Hydrogen Production and Export Locations

Site Requirements Study

July 2022

Contents

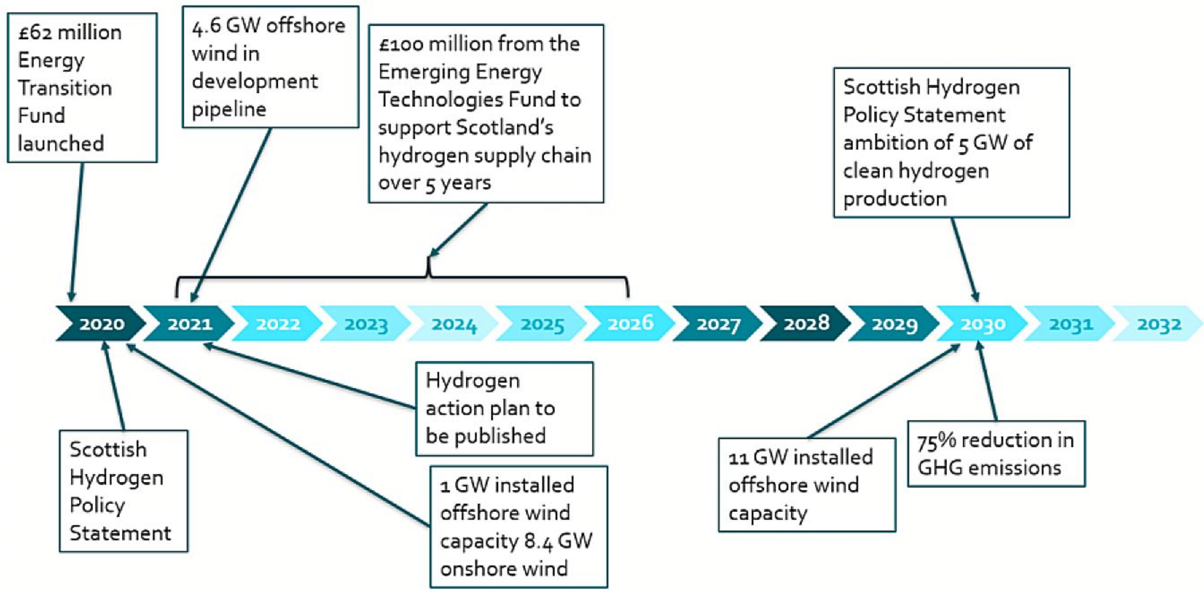
Introduction

Scotland's Hydrogen Policy Statement, published in December 2020, sets out the Scottish Government's strong support for development of a hydrogen economy in Scotland, including ambitions to achieve 5 GW of installed production capacity by 2030 and 25 GW by 2045.

In support of this ambition, Scottish Enterprise, Highlands & Islands Enterprise, and South of Scotland Enterprise have commissioned this study to assess the requirements for hydrogen production sites in Scotland. The study assess the required inputs and land areas required for production, related infrastructure and considerations for hydrogen export and planning & consenting considerations. The study is intended to act as a guide for parties exploring hydrogen production.

Hydrogen production has been assessed for both renewably powered electrolytic 'green' hydrogen and 'blue' hydrogen, produced from natural gas reformation.

Figure: Timeline for renewables and clean hydrogen ambitions in Scotland[1]
Note that offshore wind development in pipeline is significantly larger with ~25 GW capacity offered option agreements as part of Scotwind Round[1]



1. Source: Scottish Enterprise, Offshore Renewable Energy Catapult and Net Zero Technology Centre. August 2021. *Development of early, clean hydrogen production in Scotland*.


H2 Opportunities
Distribution and storage solutions
Decarbonised heat and power
Iron ore processing
Mining
Built environment
Agriculture and fertilizers
Renewable fuels/biorefining
Transportation fuels
Green hydrogen production
Traditional refining and petrochemicals
Modifications and asset repurpose

