a comprehensive Local Area Energy Plan
- further technical investigation of the optimal bulk hydrogen production sub-system configuration
- a hydrogen distribution system decision framework to support asset selection
- a hydrogen distribution system asset procurement list
- a system model or digital twin
- a 'joint regulation body' combining all regulatory stakeholders into a single body
- an 'archipelago hydrogen distribution standards lead'

These are explained and set out in more detail throughout the report.

1 Introduction

The "Integrating Tidal Energy into the European Grid" (ITEG) project is developing an integrated tidal energy and hydrogen production solution for clean energy generation (shown schematically in Figure 1 below), and demonstrating it in Orkney. The project addresses energy-related carbon emissions in North West Europe and could help to tackle grid export limitations faced in remote communities.

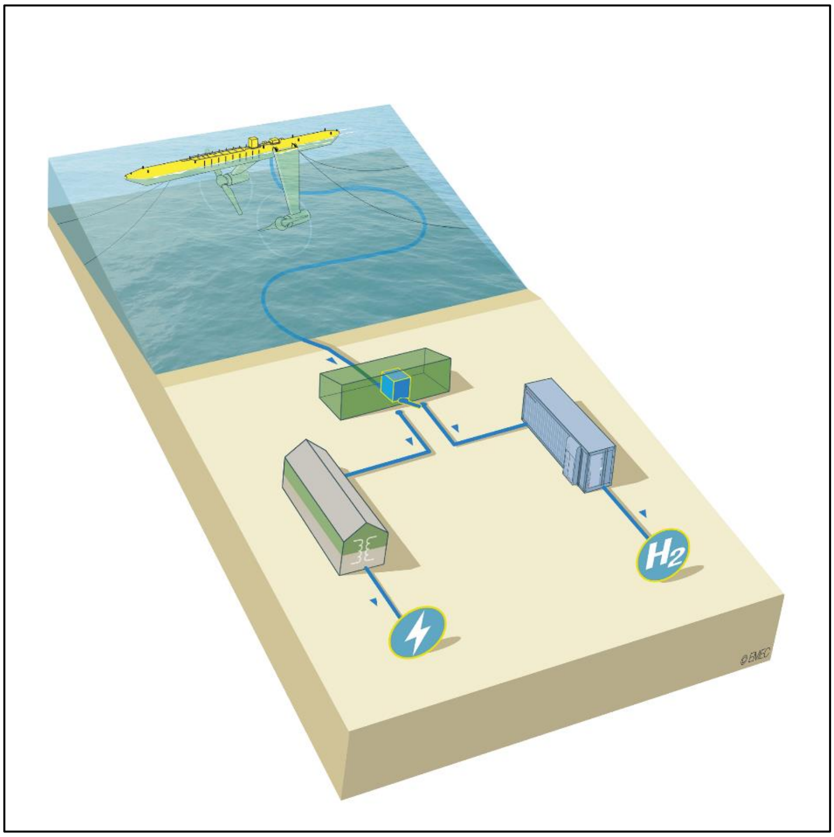

Figure 1: Schematic View of ITEG tidal energy with electrolysis system

The Long Term Impacts work package considers numerous inter-related aspects of the benefits and impacts of such systems in remote islands and coastal communities. A large part of this work package is based on detailed modelling of the Orkney energy system. The potential development of the Orkney energy system to achieve net zero targets, and particularly the possible roles for the production and use of hydrogen, deployed alongside tidal stream generation, are explored in detail in **Deliverable LT.4.2 "Whole Energy System Analysis: Long Term Impacts on the Orkney Energy System"**. That analysis includes the possible volumes and locations of deployment of the ITEG technologies under a range of scenarios, as well as an initial assessment of the potential means of hydrogen distribution within the archipelago.

That analysis is complemented by this report, **Deliverable LT.4.3 "Hydrogen Handling and Logistics"**, which identifies the challenges and opportunities associated with movement of hydrogen across a remote archipelago (such as the Orkney Islands or other sites with similar characteristics across North West Europe or elsewhere round the world). The technical elements of system specification for two scenarios that require handling of high and low hydrogen quantities are discussed. Considering these scenarios enabled identification of general challenges and opportunities to inform further work.

For the purposes of this report, 'hydrogen handling and logistics' is interpreted as a '**Hydrogen Distribution System (HDS)**', inclusive of all value chain functional elements required to move hydrogen from point of system entry to exit – particularly, entry assets at production, distribution and storage sites, marine and land transportation modes, and equipment at demand (exit) points. A high-level assessment of system requirements was undertaken with the focus on technical areas of challenge associated with HDS whole life cycle management on a remote archipelago.

There are limited examples of gas distribution networks and systems operating across remote archipelagos on which to base an assessment methodology. In Scotland, LPG is supplied from the mainland to a network at Stornoway in the Outer Hebrides, for which a technical feasibility for a green hydrogen hub was completed in June of 2021[1]. This provides an initial level of insight but does not cover the full scope intended here,. which includes wider demand distribution across more islands, distributed production across islands and centralised bulk production. Therefore, to examine the additional challenges associated with export, a combination of Systems Engineering[2] and infrastructure Asset Management[3]– an approach commonly applied in energy networks – has been used as the basis of the method.

Two primary inputs to the process have been used to provide an understanding of indicative system requirements: firstly, representative stakeholder requirements of a distribution system and, secondly, two scenarios from the Whole Energy System Analysis report LT.4.2. The scenarios have been used to provide an understanding of the orders of magnitude of hydrogen produced, imported, compressed, moved, stored and used. Together, these inputs informed the high-level system specification and the identification of challenges and opportunities for an HDS at both scales.

Challenges across high and low deployment scenarios are discussed, with opportunities for mitigation highlighted and recommendations made.

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[1] https://www.cne-siar.gov.uk/media/17452/C%203A%20-%20Outer%20Hebrides%20Energy%20Hub%20Feasibility%20Study%20Report.pdf [Accessed 21/02/22]

[2] https://www.incose.org/systems-engineering [Accessed 21/02/22]

[3] https://theiam.org/ [Accessed 21/02/22]

2 Method and Assumptions

2.1 System Approach

The Inputs-Outputs diagram is a method used to perform Systems Engineering processes[4] which captures system Inputs, Controls, Enablers, Activities and Outputs. It has been used here to frame system requirements analysis and identify key challenges. The diagram for this process is provided in Figure 2 below:

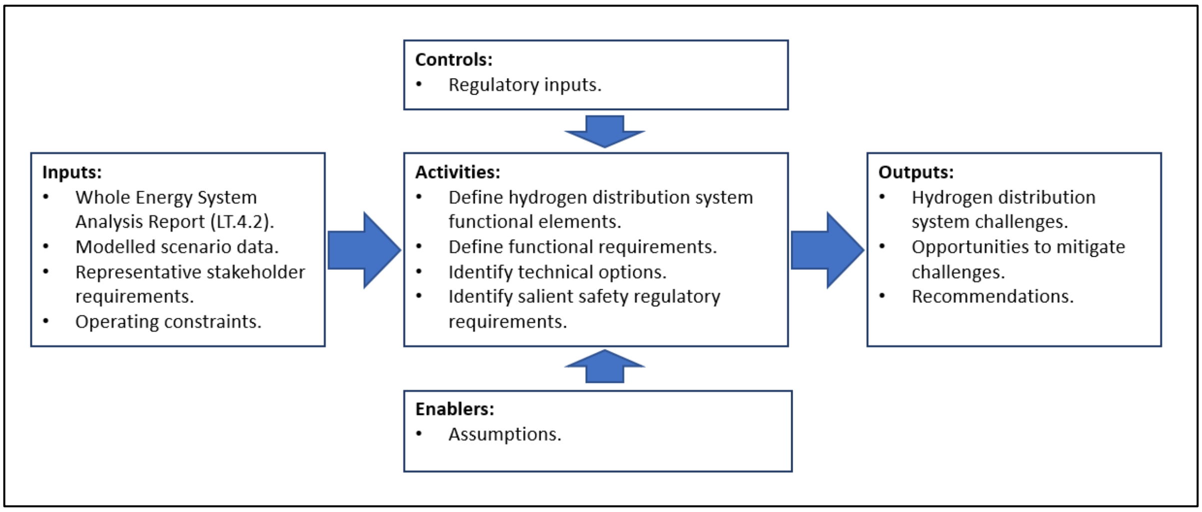

Figure 2: Inputs-Outputs Diagram

2.2 Assumptions

For the development of high-level system requirements, a set of assumptions has been made to focus the process on typical challenges associated with energy distribution. These have been applied across specification of two systems representing two scenarios that require handling of high and low hydrogen quantities, setting a basis for technical and representative stakeholder requirements that may be found on a remote archipelago.

