Scottish Enterprise

Hydrogen Economy Research: End-to-End Supply Chain Map

August 2025

Contents

Executive Summary

This report details the end-to-end supply chain requirements for hydrogen production projects at different scales: small-scale (10-20MW) and large-scale (400-600MW). The example projects are typical archetypes and location agnostic to allow this report to be applicable for a diverse range of projects across the sector.

The purpose of this work is to highlight the timelines, nature and scale of the potential opportunities presented by the developing hydrogen economy in Scotland. The main output is a clear understanding of the requirements and implications for the Scottish supply chain across the development and implementation of a hydrogen production project. This can then be utilised to better understand the supply chain requirements for the current pipeline of Scottish hydrogen projects. The report investigates the potential bottlenecks and supply chain gaps to allow Scotland to be better positioned to support companies in upskilling and scaling up through targeted investment.

The key findings from this work (summarised on the right-hand side) relate to the key supply chain differences between the two archetypes, challenges presented by the large-scale archetype in terms of resource availability and hydrogen distribution, and the current supply chain capability in Scotland.

The scale and complexity of the large-scale archetype necessitates some additional supply chain requirements. Engineering design, site preparation, project construction, key professional services such as planning, procurement, and health and safety are expected to require significant additional resource and scope when compared with that required for the small-scale archetype.

The large-scale archetype also has a significantly higher requirement for raw feedstock materials (namely water and electricity), which presents some additional challenges compared to the small-scale archetype. An alternative water resource (such as seawater) is likely to be required to meet the water demand for the large-scale project without compromising the potable water availability or triggering environmental concerns around extraction from raw water sources in Scotland.

The maximum electricity requirement for the large-scale archetype is over 4TWh per year (assuming 24-hour operations at 100% capacity). This archetype will therefore likely require a direct connection to a large-scale generation asset such as an offshore wind farm or a transmission-scale grid connection, in contrast to the small-scale archetype that can likely be serviced by a connection to the distribution grid.

Proximity to national hydrogen transport and storage infrastructure will be significant for the large-scale archetype, and alternative routes to market through hydrogen derivatives and export is likely to be a key consideration for the development of the large-scale archetype, and for the future of the Scottish supply chain.

Key Findings:

1. Due to the scale and complexity of the different archetypes, there are key differences in the respective supply chain requirements that should be considered in the context of Scotland's hydrogen project pipeline.

2. Key differences between the small and large-scale archetypes include:
   - Time and resources for development and execution of the project
   - Materials and components for the manufacturing of key equipment
   - Source of raw material inputs (water and electricity) and outputs (end uses)

3. Large-scale archetype projects could present challenges for Scotland in terms of the availability of water, electricity, materials and skills/resources, and proximity to regional/national hydrogen pipeline and large-scale storage infrastructure will be a key consideration.

4. Arup have identified key opportunities for the Scottish Supply Chain in areas such as such engineering and professional services, wind resource, specialist components manufacturing, hydrogen logistics and hydrogen export/derivatives.

Executive Summary

Key Opportunities for the Scottish Supply Chain

- Engineering services (design, construction and civils)
- Wind resource
- Professional services (legal, financial, planning)
- Specialist components manufacturing
- Hydrogen logistics
- Hydrogen export and derivatives

Potential Bottlenecks/Areas Requiring Significant Investment in the Scottish Supply Chain

- Manufacturing capacity
- Raw materials (steel, composites, materials)

This report identifies some key areas in which Scotland already demonstrates strong supply chain capabilities, and which present strong opportunities for Scotland to become a leader in the hydrogen supply chain.

Scotland already has significant engineering design and delivery capabilities, and there is more opportunity to capitalise on expertise from the oil and gas (O&G) sector, specifically in areas such as civils, construction, and commissioning.

The Scottish supply chain also shows clear strengths in wind resource, with an extensive pipeline of offshore wind farm projects. As a result, Scotland is well positioned to support the significant electricity requirements of the large-scale archetype, although intermittency of electricity supply will be a challenge.

Scotland has a significant number of companies offering professional services such as legal, financial and planning services. There is significant opportunity for these businesses to build on their hydrogen-specific offering and experience and position themselves to benefit from the growing hydrogen economy.

With regards to manufacturing of specialised components, Scotland already has several businesses specialising in the manufacturing of key parts for electrolysers and compressors - this is a sector that could be expanded and scaled up in line with incoming demand requirements.

Hydrogen logistics (e.g. tube trailer services) is an area of significant opportunity for existing logistics providers to transition to be able to offer this service for hydrogen, especially in the short term ahead of the development of national hydrogen transport and storage infrastructure.

Finally, export of hydrogen to other countries with significant demand, such as Germany, presents a unique opportunity for Scotland to be a global leader in the hydrogen industry. This opportunity is especially relevant for the large-scale archetype, which would rely on the development of a national hydrogen transport and storage network.

Key bottlenecks identified in the supply chain include large-scale manufacturing capacity for equipment such as electrolysers, compressors, storage vessels and tube trailers. Addressing these key bottlenecks would require significant investment to achieve the scale required to supply the pipeline of Scottish projects. In addition to this, Scotland currently produces few of the raw materials required for the manufacturing of plant equipment (e.g. steel) and is therefore reliant on supply of these materials from other countries.

As mentioned previously, the large-scale archetype is likely dependant on a connection to a large-scale hydrogen pipeline network to distribute hydrogen to offtakers due to the significant volumes of hydrogen produced. Plans for the development of a national hydrogen transport and storage network in the UK are still developing, and this could limit viable locations for the deployment of the large-scale archetype. However, this could be mitigated by alternative routes to market such as conversion of hydrogen into derivatives such as ammonia and methanol or a hydrogen export pipeline from Scotland to mainland Europe.

Despite the above challenges, the developing hydrogen economy presents opportunities for Scottish companies and Government to work together to counter the supply chain bottlenecks, and position Scotland as a global leader in this space.

Abbreviations

Abbreviation	Term
Al_2O_3	Aluminium Oxide
BoP	Balance of Plant
CDM	Construction Design Management
CO_2	Carbon Dioxide
COMAH	Control of Major Accident Hazards
EIA	Environmental Impact Assessment
EPC	Engineering Procurement and Construction
FEED	Front End Engineering Design
FID	Final Investment Decision
FTE	Full Time Employees
GCH	Green Cat Hydrogen
GHG	Greenhouse Gas
GW	Giga Watt
H_2	Hydrogen
HAZID	Hazard Identification
HAZOP	Hazard and Operability study
Kg	Kilograms
kWh	Kilo Watt hours
L	Litres
LOPA	Layers of Protection Analysis
LPA	Local Planning Authority
m^3	Metres cubed
MW	Megawatt
MWe	Megawatt (electrical)
MWh	Megawatt-hours
O&G	Oil and Gas
O&M	Operations and Maintenance
PEM	Polymer Electrolyte Membrane
PPA	Power Purchase Agreement
QRA	Quantitative Risk Assessment
RAG	Red/Amber/Green
SG	Scottish Government
SE	Scottish Enterprise

Section 1

Introduction

Section 1

Introduction

Green hydrogen production will play a key role in achieving the Scottish Government (SG) target of reaching net zero greenhouse gas (GHG) emissions by 2045. SG published their Hydrogen Policy Statement in 2020 which set out ambitions for 5GW of installed green hydrogen capacity by 2030, and 25GW by 2045.

The Scottish Hydrogen Assessment (2020) built on this, recognising that investing in innovation, manufacturing and infrastructure could provide jobs and economic growth – though some gaps in the supply chain were identified.

Scotland is well positioned to become a leader in this sector, having significant renewable resources, strong oil and gas sector experience, and supportive government policy. Significant developments in the hydrogen industry in Scotland are already underway, supported by the Scottish public sector's extensive work in this space. There is also a strong pipeline of green hydrogen production projects in Scotland, with varying timelines and scales, which could be supported by Scottish companies.

However, there remains a lack of understanding within the Scottish supply chain regarding the structure and timescales for the development of green hydrogen projects, and uncertainty as to exactly where, when and how companies can play a part in the sector.

This uncertainty creates a barrier to growth and investment in the Scottish hydrogen supply chain, which Scotland needs to overcome to be at the forefront of the hydrogen industry.

The objective of this work is to clearly define the end-to-end supply chain requirements for green hydrogen production projects and provide clarity as to the timelines, nature and scale of the potential opportunities presented by the developing hydrogen economy in Scotland. This will allow Scottish-based supply chain companies to position themselves to benefit from the changing energy landscape in Scotland. In addition, potential bottlenecks and current supply chain gaps are identified. Recognising these gaps will allow for targeted support for Scottish companies to upskill and upscale through targeted investment.

This work builds on previous studies, including the Assessment of Electrolysers Report (2022), the Assessment of Low-Carbon Hydrogen Supply Chain Export Opportunities (2024) and the recent Hydrogen Fact Sheets on electrolyser technology, compression, and refuelling stations published by Scottish Enterprise.

Hydrogen Economy Research: End-to-End Supply Chain Mapping

Arup End-to-End Supply Chain Mapping Approach

Section 2

WP1: Archetype Definition

Section 2.1

Archetype Context

Feedstock and Use Cases

To capture the end-to-end supply chain requirements for the development of a hydrogen production project, it is important to define inputs (feedstocks) and outputs (use cases) for the projects.

The project archetypes defined in this report reflect specific assumptions, drawn from knowledge of existing green hydrogen projects, and previous Arup project experience. However, there are other supply chain possibilities, not mentioned in detail in this report, that should also be considered.

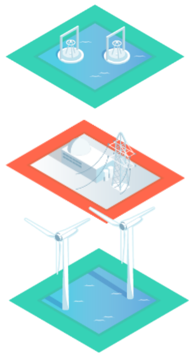
For example, while the large-scale archetype assumes a direct connection to a renewable electricity source, such as an offshore wind farm, there are examples of large-scale projects using a different approach to securing power. Rather than connecting to an offshore wind farm or other renewables, facilities could be located next to a large, overloaded substation, enabling access to low-carbon electricity from the grid.

Various input and output options for green hydrogen production facilities are highlighted on the right-hand side. The applicability of these options will vary on a project-by-project basis, and in particular with location and scale.

As the scale of a project increases, developers typically begin to move away from smaller-scale modular designs (containerised solutions), to more bespoke large-scale systems. This can be beneficial from a cost perspective, especially in terms of balancing plant equipment such as water treatment and hydrogen purification. The "tipping point" for this transition is understood to be around 30MWe, but this will vary depending on the project, technology and specific design requirements.

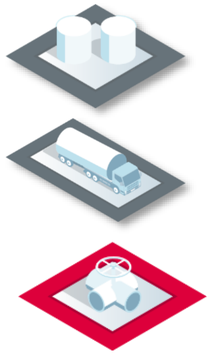
For the purposes of this project, it was necessary to define specific project archetypes as a basis for the supply chain mapping, to enable the work to be completed to a sufficient level of detail.

Detail of the archetypes and underlying assumptions that inform the basis of this work are provided in this section on the following pages.



Possible Inputs (Feedstocks)

- Potable mains water
- River abstraction
- Sea water (desalination)
- Grid connection
- Direct renewables connection



Possible Outputs (Use Cases)

- Geological storage
- Above ground storage
- Transport (hydrogen refuelling)
- Tube trailer distribution
- Direct pipeline connection to industry
- Export pipeline
- Production of derivatives

Section 2

Archetype Context

Definition of Project Archetypes

To capture the supply chain requirements across different scales of production, two typical hydrogen project archetypes were defined: one small-scale (10-20 MW) and one large-scale (400-600 MW), both polymer electrolyte membrane (PEM) technology. PEM technology was selected as this appears to be the preferred technology among developers based on the current hydrogen project pipeline, likely due to its ability to work with intermittent power supplies, high purity hydrogen output, and its compact and modular design. These project archetypes were used to map the full supply chain requirements across each project's lifecycle and to assess opportunities and bottlenecks within the supply chain and Scotland's capacity to deliver such projects.

More detailed archetypes were developed for each scale using a range of resources. The comprehensive list of hydrogen projects at various development stages across Scotland was used to understand the scale of existing projects. Additionally, the electrolyser, compression, and storage factsheets were referenced where applicable to avoid repetition of work. The list of hydrogen projects, which included information on electrolyser technology and power, served as a key resource in shaping the archetypes and the assumptions underpinning them.

Using these resources, alongside internal Arup knowledge and experience, two archetypes including their key assumptions were agreed. As well as the scale of the projects, the archetypes also defined the end use of the hydrogen, sources of raw materials and project life cycle stages.

The agreed archetypes are defined as follows:

- **Small Scale:** 10 MW PEM electrolysis
- **Large Scale:** 500 MW PEM electrolysis

The specific assumptions surrounding these archetypes are detailed in the table on the right and on the following pages. These were agreed through a workshop session.

This section highlights the key differences between the archetypes in terms of the production process, supply chain requirements and project timescales.

Parameter	Archetype 1 (Small-Scale)	Archetype 2 (Large-Scale)
Capacity	10 MWe	500 MWe
Technology	PEM (containerised)	PEM
Water input	Potable water from mains, with further purification.	Abstraction from sea (salt water) with dedicated desalination and water treatment plant.
Electricity input	Grid connected, green PPA	Direct renewable connection (e.g. wind/solar/hydropower) with backup grid connection.
Compression	Compression (up 500 bar)	No additional compression
End user	Transport (refuelling) or small industrial user (tube trailers or direct pipeline)	Large-scale industrial user or export (pipeline)
Storage	Storage (350-500 bar)	No storage
Controls	Localised control with off site access	Localised control with off site access. Separate control systems for centralised processes as required
Cooling	Containerised cooling system	Larger centralised cooling system
Civil engineering	Concrete foundations to support equipment packages	Buildings and infrastructure work

Scottish Enterprise ARUP

Section 2.1

Small-scale Archetype.

Archetype Definition

The small-scale archetype is based on a 10MW PEM electrolyser stack, the supply chain details of which can be found in the SG's Assessment of Electrolysers report[1]. Each archetype is built on a series of assumptions regarding the electricity and water source, the end use of the hydrogen, and process requirements that vary with the scale of these projects.

This archetype is designed to represent a typical PEM electrolysis project, using a containerised electrolyser solution with downstream hydrogen processing. A block flow diagram of the process is provided on the following slide.

Water purification is part of the containerised electrolyser solution, and the water connection is assumed to be mains source for potable water, which is then deionised to produce high purity water compatible with the electrolyser stack.

The electrical connection comes from the grid, to an on-site substation. A transformer and a rectifier convert the incoming electricity to a direct current of an appropriate voltage. This then passes through a power quality system to provide stability and reliability to the incoming electricity. A mains source of both electricity and water means that the location of this project is of less significance.