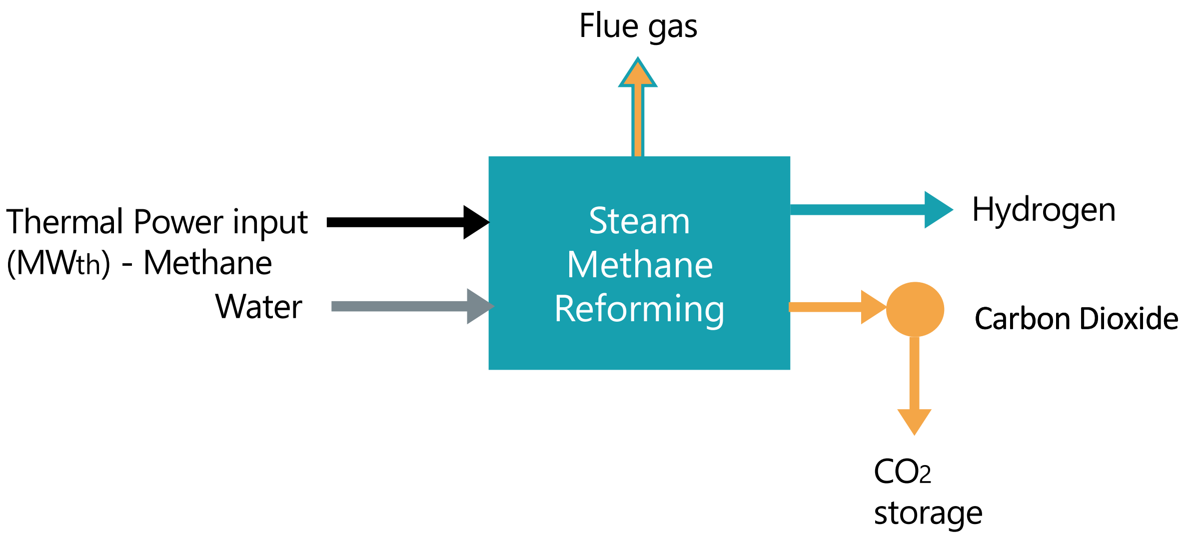
Blue Hydrogen Overview

Blue hydrogen is the production of hydrogen from fossil fuels with a carbon capture and storage process. There are three primary means of producing blue hydrogen:

- **SMR**-Produces a syngas mixture of hydrogen and carbon monoxide when methane reacts with steam in the presence of a catalyst.
- **POx**-Uses a limited amount of oxygen to prevent full oxidation of the methane feed. The pure oxygen required for this operation is produced from an air-separation unit prior to entry into the reactor.
- **ATR**-Combines the SMR and POx reaction, with the heat released from the exothermic partial oxidation reaction providing the heat for the endothermic steam methane reforming process.

SMR = Steam methane reforming;
POx= Partial oxygen;
ATR = Autothermal Reforming

Blue hydrogen production; key process inputs and outputs for Steam Methane Reforming.



Blue hydrogen production cases considered in this study.

Blue Hydrogen	Small	Medium	Large
Thermal Rating (MW_{th})	200	500	1,000

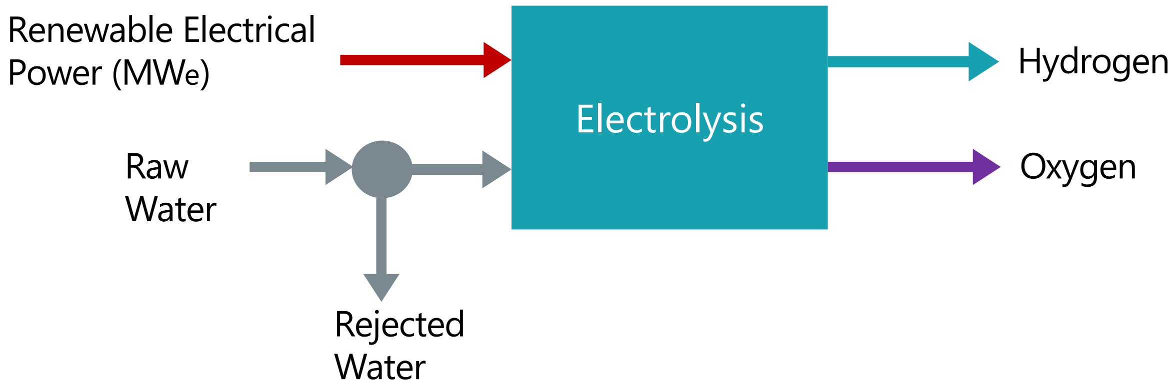
Green Hydrogen Overview

Green hydrogen uses electricity generated from renewable sources to split water into hydrogen and oxygen in a process called electrolysis. There are three primary methods of electrolysis:

- **Alkaline**-The most mature green hydrogen technology and currently the most widely used in industry. The decomposition of water occurs in an electrolyte solution of approximately 20-30% potassium hydroxide (KOH) between the anode and cathode.
- **PEM**-An ionically conductive, solid polymer replaces the liquid electrolyte of the alkaline electrolysis design.
- **SOEL**–Water vapour is used as the electrolyser feed, instead of liquid water. Steam is fed to the cathode side of the electrolyser where it is broken down into hydrogen and oxide ions. The oxide ions travel through the solid electrolyte towards the anode where oxygen is formed.