2.2.1 Technical Assumptions

This report considers the handling of gaseous hydrogen across an archipelago, including preparation for export. Hydrogen received into the distribution system from imports or production units (electrolysers) is assumed to be of sales quality, requiring no further processing or conditioning, with the exception of pressure changes and that to facilitate distribution (i.e. flow conditioning for measurement). The specific technical parameters of what constitutes sales quality are not considered here, beyond the assumption of meeting legislative and point of use requirements. The pressure regime of the distribution system serving local demand across the archipelago is assumed to be one of flow from highest pressure at the point of production to lowest at point of delivery from the system. Compression is assumed to be located closest to point of production, negating the need for compression assets elsewhere in the system.

[4] Systems Engineering Handbook, INCOSE, ISBN: 9781118999400

When a compressed gas is subject to expansion, the gas typically cools, referred to as the Joules Thomson effect. It should be noted that hydrogen has a reverse Joule-Thomson effect and will heat up on expansion[5], therefore it is assumed that pre-heating equipment is not required within the system.

2.2.2 Representative Stakeholder Needs

Energy distribution systems are influenced by, and have direct impact on, multiple stakeholders who have varying requirements from the associated infrastructure at each stage of the network asset whole-life cycle. These typically include consumers, investors, local communities, and regulators (economic, environmental and safety) amongst others. The Asset Management discipline described in the international standard ISO55000[6], is commonly used by energy network owners to structure delivery of optimal value to stakeholders from infrastructure assets. Part of this framework is the identification of stakeholders, their requirements and subsequent conversion of these to value drivers that then form the basis of strategic, tactical, and operational decision making.

For the purposes of this report, a set of standard stakeholder requirement themes have been adapted from the European MACRO project shamrock diagram[7] [8]. These are referred to as 'value drivers' through-out this report. For the purposes of this report, the supporting performance drivers listed are considered indicative of the potential requirements of stakeholders of an HDS on a remote archipelago:

Table 1: Stakeholder Requirements and System Value Drivers

Value Driver	Performance driver
Risk Exposure 	**Reliability** – Reliable supply at point of use, with lowest risk of interruptions at times of peak demand i.e. winter for building heat. Individual asset reliability, availability and maintainability have additional emphasis given remote archipelago location. **Resilience** – A system resilient to the current and future changes of operating environment i.e. climate change. **Safety** - High safety performance with minimal risks to society, public and HDS employees.
Compliance 	**Safety** – Compliance with requirements set by safety regulator(s), inclusive of hydrogen quality standards. **Environment** – Compliance with requirements of environmental regulator(s).

[5] https://www.hse.gov.uk/research/rrpdf/rr615.pdf

[6] https://www.iso.org/standard/55088.html

[7] https://www.researchgate.net/publication/228905772_Asset_Management_concepts_practices

[8] Asset Management Decision Making, The SALVO Process, ISBN: 9780956393470

Capital Value 	**Capital Costs:** Optimal costs required to minimise cost of system to distribution system customers. **Asset Life Expectancy:** Given remote, multiple islands, and potentially exposed coastal environment of the land assets, selection of standards and assets will require additional consideration for each engineering discipline i.e. mechanical, electrical, instrumentation and control.
Operational Efficiency 	**Operational Costs** – Optimal asset flexibility and costs required to minimise cost of system to customers and enable early market growth. **Performance Output** – efficient delivery of all performance requirements.
Shine 	**Quality** – High quality of service experienced by customers where security of supply and reliability are the main elements of service. **Public Image & Customer Impression** – Interactions and communications with the HDS to give customers and stakeholders confidence in reliability and safety.

2.2.3 Social Acceptance

All the value drivers captured above are impacted by, and contribute to, the social acceptance of hydrogen as an energy vector by stakeholders and customers. For the scenarios considered here it is useful to split social acceptance into the acceptance of hydrogen as a fuel and the acceptance of hydrogen infrastructure within an environment.

The H21 project[9] led by Northern Gas Networks in the UK is a group of industry innovation projects focused on gaining an understanding of the safety and feasibility of converting the existing gas network to hydrogen. One project included a study with Leeds Beckett University[10] to understand public perception of hydrogen as a domestic fuel. Although, it is not directly applicable to remote island communities, as the study focused on conversion of existing gas customers in a dense urban centre, it does provide an indication of how hydrogen may be received by customers and a wider community.

The study found that 20% of the population would accept a conversion to hydrogen with little reassurance, 12% would reject a conversion and 68% were indifferent and required further information. It concluded that communication was a fundamental enabler to address concerns and highlighting the risk that a proportion could reject hydrogen if mishandled. Translated to an HDS on a remote archipelago, this highlights the importance of communications associated with any HDS activities and the Shine value driver.

[9] https://h21.green/ [Accessed 21/02/22]

[10] https://h21.green/projects/h21-social-science-research/ [Accessed 21/02/22]

Within the ITEG project, **Deliverable LT.2.2** presents a study of the social acceptance of tidal generation, other renewables, and of hydrogen systems.

Social acceptance of infrastructure associated with hydrogen distribution is likely to be dependent on the scale and visibility of any existing, or legacy, industry and corresponding relationships between asset owners and the local community. There are examples in industry of where this can be both an enabler and hinderance to infrastructure projects. Gaining understanding of the initial position is an important element of any infrastructure development. Social acceptance is also potentially covered by legislation in the UK – specifically the Planning Act 2008 may apply, dependent on the project details.

This report assumes that hydrogen use as a fuel and hydrogen infrastructure developments are widely socially accepted.

3 Hydrogen Distribution System Challenges and Opportunities

3.1 System Specification

Two scenarios from LT4.2, have been selected and used as the core inputs for specification of each Hydrogen Distribution System (HDS), referred to as 'small-scale' and 'large-scale'. These scenarios have been selected as examples of low and high hydrogen quantities, requiring systems with different entry and exit characteristics. The systems are intended to be representative of an HDS in a 'typical' remote archipelago location, and are not applicable directly to any specific location. This approach is reflected in the high-level discussion during the system specification process.

Scenario data, combined with the assumptions and representative stakeholder requirements have been used to generate outline system specifications for both a small and large scale HDS. The details of functional element definition, functional requirement definition, identification of high-level technical options and challenges are set out in the Appendices at sections 5 & 6. The content here in section 3 provides an overview of the HDS characteristics, relevant legislation, and key challenges and opportunities.

3.2 Small-Scale HDS Characteristics

Derived from scenario 2 in LT.4.2, the small-scale system consists of a single production point producing 3 GWh/yr, the majority of which is distributed from a central distribution point located on a separate island supplied by a 'trunk' route from a single production point. Early adoption of hydrogen results in the maximum production quantity being reached in the 2030s and remaining consistent through to 2050. Demand is dispersed across 10 islands with a single point of demand consuming 30%. Building demand is dispersed across these islands with a single concentrated urban area included. Compression is carried out at a single point.

A key feature of this system is reliance on a sole point of production, trunk route and distribution node. Driven by the inherent nature of a remote archipelago, security of supply for customers is likely to be a fundamental factor in system design and operating decisions. The low quantities of hydrogen and distribution across islands with multiple sea crossings is likely to amplify the need to maintain a cost-optimal system at each step in the value chain and each phase of growth. It was assumed this would drive a need to make use of existing infrastructure and design for system flexibility to enable efficiencies. This is likely to be particularly important in the early stages of system development. Examples of such existing infrastructure are shown in Figure 3 and Figure 4, comprising the Shapinsay ferry in Orkney and one of EMEC's hydrogen tube trailers being disembarked.