The hydrogen produced from the electrolyser is purified through a hydrogen oxygen separator, and an adsorption dryer to achieve a hydrogen purity suitable for the end use application. For this archetype, the hydrogen is compressed to high pressure (350-500 bar) and stored in high pressure above-ground storage vessels.

The hydrogen use case for this archetype is assumed to be small-scale industrial applications and transport offtakers (supply via tube trailers and hydrogen refuelling stations).

In terms of the timeline for the small-scale archetype, the project development stage is estimated to span roughly 10-18 months, with a further 12-24 months for execution phase. The operation lifetime is expected to be 15-25 years, project dependent. Following the cease of operations at the plant, the end-of-life stage is estimated to span 1-3 years, to allow for full decommissioning and site restoration.

The justification for these assumptions is drawn from previous Arup experience in the green hydrogen sector, literature review and data provided by Scottish Enterprise.

Parameter	Assumption
Technology	Containerised PEM electrolysis
Electrolysis capacity	10 MWe
Electricity supply	Grid connection
Electrolyser energy consumption	56.3 kWh/kg (70% efficiency)
Balance of Plant (BoP) energy consumption	5.6 kWh/kg (10% of electrolyser requirement)
Total annual electricity consumption	96 GWh/year
Electrolyser load factor	100% (24 hrs operation)
Water supply	Mains water (potable)
Water requirement (incl. reject and process water)	20 L/kg hydrogen
Water consumption	85 m3/day (including reject)
Compression type	Reciprocating compressor
Compression pressure	350-500bar
Storage type	High pressure storage tanks
Storage pressure	350-500bar

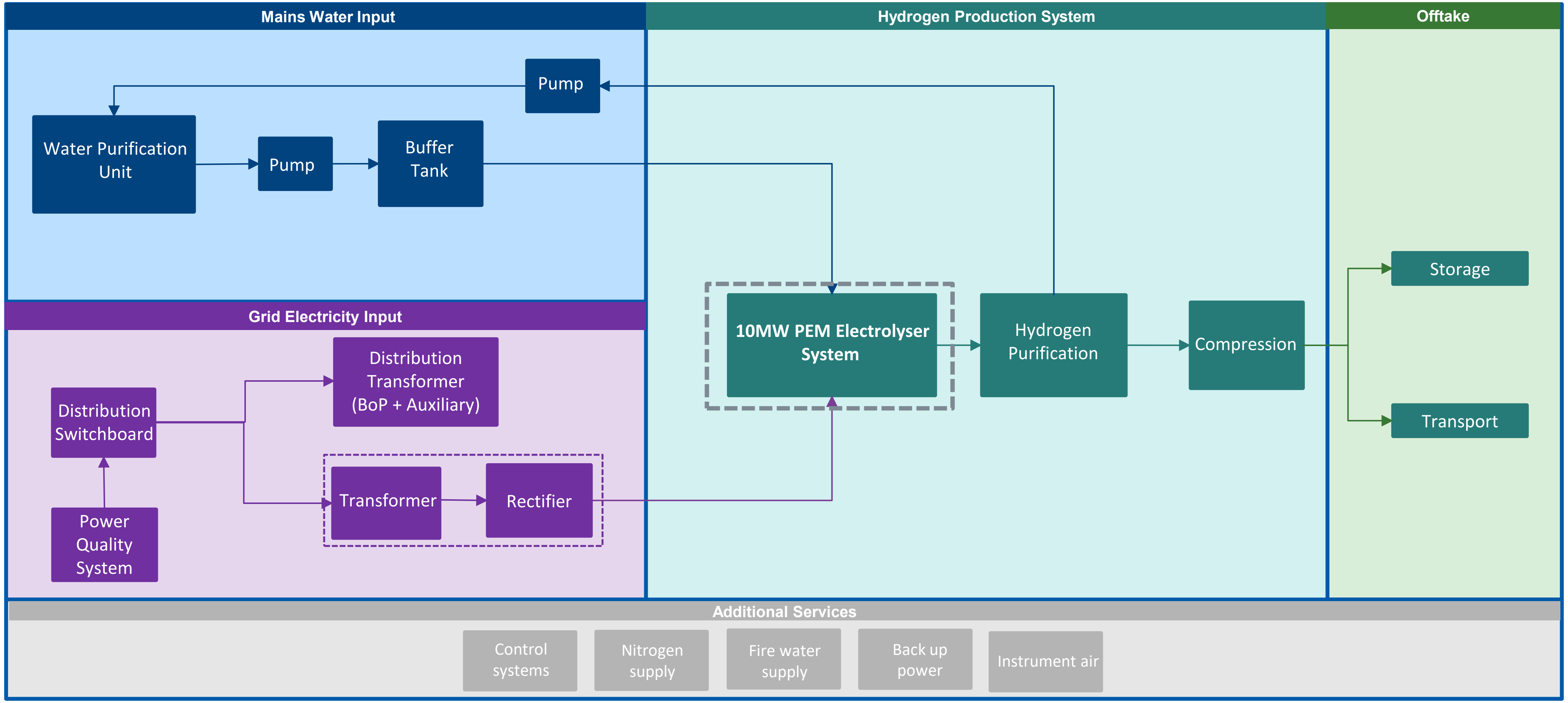
Agreed Small-scale Archetype Assumptions Overview

1 – Assessment of Electrolysers Report – Scottish Government

Section 2.1

Small-scale Archetype

Archetype Definition



Block Flow Diagram for Small-scale Archetype

The dashed line surrounding the transformer and rectifier shows that they are often included in the electrolyser
The dashed line around the electrolyser is the containerised cooling system

Section 2.2

Large-scale Archetype

Archetype Definition

The large-scale archetype is based on a 500MW PEM electrolysis plant, made up of multiple electrolysis units. The supply chain requirements for the large-scale archetype are similar in many ways to the small-scale archetype – however there are a few key differences that should be considered.

Firstly, due to the scale of the project, using a potable water source (as the small-scale archetype does) is likely to be a challenge, and therefore this archetype assumes process water is sourced from the sea, requiring an extra stage of water purification through reverse osmosis desalination, before deionisation can occur.

In contrast to the small-scale archetype, the water purification and thermal management (cooling) systems are centralised (not contained within the electrolyser package). Using the sea as a water source does put more restriction on the project location, as it must be in a costal location.

The electrical system in this archetype is similar to the small-scale with respect to equipment, however, due to the significant electricity requirement for this archetype, direct connection to a renewable generation source such as a large-scale offshore wind farm is likely required, in addition to a grid connection for back-up electricity. An electrical system comprising a transformer, rectifier and power quality system is used to regulate the supply of electricity.

The electrolyser system and balance of plant design for this archetype is more likely to be a bespoke design rather than an “off the shelf” packaged system as seen in the small-scale archetype. This will be managed through centralised control systems with separate infrastructure for cooling and water treatment.

Following the electrolysis process, the same hydrogen purification stages as for the small-scale archetype are required (hydrogen oxygen separator and an adsorption dryer), but without the requirement for compression or significant storage of the hydrogen.

The use case for this archetype is assumed to be a large-scale industrial offtaker or hydrogen export through a pipeline, hence requiring no additional compression or storage upstream of the pipeline/offtaker.

The timeline for the development and execution of the large-scale archetype project is expected to be significantly longer than for the small-scale archetype due to additional complexity and more stakeholders (see Section 3 for more detail).

The justification for these assumptions is drawn from previous Arup experience in the green hydrogen sector, literature review and data provided by Scottish Enterprise.

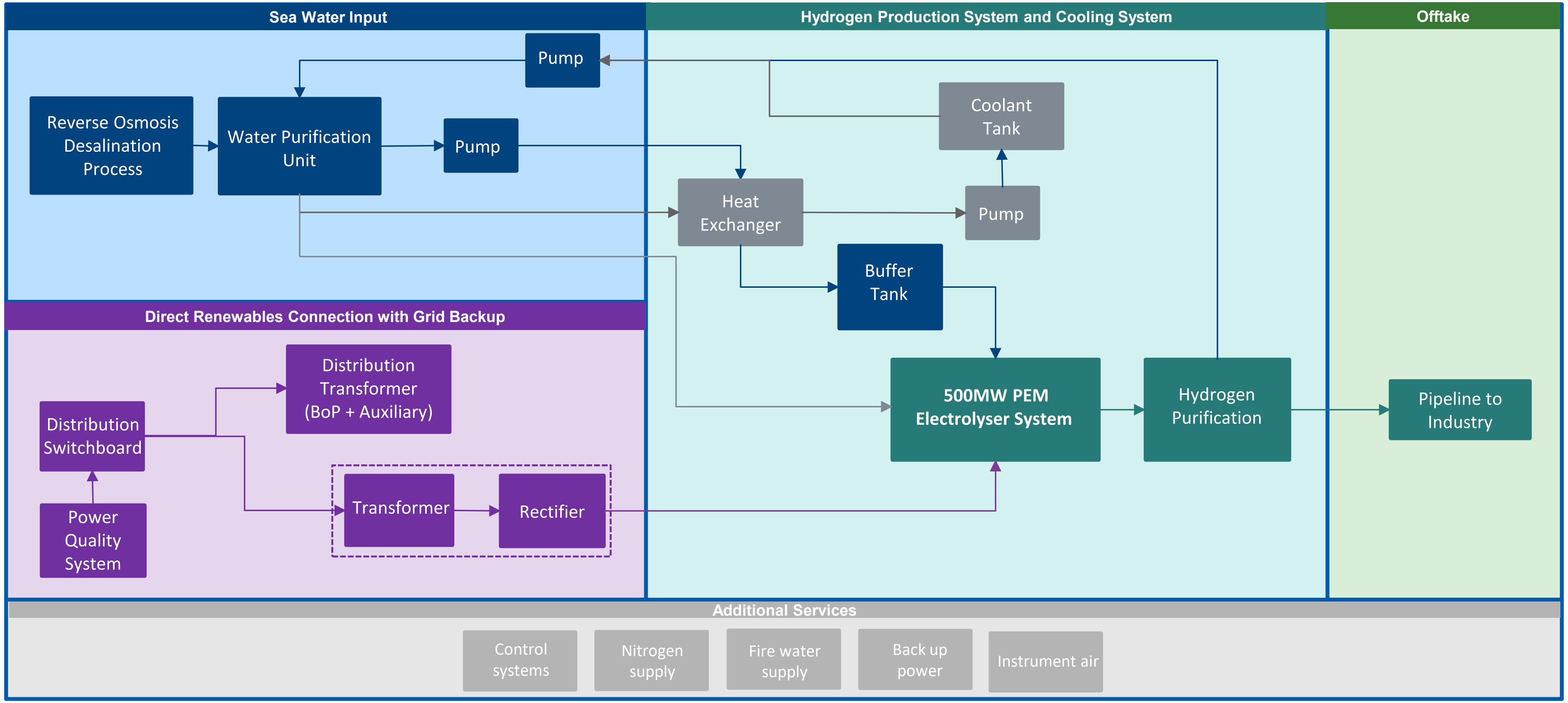
Parameter	Assumption
Technology	PEM electrolysis
Electrolysis capacity	500 MWe
Electricity supply	Direct connection to renewable energy, with backup grid connection
Electrolyser energy consumption	56.3 kWh/kg (70% efficiency)
Balance of Plant (BoP) energy consumption	5.6 kWh/kg (10% of electrolyser requirement)
Total annual electricity consumption	4.8 TWh/year
Electrolyser load factor	100% (24 hrs operation)
Water requirement (incl. reject and process water)	80 L/kg hydrogen
Water supply	Sea water (with desalination)
Water consumption	17,000 m3/day (including reject)
Compression type	-
Compression pressure	-
Storage type	-
Storage pressure	-

Agreed Large-scale Archetype Assumptions Overview

Section 2.2

Large-scale Archetype

Archetype Definition



The dashed line surrounding the transformer and rectifier shows that they are often included in the electrolyser

Block Flow Diagram for Small-scale Archetype

Section 3

WP2: Supply Chain Mapping

Scottish Enterprise ARUP

Section 3

Supply Chain Definitions

The supply chain was separated into three overarching groups, Products, Services and Solutions.

Products
Physical elements within the supply chain, such as an electrolyser, compressor or electrical equipment.

Solutions
Capabilities that directly deliver products, such as manufacturing, construction or integration capability.

Services
Auxiliary capabilities that support the delivery of products, such as engineering, environmental, operations and maintenance or financial services.

These sections are broken down further in the following slides to provide more detail and capture specific products, skills and trades required.

To support the supply chain mapping work, the project lifecycle was divided into distinct phases:

- Development
- Execution
- Lifetime
- End of life

These are defined in the table below.

Project Stage	Development	Execution	Lifetime	End of life
Assumption	All activities up until final investment decision	All activities from final investment decision to commercial operations date	All activities whilst hydrogen production facility is operational	Decommissioning activities from cease of hydrogen production

Project Lifecycle Phases Definitions

Section 3.1

Supply Chain Matrix

Products

As part of this assessment, key products – physical elements of the supply chain – were broken down further into individual components. Products used in the supply chain for a green hydrogen project can be typically categorised as follows:

- **Key Equipment** – Pieces of equipment essential to the expected operation of the plant, i.e. electrolysers, water treatment system and the electrical system.
- **Ancillary Equipment** – Equipment supporting operation of the main equipment but not directly involved in the production process such as gaskets, flanges, valves, and hydrogen end use equipment (tube trailers and hydrogen refuelling stations).
- **Raw Materials** – Feedstocks and other materials used in the production of green hydrogen e.g. water and electricity.

These sub sections were broken down further and additional detail for each supply chain item is provided in the matrices (Appendices A and B). Key differences in the product supply chain for the different archetypes are highlighted on the right-hand side and in the following slide.

Key Equipment

Electrolysers

Small scale: Containerised PEM electrolyser system, "off-the-shelf" model, with containerised cooling, water treatment systems and BoP, as described in the Scottish Enterprise electrolyser fact sheet.

Large scale: Non-containerised PEM electrolyser units, with separate cooling, water treatment and other BoP systems.

Compression

Small scale: High pressure compression (up to 500 bar)

Large scale: No compression required (outlet pressure 30-40bar)

Storage

Small scale: The type of offtakers envisaged for the small-scale archetype (transport, small-scale industry) necessitates high pressure hydrogen storage to effectively manage supply and demand.

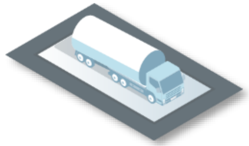
Large scale: No storage - hydrogen is assumed to be fed directly into a pipeline for export.

Section 3.1

Supply Chain Matrix

Products

Ancillary Equipment



Tube Trailers

Small scale: Required for the delivery of high-pressure hydrogen to industrial customers and refuelling stations. Additional civils and piping required at production site and offsite at offtakers. Associated equipment provided in Appendices A&B.
Large scale: Not required.