PEM = Polymer Electrolyte Membrane;
SOEL = Solid Oxide Electrolyser

Green hydrogen production; key process inputs and outputs.



Green hydrogen production cases considered in this study.

Green Hydrogen	Small	Medium	Large
Power Input Rating (MW_e)	200	500	1,000

Example Case

Hydrogen & Ammonia Production, Conversion and Storage

Blue hydrogen & ammonia

Input

Plant Size (MWth)	Electrical Power (MW)	Water (te/h)	Natural Gas (million scf/day)
200	21	29	19
1000	106	143	95

Blue hydrogen production footprint (SMR)

200 MW; 1.1 ha

1000 MW; 2.8 ha

Carbon dioxide pipeline

Hydrogen

Plant Size (MWth)	Hydrogen (te/h)
200	5
1000	25

Nitrogen

Ammonia conversion & 7-day storage footprint

200 MW; 1.6 ha

1000 MW; 5.9 ha

Export

Plant Size (MWth)	Ammonia (m^3/yr)
200	370,000
1000	1,848,000

Green hydrogen & ammonia

Input

Plant Size (MW)	Electrical Power (MW)	Raw Water (te/h)
200	210	64
1000	1,100	319

Green hydrogen production footprint (Alkaline, 98% Capacity Factor on electricity supply)

200 MW; 3 ha

1000 MW; 15 ha

Hydrogen

Plant Size (MW)	Hydrogen (te/h)
200	3.4
1000	16.8

Nitrogen

Ammonia conversion & 7-day storage footprint

200 MW; 1.2 ha

1000 MW; 4.4 ha

Export

Plant Size (MW)	Ammonia (m^3/yr)
200	245,000
1000	1,223,000

SMR = Steam methane reforming

Example Case

Hydrogen & LOHC Production, Conversion and Storage

Blue hydrogen & LOHC

Input

Plant Size (MWth)	Electrical Power (MW)	Water (te/h)	Natural Gas (million scf/day)
200	16	29	19
1000	82	143	95

200 MW; 1.1 ha

1000 MW; 2.8 ha

Blue hydrogen production (SMR)

Carbon dioxide pipeline

Hydrogen

Plant Size (MWth)	Hydrogen (te/h)
200	5
1000	25

Toluene

200 MW; 1.9 ha

1000 MW; 5.6 ha

LOHC (MCH) conversion & 7-day storage

Export

Plant Size (MWth)	LOHC (MCH) (m³/yr)
200	944,000
1000	4,718,000

Green hydrogen & LOHC

Input

Plant Size (MW)	Electrical Power (MW)	Raw Water (te/h)
200	210	64
1000	1,000	319

200 MW; 3 ha

1000 MW; 15 ha

Green hydrogen production footprint (Alkaline, 98% Capacity Factor on electricity supply)