Figure 3: Mobile Hydrogen Storage Unit, Coming off the Shapinsay Ferry
(image courtesy of EMEC and of Colin Keldie, BIGH_2IT)

Figure 4: The Shapinsay Ferry
(image courtesy of EMEC and of David Hibbert, Orkney Islands Council)

The need for transportation and handling operations in both onshore and marine domains presents a complex regulatory compliance environment. Indicative system requirements are set out in the appendices, identifying system elements, high level functional requirements and the links between these elements and the value drivers. The system functional elements are shown in Figure 5.

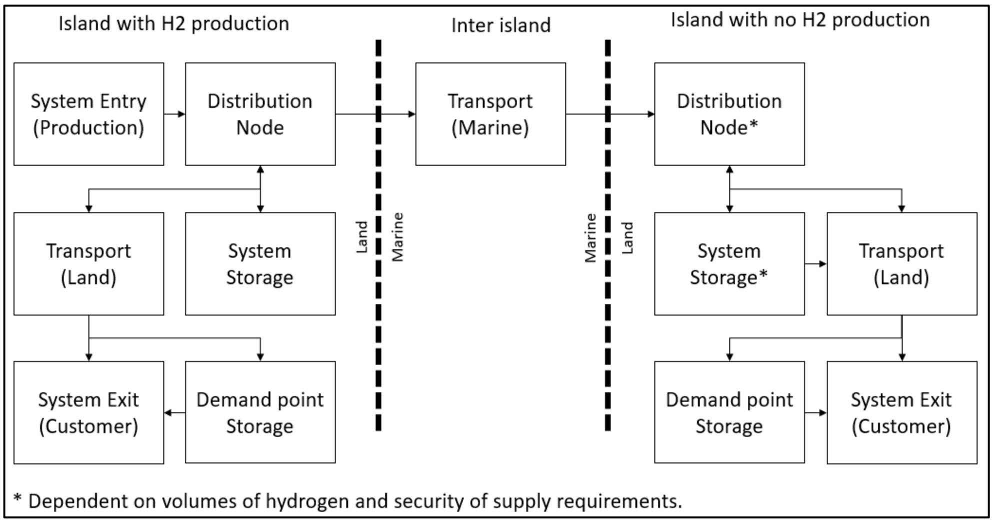

Figure 5: Small-Scale System Functional Elements

3.2.1 Small-Scale HDS Challenges

Analysis of the scenario and system requirements identified potential challenges. A full list of these, aligned to the value drivers described earlier, is provided in section 5.2. Key challenges that, if mitigated, have a positive impact on both system value provided and other interacting challenges, are highlighted in Table 2.

Table 2: Key Small-Scale HDS Challenges to be Mitigated

	**Risk Exposure:** 1. Optimal geographical distribution and quantity of storage across the system to maintain both individual and system security of supply is complex.
 	**Compliance and Capital Value:** 2. Use of existing infrastructure i.e. ports, roads and maritime vessels is essential to establishing the distribution system and limiting capital costs of maritime transport. 3. Management of multiple regulatory regimes in combination with limited volumes of hydrogen demand bring additional whole life cycle challenges, increasing the importance of both optimal capital investment decision making and technical design.
	**Operational Efficiency:** 4. Operating on an archipelago increases the emphasis on asset reliability, availability and maintainability performance and subsequent impact on operational efficiency. 5. Use of existing infrastructure is fundamental to limiting capital and operational expenditure.
	**Shine:** 6. High interdependencies between risk exposure performance, intangibles, social acceptance of hydrogen and demand.

3.3 Large-Scale HDS Characteristics

Derived from scenario 7 in LT.4.2, the large-scale system required is more widespread, complex and dynamic through the planning period. Hydrogen is imported (up to 12 GWhr/yr) into a single location during the initial part of the planning period and ceases in 2040. Hydrogen production sites and volumes grow through the 2030s to a peak in 2050 with a single 'bulk' site (500 GWh/yr), two 'medium' sites (30-50 GWh/yr) and eight 'small' production sites (<15 GWh/yr). Local demand is driven by hydrogen use for ferry fuel (30 GWh/yr) and building demand (20 GWh/yr) across 15 islands. Distribution of building demand is proportioned to island population. Export volumes are established rapidly and grow to a peak of 650 GWh/yr by 2050.

The distribution system to serve this scenario results in a local system for building and transport demand supplied from the single import point. As local production (10 sites) and bulk production develop, a widespread local distribution system is required with a separate sub-system to move the bulk hydrogen produced for export. Bulk hydrogen production and export facilities were assumed to be located on different islands. Routes moving various quantities exist between multiple islands requiring multiple distribution nodes, which are located across the archipelago. There are multiple points of compression, these are assumed to be co-located at production plants through-out.

In comparison to the small- scale system, hydrogen quantities, asset geographical distribution, system complexity, local distribution system scale and functional requirements are all increased. This is inherently a more challenging system where all value drivers are increased, but the key value drivers are likely to be risk exposure due to the increased volume of product across the archipelago, compliance due to the various scales and types of assets, and capital value due to the change from import to local and bulk production on the archipelago. Section 6 sets out the indicative system requirements, identifying system elements, high level functional requirements and the links between these elements and the value drivers. The system functional elements are shown in Figure 6.

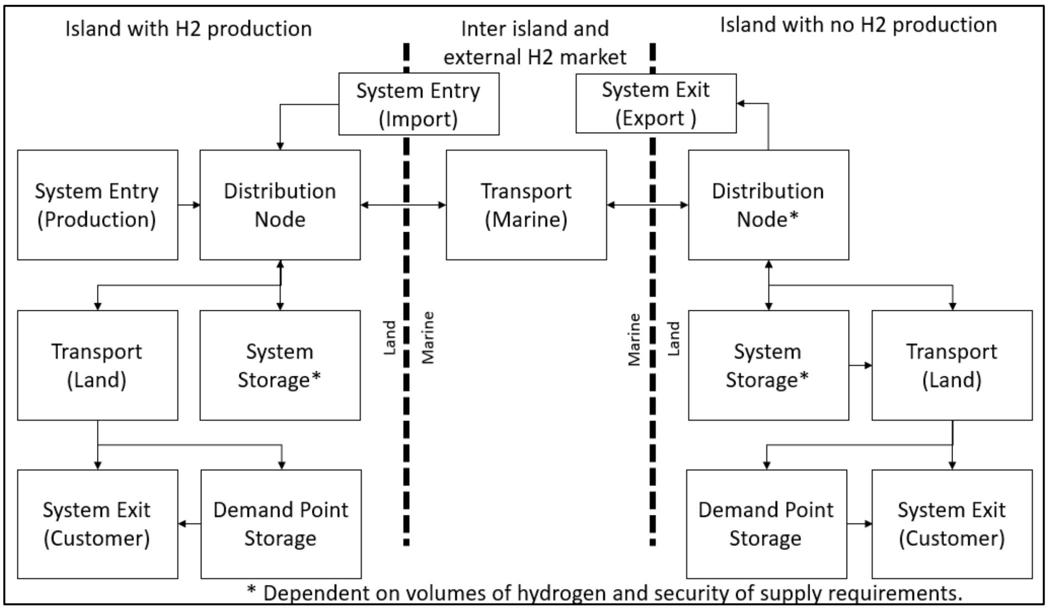

Figure 6: Large-Scale System Functional Elements

3.3.1 Large-Scale HDS Challenges

Analysis of the scenario and system requirements has been carried out to identified potential challenges. A full list of these challenges, aligned to the value drivers described earlier, is provided in section 6.2. Key challenges that, if mitigated, have a positive impact on value provided and other interacting challenges, are highlighted in Table 3.