Desalination Equipment

Small scale: Not required due mains potable water source
Large scale: Seawater requires additional treatment to meet the purity requirements for the electrolyser. This will come through reverse osmosis desalination.

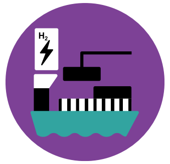
Thermal management

Small scale: The cooling system is containerised in the electrolyser.
Large scale: A centralised cooling system will be required for the large-scale archetype typically using cooling towers.

Raw Materials

Direct Renewable Connection

Small scale: Not required – archetype is assumed to utilise direct grid connection only.
Large scale: Required to meet the large green electricity demands for this archetype. A backup grid connection is also needed due to the intermittent nature of renewable supply.



Water (Sea Source)

Small scale: Not required due to a direct mains potable water source (water demand roughly 20L/kg H_2)
Large scale: Likely required for a project of this scale. Additional water is required to account for losses during desalination process (roughly 80L/kg H_2).

Scottish Enterprise ARUP

Section 3.1

Supply Chain Matrix

Services

Similarly to the products, project services – capabilities supporting the delivery of products – were broken down further into more detail. Services for the delivery of a hydrogen production facility can be broadly described as follows:

- **Engineering** – Services relating to the design of equipment and the project site, such as civil, process and electrical design
- **Project management** – The planning and organisation of resources to achieve project objectives such as project coordination (budgets, schedules etc), stakeholder management and procurement.
- **Professional Services** – Expertise and advisory services that support the delivery of the project, such as legal, financial and health and safety services.

These sub sections were broken down further and additional detail for each supply chain item is provided in the matrices (Appendices A and B). Key differences in the services supply chain for the different archetypes are highlighted on the right-hand side and in the following slide.

Engineering Services

Small scale: Engineering services to support the safe design and delivery of the project in accordance with appropriate design standards and regulations.
Large scale: Similar requirement to small-scale archetype services but larger engineering resource required due to additional complexity and safety implications.

Design Management

Small scale: Involves management of the engineering design throughout the various stages of design (feasibility, pre-FEED, FEED, detailed design).
Large scale: Same stages but additional time and resources required.

Mechanical Design

Small scale: Involves the design of HVAC and pipeline systems, throughout the design management phase, with the timeline and level of detail varying dependent on the design management stage.
Large scale: Scope largely the same as for small-scale, but additional time and resources required.

Geotechnical Design

Small scale: Involves services such as ground investigation and site studies, throughout design management phase, with the timeline and level of detail varying dependent on the design management stage.
Large scale: Scope largely the same as for small-scale, but additional time and resources required.

Section 3.1

Supply Chain Matrix

Services

Engineering Services

Electrical Engineering

Small scale: Services such as grid connection studies, and electrical system design throughout design management phase, with the timeline and level of detail varying dependent on the design management stage.

Large scale: Scope largely the same as for small-scale, but additional time and resources required.

Process Engineering

Small scale: Involves completing process safety studies and commissioning plans throughout design management phase, with the timeline and level of detail varying dependent on the design management stage.

Large scale: Scope largely the same as for small-scale, but additional time and resources required.

Construction and Civil Design

Small scale: Services such as building and structural design, foundation design and additional infrastructure. This design occurs throughout design management phase, with the timeline and level of detail varying dependent on the design management stage.

Large scale: Scope largely the same as for small-scale, but additional time and resources required.

Professional Services

Small scale: General support across areas such as legal, insurance, planning and project finance.

Large scale: Additional resource required to account for larger project – specifics highlighted below:

Legal (Hydrogen Offtake Agreements, LCHA Compliance and Electricity Supply)

Small scale: Relatively low resource (likely 1-2 hydrogen offtakers, PPA for 100% of power).

Large scale: Additional resource required (significant number of hydrogen offtakers, added complexity in power supply (direct-wire electricity and grid connection).

Environmental

Small scale: Limited environmental surveys – location dependent.

Large scale: Likely requires Environmental Impact Assessment (EIA), designed to assess the full environmental consequences of the project and can be resource-intensive.

Planning, Permitting and Consenting Services*

Small scale: Planning permission granted through the Local Planning Authority (LPA), less time-intensive permits and consents.

Large scale: Likely will require EIA and final approval from the Scottish Government, requiring additional time and services.

* It is understood that a report is due to be published by the Scottish Government on the planning process and regulations for hydrogen production projects, which will provide further clarity on these requirements.

Section 3.1

Supply Chain Matrix

Solutions

Solutions– capabilities that directly deliver products – involved in the hydrogen supply chain were also broken down and can be widely categorised as presented below:

- **Engineering Solutions** – delivering solutions relating to the built environment such as commissioning, operations, maintenance and manufacturing
- **Logistics** – solutions involving the movement of goods to a customer, such as equipment delivery, system packing and transport.
- **Site Solutions** – on site solutions relating to the upkeep and safety of the site such as waste management, safety or labour

These sub sections were broken down further and additional detail for each supply chain item is provided in the matrices (Appendices A and B). Key differences in the solutions supply chain for the different archetypes are highlighted on the right-hand side and in the following slide.

Engineering Solutions

Manufacturing

Small scale: Involves the manufacture of essential process components such as electrical or mechanical components. For example, pumps and transformers.
Large scale: Similar to small scale besides component differences such as bespoke electrolyser design or desalination equipment, and on a larger scale.

Decommissioning

Small scale: End of life decommissioning of components, site and materials used in the project.
Large scale: Similar to small scale, but a much larger operation in terms of time and resources.

Operations and Maintenance

Small scale: Ensuring that all equipment is functioning to its purpose and carrying out required planned or preventative maintenance if his is not the case. Will be carried out by on call engineers for the small scale.
Large scale: Similar tasks will be carried out regardless of scale, however O&M will likely be carried out by onsite engineers due to the scale of the project.

End Use Solutions

Small scale: Tube trailers and hydrogen logistics operations, refuelling solutions
Large scale: Hydrogen transport and storage network operations

Scottish Enterprise ARUP

Section 3.1

Supply Chain Matrix

Solutions

On Site Solutions

Control System

Small scale: Relatively small-scale control system, potential for remote operations and control.

Large scale: Centralised control systems for water treatment or cooling, onsite engineers and control room.

Labour

Small scale: Will require on call engineers and staff to carry out control or O&M services, as well as training for these staff.

Large scale: More extensive training and staff resources will be required for the on-site engineers and staff.

Civils Preparations

Small scale: Groundworks and site clearance will be undertaken during the project development and site remediation will form a part of the end-of-life solutions required as the project is decommissioned. Consideration required for installing refuelling station and tube trailer infrastructure.

Large scale: Similar to small-scale but significantly higher resource and time. Consideration required for installing seawater treatment facility and pipeline distribution infrastructure.

Section 3.2

Hydrogen Derivatives

As discussed previously, the offtake for the large-scale archetype is assumed to be a pipeline connection to a large-scale industrial offtaker(s), or export route. However, the production of derivatives such as methanol or ammonia could also be considered as an alternative route to market. The below section discusses these production processes at a high-level and also touches on the potential role of geological hydrogen storage for the large-scale archetype.

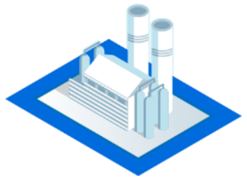
Ammonia Production

Ammonia is typically produced through the Haber-Bosch process, reacting hydrogen with nitrogen. By using green hydrogen in this process, the carbon footprint of the process, and hence the end product can be significantly reduced. The supply chain for this derivative production is comparative to hydrogen production with respect to general services and solutions (e.g. engineering, construction etc), however the required products will vary as highlighted below:

- **Iron** – Typically iron is used as the catalyst in the ammonia production process, it is combined with other materials such as Al_2O_3 as a promoter.[1]
- **Nitrogen** – Nitrogen is required as the other feedstock for this process and is typically extracted from the air.
- **Reactor** –This process requires a catalytic reactor such as a fixed or fluidised bed reactor to carry out the ammonia production process.[2]

E-Methanol production

Similarly to ammonia, hydrogen is used in the production of methanol which is typically used in fuels, or as a chemical feedstock across the world. Methanol is typically generated through Fisher-Tropsch synthesis which again requires a similar supply chain to green hydrogen with a few key differences:



- **Fixed bed catalytic reactor**[3] - The feedstock gas passes through a fixed catalytic bed to speed up the reaction and create hydrocarbons from H_2 and CO_2.
- **Catalyst** – CO_2 hydrogenation typically takes place over a metallic catalyst, the main components of which could be copper and zinc, combined with other additives.[4]
- **CO_2 source** – This is the other feedstock that is combined with hydrogen for the production of e-methanol.

Long term storage

Large-scale hydrogen storage typically requires specific geological conditions, such as underground salt caverns. In Scotland, limited sites for long-duration hydrogen storage have been identified - however, investigations are ongoing into other potential options for hydrogen storage in Scotland, such as porous geological formations, which are more readily available in Scotland.[5]

1 - Development and Recent Progress on Ammonia Synthesis Catalysts for Haber–Bosch Process
2 - Optimal Design of Ammonia Synthesis Reactor for a Process Industry – ScienceDirect
3 - An overview of Fischer-Tropsch Synthesis: XtL processes, catalysts and reactors – ScienceDirect
4 - Renewable methanol production from green hydrogen and captured CO2: A techno-economic assessment – ScienceDirect
5 - Hydrogen storage in porous geological formations – onshore play opportunities in the midland valley (Scotland, UK) - ScienceDirect

Scottish Enterprise ARUP

Section 3.3

Supply Chain Requirements - Duration and Scale

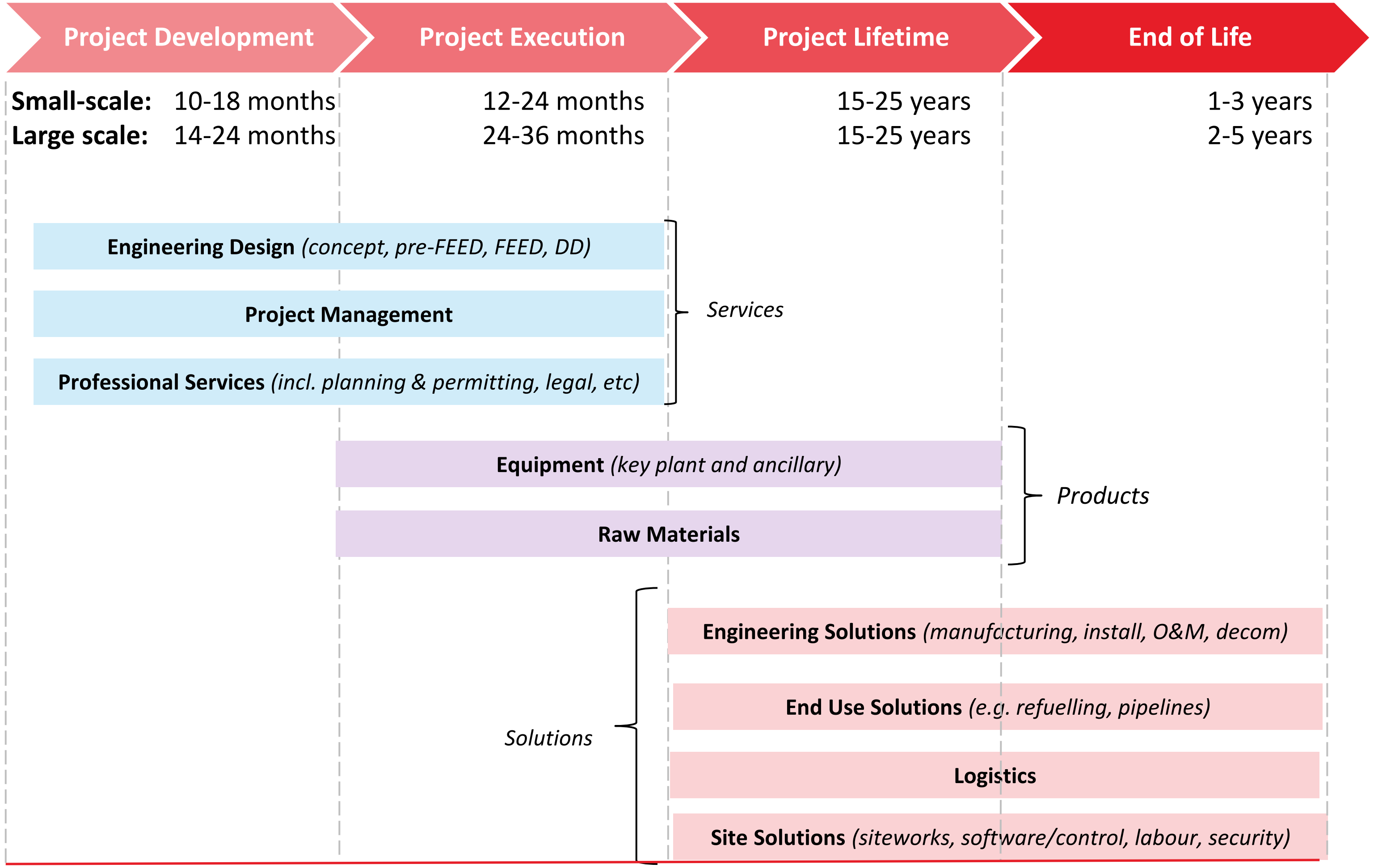
Supply Chain Requirements Throughout the Project Lifecycle

In addition to mapping the supply chain requirements, Arup have considered the associated scale (how much) and duration (how long) for each of the supply chain requirements for the different archetypes.

The diagram opposite shows a high-level overview of a typical project development timeline for each archetype.

The specific differences in supply chain requirements between the archetypes (as discussed in Section 3.1) are highlighted further in a more detailed breakdown of project timelines on pages 25-30, and in the respective Supply Chain Matrices (Appendices A and B).

Page 24 provides a supporting narrative for the supply chain requirements throughout the project lifecycle.



Overview of Full Project Lifecycle for Small and Large-scale Archetypes

Section 3.3

Supply Chain Requirements – Duration and Scale

Supply Chain Requirements Throughout the Project Lifecycle

This section provides some high-level narrative for the supply chain requirements throughout a typical green hydrogen project lifecycle, generally applicable across both archetypes.

Engineering Design

Engineering design during project development is managed in key design stages (feasibility/concept, pre-FEED and FEED and detailed design), with each design stage involving input from a variety of different engineering specialisms (electrical, process, geotechnical, mechanical and civil). Earlier design stages (concept and pre-FEED) will require less engineering resource, but this will increase as the project matures, e.g. during FEED and detailed design.