Hydrogen

Plant Size (MW)	Hydrogen (te/h)
200	3.4
1000	16.8

Toluene

200 MW; 1.6 ha

1000 MW; 4.5 ha

LOHC (MCH) conversion & 7-day storage

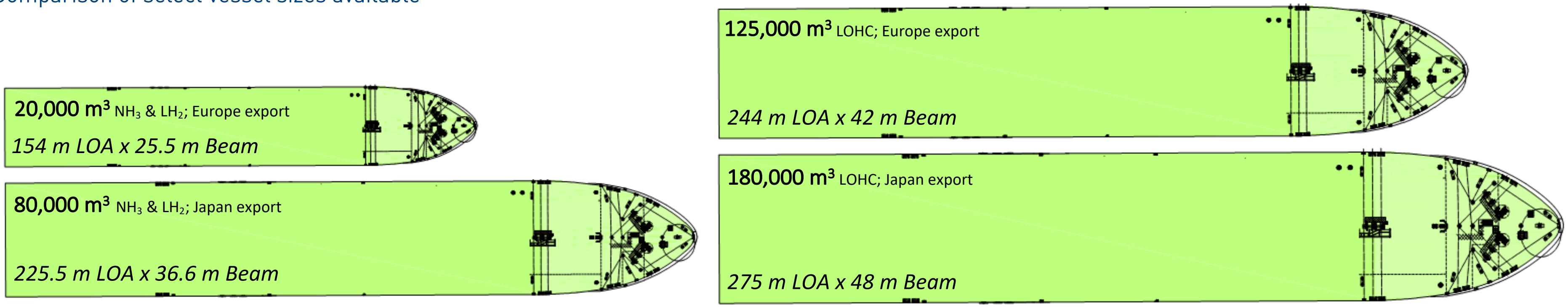
Export

Plant Size (MW)	LOHC (m³/yr)
200	624,000
1000	3,121,000

LOHC = Liquid Organic Hydrogen Carrier;
MCH = methylcyclohexane;
SMR = Steam methane reforming

Vessel Capacities for European and Japanese Export Markets

Comparison of select vessel sizes available



Export Route: from Scotland to sites located in located in Germany, the Netherlands, Belgium and Japan.

Scenarios based on concept deigns. There is limited data on H_2 and CO_2 vessels as they are still in the development stage; scheduled for launch 2030 (H_2) and 2025 (CO_2).

Blue hydrogen export scenarios	**Europe Export**		**Japan Export**	
Product	**Vessel Size**	**Qty vessels**	**Vessel Size**	**Qty vessels**
Ammonia (NH_3)	Capacity = 20,000 m³ Operating draft = 8.3 m	Up to 3	Capacity = 80,000 m³ Operating draft = 12.7 m	Up to 8
Liquid hydrogen (LH_2)	Capacity = 20,000 m³ Operating draft = 6.7 m	Up to 3	Capacity = 80,000 m³ Operating draft = 7.8 m	Up to 13
Liquid Organic Hydrogen Carriers (LOHC)	Capacity = 125,000 m³ Operating draft =13.6 m	Up to 2	Capacity = 180,000 m³ Operating draft = 15.9 m	Up to 9

Indicative Costs and Timeline for Planning, Permitting and Safety Consent

Permit/Consent	Relevant Authority	Preparation (months)	Application determination (months)	Preparation/ Professional Fees	Application Fees	Blue	Green
Town and Country Planning (Scotland) Act 1997 The Town and Country Planning (EIA) (Scotland) Regulations 2017	LPA	8	4	£50,000 - £300,000	Dependent on the site area. Upfront cost: up to £30,240. Cost per hectare: £200 - £401	✓	✓
The Electricity Act 1989 – Section 36 (S36) Consent (Green Hydrogen Only) – used for the granting of consents for Electricity Generating Stations exceeding 50MW The Electricity Works (Environmental Impact Assessment) (Scotland) Regulations 2017	ECU	8	6	£30,000 (assumed when combined with TCPA Planning Application and EIA)	Dependent on capacity of Electricity Generating Station Upfront cost: between £125,000 and £280,000 (assuming EIA is required)	N/A	Applicable where electricity produced exceeds 50 MW.
Pollution Prevention and Control Permit Water Activities (Controlled Activities) Consent	SEPA	8	4	£45,000-£180,000		✓	✓
The Town and Country Planning (Hazardous Substances) (Scotland) Regulations 2015	LPA	1	2	£1,000 - £5,000	£1,000	✓	✓
The Pipeline Safety Regulations 1996	HSE	Notification 6 months prior to construction and 14 days prior to operation. MAPD prepared prior to design completion.		Initial costs: £25,000-100,000	Annual: £5,000 - £20,000 As required for MAPD Update: £10,000-50,000	✓	Only if export pipeline
The Control of Major Accident Hazards Regulations 2015 (COMAH)	HSE/SEPA	Notification must take place 3-6 months before construction and again 3-6 months before operation. If Upper Tier, must submit SR on same timescales.		Initial costs: £100,000-£400,000	Annual: £20,000-£80,000 Safety report update (every 5 years): £50,000-£200,000 (Upper Tier only)	✓	✓

Please note the information provided above is indicative. The requirements, timelines and costs can vary widely across hydrogen projects; some considerations include location, hydrogen type (green or blue), size, storage, export (pipeline, transport) and potential on-site electricity generation. Fees are also subject to regular revision and should be checked in advance of a detailed scheme being brought forward.