Table 3: Key Large-Scale HDS Challenges to be Mitigated

	Risk Exposure: 1. Optimal geographical distribution and quantity of storage across the system to maintain both individual and bulk security of supply is complex. Driven by supply, demand, and export profile change through the planning period. 2. Use of imports couples system resilience to the import market. 3. The large-scale system has increased demand and an increased number of sites. There is a coupling of transport infrastructure (ferries) reliant on hydrogen supply and hydrogen supply reliant on transport infrastructure (during early stages of hydrogen development). This shows the need for a robust approach to security of supply and development of a system storage philosophy to mitigate risks associated with the wide influence on the archipelago energy and transport infrastructure.
	Compliance 4. Introduction of a piped distribution network serving customers and sub-sea pipelines transporting bulk hydrogen introduce additional legislative compliance and regulatory requirements.
	Capital Value: 5. Optimisation of asset acquisition decisions and capital deployment through both the growth of hydrogen demand and shift from imported to local production supplies. An additional challenge exists to avoid stranded assets used for imports. 6. In comparison to the small-scale system, emphasis on optimal capital investment decision making and technical design focused on enabling larger volumes of hydrogen movement long term. 7. Where use of existing transport assets becomes infeasible a need for capital investment in new assets will arise. Optimal selection of the right size and technology for assets will be a challenge as the HDS grows and technology develops.
	Efficiency: 8. Operating on an archipelago increases the emphasis on asset reliability, availability, and maintainability performance, with a subsequent impact on operational efficiency. 9. With a high volume of assets across the archipelago optimisation of operations and maintenance activities is likely to be more challenging, requiring additional management overhead.

	Shine 10. Close interdependencies between risk exposure performance, intangibles, social acceptance of hydrogen and demand.

3.4 Movement of Bulk hydrogen

By locating the bulk hydrogen production and export facilities on separate islands, the large-scale system highlighted a challenge of realising whole-life-cost performance – particularly, the technical options available to move large quantities of energy between islands.

Technically this could be in the form of cables to transport electricity, and either sub-sea pipelines or maritime vessels to transport hydrogen. Any selection will likely be based on location factors including onshore geography, offshore geography, cost implications and volumes of energy to be transported. Any archipelago considering large scale hydrogen would benefit from an early technical study to identify feasible options.

Small-scale systems have been operated in Orkney using tube trailers transported on ferries. However, there are considerable limitations and constraints imposed by maritime safety regulations relating to the transportation of gases which are classified as dangerous goods – presently including hydrogen. These are discussed further in section 3.5.5. Small-scale systems must therefore consider these safety requirements as a fundamental aspect of system design and operation.

Although this has been made to work on Orkney for the relatively small scale of hydrogen transported to date, it presents significant challenges to commercial viability in the long term, and especially for larger scale systems with larger volumes of hydrogen to be transported at greater frequencies. Unless this changes, larger scale systems will probably have to consider the installation of sub-sea hydrogen pipework systems as a more commercially-viable alternative.

3.5 Legislation and Regulations

Where specific legislation and regulations are cited in this report, these citations are intended to identify some examples of the most relevant regulations, rather than providing a comprehensive and exhaustive list. With the project implementation being carried out in Orkney, regulations are discussed foremost from a UK perspective – again providing examples, rather than a comprehensive review of all regulations across all relevant EU member states (which is outside the scope of this report). The HyLaw project has compiled a database[11] of existing legislation and regulations relevant to fuel cell and hydrogen applications and legal barriers to their commercialisation.

3.5.1 Land Based Assets

In the context of this document land based, fixed assets are permanently or semi-permanently fixed assets that form part of hydrogen system sites or are located at customer premises associated with transportation of hydrogen i.e. pipework, valves and pressure vessels. Safety legislative requirements are fundamental factors influencing each stage of the HDS life cycle, ultimately driven by the Health and Safety at Work Act[12]. A selection of the core regulations likely to drive requirements for compliance and risk management include:

- Control of Major Accident Hazards Regulations (COMAH, UK implementation of the EU Serveso 3 Directive).[11]
- Pressure System Safety Regulations (PSSR). [11]
- Dangerous Substances and Explosive Atmospheres Regulations (DSEAR, UK implementation of the EU ATEX Directives 137 and 95). [11]
- Pressure Equipment (Safety) Regulations (PE(S)R, originally UK implementation of EU Directive 2014/68/EU). [11]
- Management of Health and Safety at Work Regulations. [11]
- Control of Substances Hazardous to Health (COSHH). [11]

Applicability of the COMAH regulations is dependent on the quantity of dangerous substance present on site, discussed further below.

3.5.2 Land Transport Assets

Land transport assets are those used to transport hydrogen between sites (import, production, storage, distribution, export) or to customers. Road or pipe modes are considered options. Road transport is regulated by a combination of the Carriage of Dangerous Goods and Use of Transportable Pressure Equipment Regulations[11] and the European ADR “Accord Européen relatif au transport international des marchandises dangereuses par route” [11].

Any onshore pipe networks including pipes (<7barg) and pipelines (>7barg) will introduce additional economic, environmental and safety regulatory requirements. Potentially including The Gas Act[11], Ofgem licence regulations[11] and The Pipelines Safety Regulations (PSR)[11].

[11] https://www.hylaw.eu/database

[12] See section 7

3.5.3 Marine Transport Assets

Marine transport assets are those used to transport hydrogen between distribution nodes on different islands. This could be done by maritime vessel or offshore pipelines. The International Convention for the Safety of Life at Sea 1974 (SOLAS)[13] is the overarching international legislative instrument that provides provisions for the carriage of goods considered dangerous or a marine pollutant, specifically in the form of the International Maritime Dangerous Goods Code (IMDG)[14].

Carriage of hydrogen in a maritime environment in the UK is subject to two pieces of legislation The Merchant Shipping (Dangerous Goods and Marine Pollutant) Regulations, enforced by the Department for Transport, and The Dangerous Substances in Harbour Areas Regulations (DGHAR), enforced by the UK Health and Safety Executive (HSE). The potential to use passenger ferry infrastructure for hydrogen transport is limited by these regulatory requirements, and this is further discussed below.

Safety regulations of offshore pipelines in UK territorial waters and UK Continental Shelf are covered by the Pipeline Safety Regulations (PSR) [11] enforced by the HSE.

3.5.4 Key Regulation – Control of Major Accident Hazard Regulations

System storage is likely to be a material contributor to system risk exposure and compliance performance. COMAH regulations categorise hydrogen as a Dangerous Substance and any facility with a 'qualifying quantity' present is subject to the regulations. In addition, the qualifying quantity determines which tier (Lower or Upper) of requirements apply to the site. For hydrogen, the lower tier quantity is ≥5 tonnes, and upper ≥50 tonnes. Any HDS storage site could be impacted by the COMAH regulations. This is likely to be driven by the security of supply requirements, corresponding required quantities and location of hydrogen specified in a system storage philosophy.

Smaller storage will be needed at or near points of use, providing a similar function to those seen with LPG distribution systems. These are likely to fall below the minimum qualifying quantity for the COMAH regulations to be applicable but would need to be assessed on a case-by-case basis.

3.5.5 Key Regulation - Merchant Shipping (Dangerous Goods and Marine Pollutant) Regulations

The method and options for moving hydrogen between islands is likely to be a material influencing factor on overall performance of the HDS. Use of existing infrastructure is a potential source of efficiency, particularly in the early stages of system development. However, the scale of efficiencies is likely be constrained by legislative safety requirements.

Ferries are the main maritime transport infrastructure operating in an archipelago environment. Considered a 'lifeline service', driven by the need to reliably transfer all people, road vehicles and cargo needed for island life. Ferries, as vessels for the transport of passengers, are subject to restrictions on the movement of dangerous goods on these services. Although exceptions can be obtained for the movement of fuel, these can be limiting, particularly on the practicalities of

[13] https://www.imo.org/en/OurWork/Safety/Pages/DangerousGoods-default.aspx#:~:text=The%20IMDG%20Code%20was%20developed,prevent%20pollution%20to%20the%20environment. [Accessed 21/02/22]

[14] https://www.imo.org/en/OurWork/Safety/Pages/DangerousGoods-default.aspx [Accessed 21/02/22]

hydrogen transportation. Experience of hydrogen movement in the Orkney Islands has highlighted a need for specific road transport assets that meet requirements for carriage on maritime transport, including installation of integrated safety systems and enhanced maintenance (and inspection) regimes to meet exemption requirements. Operational constraints have also been experienced including the number of trailers carried per vessel, the position of trailers on vessels during transit, ventilation requirements. Even with these in place, it is sometimes necessary to charter ferries specifically for the movement of hydrogen trailers.