Process safety design is critical across the full project development and execution phases, ramping up throughout the design management stages. This will include studies such as HAZID, HAZOP, LOPA and QRA.

Project Management

Project coordination (budgets, schedules, resourcing, reporting) and stakeholder management are required across all stages of the project lifecycle, to ensure smooth delivery, operation and decommissioning of the project. Procurement services are typically required from pre-FEED onwards, from initial engagement to order placement (execution phase). Owner's engineer and CDM management are key services usually procured from kick-off of FEED until the end of the execution phase.

Professional Services

General health and safety (additional to the process safety discipline, e.g. training, audits), and legal services are typically deployed across the full project lifecycle, with peaks and troughs in terms of resource requirement depending on the stage of the project. Project finance services are typically required to support the project through to Final Investment Decision (FID). Planning, permitting and consenting services are critical, especially during the development and execution stages, but a light resource may also be required during operations and end-of-life to maintain and terminate the relevant permissions.

Equipment and Raw Materials

Early-stage discussions with electricity and water providers will start from at least pre-FEED stage, with engagement continuing up until the point at which a supply agreement is signed (end of development phase). The design and connection works will take place during project execution, with the resource requirement captured under engineering design and engineering solutions (construction, installation and commissioning). Key equipment and end-use solutions will be utilised throughout the project operational phase.

Manufacturing and Assembly

Following the detailed design phase, manufacturing and assembly of bespoke equipment for the facility commences. "Off-the-shelf" equipment that is not project-specific, e.g. electrolyser stacks, compressor parts, etc, can be manufactured well in advance of order placement and are therefore not captured here.

Construction, Installation and Commissioning

This phase of the project begins towards the end of the execution phase, following the manufacture, assembly and delivery of key equipment to the site.

Site Solutions and Logistics

Site solutions, such as control systems, security, waste management, safety management and logistics are typically required from the point at which works start on site (end of execution phase), through to the project end-of-life phase.

Operations and Maintenance

During the operational phase of the plant, operations and maintenance solutions are required for the everyday running of the facility and maintenance of plant equipment. This will require skilled personnel with knowledge and experience in how to safely operate and maintain and a hydrogen production facility and associated equipment/infrastructure.

Decommissioning

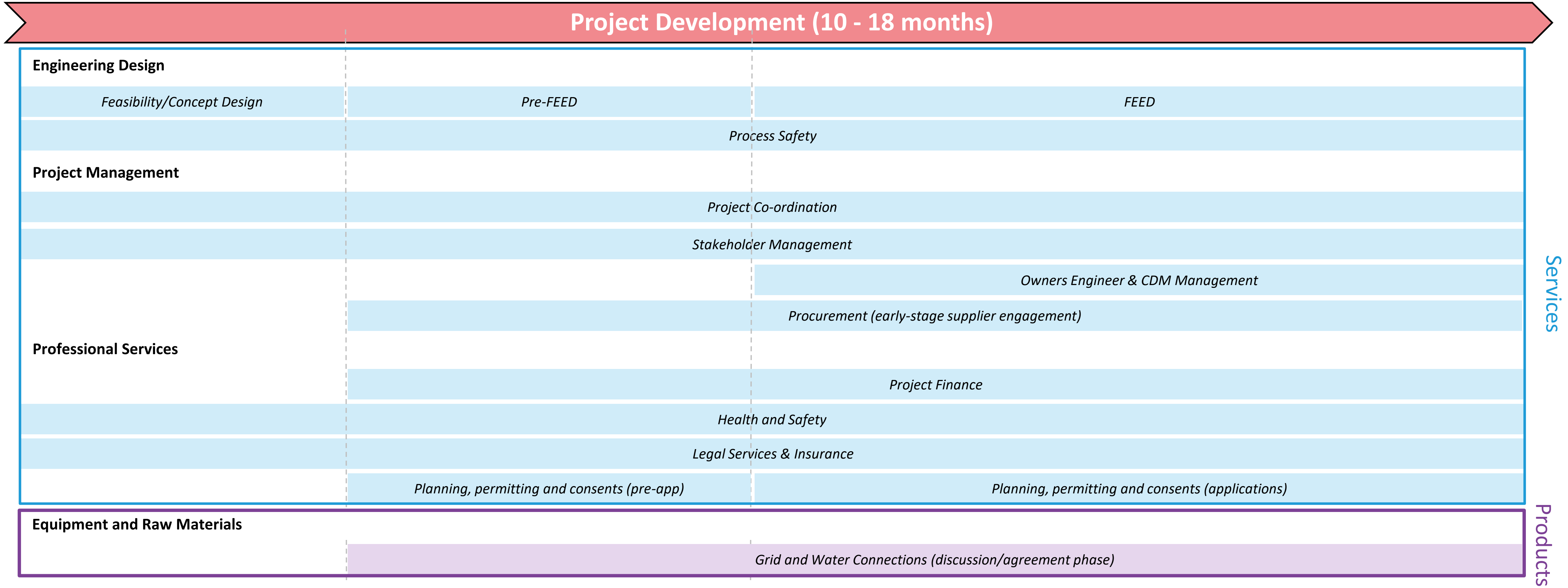
At the end of the operational lifetime of the facility, the plant equipment must be decommissioned and the site restored to its previous condition. Equipment and site materials will either be repurposed, recycled or disposed of, and this process is likely to be relatively resource-intensive, especially for the large-scale archetype.

Section 3.3

Small-scale Archetype

Project Development Timeline

Note: The following diagrams (pages 24 to 29) are designed to provide an indicative view of the general sequencing of supply chain requirements throughout the project lifecycle. They do not constitute or represent a fully detailed project schedule.

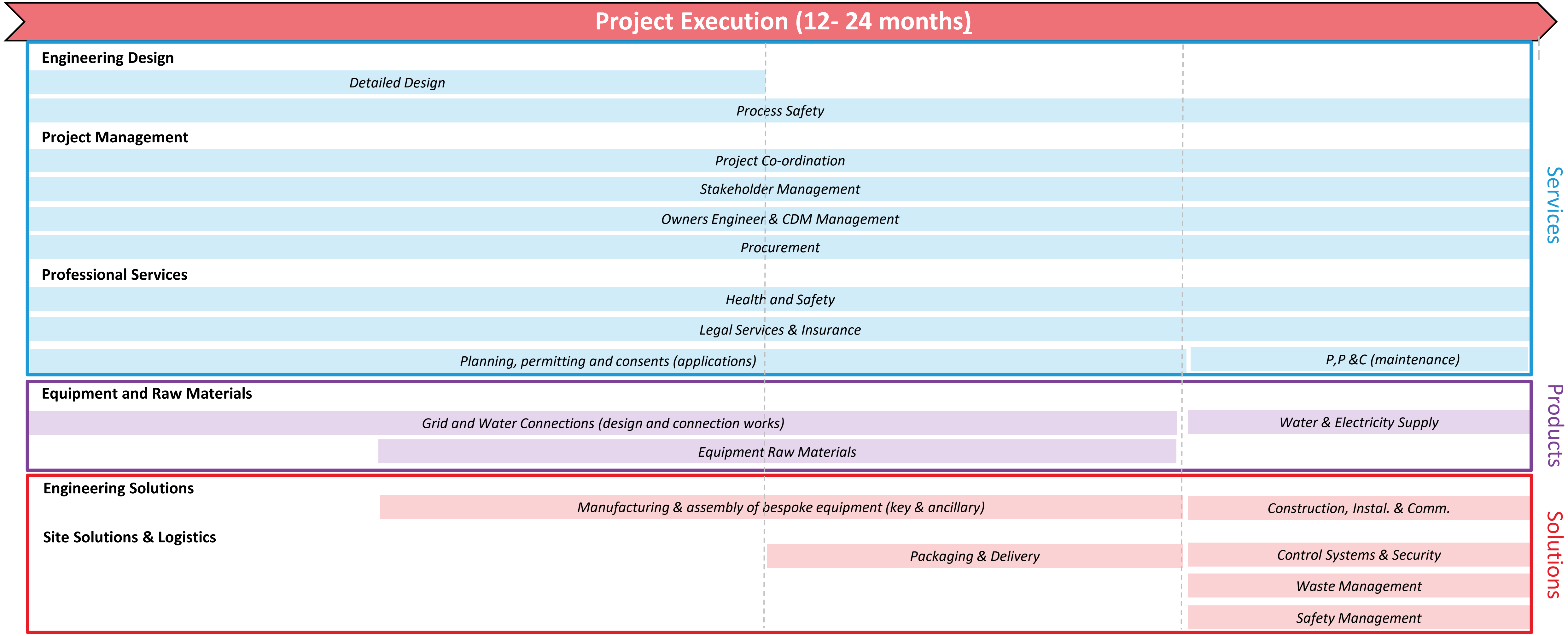


Project Development Phase Timeline and Supply Chain Overview

Section 3.3

Small-scale Archetype

Project Execution Timeline



Scottish Enterprise ARUP

Section 3.3

Small-scale Archetype

Project Lifetime and End-of-Life Phase

Project Lifetime (15- 25 years) | **End of Life (1-3 years)**

Services

Project Management

- *Project Co-ordination* (Project Lifetime and End of Life)
- *Stakeholder Management* (Project Lifetime and End of Life)

Professional Services

- *Health and Safety* (Project Lifetime and End of Life)
- *Legal Services & Insurance* (Project Lifetime and End of Life)
- *Planning, permitting and consents (maintenance)* (Project Lifetime)
- *Planning, permitting and consents (termination)* (End of Life)

Products

Equipment and Raw Materials

- *Water & Electricity Supply*
- *Water & Electricity Decomm.*
- *Key and ancillary equipment* (Project Lifetime)

Solutions

Engineering Solutions

- *Operations and Maintenance* (Project Lifetime)
- *Equipment decommissioning & site restoration* (End of Life)

End Use Solutions

- *Pipelines* (Project Lifetime)
- *Tube trailers* (Project Lifetime)
- *Hydrogen refuelling* (Project Lifetime)

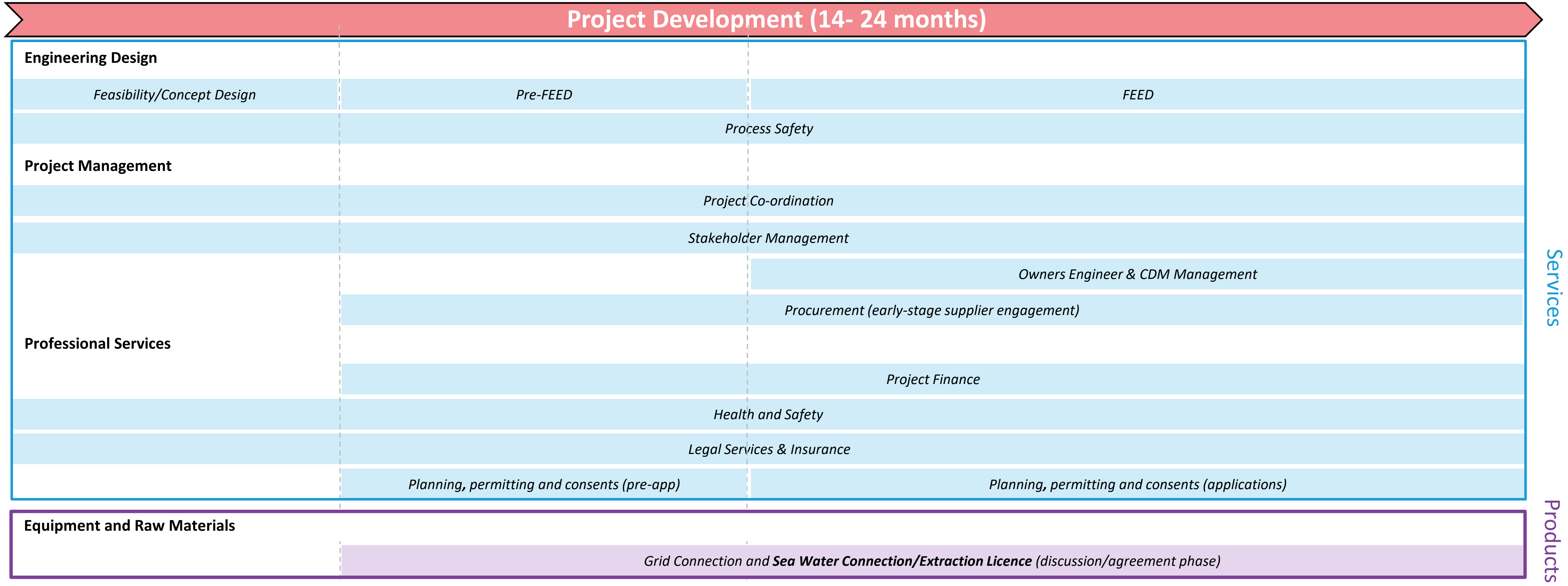
Site Solutions & Logistics

- *Control Systems & Security* (Project Lifetime)
- *Waste Management* (Project Lifetime and End of Life)
- *Safety Management* (Project Lifetime and End of Life)