Indicative Planning, Permitting Timelines

Activity	Month															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Permitting and Controlled Activities Application Programme																
Pre-application discussions with SEPA	■	■														
Application(s) drafting and submission	■	■	■	■	■	■	■	■								
SEPA consultation, application determination & issue									■	■	■	■				
High level Planning Programming																
Screening request (if required)	■															
Pre-application notice (PAN) (Major/Local PP Only)	■															
Pre-application engagement with LPA/ECU	■	■	■													
Statutory Pre-Application Consultation/Stakeholder engagement		■	■	■												
Gatechecking (S36 Only)	■	■	■													
Issue public notice									■							
LPA application(s) drafting and submission (planning application, S36 (if required) and EIA)	■	■	■	■	■	■	■	■								
LPA application determination (Full PP) / ECU application determination (S36)									■	■	■	■	■	■		

Please note the information provided above is indicative. The requirements and timelines can vary widely across hydrogen projects; some considerations include location, hydrogen type (green or blue), size, storage, export (pipeline, transport) and potential on-site electricity generation. Fees are also subject to regular revision and should be checked in advance of a detailed scheme being brought forward.

Indicative Safety Consenting Timelines

Activity	Month																Construction	Operation
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16		
High level CoMAH and Hazardous Substance Consent Programme																		
Hazardous Substances Consent																		
HSC Application										■	■							
HSC Determination												■	■					
Pipeline Safety Regulations (applies to all blue hydrogen and green hydrogen projects with export pipeline)																		
Preparation of Major Accident Prevention Document prior to design completion						■	■	■	■	■	■	■						
Notification 6 months prior to construction										■								
Notification 14 days before use																	■	
Lower Tier COMAH																		
Notification 3-6 months prior to construction										■								
Notification 3-6 months prior to operation																	■	
MAPP – available at pre-construction notification								■	■	■								
Ongoing regulatory interventions throughout life										■	■	■	■	■	■	■	■	■
Upper Tier COMAH																		
Notification 3-6 months prior to construction										■								
Notification 3-6 months prior to operation																	■	
MAPP – submitted with the Safety Report								■	■	■								
Safety Report (PCSR, POSR and OSR)	■	■	■	■	■	■	■	■	■	PCSR	■	■	■	■	■	■	POSR	OSR
Ongoing regulatory interventions throughout life										■	■	■	■	■	■	■	■	■

Please note the information provided above is indicative. The requirements and timelines can vary widely across hydrogen projects; some considerations include location, hydrogen type (green or blue), size, storage, export (pipeline, transport) and potential on-site electricity generation. Fees are also subject to regular revision and should be checked in advance of a detailed scheme being brought forward.

Hydrogen – Case Studies

Port of Hamburg

- One of the world's largest electrolysers (100 MWe) is planned to be constructed at the Port of Hamburg (Germany's largest seaport) for the production of green hydrogen by 2025.
- Key Stakeholders include: Vattenfall, Shell, Mitsubishi Heavy Industries & Hamburg Wärme.
- Location: Moorburg, Germany. Hamburg,

- The site in question previously hosted the Moorburg coal-fired power station.
- It is connected to both the national 380 kV transmission power system and Hamburg's local 110 kV power grid.
- The electrolyser will be powered from wind/solar located on the Moorburg site.
- The site allows ships to dock directly at the site to use the quay and port facility as an import terminal.
- Hamburg's gas network company intends to establish a hydrogen network at the port within 10 years and has already begun implementation of the requisite distribution infrastructure.
- Local presence of potential green hydrogen customers.
- Future development of the site into a"Green Energy Hub" is planned.

Port of Rotterdam

- Rotterdam port authority, in collaboration with stakeholders, is seeking to implement a large-scale hydrogen network across the port to facilitate hydrogen production, import, application and transport to northern European countries. The port has been identified as a European hydrogen hub.
- Key Stakeholders include: Port of Rotterdam Authority, Gasunie, Shell & Uniper.
- Location: Rotterdam, the Netherlands.

- The port location is intended to facilitate hydrogen production,use (particularly in industry), and importation.
- A 'hydrogen backbone' is planned to be operational by 2023 which would supply companies with hydrogen produced at 'conversion parks' located in the port. The backbone will connect to the local gas network managed by Gasunie) and 'corridors' leading to other local industrial areas.
- A term Green hydrogen from offshore wind power(~2GW) would power electrolysis at the conversion park for green hydrogen (H2-Fifty and Shell related projects).
- Blue hydrogen would also feed into the backbone with CO_2 by-product being sequestered via the Porthos CCS project.
- Other planned off-takers include surface transport, shipping and heating.

Hydrogen Production and Export Locations

Site Requirements Study