Although there would be significant benefits from an agreed, standardised approach to the movement of hydrogen on ferries which would make this much easier, it is unlikely in practice that these requirements will be changed in the near future to the extent required to enable movement of the amount of hydrogen modelled. This identifies a fundamental need to consider maritime safety requirement constraints in the design of an archipelago HDS at each stage and in each domain of development.

Although this has been made to work on Orkney for the relatively small scale of hydrogen transported to date, it presents significant challenges to commercial viability in the long term, and especially for larger scale systems with larger volumes of hydrogen to be transported at greater frequencies. Unless this changes, larger scale systems will probably have to consider the installation of sub-sea hydrogen pipework systems as a more commercially-viable alternative.

3.6 Opportunities

Following review of the system requirements, process and challenges identified, the opportunities below have been identified. The basis of these opportunities, listed in no specific order, is resolution of challenges to the delivery of optimum value from an HDS to archipelago stakeholders:

1. **Common (Cross Archipelago) standards** – The volume of legislation and regulations applicable to an HDS operating across an archipelago has been identified as a challenge to compliance performance and operational efficiency. Development of a common set of standards and procedures for application to system operators (asset owners) has the potential to reduce risk exposure and support operational efficiencies.
2. **Asset standardisation** – Adoption of standard assets across the distribution system could support interoperability, operational efficiency and, done correctly, reduce risk exposure challenges. This needs to be balanced against risks of single common failure mode and achieving reliability performance.
3. **Multi-function assets** – For transport assets this could be trailers that carry out land and sea transport as well as storage functions. This could support flexibility and higher performance across risk exposure, compliance, capital, and operational efficiency value drivers. In addition, this could provide the flexibility required at the early stages of any hydrogen system development.
4. **Maritime transport strategy –** To mitigate the risk of maritime regulation becoming a constraint on HDS growth, a strategy including a hierarchy of options and action points to increase capacity or technology deployment would be beneficial. Options could include a specific vessel(s) for hydrogen use, a roll-on/roll-off cargo or small sized pressurised hydrogen carrier. Optimisation could be achieved by aligning investment decisions and commissioning times to hydrogen production development. For large hydrogen movements a strategy for the deployment of sub-sea pipelines should be considered.
5. **Land based transport strategy –** To manage weight limitations associated with use of island roads, a strategy of hydrogen transport route planning and investment, integrated with island road infrastructure could provide an opportunity to optimise cost across both road and hydrogen systems.
6. **Skills** – Early understanding of the skills needed to support an HDS, including visibility of any challenges to decision-makers is an opportunity to mitigate constraints.
7. **Modular and portable assets** – Use of modular and portable assets to enable flexible growth in the early phases of HDS development and avoidance of stranded assets can bring cost benefits to the system.
8. **Security of supply** – Development of a system storage specification methodology is key to mitigate reliability and resilience risks from interruptions at each point in the value chain. Where required this should include consideration of coupling of the HDS to other island infrastructure reliability needs such as the ferries.

9. **Optimal decision-making** – A common decision-making framework applicable across the distribution system would enable risk-based value driven decisions[15] aligned to archipelago stakeholder requirements through each stage of the lifecycle.
10. **Small-scale systems** – Minimised complexity and maintenance through design and asset acquisition would support capital value and operational efficiency value driver performance.
11. **Local benefit from a large-scale system** - Enabling the local distribution system to benefit from the presence of bulk production and export operation is critical to local value return and stakeholder acceptance.
12. **Stakeholder involvement with value drivers** - Regular engagement with stakeholders across the archipelago is fundamental to development of appropriate value drivers, ensuring they remain current and managing a system that delivers to these.

[15] https://theiam.org/knowledge-library/subjects-6-and-7-capital-investment-operation-and-maintenance-decision-making/ [Accessed 21/02/22]

4 Conclusions and Recommendations

Handling and logistics of hydrogen on a remote archipelago is subject to several challenges, driven primarily by the inherent nature of physical geography in these locations. The need to have a combination of road, fixed, and maritime assets operating in challenging onshore, coastal, and offshore domains creates complexity, including an increased, unavoidable, level of regulatory and technical challenges rarely found in a geographical area of comparable size. These challenges are further amplified by remoteness.

However, opportunities identified in this report (section 3.6) indicate that there are options to mitigate these using value-based decisions, that take a whole system view. In a complex operating environment, a scaled, coordinated and systems-based approach is needed to meet stakeholder requirements through delivery of optimised system performance.

To enable a high-level structured discussion of hydrogen logistics challenges on an archipelago, tools from Systems Engineering and Asset Management disciplines have been used. Two key inputs to these were hydrogen demand scenarios selected from the LT4.2 deliverable and a set of specific of assumptions. These include assumed representative stakeholder requirements, which were converted to the system value drivers: Risk Exposure, Compliance, Capital Value, Operational Efficiency and Shine. Used in both system specification and analysis, these value drivers provide a clear line of sight to stakeholder requirements. The result was identification of areas that may be a challenge to optimal delivery of value that meets these requirements. Specification of an HDS (Hydrogen Distribution System) to serve each of the two scenarios enabled further consideration of how requirements and value delivery challenges may differ with scale.

Any HDS operating across an archipelago will need to consider operation of assets across multiple regulatory regimes - onshore, coastal, and offshore. This introduces a considerable burden of compliance requirements, with multiple regulatory bodies and other stakeholders, in what can be a reasonably small geographical area. One further impact of this is an increase to the challenge of optimum asset selection during uncertainty and early phases of system growth, driving a need for assets that are compliant in multiple operating domains and flexible enough to meet system requirements through their asset life. The same root driver to this challenge, geography, has an impact on the security of supply requirements and resilience needs of the HDS, driving a need for assets that produce, store, and move hydrogen between islands with high reliability and availability. These challenges, and the need for realisation of capital value and operational efficiency performance in a remote environment, add further emphasis to the challenge of optimal capital decisions.

By viewing the challenges at a system level, opportunities have been identified to optimise mitigation across the life-cycle of the HDS. Although the relative importance of drivers may differ by scale of the system some common themes emerged.

These include adoption of common standards to limit costs and risks associated with multiple regulatory regimes; asset standardisation to support operational efficiency; and selection of multi-functional assets to optimise flexibility. Gaining an understanding of skills requirements across the system provides an opportunity to remove constraints and optimise deployment of personnel. Seeing security of supply through the lens of a system creates an opportunity for a system-wide methodology to optimise location, cost and risks in the system. All these opportunities are reliant on optimal decision-making at each stage of the HDS asset life, for which a decision-making framework would be beneficial. This would be strengthened with supporting strategies for both maritime and land-based transport of hydrogen.

For a small-scale HDS, realising high operational performance will be key to system sustainability. This will require decisions to minimise maintenance needs in a harsh operating environment including coastal and offshore domains. In the case of a larger-scale system, there is an opportunity for the local system to benefit from the presence of this infrastructure in terms of security of supply, skills, resilience and possibly hydrogen price.

This report has focused on identification of the high level technical and safety challenges of an HDS, based on broad assumptions of social acceptance and stakeholder requirements. Any development of an HDS would benefit from engagement with stakeholders to ensure that real-world stakeholder requirements are used in generation of system value drivers, leading to genuine local benefit. This should include work (building on the work presented in deliverable LT.2.2) to gain a clear understanding of social acceptance of hydrogen as a fuel and associated infrastructure, both in remote archipelagos generally and in specific proposed locations prior to deployment.