Section 3.3

Large-scale Archetype

Project Development Phase

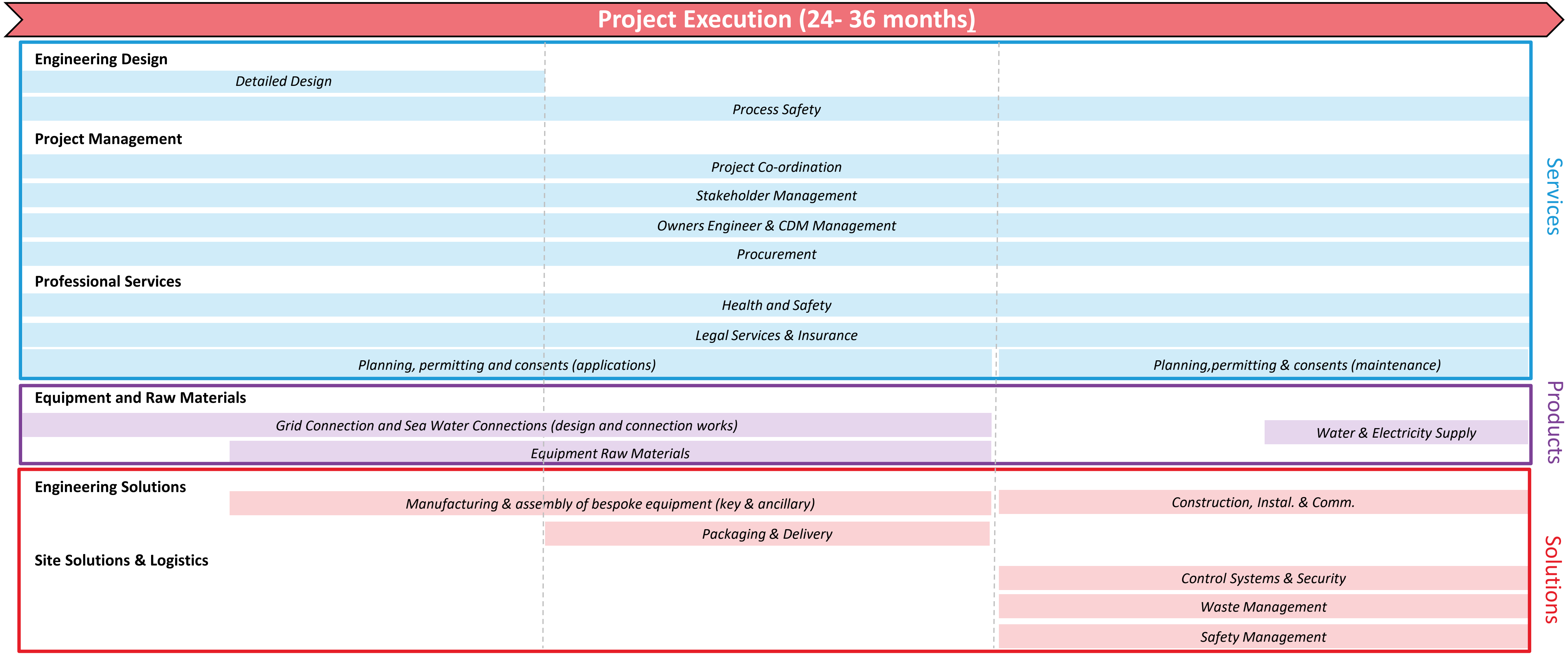


Project Development Phase Timeline and Supply Chain Overview

Section 3.3

Large-scale Archetype

Project Execution Phase



Project Execution Phase Timeline and Supply Chain Overview

Scottish Enterprise ARUP

Section 3.3

Large-scale Archetype

Project Lifetime and End-of-Life Phase

	Project Lifetime (15- 25 years)	End of Life (2-5 years)
Services		
Project Management		
	Project Co-ordination	Project Co-ordination
	Stakeholder Management	Stakeholder Management
Professional Services		
	Health and Safety	Health and Safety
	Legal services & Insurance	Legal services & Insurance
	Planning, permitting and consents (maintenance)	Planning, permitting and consents (termination)
Products		
Equipment and Raw Materials		
	Water & electricity supply	Water & electricity supply; Water & electricity decomm.
	Key and ancillary equipment	
Solutions		
Engineering Solutions		
	Operations and Maintenance	Equipment decommissioning and site restoration
End Use Solutions		
	Pipelines	
Site Solutions & Logistics		
	Control Systems & Security	
	Waste Management	Waste Management
	Safety Management	Safety Management

Project Lifetime and End-of-Life Phase Timeline and Supply Chain Overview

Section 4

WP3: Scottish Supply Chain Capabilities

Section 4.1

Scottish Supply Chain Capabilities

Overview and Methodology

The supply chain components of both the small- and large-scale matrices were qualitatively assessed based on the current capability of Scottish companies to supply these components or services to hydrogen production projects. This relied on the internal experience of the project team and various experts within Arup, referring to SE's non-exhaustive companies list where appropriate.

Each component in the matrix was assigned an indicative red/amber/green (RAG) rating according to the criteria outlined in the table opposite. Where capabilities exist within the Scottish supply chain but not specifically in relation to hydrogen projects, consideration was given to the transferability of skills and suitability of products for use in the sector, and any significant barriers to transition.

Some key strengths, opportunities and potential bottlenecks in the Scottish supply chain have been identified as a result of this analysis, which are shown and discussed in the following section.

Existing Capability in Scotland	Transferrable Skills/Products	Capability
Strong capability currently present in Scotland operating specifically within the hydrogen supply chain.	Skills/products are highly transferable to the hydrogen industry, or capability is non-hydrogen specific.	Strong
Medium capability currently present in Scotland operating specifically within the hydrogen supply chain.	Skills/products are relatively transferable to the hydrogen industry.	Medium
Low or no capability currently present in Scotland operating specifically within the hydrogen supply chain.	Limited transferable skills/products. Significant retraining/investment is required to compete in the hydrogen industry.	Limited

Scottish Supply Chain Capability Assessment Criteria

Section 4.1

Scottish Supply Chain Capabilities

Summary of Performance

Services

Design management and engineering design services (specifically process design, geotechnical design, and mechanical design) all have strong Scottish supply chain capability. Scotland's strength in this area is likely underpinned by existing and transferrable skills from the historic O&G sector.

Professional services such as project management, financial and legal services, are also strengths within the Scottish supply chain, but there are opportunities for these companies to strengthen their offering and experience in the hydrogen industry.

Opportunities for further development in the supply chain were identified in areas such as construction and civils design, insurance, planning and permitting specialists and hydrogen specific health and safety training.

Solutions

Solutions capability in areas such as construction and commissioning, waste management and site safety and security is also strong in Scotland, again likely due to the influence of the O&G sector.

Potential bottlenecks in terms of solutions include hydrogen-specific operations and maintenance services and hydrogen logistics.

Hydrogen-specific decommissioning services was also identified as an area with low capability in Scotland. This is largely due to the current lack of operational facilities, and a lack of facilities in Scotland, and across the globe that have reached end of life. However, Scotland was an early mover in the hydrogen market and therefore will be one of the first countries to gain this decommissioning experience and are well positioned to draw on expertise from the oil and gas sector.

Products

Scotland's capability in the products supply chain generally scored lower, although there were some products with a notably higher number of suppliers/manufacturers in Scotland, such as sensors and control systems.

Strong capability was noted for wind resource for the large-scale archetype due to proximity of planned offshore wind farms, though grid connection timelines could cause delays for both archetypes.

Most supply chain components across both archetypes were indicatively rated as medium capability, with a small number of companies offering these products but significant opportunity for expansion of manufacturing capability.

Key components such as electrolyser equipment and compressors have some limited manufacturing capability in Scotland; however, the supply chain would benefit from a ramp up in scale and technology offering.

Tube trailers and raw materials such as steel also have limited large-scale manufacturing presence in Scotland, creating significant reliance on external markets for these products and materials.

Scottish Enterprise ARUP

Section 4.1

Scottish Supply Chain Capabilities

Summary of Performance

Capability	Services	Solutions	Products		
	Both Archetypes	Both Archetypes	Both Archetypes	Small-scale	Large-Scale
Strong	• Engineering design • Project management • Professional services	• Construction / commissioning • Waste management • Site security • Site safety	• Sensors • Back up power fuel (diesel, H_2) • Control systems		• Wind resource
Medium	• Civils • Insurance • Planning, permitting, consenting and regulation • Health and safety	• Manufacturing • Installation / assembly • Site preparation	• Electrical management equipment (transformers, switchgear, cabling) • Mechanical process connections (flanges, gaskets, pumps)	• Hydrogen refuelling station equipment • Process equipment	• Water piping and storage vessels (pre- and post-treatment)
Limited	-	• Decommissioning • Operations & maintenance • Hydrogen logistics	• Electrolyser manufacturing • Raw materials (steel, composites) • Hydrogen purification	• Hydrogen distribution • Tube trailer equipment • Compressors	• Thermal management equipment • Water treatment membranes / resins • Process equipment

Scottish Supply Chain Scoring vs Criteria

Scottish Enterprise ARUP

Section 4.1

Scottish Supply Chain Capabilities

Conclusions and Opportunities

The Scottish capability for services does not differ significantly between the small- and large-scale archetypes in terms of scope, but the scale of resources required will differ between these two cases. There are slight differences in the solution capabilities between the archetypes due to the different methods for hydrogen end use. Contrasting supply chain elements and capabilities are found in the products, due to significant differences in the scale of the products and utilities required. The key differences in the supply chains for each archetype are outlined below and summarised in the table on the following slide.

Small-scale

Scotland has relatively low capability in terms of manufacturing of key equipment required for hydrogen production at this scale, such as electrolysers, compressors and tube trailer apparatus (tractors and type IV storage vessels). There is medium capability for refuelling station equipment, including the lower grade (type III) storage vessels.

Large-scale

The need for a separate water treatment system for seawater in the large-scale presents mixed capability, designated as medium for pumps, piping and storage and low for the resins and membranes required. Due to the volumes of hydrogen being produced in the large-scale archetype, it is expected that a large-scale hydrogen network will be required to distribute the product to offtakers. Whilst plans for this exist in the UK, connection locations in Scotland are not yet clearly defined and timelines are uncertain. However, there is potential to explore other routes to market for the large-scale hydrogen archetype, such as derivative production to produce compounds easier to handle (e.g. ammonia, methanol, SAF), and by exploring export opportunities to other countries.

Opportunities

The strong Scottish capability in the engineering services supply chain provides a unique opportunity for Scotland to become a leader in this space, especially if further skills and jobs from the O&G sectors can be transitioned to hydrogen.

Scotland currently has limited capacity in the large-scale manufacturing of key equipment such as electrolysers. There is a significant opportunity for the Scottish supply chain to develop its capability here, and in addition capitalise on opportunities relating to the integration and assembly of these products.

Professional services such a legal, financial and planning and permitting expertise could be strengthened through building out hydrogen-specific expertise and experience, and this could be achieved if the significant pipeline of hydrogen projects in Scotland are incentivised to use local services providers.

Scotland have a number of providers of refuelling station solutions, however there is currently limited manufacturing capability for tube trailers and tractors for distribution. Increased capability here could see Scotland become an industry leader in hydrogen refuelling and production and logistics of tube trailer apparatus.

Scotland has limited capability in terms manufacturing the resins and membranes used in purification of seawater required at large-scale, creating a reliance on external markets. Operators in this space could be engaged to explore the potential of establishing a manufacturing facility in Scotland.

Decommissioning of green hydrogen production projects is a relatively unchartered space due to the lack of projects at end-of-life stage, though Scotland has capability here due to previous O&G experience which could be capitalised on.

Due to the volumes of hydrogen produced in the large-scale archetype, other routes to market such as derivative production could be explored to reduce reliance on a hydrogen transport and storage network. Scotland currently have relatively low capability for large-scale production of chemicals and the associated processing equipment; however, this is also an area that could utilise existing skills and expertise from the O&G sector.

Next Steps

This preliminary analysis of Scottish companies present in the hydrogen supply chain indicates where strengths and opportunities are. However, further work is required to better understand the specific capabilities of the existing companies in terms of scale, expertise and Scottish operations, and therefore a better understanding of the gaps and bottlenecks.

Derivatives were discussed as a potential solution to constraints surrounding the transport and storage of large volumes of hydrogen. Further work could consider supply chain components for various derivative production methods and analyse the feasibility, route to market and potential for export of these fuels.

Section 4.2

Case Studies

With several world leading projects having been developed and many more in the pipeline, Scotland already has a rich and diverse hydrogen supply chain, relative to other countries.

Companies in Scotland actively engaged in hydrogen range from very small companies with a passion for developing skills through to multi-nationals with a significant presence in developing, executing and operating projects. The reasons for engaging with the hydrogen supply chain are equally diverse and include new start-ups, spun out of universities with innovative ideas through to companies whose main business has been oil and gas but who are looking to make a Just Transition.

This section describes five companies in Scotland that operate across the hydrogen supply chain:

- Swagelok Scotland,
- Glacier Energy,
- Green Cat Group,
- Arup,
- NorCo.

These five companies offer products, services or solutions in different parts of the project process. Several of these companies have been involved in hydrogen in Scotland for over a decade. They show that being part of the hydrogen supply chain in Scotland can lead to exciting opportunities to work on projects that can make a real difference to our Net Zero ambitions by supporting the decarbonisation of sectors that are otherwise difficult to reach. The success of these companies within the hydrogen economy, both in Scotland and wider, can act as a guide to others who are considering extending into the hydrogen market. These five are a selection of the many hydrogen focussed or hydrogen adjacent companies that operate throughout Scotland and can support green hydrogen projects across their lifetimes.

Section 4.2

Case Studies

Swagelok Scotland

Swagelok Scotland, Teesside & Ireland supports the hydrogen economy and broader clean energy landscape from its bases across the regions it serves, as the global shift towards clean and sustainable energy gathers momentum.

Swagelok Scotland is part of the global Swagelok network, providing trusted fluid system solutions backed by decades of technical expertise. The company expanded its regional footprint in 2012 to include sites in Teesside and Ireland, enhancing its ability to deliver localised support across key energy hubs.

The company operates 2 facilities within Scotland out of Aberdeen (Head Office) and Motherwell. The Aberdeen facility serves as the central hub for customer service, order fulfilment, a walk-in trade counter, and its on-site Training Academy. Here, Swagelok offers industry-recognised technical training, including ECITB-approved courses, Swagelok Small Bore Tubing, and hydrogen installer and design certifications.

Meanwhile, the Motherwell facility is dedicated to advanced assembly services, supporting complex builds that include orbital welding, hose assembly, helium leak testing for essential hydrogen applications. The site also features a class 6 clean room with a class 4 laminar flow bench for sensitive builds and replicates Aberdeen's training capabilities to serve customers across multiple sectors, with a strong focus on clean energy.

Swagelok's 75 years of experience in managing hazardous fluids and small-molecule gases under pressure led to a natural evolution into the hydrogen sector.

The company's local teams, which include Field Engineers and Clean Energy Subject Matter Experts, have been involved in several landmark hydrogen projects. These include H100 Fife, hydrogen-fuelled public transportation, developments in Orkney's hydrogen infrastructure and collaborations on hydrogen flow laboratories.

Swagelok's product and service offerings are designed to meet the rigorous demands of hydrogen systems, from production and distribution to storage, refuelling infrastructure, and vehicle integration. These components play a critical role in ensuring the safety and performance of electrolysers, fuel cells, and containment systems used across the hydrogen supply chain.

As the UK and Ireland continue to scale up clean energy ambitions, Swagelok's regional presence and technical capabilities are supporting customers with access to the expertise and components needed to meet today's challenges and prepare for tomorrow's energy solutions.

Swagelok Scotland | Teesside | Ireland

Section 4.2

Case Studies

Glacier Energy

Glacier Energy specialises in the design and manufacture of innovative hydrogen products to reliably store and move hydrogen. Utilising their 120-years of experience in pressure vessel design and manufacture, Glacier Energy is developing a range of proprietary hydrogen products consisting of type I static storage solutions Hy-Edge and Hy-Vault, as well as a Type IV MEGC trailer solution, Hy-Vision. Glacier Energy also plans to offer inspection and maintenance services for its proprietary hydrogen products, including those that were manufactured by a third party.