In addition to addressing the opportunities set out above, the following recommendations have been developed, which should be considered in consultation with stakeholders:

1. Stakeholder engagement activities should be undertaken to understand priorities for a remote archipelago community. This will enable tailored value and performance drivers for the archipelago to be developed.
2. Further social acceptance research of hydrogen on remote archipelagos should be conducted. Likely efficiencies are available if combined with stakeholder engagement activities.
3. An additional review of regulation and legislation domains is required. As part of this review, identification of the key legislative instruments that drive other requirements and inter-dependencies will enable more efficient decision-making through the whole life of any HDS.
4. A specific HDS strategic plan should be developed to deliver hydrogen infrastructure that aligns with the most likely scenario for the archipelago, based on local forecasts and objectives. Ideally this should be done as part of development of a comprehensive Local Area Energy Plan.
5. Using strategic planning as a basis, an HDS decision framework should be developed to support correct selection of hydrogen handling and logistics assets.
6. Further technical investigation into the optimal bulk hydrogen production sub-system configuration is required.
7. The appetite should be explored for a 'joint regulation body' combining all regulatory stakeholders into a single body, to facilitate appropriate regulation of an archipelago HDS. (If this is not achievable, then a pragmatic alternative would be the consideration at least of a common approach and agreement between bodies to ensure simplification, cost reduction and replicability).
8. An HDS asset procurement list should be developed, including assets that have the capability to operate in coastal environments, are modular and can perform multiple functions in an archipelago operating environment.

9. An 'archipelago hydrogen distribution standards lead' should be appointed, responsible for ensuring consistency and compliance of assets across the archipelago, and delivery of system-wide skills required. This individual would help to deliver the competence levels required to support risk reduction associated with asset reliability, availability, and maintainability.
10. A system model or digital twin should be developed to enable testing of configurations and to support optimal decisions during system design stages.

5 Appendix A: Indicative System Requirements and Challenges for Small-Scale HDS

5.1 Small-Scale HDS Requirements

Section 3.2, gives an overview of the small-scale system characteristics.

In this appendix indicative system requirements are developed for the small-scale system from a desktop study. The activities undertaken include identification of functional elements and functional requirements, with subsequent highlighting of assignment of key links to performance drivers and technical decisions.

5.1.1 Functional Elements

Functional elements required for a small-scale distribution system are illustrated in the block diagram at Figure 7 below:

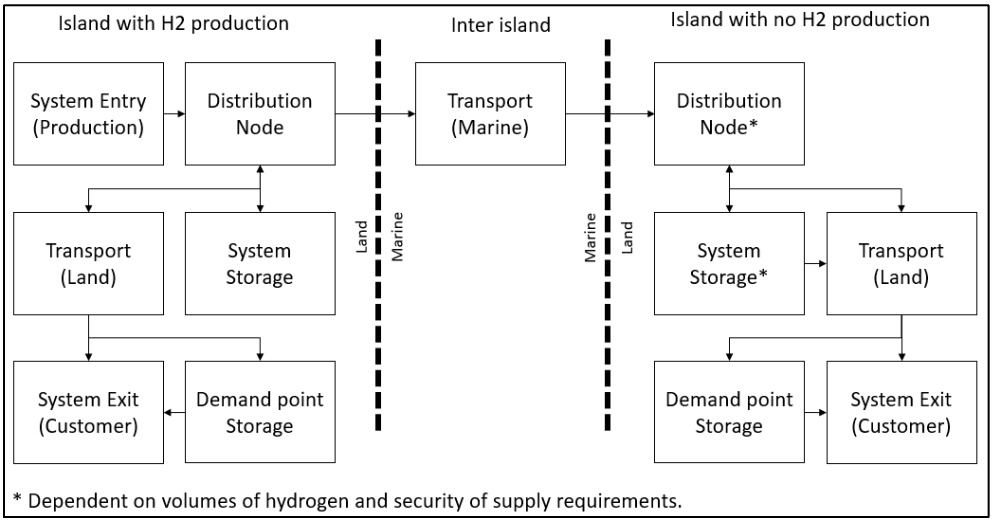

Figure 7: Small-Scale System Functional Elements

Each functional element is briefly discussed including identification of the main functional requirements of each and a link to value drivers identified.

5.1.2 System Entry

The volume of hydrogen produced in the small-scale scenario is from a single point and the comparatively low quantity remains stable from 2030. This means that any system entry assets will be sole points of service failure and risk exposure of performance drivers (reliability, availability, and maintainability) will need to be considered in decisions. This element is also likely to include measurement of hydrogen quality and quantity, where any drop in performance could have a system-wide economic impact.

5.1.3 Distribution Node

Required to receive hydrogen from system entry, transport or storage elements, the distribution node element will need to perform some or all the following functions to gaseous hydrogen: filter, measure (quality and quantity), compress (at production only), decompress and facilitate loading/unloading. The most material technical decision is likely to be compressor selection. Compression of gas is an energy intensive and typically high-cost activity. Appropriate selection of compressor package at time of design and optimisation of operation will influence system operational efficiency.

5.1.4 Storage

Security of supply is an important factor to the small-scale system and storage elements will need to provide the following storage functions: enable transport time flexibility, enable flexibility at system exit point, enable flexibility of production patterns, support system responses to diurnal and seasonal variation, and support security of supply at the extremities of the system. A storage requirement is assumed both for the system as a whole and at the demand points.

5.1.5 Transport (Land)

The functional requirement of land-based transport includes movement of large amounts of hydrogen between distribution nodes (trunk), movement of hydrogen to and from marine transport points, and movements to points of demand. Movement of hydrogen on the trunk route between production and the main distribution node is likely to have different operational needs to that of onward distribution to customers, which will be required to access domestic properties using small roads and tracks, regulate (decompress) hydrogen and measure the amount dispensed. Flexibility of the transport selection in the initial growth phase of the system is important and selection of land transport technology is likely to be a significant influencing factor on system performance.

The quantity of hydrogen demand modelled in the low hydrogen scenario for urban centres is unlikely to justify an extensive piped hydrogen distribution network. However, there may be areas in which small networks can be justified for operational efficiency reasons. It may be useful to closely monitor the progress of the transition of the Stornoway network to hydrogen[16] and engage with stakeholders to understand feasibility.

5.1.6 Transport (Marine)

Functional requirements of the marine transport node are to: move bulk hydrogen between the production island and that with the main distribution node, movement of hydrogen from islands with distribution nodes to islands with system exit points to supply customers. Given the small volumes of hydrogen in the system, any marine transport is likely to be a combination of road and maritime transport technologies i.e. trailers, lorries using ferries and harbours.

5.1.7 System Exit Point

System exit points will provide the infrastructure required to receive hydrogen from road transport and provide the supply to customers. This is likely to be pipework combined with small

[16] https://www.cne-siar.gov.uk/media/17452/C%203A%20-%20Outer%20Hebrides%20Energy%20Hub%20Feasibility%20Study%20Report.pdf [Accessed 21/02/22]

scale storage assets and an outlet to customers. Located close to customer properties, a balance of flexible assets, costs, risk exposure and Shine performance will be required.

5.1.8 All Elements

Common across all the functional elements is the need for competent personnel at each stage of the system life cycle. Given the volume of hydrogen in a small system this is likely to require multi-skilled individuals to support system resilience and operational efficiency performance.

5.2 Small-Scale HDS Identified Challenges

Table 4: Small-Scale System Challenges

Value driver	Challenge
Risk Exposure 	• Additional asset reliability and resilience performance is required across the distribution system due to remoteness of location. Specifically, local climate, reliance on existing infrastructure (road, ferries and harbours) and potential additional time required for any repairs. • Optimal geographical distribution and quantity of storage across the system to maintain both individual and system security of supply is complex.
Compliance 	• Located across an archipelago the distribution system interacts with multiple legislative requirements and regulatory stakeholders in both the land and marine environments. • Introduction of a piped distribution network serving customers introduces additional compliance and regulatory requirements.
Capital Value 	• Use of existing infrastructure i.e. ports, roads and maritime vessels is essential to establishing the distribution system and limiting capital costs of maritime transport. • In an archipelago setting there is an increased volume of assets exposed to coastal operating environments which may drive increased capital costs. • Optimum flexibility of assets is required to support early development of the market. • The multiple regulatory regimes, combined with limited volumes of demand, bring additional whole life cycle cost challenges and additional emphasis on optimal capital investment decision making and technical design.
Operational Efficiency	• Use of existing infrastructure is fundamental to limiting operational expenditure on maritime transport.

	• Limited hydrogen quantity moving through the distribution system drives need to limit overheads. • Operating on an archipelago increases the emphasis on asset reliability, availability and maintainability performance and subsequent impact on operational efficiency. • Availability of skills to install, maintain, modify, and decommission assets in a remote location. • Optimising compressor performance is an important contributory factor to operational efficiency.
Shine 	• Location of distribution node assets needs to consider intangible impacts e.g. operator reputation or visual impact of assets. • Remote archipelago location likely to drive additional focus on actual and perceived security of supply performance impacting social acceptance.

6 Appendix B: Indicative System Requirements and Challenges for Large-Scale HDS

6.1 Large-Scale HDS Requirements

Section 3.3, gives an overview of the large-scale system characteristics.

In this appendix indicative system requirements are developed for the large-scale system from a desktop study. The activities undertaken include identification of functional elements and functional requirements, with subsequent highlighting of assignment of key links to performance drivers and technical decisions.

6.1.1 Functional Elements

The large-scale system has the same functional elements as the small-scale system except that it also includes additional functional elements for System Entry (Import) and System Exit (Export). The system can be split into two sub-systems, one supplying 'local' demand moving relatively small quantities of hydrogen and the 'bulk' sub system moving hydrogen for the export market. Discussion within functional elements is split under these headings, to identify requirements (even though they may not always be differentiated in practice).

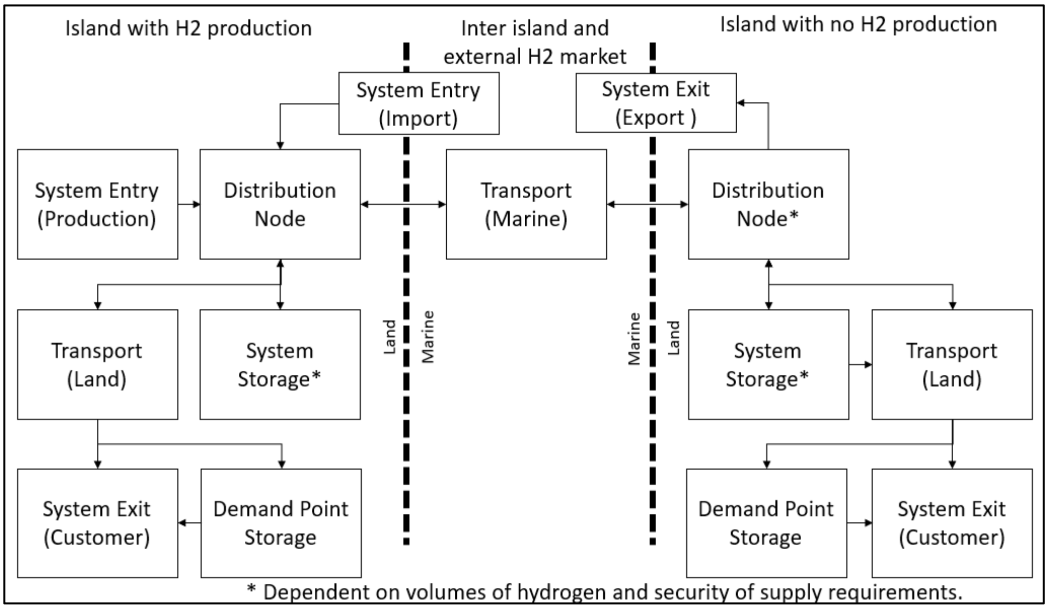

Figure 8: Large-Scale System Functional Elements

6.1.2 System Entry

Import

A single point for bulk hydrogen importation is assumed (in the particular scenario used for this analysis) for the 2020s and 2030s meeting local demand across the archipelago prior to commencement of widespread local and bulk production. The import elements are required to receive hydrogen from marine transportation, measure hydrogen quantity and quality. Given the short period of time over which importation would be required and the volume of hydrogen in the scenario (up to 12 GWhr/yr), the technical options are likely to be relatively small scale and utilise existing infrastructure where possible. This is likely to drive possible use of ISO containers or small hydrogen carrying vessels that can be accommodated in existing, modified or small port infrastructure. As the primary source of supply to the archipelago over the first 10-15 years (in the particular scenario used for this analysis), the import operation will determine system risk exposure performance.

Local Production

Hydrogen production units distributed on different islands, provide multiple entry points into the system. These will require connections to production and measurement assets. The increased number and distribution have the potential to improve system risk exposure for resilience and reliability but increases the safety and wider compliance requirements.

Bulk Production

Large scale hydrogen production for the export market (Bulk) requires connection assets to the hydrogen production facilities and measurement capability. The hydrogen production assets are assumed to be on a different island to that of the export terminal. Therefore, system connection, and potentially compression, is on the island of production with processing for export on another. Configuration and operational interactions of hydrogen production assets, system entry pipework and compressors will need careful consideration, not in scope here. A single-entry point into the system is assumed for purpose of discussion here.

6.1.3 Distribution Node

Local Distribution

Local distribution nodes have similar requirements as identified in the small-scale system but are more numerous and handling increased quantities of hydrogen. An increased number are likely to be subject to the COMAH regulations. Those located next to system entry points will have compression requirements increasing the potential impact on system capital value and operational efficiency performance. The increase in number, physical scale and visibility of the nodes is likely to increase the impact on shine performance. Inclusion of local distribution functionality at the bulk hydrogen sub system nodes enables the local distribution system and stakeholders to benefit from additional resilience and reliability provided by the presence of a bulk hydrogen production operation on the archipelago.

Bulk Distribution

There are two distribution nodes in the bulk hydrogen sub-system, shown in Figure 9Figure 8.

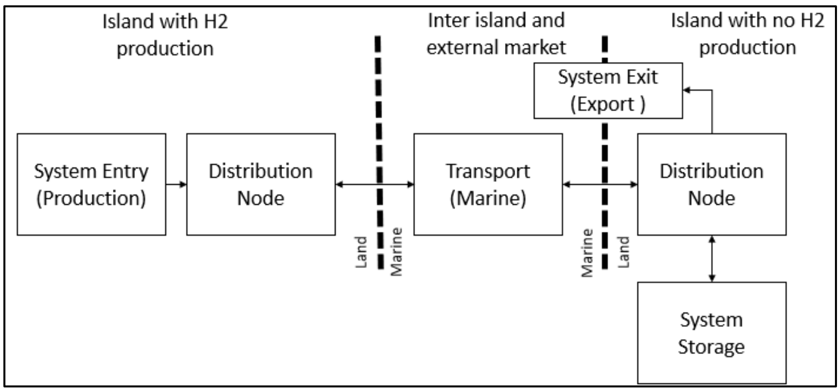

Figure 9: Bulk Distribution Sub-System

The functional requirement on the island with hydrogen production is to prepare the produced hydrogen for onwards movement to the export facilities. The additional functional requirements of this element are to filter, measure, compress and control the flow of hydrogen entering the marine transport element, assumed to be a sub-sea pipeline. The distribution node located at the export point includes the functional elements of receiving hydrogen from the subsea pipeline, facilitation of pipeline inspection, flow and or pressure control to supply the system exit export point.

6.1.4 Storage

Local

The increase in total demand and addition of hydrogen powered ferries as demand, served by the large-scale system, will increase the importance of the security of supply and enabling storage philosophy. The functional elements remain the same as the small-scale system, although system storage sites will be more widespread and larger, increasing the scale of risk exposure and compliance performance. The increase in scale may also enable consideration of different technology types across the system to further support system risk exposure performance.

Bulk

The functional requirement of any storage element with the bulk hydrogen sub-system is driven by the requirements of the export market served and technology choice to deliver hydrogen to the market i.e. maritime vessel or sub-sea pipeline. This could drive the need for specific large-scale hydrogen storage assets, which may trigger consideration of a change of phase of hydrogen or use of any line pack in the subsea pipeline(s). Dependent on distance between islands it should be noted line pack availability could be negligible due to the volumetric energy density of hydrogen.

There may a requirement to supply the local distribution system with hydrogen from the bulk store.