Glacier Energy was founded in Scotland in 2011, traditionally focused on conventional energy. However, the business naturally has products and services that are required in multiple decarbonisation projects, including hydrogen. Glacier Energy operate throughout the UK with Scottish sites in Glasgow, Aberdeen and Methil and deliver their products and services globally.

Glacier Energy has been involved in supporting various UK and European early-stage hydrogen projects. This has initially been by supplying steel pressure vessels for stationary hydrogen storage. Glacier Energy see mobile hydrogen storage, i.e. MEGC trailers, as an emerging potential market. Their team has therefore designed a MEGC trailer solution, Hy-Vision®, which contains multiple proprietary composite vessels to store and move hydrogen. The solution is due to be brought to market in 2026.

The product has been designed at high pressure and aims to be more light-weight compared to existing technology that is currently available in the market. The development of Hy-Vision® has been supported by the Scottish Government and the National Composite Centre.

Glacier Energy believes Hy-Vision can support the development of the UK hydrogen market by supplying a lightweight, safe, low-maintenance hydrogen transport solution from the source of production to final use.

Glacier Energy also aims to be active within the supply chain during the products operational lifetime by offering recertification, warranty and maintenance packages.

Glacier Energy

Section 4.2

Case Studies

Green Cat Group

The Green Cat Group, founded in 2005, believe that hydrogen represents a key element in the energy transition - as a decarbonisation option for hard-to-electrify applications, as well as an effective route to market for otherwise curtailed electrons.

Green Cat Hydrogen

Green Cat Hydrogen (GCH), a renewable hydrogen project developer with offices in Edinburgh and Glasgow, was founded in 2022

GCH was established to enable the decarbonisation of industry and facilitate the continued build out of renewable generation assets. Their hydrogen projects co-locate with renewable energy assets where practicable and support the development of new-build assets.

The GCH team is made up of multi-disciplinary engineers, project managers and finance specialists who work across the entire project range, including engineering, planning and commercial. They leverage the expertise of the wider Green Cat Group to determine where hydrogen is a viable route to market for constrained electricity and determine potential local users of that hydrogen, with a strong emphasis on hard-to-electrify sectors.

GCH is backed by RWE Energy Transition Investments through a multi-million-pound equity investment. This partnership supports the growth of the team and the acceleration of the project pipeline. GCH operates independently from the RWE Group.

GCH are actively developing a portfolio of hydrogen production projects across Scotland, with three of those shortlisted in the second Hydrogen Allocation Round. These projects will be developed by GCH and delivered by the wider Green Cat Group where possible, supporting the Scottish supply chain by keeping the knowledge and experience within Scotland.

GCH will own, operate, maintain and ultimately decommission the assets upon completion, making them active across the whole project lifecycle. Their current projects focus on a hub and spoke model where the hydrogen production facility is co-located with renewable generation assets and is distributed to customers via high pressure tube trailers.

GCH’s future plans include developing further hydrogen projects around the UK. However, future projects will continue to focus on enabling the use of otherwise curtailed renewable electricity, supporting the build-out of new renewable generation, and delivering sensible decarbonisation solutions for hard-to-abate sectors.

Green Cat Renewables

Green Cat Renewables offer a broad spectrum of consulting services – from planning to engineering – to hydrogen project developers across the industry. They are currently acting at the delivery partner for the Creed project in the Western Isles. Green Cat Renewables also acted as designer for the HydroGlen project in Aberdeenshire.

Green Cat Contracting

Green Cat Contracting offer civil contracting services for hydrogen projects and are currently acting as the EPC contractor for the HydroGlen project in Aberdeenshire, on behalf of the James Hutton Institute, and the Creed project in the Western Isles.

Section 4.2

Case Studies

Arup

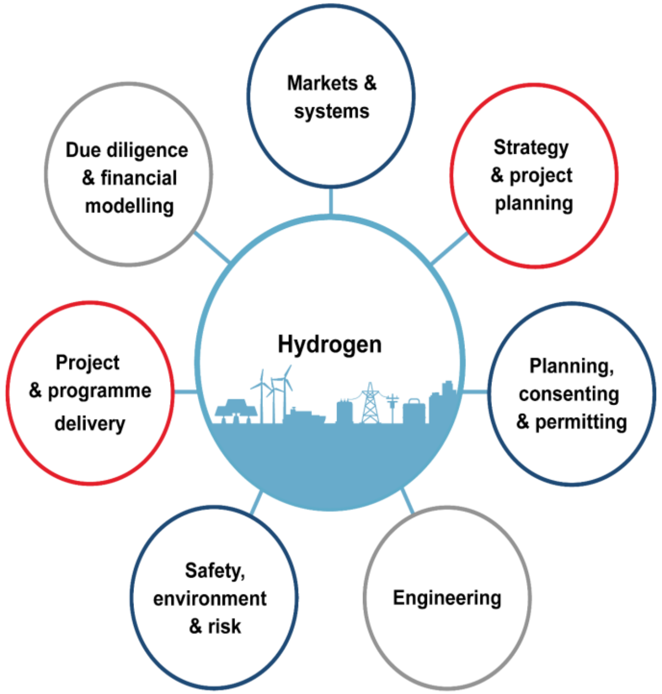
Arup is a global consultancy offering advisory and technical expertise across more than 150 disciplines. It advises on, plans, and designs the future of the built environment using a Total Design approach, developing creative, practical, and effective solutions. The firm employs over 18,500 people across 34 countries.

In Scotland, Arup has been active for more than 60 years, with offices in Edinburgh and Glasgow. Its work in hydrogen spans nearly two decades, supporting projects from The Hydrogen Office to SGN's H100 in Fife. In 2021, Arup delivered the Scottish Hydrogen Assessment for the Scottish Government, a key input to the Hydrogen Action Plan.

Arup believes that low- or zero-emission hydrogen production, transport, storage, and use play a vital role in decarbonising hard-to-abate sectors such as aviation and steel production, and in enabling energy storage to support renewables. This was highlighted in its 2019 white paper, Establishing a Hydrogen Economy.

With global experience and local knowledge, Arup supports hydrogen project delivery across the supply chain and lifecycle, from strategy, planning, and investment advisory to engineering and implementation. Its geotechnical expertise also supports the potential rollout of geological hydrogen storage.

By connecting policy, engineering, and commercial insights, Arup delivers sustainable solutions that meet client needs, grow the hydrogen economy, and address the climate crisis, nature loss, and resource efficiency. Looking ahead, Arup aims to continue supporting clients in delivering the next generation of hydrogen projects to help drive the transition to net zero.



Section 4.2

Case Studies

Norco Group

Norco Group was established in 1991 following a management buyout of the battery division of the Northern Cooperative Society (Norco) in Aberdeen. At the time, the company focused on operating and maintaining battery-powered milk floats and an increasing fleet of electric forklift trucks. Recognising the potential in battery rental, the business rebranded as Norco Batteries and began offering traction battery rental and maintenance services across the UK.

Headquartered in Aberdeen with a manufacturing and warehouse facility in Newbridge. Norco has evolved significantly over the past three decades. The company has expanded its expertise in stored energy systems and recently launched a dedicated hydrogen department to support the growing demand for clean energy solutions.

Norco manages the operations and maintenance management of the hydrogen refuelling stations in Aberdeen. The skills developed supporting batteries and the oil and gas sectors have provided a strong foundation for transitioning into hydrogen technologies. Norco now offers 24/7 operations and maintenance support for hydrogen equipment owners, with a long-term vision to expand these services across Scotland as new hydrogen projects emerge.

Looking ahead, Norco hope to develop greater links between their battery services and their hydrogen work by providing both the battery systems and the operations and maintenance package. Norco aims to integrate its battery and hydrogen services by offering complete solutions that include battery systems alongside operations and maintenance packages. The company sees significant potential in combining solar energy, battery storage, and hydrogen production where all their skills work together.

In addition, Norco supports original equipment manufacturers in the hydrogen sector. Norco believes that in providing reliable post-installation support, they hope to address a common challenge faced by many Scottish hydrogen projects: the lack of ongoing technical assistance.

As hydrogen projects reach the end of their lifecycle, Norco believe they are well placed to support the decommission and potential re-use of hydrogen equipment. Through working with equipment manufacturers, and project developers, Norco believes reusing hydrogen infrastructure can unlock further opportunities and training across the sector.

Section 5

Conclusions

Scottish Enterprise ARUP

Section 5

Conclusions

This report highlights the end-to-end supply chain for two different scales of electrolytic hydrogen projects in Scotland. It provides an overview of the supply chain requirements for a small scale (10MW) and large scale (500MW) hydrogen production project, informed by publicly available information, Arup's extensive knowledge and experience in the hydrogen sector, and the fact sheets and databases provided by SE. The main outputs from this report are a clear understanding of the timelines and scales of the supply chain for hydrogen projects of different scales, and the identification of opportunities and bottlenecks in Scotland's capability to meet these supply chain requirements.

Supply Chain

The comprehensive mapping and break down of the hydrogen supply chain highlighted several differences in requirements for the small-scale archetype and large-scale archetype. Mostly, variance in the supply chain was a matter of scale both in terms of the materials and resources required for the delivery of the project. However, there were some respects in which the supply chain differed significantly.

The smalls scale archetype is serviced by a grid connection and potable water source, with hydrogen offtaker from small-scale industry and transport users, supplied via tube trailers and hydrogen refuelling stations. The large-scale project, due to the volumes required, shows variation in the raw material and end use solution supply chain.

It is assumed that the water supply will be drawn directly from the sea, requiring desalination before it reaches an acceptable purity, and the required electricity will come from a direct connection to a renewable electricity source, such as an offshore wind farm, with a grid connection as back-up. The produced hydrogen is assumed to be supplied to industry or exported via pipeline, however hydrogen derivatives were also discussed as an alternative route to market.

Scottish Capability

Scotland has key areas of strength particularly in providing engineering and professional services. Engineering services such as commissioning, EPC and FEED/pre-FEED are strong due to extensive experience drawn from the oil and gas sector. More opportunities exist in Scotland's significant current and potential capacity for offshore wind electricity production, and in existing expertise within the manufacturing of specialist components, which can be scaled up as more large-scale projects are deployed.

However, there are bottlenecks and areas for improvement in Scotland's capability, which lie mainly in the manufacturing of key plant equipment and raw materials such as steel, of which significant quantities will be required to supply projects like the large-scale archetype. Proximity to a hydrogen transmission system was also identified as a potential bottleneck to deployment of the large-scale archetype, and this could have implications for the supply chain in the context of requirements for other routes to market, such as production of derivatives and hydrogen export.

Next Steps

The below work packages are recommended as next steps to build on this work and continue to progress the development of the hydrogen supply chain in Scotland:

- Further investigation and qualitative analysis of the current Scottish hydrogen supply chain capabilities, specifically with respect to scale of the capability and specific product offerings.
- End-to-end supply chain analysis for hydrogen end-use technologies, such as hydrogen refuelling, hydrogen storage and industrial applications, and production of hydrogen derivatives (e.g. methanol, ammonia, SAF) to support further understanding within the Scottish supply chain of the potential opportunities in this market
- Further investigation into the technical and commercial viability of the production of hydrogen derivatives in Scotland as a route to market for large-scale hydrogen producers.

Appendix A

Supply Chain Matrix (Small-Scale)

Supply Chain Element	Supply Chain Sector	Supply Chain Sub Sector	Supply Chain Component	Individual Components/Materials	Definition	How long (duration of project)	How much (Equipment)	How much (FTE) - average	Project Development	Project Execution	Project Lifetime	Project end of life	RAG Indicator
Services	Engineering	Design Management	Feasibility/concept design		A study used to assess the early stage technical and commercial viability of the project.	2-3 months		<2 FTEs	x				1
			Pre-FEED		Feasibility studies, technology selection and process design required prior to beginning Front End Engineering Design (FEED)	3-5 months		2-5 FTEs	x				1
			FEED		FEED focusses on the project specific technical and economic requirements	4-9 months		5-20 FTEs	x				1
			Detailed engineering design		In depth project design to prepare for plant commissioning, construction and component procurement	8-12 months.			x	x			1
		Electrical design	Electrical design		The design and specification of the electrical components and system	As above throughout design management phases.		2-5 FTEs	x	x			1
			Backup power generation design		Design of backup power system in case of power failure				x	x			1
			Grid connection studies		A study ensuring the new system can connect to the network without causing issues				x	x			1
		Process Design	Process safety studies		The management of processes and systems to prevent major incidents	As above throughout design management phases.		2-5 FTEs	x	x			1
			Commissioning planning		Planning of commissioning procedures					x			1
		Geotechnical design	Siting Study		An assessment of occupied buildings nearby to the project site which could be exposed to project related hazards	As above throughout design management phases.		<2 FTEs	x	x			1
			Ground investigation		An assessment of subsurface conditions of the proposed project site			<2 FTEs	x	x			1
			Flooding risk		Assessment of the likelihood of the project site to be affected by flooding			<2 FTEs	x	x			1
		Mechanical design	HVAC system design		Design of the system used to control temperature, flow and purity of the air system for the project	As above throughout design management phases.		<2 FTEs	x	x			1
			Component Specification		Design of a detailed blueprint for a specific piece of equipment such as a compressor or heat exchanger			2-5 FTEs	x	x			1
			Piping system design		Design of the pipeline systems used to transport liquids or gases				x	x			2
		Civils design	Buildings and structural design		The creation of safe and stable structures to withstand external forces	As above throughout design management phases.		<2 FTEs	x	x			2
			Foundations		Construction plans for the building foundations			<2 FTEs	x	x			2
			Access & egress roads		Internal roads to connect the facility to main roads			<2 FTEs	x	x			2
			Infrastructure design		Design of basic service systems such as site water or electricity			<2 FTEs	x	x			2
	Project Management	Procurement	Equipment order placement		Initiating and executing the purchase of equipment	18-24 months		<2 FTEs		x			1
			Contractual agreements		Arranging contracts for the delivery of plant components				x	x			1
			Services procurement		Initiating and executing the procurement of services				x	x			1
		Project Coordination	Project schedule		Comprehensive timeline outlining tasks and deliverables	18-32 years (full project lifecycle)		2-5 FTEs	x	x			1
			Project budget		The total cost of the project				x	x			1
			Resource allocation		The process of distributing available resources across the project				x	x			1
			Interface management		Managing the coordination between the various teams working to deliver the project				x	x	x		1
			Progress reporting		Providing an update on the progression of the project				x	x	x		1
			Risk and opportunity management		Systematic process of identifying and mitigating risks and opportunities				x	x	x	x	1
		Stakeholder Management	Stakeholder engagement & communications		Careful management of key stakeholders with interest and influence in the project	18-32 years (full project lifecycle)		2-5 FTEs	x	x	x	x	1
			Community benefits		Measures incorporated into a project to add social value				x	x	x	x	1
			Marketing		Promotion of and education about the project				x	x	x	x	1
		Owners Engineer	Contractor oversight		Oversight of contractor work packages	16-24 months		2-5 FTEs	x	x			1
			Contractor management		Management of and communication with contractors				x	x			1
			Design reviews		Technical validation of a design				x	x			1