6.1.5 Transport (Land)

Local

The required functions from land-based transportation of hydrogen stay broadly similar to the small-scale system. The increased demand and volumes of hydrogen increases the technical options available, potentially increasing the feasibility of onshore piped network to and within urban centres. Pipe networks to large user points of use such as the ferry storage filling points may also become feasible. Wider technical options may require consideration due to increased use of existing infrastructure such as roads prompting a need to improve that infrastructure or select assets that do not have a detrimental impact on existing.

Bulk

Onshore movement of bulk hydrogen will be required between system entry points from production, distribution nodes, subsea pipelines and export points. Given the volume of hydrogen, onshore pipelines or pipework, depending on distance required are likely to be the optimum technology option. Design and construction of these assets will impact on the system capital value performance.

6.1.6 Transport (Marine)

Local
The functional requirement of this element is broadly similar to that of the small-scale system. However, the increase in quantities and number of routes for hydrogen movement through the planning period introduces additional technical considerations. The constraints associated with use of existing infrastructure likely to require earlier decisions on larger assets to support projected growth for the larger system. This could create a scenario in which it is advantageous to introduce specific flexible hydrogen maritime vessels and coastal infrastructure in the early stages of the larger system, with additional assets or sub-sea pipeline being introduced in the latter part of the planning period. Decisions on marine transport technology selection will impact all of the value drivers identified, with capital costs being a key performance driver.

Bulk
Hydrogen production and export facilities on different islands create a need for transport of bulk hydrogen between the two through the marine environment. The options and efficiencies associated with this approach are not discussed here but captured as challenges. The functional requirement for the transport is movement of bulk hydrogen in a single direction between the two islands and potential provision of line pack capacity (determined by length and diameter) to support export processing activities. Technology options are limited to offshore pipeline or maritime transport, with the offshore pipeline being most likely. This functional element would have significant impact on the capital costs.

6.1.7 System Exit Point

Export
The functional element of the export element is directly dependent on the form in which hydrogen is exported from the archipelago. In a gaseous form this could be as a subsea pipeline to a mainland transmission system, nearby sub-sea hydrogen network, offshore hydrogen infrastructure or via maritime transport to a wider market. Each will have a specific set of technical requirements that directly impact the functional elements of the archipelago export point. A sub-sea pipeline is assumed here and therefore functional elements are likely to include compression, flow control, measurement and possibly storage. This functional element will have a relatively large impact on all value drivers.

Customer
Functional elements are the same as that for the small-scale system, with scale of performance drivers increasing proportionate to system scale. The volume of local customer exit points in the large-scale system is higher and more widespread across more islands. The inclusion of ferries as a customer in the system introduces the additional consideration of handling large quantities of hydrogen for a single customer. Further, the HDS and archipelago transport systems become coupled in terms of reliability and resilience.

6.2 Large Scale HDS Identified Challenges

Table 5: Large-Scale System Challenges

Value driver	Challenge
Risk Exposure 	• Optimal geographical distribution and quantity of storage across the system to maintain both individual and bulk security of supply is complex. Supply, demand, and export profiles changes through planning period add further complexity. • Additional asset reliability and resilience performance required across the distribution system due to remoteness of location. Specifically, local climate, reliance on existing infrastructure and potential additional time required for any repairs. • Increased volume of hydrogen on the archipelago increases risk exposure. With subsequent impact on the management overhead. • Use of imports couple system reliance to import market. • Establishment of bulk hydrogen production creates both the challenge and opportunity to ensure the local distribution system benefits i.e. additional resilience, skills and reliability. • System Entry - bulk production reliability is a single source of supply to export facility and configuration. • Increased demand and increased number of sites. There is a coupling of transport infrastructure (ferries) reliant on hydrogen supply and hydrogen supply reliant on transport infrastructure (during early stage of hydrogen development). This shows the need for a robust approach to security of supply and development of a system storage philosophy to mitigate risks associated with the wide influence on the archipelago energy and transport infrastructure. • Additional transport movements impact on existing infrastructure (Roads, Ferries and Harbours)
Compliance 	• With assets located across an archipelago the distribution system interacts with multiple legislative requirements and regulatory stakeholders in both the land and marine environments. • Supply to export market potentially introduces additional compliance requirements for bulk production that could impact on the local distribution system. • Introduction of a piped distribution network serving customers and sub-sea pipelines introduces additional legislative compliance and regulatory requirements.
Capital Value	• Optimisation of HDS asset acquisition decisions and capital deployment through the growth of hydrogen demand and a shift from imported to

	local production supplies. Additional challenge to avoid stranding of assets used for imports. • Archipelago geography results in an increased volume of assets exposed to costal operating environments which may drive increased capital costs. • Optimum flexibility of assets is required to support early development of market. • Increased volumes of hydrogen transported by road may trigger infrastructure investment requirements. • The multiple regulatory regimes bring additional whole life cycle challenges and dimensions to decision making. • Emphasis on optimal capital investment decision making and technical design focused on enabling larger volumes of hydrogen movement. • Optimisation of the bulk hydrogen sub-system process at design stage for whole life value. • Increased local distribution node assets will introduce a need to optimise location and functionality of distribution nodes through the growth stage of local production to the final system. • Bulk storage requirements and capital costs influenced by export market requirements. • Increased storage assets extend the challenge of optimising across the system. • Use of hydrogen by ferries introduces a challenge to optimise supply infrastructure to ferry filling points as ferry use grows. • Challenges where use of existing transport assets becomes infeasible will drive the need for capital investment in new assets. Optimal selection of the right size and technology will be a challenge as growth of HDS increases and available technology changes.
Operational Efficiency	• Operating on an archipelago increases the emphasis on asset reliability, availability and maintainability performance and subsequent impact on operational efficiency. • Availability of skills to install, commission, maintain, modify and decommission assets in a remote location. • Optimising compressor performance is an important contributory factor to operational efficiency, particularly for bulk hydrogen movement. • With a high volume of assets across the archipelago optimisation of operations and maintenance activities will require some consideration.
Shine	• Location of distribution node assets needs to consider intangible impacts e.g. operator reputation or visual impact of assets.

	• Remote archipelago location likely to drive additional focus on actual and perceived security of supply performance impacting social acceptance. • Close interdependencies between risk exposure performance, intangibles, social acceptance of hydrogen and ultimately demand. Applies across the local hydrogen production, local use and bulk hydrogen production.

7 Appendix C – Legislation and Regulation References

Table 6 provides links to key UK legislation and regulation which would be applicable to the ITEG installation on Orkney. For wider EU regulations refer to the HyLaw Online Database at https://www.hylaw.eu/database

Table 6: Legislation and Regulation References

Health and Safety at Work Act	https://www.legislation.gov.uk/ukpga/1974/37/contents
Control of Major Accident Hazards Regulations (COMAH, UK implementation of the EU Serveso 3 Directive).	https://www.legislation.gov.uk/uksi/2015/483/contents/made
Pressure System Safety Regulations (PSSR)	https://www.legislation.gov.uk/uksi/2000/128/contents/made
Dangerous Substances and Explosive Atmospheres Regulations (DSEAR, UK implementation of the EU ATEX Directives 137 and 95)	https://www.legislation.gov.uk/uksi/2002/2776/contents/made
Pressure Equipment (Safety) Regulations (PE(S)R, originally UK implementation of EU Directive 2014/68/EU)	https://www.legislation.gov.uk/uksi/2016/1105/contents
Management of Health and Safety at Work Regulations	https://www.legislation.gov.uk/uksi/1999/3242/contents/made
Control of Substances Hazardous to Health (COSHH)	https://www.legislation.gov.uk/uksi/2002/2677/contents/made
The Gas Act	https://www.legislation.gov.uk/ukpga/1986/44/contents
Ofgem licence regulations	https://www.ofgem.gov.uk/industry-licensing/licences-and-licence-conditions
The Pipelines Safety Regulations.	https://www.legislation.gov.uk/uksi/1996/825/contents/made
Carriage of Dangerous Goods and Use of Transportable Pressure Equipment Regulations	https://www.legislation.gov.uk/uksi/2009/1348/contents/made

European ADR "Accord Européen relatif au transport international des marchandises dangereuses par route"	https://www.hse.gov.uk/cdg/manual/index.htm

*All links accessed 21/02/22