Supply Chain Element	Supply Chain Sector	Supply Chain Sub Sector	Supply Chain Component	Individual Components/Materials	Definition	How long (duration of project)	How much (Equipment)	How much (FTE) - average	Project Development	Project Execution	Project Lifetime	Project end of life	RAG Indicator
			Technical advisory		Guidance of field specific issues				x	x			1
		CDM management	Principal Contractor		The main contractor appointed by the client to manage and control the construction phase of the project	16-24 months		20+ FTEs	x	x			1
			Principal Designer		Organisation appointed by the client to take control of the pre-construction phase of the project			<2 FTEs	x	x			1
	Professional Services	Project Finance	Investor/funder due diligence		Technical and financial due diligence to support FID	6-8 months		2-5 FTEs	x				2
			Funding application support		Guidance through grant and funding requests				x				2
		Health and Safety	Studies and investigations		Research and enquiries into potential health and safety issues	18-32 years (full project lifecycle)		<2 FTEs	x	x	x		2
			Audits		An official inspection into health and safety measures				x	x	x	x	2
			Risk assessments		Process to identify safety issues				x	x	x	x	2
			Training		Health and safety training for carrying out project specific work				x	x	x	x	2
		Insurance	CAR Insurance		Contractors all risk Insurance - provides against risks associated with construction projects	3-6 months		<2 FTEs		x			2
			Employers Liability Insurance		Protects businesses against claims made by employees for injury or illness	16-28 years (operation and end-of life)				x	x	x	2
			Professional Indemnity Insurance		Provides compensation in the event of being charged with errors	16-28 years (operation and end-of life)				x	x	x	2
			Business Interruption Insurance		Coverage to replace income lost if business is halted	15-25 years (operations)					x		2
			Environmental Liability Insurance		Coverage for losses to do with environmental damage	16-28 years (operation and end-of life)				x	x	x	2
			Property and Equipment Insurance		Covers loss or damage of equipment or buildings	16-28 years (operation and end-of life)				x	x	x	2
			Public Liability Insurance		Protection against claims made by a member of the public	16-28 years (operation and end-of life)				x	x	x	2
			Cyber Insurance		Protects from incidents involving cybersecurity	16-28 years (operation and end-of life)				x	x	x	2
		Legal	Regulatory compliance		Legal support to ensure compliance with relevant regulations (e.g. LCHA)	18-32 years (full project lifecycle)		<2 FTEs	x	x	x	x	1
			Site Lease/Access		Legal support to aid negotiations for an agreement to occupy, build and operate a site			2-5 FTEs	x	x	x	x	1
			Power supply agreement (grid connection, PPA)		Legal support to aid agreement between a generator, distributor and offtake for the purchase and supply of power				x	x	x	x	1
			Water utilities agreement		Legal support to aid agreement between provider and offtaker for the purchase and supply of water			<2 FTEs	x	x	x	x	1
			Hydrogen offtake agreements		Legal support to aid agreement between a generator, distributor and offtake for the purchase and supply of hydrogen				x	x	x	x	1
			Procurement agreements (equipment and services)		Legal support to aid agreement between manufacturer and constructor for the purchase and supply of equipment				x	x	x	x	1
		Planning, permitting, consenting and regulation	Stakeholder engagement		Community and stakeholder engagement to support the planning process	18-32 years (full project lifecycle)		<2 FTEs	x	x	x	x	2
			Environmental surveys		Collection of data and surveys to assess environmental impact of project	6-12 months			x	x			2
			Planning permission		Support with the planning application to a relevant authority	14-16 months			x	x			2
			Permits, consents and licences		Support with acquiring additional permissions that may be required to carry out a proposed development	18-32 years (full project lifecycle)			x	x	x	x	2
			Containerised Electrolyser		Small scale 10 MW PEM electrolyser. See Arup's Scottish Electrolyser Assessment and SE's electrolyser fact sheet for more information		Supplier specific (e.g. 2x 5MW systems)			x	x		3
			Compression	Reciprocating compressors	Positive displacement machine that uses a piston to compress gases to higher pressures	-	Supplier specific (e.g. 2x 1000 NM3/h compressors)			x	x		3
				Power Quality System	The use of harmonic filtering and power factor correction to improve the quality of the power supply to the plant		(1-4 items)			x	x		2
				Customer Distribution Switchboard	A point where incoming power is divided into separate circuits		(1-4 bays)			x	x		2

Supply Chain Element	Supply Chain Sector	Supply Chain Sub Sector	Supply Chain Component	Individual Components/Materials	Definition	How long (duration of project)	How much (Equipment)	How much (FTE) - average	Project Development	Project Execution	Project Lifetime	Project end of life	RAG Indicator
Products	Equipment	Key Equipment	Electrical Management	Transformers	Provides electricity at the final voltage, ready for consumers, and use for BoP and auxiliary plant operations		(1-4 items) 33kV/11kV			x	x		2
				Switchgear	Device used to connect and control electrical equipment		(1-4 items)			x	x		2
				Cabling	Electrical transport equipment		(5-10 items)			x	x		2
				Rectifier	Device that converts alternating current to direct current		(1-4 items)			x	x		3
				Hydrogen generator	Combination of a hydrogen engine with a generator to generate electricity		(1-4 items) Typically, 5-20% of capacity (0.5 - 2MW)			x	x		3
				Diesel generator	Combination of a diesel engine with a generator to generate electricity					x	x		3
				Batteries	Device where chemical energy is converted to electrical energy					x	x		3
			Control systems	Sensors (Flow, comp, Pressure)	Device which detects and records a physical property		(50-100 items)			x	x		1
			Hydrogen high pressure storage vessels	Aluminium/Steel liner	Liner used in a storage tank to prevent chemical reaction		(5-10 items) Storage volume typically 2-5 tonnes				x		3
				Carbon fibre composite	Material with high mechanical strength used in high pressure storage vessels					x	x		3
		Ancillary equipment	Mechanical connections	Valves	Mechanical component used to block or change the flow of a liquid or gas		(10-50 items)			x	x		2
				Flanges	A means of securing or stabilising connections between components					x	x		2
				Gaskets	Used to seal the connection between components					x	x		2
				Pumps	A mechanical device used for the transport of liquid or gas					x	x		2
			Safety and control equipment	Sensors (flow, comp, pressure)	Device which detects and records a physical property		(50-100 items)			x	x		1
				Pressure relief valves	Safety device which controls or limits pressure					x	x		2
				Instrumentation	Measuring instruments used for recording physical properties		(50-100 items)			x	x		2
				Communication cables and system	Network to facilitate the transmission of information		-			x	x		2
				Control Panel	User interface for control system		(1-4 items)			x	x		2
			Hydrogen refuelling station	Dispensers	Equipment that provides compressed hydrogen fuel		(1-4 items)			x	x		2
				Hydrogen storage tanks (type III)	See SE hydrogen compression fact sheet		(10-50 items)				x		2
				Chiller	Component used for cooling a fluid		(5-10 items)				x		2
			Hydrogen Distribution	Tube Trailers (type IV storage vessel)	Storage containers designed for operation at higher pressures than type III and suitable for road transport		(5-10 items)			x	x		3
				Tube trailer tractor	Vehicle used for the movement of hydrogen storage tubes		(5-10 items)				x		3
				Pipelines	Pipes used in the transport of fluids		(5-10 items)			x	x		2
	Raw Materials	Water	Mains Source	Mains Source	Potable water source provided from treatment plants		Circa. 20L/kg of hydrogen (including reject and cooling)		x	x	x	x	1
		Electricity	Grid connection	Grid connection	Grid electricity supplied via the electricity grid		Circa. 62 kWh/kg hydrogen, including BoP		x	x	x	x	2
		Other	Nitrogen supply	Nitrogen supply	Nitrogen used as a safety gas in the process for purging and equipment testing		Circa. 1-5 Nm3/kg hydrogen			x	x	x	3
			Steel	Steel	Metal alloy used for the manufacture of most process components		-			x	x	x	3
			Coolant	Glycol	Fluid used to manage the temperature of process materials		-			x			2
			Backup power	Fuel (e.g. diesel, hydrogen)	Fuel used in the generator providing a backup power for the process		Fuel volume requirements will vary depending on power outage frequency and duration.			x			1
		Manufacturing	Mechanical components		Essential parts of process components	3-6 months		2-5 FTEs		x			2
			Electrical components		Components that use electricity to perform a function					x			2
			Specialised pieces		Bespoke equipment components					x			2
		Assembly	Electrical component assembly		Fitting together parts of electrical components	3-6 months		2-5 FTEs		x			1
			Mechanical components assembly		Fitting together parts of mechanical components					x			1
		Construction /	Testing and certification		Checking the conformity of components to regulations and standards					x			1

Supply Chain Element	Supply Chain Sector	Supply Chain Sub Sector	Supply Chain Component	Individual Components/Materials	Definition	How long (duration of project)	How much (Equipment)	How much (FTE) - average	Project Development	Project Execution	Project Lifetime	Project end of life	RAG Indicator
Solutions	Engineering solutions	Construction / Commissioning	Equipment installation		Fitting assembled components into the production process	4-6 months		2-5 FTEs			x		1
			Equipment commissioning		The procedure of ensuring all equipment is functioning as intended						x		1
		O&M	Operations		Activities ensuring that assets and equipment function properly	15-25 years		2-5 FTEs			x		3
			Planned maintenance		Proactive strategy for asset upkeep							x	3
			Preventative maintenance		Maintenance carried out to reduce the likelihood of equipment failure							x	3
		Decommissioning	Condition assessment		Evaluation of the current state of the equipment	1-3 years		5-20 FTEs				x	3
			Decommissioning plan		Document that contains detailed information of decommissioning. Includes the sequence, strategy and schedule of activities							x	3
			Site restoration		Returning a site to its original state							x	1
			Reuse/repurpose materials		Using products again or for different functions							x	3
			Scrap material/waste disposal		Handling of all waste to reduce its impact on the environment					x	x		3
			Materials recycling		Converting waste into new products					x	x		2
	End use solution	Supply to offtakers	Tube Trailer operations		The supply of hydrogen product over roads, on the back of trailers	1-2 months		This could be explored in significantly more detail in a specific supply chain research project on end use solutions		x	x		2
			Refuelling infrastructure		Additional equipment associated with the use of hydrogen in the transport industry			This could be explored in significantly more detail in a specific supply chain research project on end use solutions		x	x		2
	Logistics	Equipment Delivery	System packaging		Coordinated transport and storage of material goods	1-2 months		<2 FTEs		x	x		2
			Transport and delivery		Moving goods/equipment from the producer to the consumer					x	x		2
	Site	Software	Metering and Data collection		Capturing and analysing data	15-25 years	(10-50 items)			x			2
			Control system		Set of devices that manage and direct the behaviour of a system		1 package			x			2
		Site preparation	Site clearance		The removal of existing obstructions from land	3-6 months		20+ FTEs		x			2
			Groundworks		Preparatory construction activities such as excavation					x	x	x	1
			Remediation		Removal of contaminated water or soil to reduce environmental impact					x	x	x	1
		Security	CCTV		Cameras located around the site to capture security issues	15-25 years	(10-50 items)			x	x		1
			Physical Security		Physical security (e.g. fences, barriers, signage)		(10-50 items)			x	x		1
		Labour	Operating staff		On site staff employed to ensure day to day normal operation of the plant	16-28 years (operation and end-of life)		2-5 FTEs		x	x	x	1
			Training		Teaching staff the skills to safely operate the site			<2 FTEs		x	x	x	1
		Waste management	Chemical		The disposal of chemicals to reduce harmful impact	16-28 years (operation and end-of life)		<2 FTEs		x	x	x	1
		Safety	Fire and explosion safety		A set of practises to prevent or mitigate fire damage	18-32 years (full project lifecycle)		<2 FTEs		x	x	x	1
			Emergency procedures		A set of practises designed to prevent or mitigate emergencies					x	x	x	1
			Emergency shutdown system		Control system designed as a last resort to prevent catastrophic impacts of emergencies					x	x	x	1

Appendix B

Supply Chain Matrix (Large-Scale)

Supply Chain Element	Supply Chain Sector	Supply Chain Sub Sector	Supply Chain Component	Individual Components/Materials	Definition	How long (duration of project)	How much (Equipment)	How much (FTE) - average	Project Development	Project Execution	Project Lifetime	Project end of life	RAG Indicator
Services	Engineering	Design Management	Feasibility/concept design		A study used to assess the early stage technical and commercial viability of the project.	2-3 months		2-5 FTEs	x				1
			Pre-FEED		Feasibility studies, technology selection and process design required prior to beginning Front End Engineering Design (FEED)	4-6 months		5-20 FTEs	x				1
			FEED		FEED focusses on the project specific technical and economic requirements	8-12 months		5-20 FTEs	x				1
			Detailed engineering design		In depth project design to prepare for plant commissioning, construction and component procurement	12-18 months.		5-20 FTEs	x	x			1
		Electrical design	Electrical design		The design and specification of the electrical components and system	As above throughout design management phases.		5-20 FTEs	x	x			1
			Backup power generation design		Design of backup power system in case of power failure				x	x			1
			Grid connection studies		A study ensuring the new system can connect to the network without causing issues				x	x			1
		Process design	Process safety studies		The management of processes and systems to prevent major incidents	As above throughout design management phases.		5-20 FTEs	x	x			1
			Commissioning planning		Planning of commissioning procedures					x			1
		Geotechnical design	Siting Study		An assessment of occupied buildings nearby to the project site which could be exposed to project related hazards	As above throughout design management phases.		2-5 FTEs	x				1
			Ground investigation		An assessment of subsurface conditions of the proposed project site			2-5 FTEs	x				1
			Flooding risk		Assessment of the likelihood of the project site to be affected by flooding			<2 FTEs	x				1
		Mechanical design	HVAC system design		Design of the system used to control temperature, flow and purity of the air system for the project	As above throughout design management phases.		2-5 FTEs	x	x			1
			Component Specification		Design of a detailed blueprint for a specific piece of equipment such as a compressor or heat exchanger			2-5 FTEs	x	x			1
			Piping Design		Design for the various system used to transport liquids or gases			2-5 FTEs	x	x			1
			Pipeline system design		Design of the pipeline taking hydrogen directly to offtakers			2-5 FTEs	x	x			2
		Civils design	Buildings and structural design		The creation of safe and stable structures to withstand external forces	As above throughout design management phases.		2-5 FTEs	x	x			2
			Foundations		Construction plans for the building foundations			2-5 FTEs	x	x			2
			Access & egress roads		Internal roads to connect the facility to main roads			<2 FTEs	x	x			2
			Infrastructure design		Design of basic service systems such as site water or electricity			2-5 FTEs	x	x			2
	Project Management	Procurement	Equipment order placement		Initiating and executing the purchase of equipment	3-5 years (across development and execution)		2-5 FTEs		x			1
			Contractual agreements		Arranging contracts for the delivery of plant components				x	x			1
			Services procurement		Initiating and executing the procurement of services				x	x			1
		Project Coordination	Project schedule		Comprehensive timeline outlining tasks and deliverables	20-35 years (full project lifecycle)		2-5 FTEs	x	x			1
			Project budget		The total cost of the project			2-5 FTEs	x	x			1
			Resource allocation		The process of distributing available resources across the project			2-5 FTEs	x	x			1
			Interface management		Managing the coordination between the various teams working to deliver the project			2-5 FTEs	x	x	x		1
			Progress reporting		Providing an update on the progression of the project			2-5 FTEs	x	x	x		1
			Risk and opportunity management		Systematic process of identifying and mitigating risks and opportunities			2-5 FTEs	x	x	x	x	1
		Stakeholder Management	Stakeholder engagement & communications		Careful management of key stakeholders with interest and influence in the project	20-35 years (full project lifecycle)		2-5 FTEs	x	x	x	x	1
			Marketing		Measures incorporated into a project to add social value			2-5 FTEs	x	x	x	x	1
			Community benefits		Promotion of and education about the project			2-5 FTEs	x	x	x	x	1
			Contractor oversight		Oversight of contractor work packages					x			1

Supply Chain Element	Supply Chain Sector	Supply Chain Sub Sector	Supply Chain Component	Individual Components/Materials	Definition	How long (duration of project)	How much (Equipment)	How much (FTE) - average	Project Development	Project Execution	Project Lifetime	Project end of life	RAG Indicator
		Owners Engineer	Contractor management		Management of and communication with contractors	3-5 years (across development and execution)		5-20 FTEs		x			1
			Design reviews		Technical validation of a design					x			1
			Technical advisory		Guidance of field specific issues					x			1
		CDM management	Principal Contractor		The main contractor appointed by the client to manage and control the construction phase of the project	3-5 years (across development and execution)		20+ FTEs	x	x			1
			Principal Designer		Organisation appointed by the client to take control of the pre-construction phase of the project			<2 FTEs	x	x			1
	Professional Services	Project Finance	Investor/funder due diligence		Technical and financial due diligence to support FID	1-2 years		2-5 FTEs	x				2
			Funding application support		Guidance through grant and funding requests			2-5 FTEs	x				2
		Health and Safety	Studies and investigations		Research and enquiries into potential health and safety issues	20-35 years (full project lifecycle)		2-5 FTEs	x	x	x		2
			Audits		An official inspection into health and safety measures				x	x	x	x	2
			Risk assessments		Process to identify safety issues				x	x	x	x	2
			Training		Health and safety training for carrying out project specific work				x	x	x	x	2
		Insurance	CAR Insurance		Contractors all risk Insurance - provides against risks associated with construction projects	20-35 years (full project lifecycle)		<2 FTEs		x			2
			Employers Liability Insurance		Protects businesses against claims made by employees for injury or illness					x	x	x	2
			Professional Indemnity Insurance		Provides compensation in the event of being charged with errors					x	x	x	2
			Business Interruption Insurance		Coverage to replace income lost if business is halted						x		2
			Environmental Liability Insurance		Coverage for losses to do with environmental damage					x	x	x	2
			Property and Equipment Insurance		Covers loss or damage of equipment or buildings						x	x	2
			Public Liability Insurance		Protection against claims made by a member of the public					x	x	x	2
			Cyber Insurance		Protects from incidents involving cybersecurity						x	x	2
		Legal	Regulatory compliance		Legal support to ensure compliance with relevant regulations	20-35 years (full project lifecycle)		<2 FTEs	x	x	x	x	1
			Site Lease/Access		Legal support to aid negotiations for an agreement to occupy, build and operate a site			2-5 FTEs	x	x	x	x	1
			Power supply agreement (grid connection, PPA)		Legal support to aid agreement between a generator, distributor and offtake for the purchase and supply of power				x	x	x	x	1
			Water utilities agreement		Legal support to aid agreement between provider and offtaker for the purchase and supply of water			<2 FTEs	x	x	x	x	1
			Hydrogen offtake agreements		Legal support to aid agreement between a generator, distributor and offtake for the purchase and supply of hydrogen				x	x	x	x	1
			Procurement agreements (equipment and services)		Legal support to aid agreement between manufacturer and constructor for the purchase and supply of equipment				x	x	x	x	1
		Planning, permitting, consenting and regulation	Stakeholder engagement		Community and stakeholder engagement to support the planning process	20-35 years (full project lifecycle)		2-5 FTEs	x	x	x	x	2
			Environmental surveys		Collection of data and surveys to assess environmental impact of project				x	x			2
			Planning permission		Support with the planning application to a relevant authority				x	x			2
			Permits, consents and licences		Support with acquiring additional permissions that may be required to carry out a proposed development				x	x	x	x	2
			Bespoke large Electrolyser	500MW PEM Electrolysis Unit	500MW PEM electrolyser for large scale use. See the Scottish Electrolyser Assessment (2022) and SE's electrolyser fact sheet for more information		Supplier specific (e.g. 25x 20MW units)			x	x		3
			Thermal management	Heat exchanger	Used to transfer heat between two fluids		(10-50 items)			x	x		2
				Pump	A mechanical device used for the transport of fluids		(10-50 items)			x	x		2
				Cooling Tower	Device used to remove heat from a system and transfer it to the atmosphere		(1-4 items)			x	x		3

Supply Chain Element	Supply Chain Sector	Supply Chain Sub Sector	Supply Chain Component	Individual Components/Materials	Definition	How long (duration of project)	How much (Equipment)	How much (FTE) - average	Project Development	Project Execution	Project Lifetime	Project end of life	RAG Indicator
Products	Equipment	Key Equipment		Expansion vessel	Used in heating systems to regulate the volume of a fluid or a gas		(10-50 items)			x	x		3
			Electrical Management	Power Quality System	The use of harmonic filtering and power factor correction to improve the quality of the power supply to the plant		(1-4 items)			x	x		2
				Switchboards	A point where incoming power is divided into separate circuits		(5-10 bays)			x	x		2
				Transformers	Provides electricity at the final voltage, ready for consumers, and use for BoP and auxiliary plant operations		(5-10 items) 400kV/132 kV and 133/11kV			x	x		2
				Switchgear	Device used to connect and control electrical equipment		(10-50 items)			x	x		2
				Cabling	Electrical transport equipment		Project specific			x	x		2
				Rectifier	Device that converts alternating current to direct current		(10-50 items)			x	x		3
				Hydrogen generator	Combination of a hydrogen engine with a generator to generate electricity		Typically, 5-20% of capacity (25-100MW - made up from smaller units)			x	x		3
				Diesel generator	Combination of a diesel engine with a generator to generate electricity					x	x		3
				Batteries	Device where chemical energy is converted to electrical energy					x	x		3
				Onsite substation	Facility designed to reduce the high voltage of electrical transmission to a voltage suitable for consumption		550-600 MVA (assuming grid connection for full capacity)			x	x		2
			Water treatment (Continuous Electro deionisation)	Ion exchange membrane	Membrane that selectively transports ions through it.		(5-10 items)			x	x		3
				Ion-exchange resins	Resin that exchanges ions in a solution with ions on the resins surface		(5-10 items)			x	x		3
				Pumps	A mechanical device used for the transport of fluids		(10-50 items)			x	x		2
				Buffer tank (Plastic)	Storage system used to manage the flow and condition of water		(5-10 items)			x	x		2
			Desalination system (Reverse Osmosis)	Pumps	A mechanical device used for the transport of fluids		(10-50 items)			x	x		2
				Ultrafiltration membrane	Semi permeable membrane used in pressure driven filtration processes		(5-10 items)			x	x		3
				Pipelines	Pipes used in the transport of fluids		Project specific			x	x		2
				Reverse osmosis membrane	Semi permeable membrane used in reverse osmosis where pressure is used to overcome osmotic pressure that favours even distributions		(5-10 items)			x	x		3
				Storage Tank	Large container for water storage		(5-10 items)			x	x		2
			Control systems	Sensors (Flow, comp, Pressure)	Device which detects and records a physical property		(100-500 items)			x	x		1
		Ancillary equipment	Mechanical connections	Valves	Mechanical component used to block or change the flow of a liquid or gas		(100-500 items)			x	x		2
				Flanges	A means of securing or stabilising connections between components		(100-500 items)			x	x		2
				Gaskets	Used to seal the connection between components		(100-500 items)			x	x		2
				Pumps	A mechanical device used for the transport of liquid or gas		(100-500 items)			x	x		2
			Safety and control equipment	Sensors (flow, comp, pressure)	Device which detects and records a physical property		(100-500 items)			x	x		1
				Pressure relief valves	Safety device which controls or limits pressure		(50-100 items)			x	x		2
				Instrumentation	Measuring instruments used for recording physical properties		(100-500 items)			x	x		2
				Communication cables and system	Network to facilitate the transmission of information		-			x	x		2
				Control Panel	User interface for control system		(1-4 items)			x	x		2
			Hydrogen Purification	De-oxygenation	The act of removing oxygen from the hydrogen flow stream		(5-10 items)			x	x		3
				H2/Water separator	Component used to remove water from the hydrogen flow stream		(5-10 items)			x	x		3
				Adsorption Dryer	Component where water is removed from a flow stream by being chemically bound to an adsorbent		(5-10 items)			x	x		3
	Raw materials	Water	Sea Water	Sea Water	Salt water extracted directly from the sea		Circa. 80L/kg of hydrogen (including reject)			x	x		1
		Electricity	Grid connection	Grid connection	Grid electricity provided from various generation sources		Circa. 62 kWh/kg hydrogen, including BoP)		x	x	x	x	2
			Direct Connection to renewables	Direct Connection to renewables	Direct wired connection to a renewable source of electricity such as a wind or solar farm					x	x		1
			Nitrogen supply	Nitrogen supply	Nitrogen used as a safety gas in the process for purging and equipment testing		Circa.1-5 Nm3/kg hydrogen			x	x	x	3

Supply Chain Element	Supply Chain Sector	Supply Chain Sub Sector	Supply Chain Component	Individual Components/Materials	Definition	How long (duration of project)	How much (Equipment)	How much (FTE) - average	Project Development	Project Execution	Project Lifetime	Project end of life	RAG Indicator
		Other	Steel	Steel	Metal alloy used for the manufacture of most process components		-			x	x		3
			Coolant	Glycol	Fluid used to manage the temperature of process materials		-			x	x	x	3
			Backup power	Fuel (e.g. diesel, hydrogen)	Fuel used in the generator providing a UPS for the process		Fuel volume requirements will vary depending on power outage frequency and duration.			x	x	x	1
Solutions	Engineering solutions	Manufacturing	Mechanical components		Essential parts of process components	6-20 Months		5-20 FTEs		x			2
			Electrical components		Components that use electricity to perform a function					x			2
			Specialised pieces		Bespoke equipment components					x			2
		Installation / Assembly	Electrical component assembly		Fitting together parts of electrical components	6-12 months		5-20 FTEs		x			2
			Mechanical components assembly		Fitting together parts of mechanical components					x			2
		Construction / Commissioning	Testing and certification		Checking the conformity of components to regulations and standards	12-18 Months		5-20 FTEs		x			1
			Equipment installation		Fitting assembled components into the production process					x			1
			Equipment commissioning		The procedure of ensuring all equipment is functioning as intended					x			1
		O&M	Operations		Activities ensuring that assets and equipment function properly	15-25 years (operations)		2-5 FTEs			x		3
			Planned maintenance		Proactive strategy for asset upkeep						x		3
			Preventative maintenance		Maintenance carried out to reduce the likelihood of equipment failure						x		3
		Decommissioning	Condition assessment		Evaluation of the current state of the equipment	2-5 years (End of Life)		5-20 FTEs				x	3
			Decommissioning plan		Document that contains detailed information of decommissioning. Includes the sequence, strategy and schedule of activities							x	3
			Reuse/repurpose materials		Returning a site to its original state							x	3
			Site restoration		Using products again or for different functions							x	1
			Scrap material/waste disposal		Handling of all waste to reduce its impact on the environment							x	3
			Materials recycling		Converting waste into new products							x	3
	End Use Solutions	Supply to offtakers	Pipeline to offtakers		Supply of hydrogen product to consumers through a direct hydrogen pipeline	15-25 years (operations)		This could be explored in significantly more detail in a specific supply chain research project on end use solutions		x	x		3
			Derivative Production		Production of Ammonia, Methanol or SAFs			This could be explored in significantly more detail in a specific supply chain research project on end use solutions			x		3
	Logistics	Equipment Delivery	System packaging		Coordinated transport and storage of material goods	15-25 years (operations)		2-5 FTEs		x	x		2
			Transport and delivery		Moving goods/equipment from the producer to the consumer					x	x		2
	Site	Software	Metering and Data collection		Capturing and analysing data	15-25 years (operations)	(100-500 items)			x	x		2
			Control system		Set of devices that manage and direct the behaviour of a system		(1-5 packages)			x	x		2
		Site preparation	Site clearance		The removal of existing obstructions from land	6-9 Months		50+ FTEs		x			2
			Groundworks		Preparatory construction activities such as excavation					x			2
			Remediation		Removal of contaminated water or soil to reduce environmental impact	3-6 months				x			2
		Security	CCTV		Cameras located around the site to capture security issues	20-35 years (full project lifecycle)	(50-100 items)			x	x	x	1
			Physical Security		Physical security (e.g. fences, barriers, signage)		(50-100 items)			x	x	x	1
		Labour	Operating staff		On site staff employed to ensure day to day normal operation of the plant	20-35 years (full project lifecycle)		5-20 FTEs		x	x		1
			Training		Teaching staff the skills to safely operate the site			<2 FTEs		x	x		3
		Waste management	Chemical		The disposal of chemicals to reduce harmful impact	20-35 years (full project lifecycle)		2-5 FTEs		x	x	x	1
			Waste water		The disposal of contaminated water to reduce harmful impact					x	x	x	1
		Safety	Fire and explosion safety		A set of practises to prevent or mitigate fire damage	20-35 years (full project lifecycle)		2-5 FTEs		x	x	x	1
			Emergency procedures		A set of practises designed to prevent or mitigate emergencies					x	x	x	1
			Emergency shutdown system		Control system designed as a last resort to prevent catastrophic impacts of emergencies					x	x	x	1