Scot2Ger

Development of a Green Hydrogen Supply Chain from Scotland to Germany

Contents

The future hydrogen system: diverse and interconnected

The hydrogen supply chain can be split into three stages:

Making it.

Moving it.

Using it.

With international trade being essential

Scot2Ger Pre-feasibility Study

The Scot2Ger Pre-feasibility Study has reviewed various plant and supply chain configurations, their technical feasibility and outline costs as well as identifying the main challenges for this ambitious project.

The Study has confirmed the capability of Scotland to supply green hydrogen and derivatives to Germany as well as the feasibility of building a supply chain.

Demand for hydrogen in Germany is immediate and is increasing rapidly. The project to supply will form a bridgehead to the delivery in the medium and longer term of large volumes to Germany. This, in turn, will support the development of the hydrogen economy in Scotland.

The study has confirmed the important role that this project can play in establishing Scotland as an early leader in the supply of green hydrogen to Germany to help tackle climate change and to contribute to energy security in Europe.

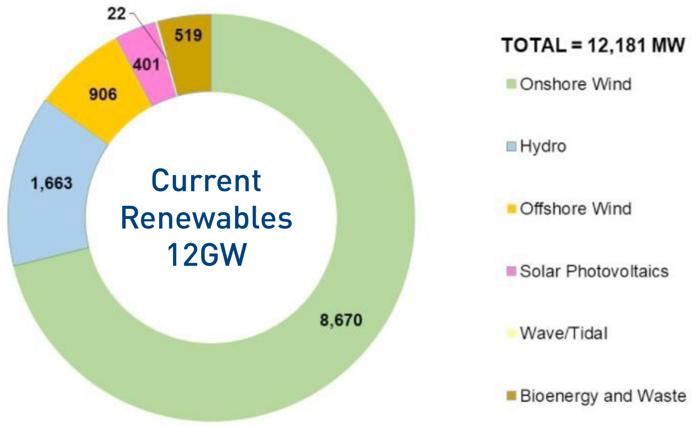
Supply from Scotland

Before 2030:
New low-cost onshore wind projects already under development

From 2030:
New low-cost offshore wind

Largest resource in Europe

Lowest cost of production



Note: Bioenergy and Waste includes biomass (271 MW), landfill gas (116 MW), energy from waste (70 MW), anaerobic digestion (55 MW) and sewage sludge digestion (7MW).

25% of Europe's wind resource

Territorial waters 462,000km²*

Just 10% delivers >300GW

Highest productivity in Europe:

up to 60% capacity factor

No other country offers this combination

* Facts and figures about Scotland's sea area (coastline length, sea area in sq kms) | Marine Scotland Information

Hydrogen Production and Transport

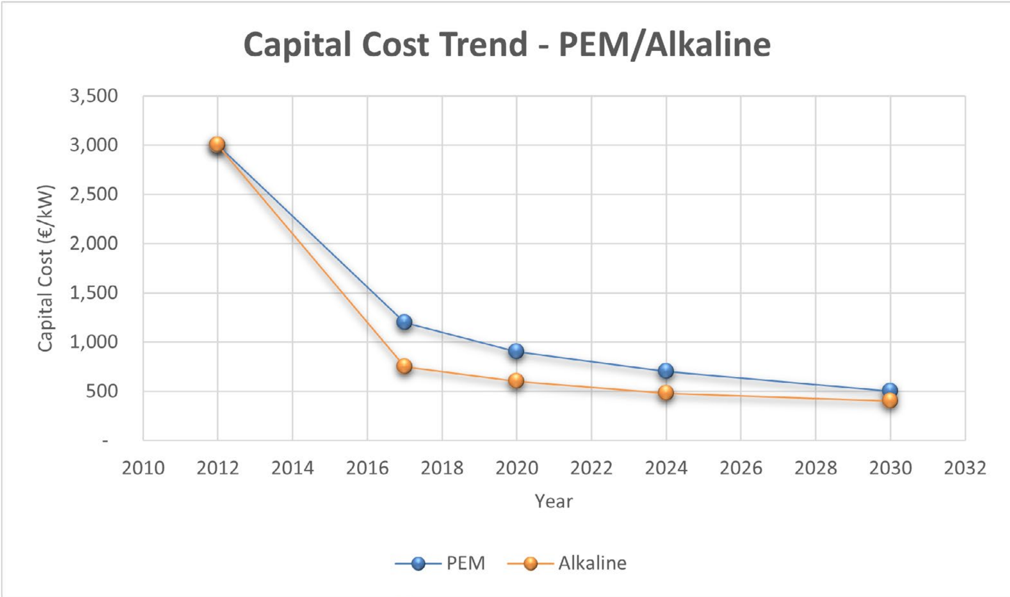
Production costs falling rapidly due to:

- **manufacturing scale up**
- **technology development**
- **large scale deployment**

Electrolyser technologies assessed:

- **PEM & alkaline both contenders**
- **Rapid cost reduction as industry scales up**
- **Fully decarbonised grid will provide operational flexibility**

However grid use of system charges and policy costs are problematic - these could be reduced for green hydrogen. Water availability excellent in Scotland,



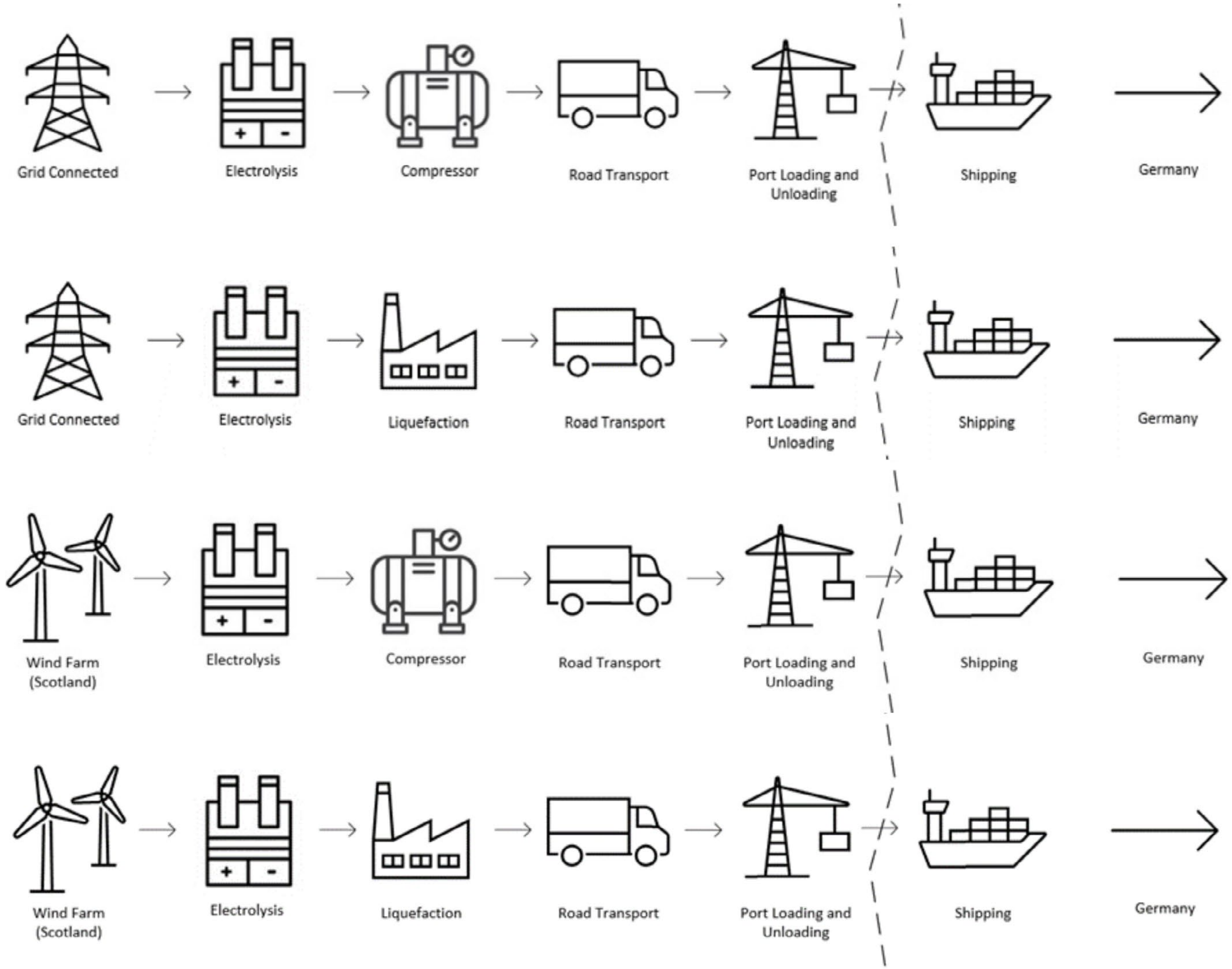
Transport vector options:

- **Compressed hydrogen**
- **Liquid hydrogen**
- **Ammonia**
- **Liquid Organic Hydrogen Compounds**

Compressed & liquid hydrogen assessed in detail
Design basis 50TPD reflecting German client demand
136MW electrolysis capacity
Liquid hydrogen benefits from reduced transport costs
However the associated technologies require further review
Larger volumes may favour ammonia

TPD = tonnes per day

Four options considered



Modelling & LCOH* determined for each option:

- **Behind meter vs grid connected**
- **Compressed vs liquid hydrogen**

Other variables considered:

- **Electrolyser capacity**
- **Liquefaction capacity (where relevant)**
- **Fixed storage capacity**
- **Number & cost of containers**
- **Ship capacity & frequency**
- **Grid power cost**

Capex & opex based on Wood information
Efficiencies based on Wood information

* Levelised Cost of Hydrogen

Outcomes:

Levelised costs appropriate for early stage demonstrator

Design optimisation will further reduce costs

Hybrid behind the meter and grid connected options may work well

Early deployment will facilitate future cost reduction through:

- **Exports scale-up**
- **Learning & optimisation**
- **Manufacturing growth**
- **Technology development**
- **Supply chain investment and confidence**

An early move is very much to Scotland's advantage

Maximising our competitiveness against other countries

Ports

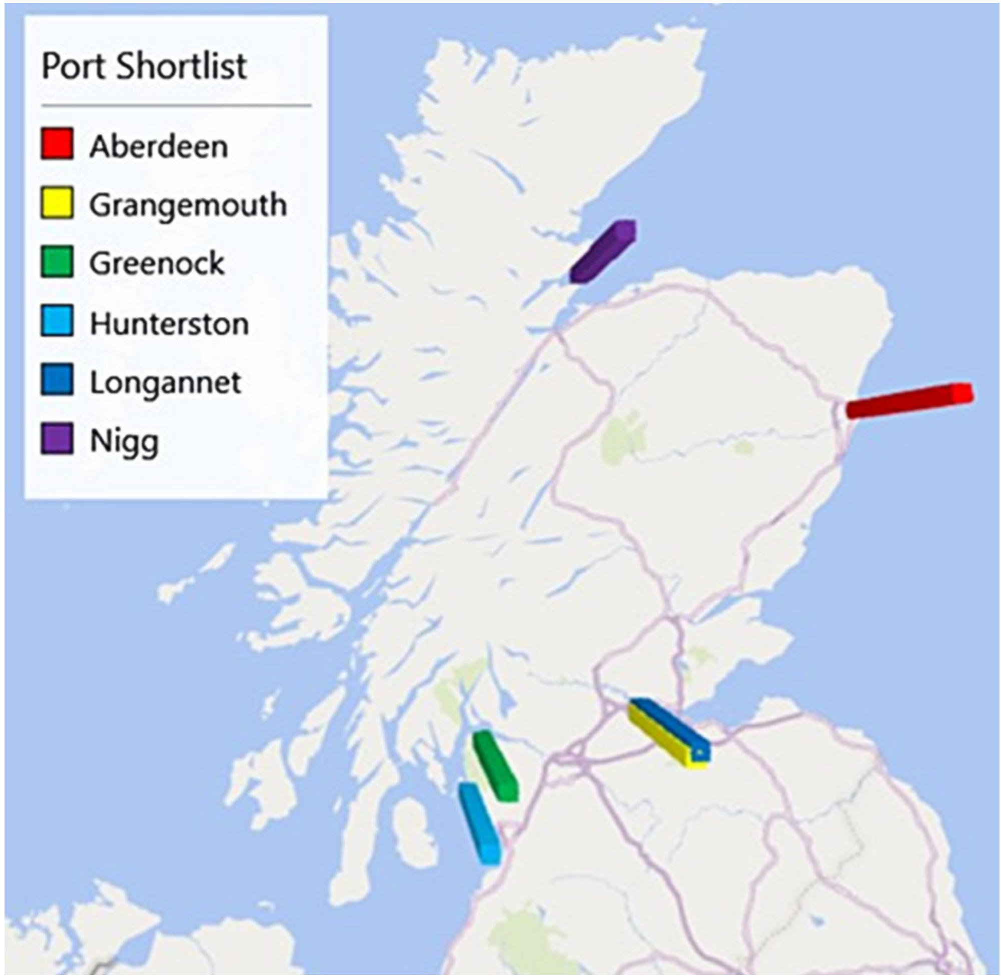
32 ports consulted
Most responded

Assessment reveals four leading options:

- Aberdeen
- Cromarty/Nigg
- Grangemouth/Longannet
- Greenock/Hunterston

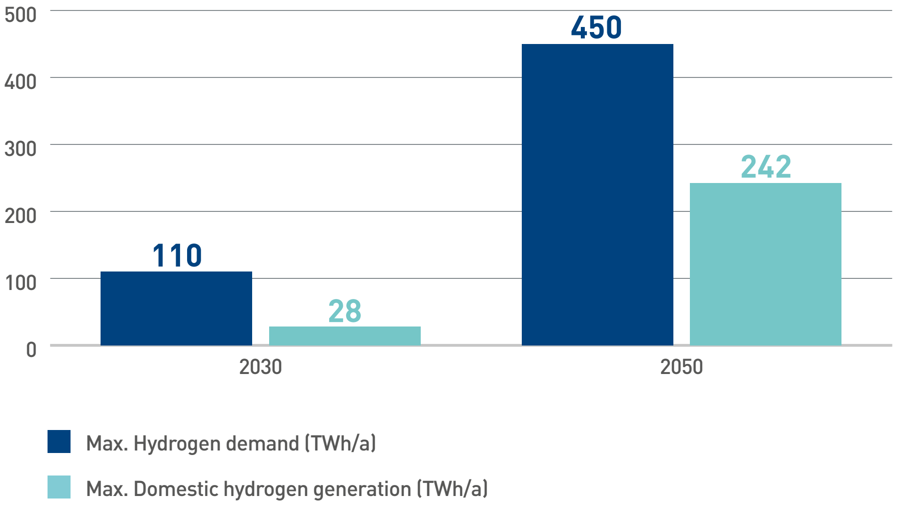
These ports offer benefits of scale, location, infrastructure and proximity to renewable resources.

Green Freeport status is currently being determined for Scottish ports. Should this apply to the export port then there will be a beneficial impact through reduced taxes and duties.



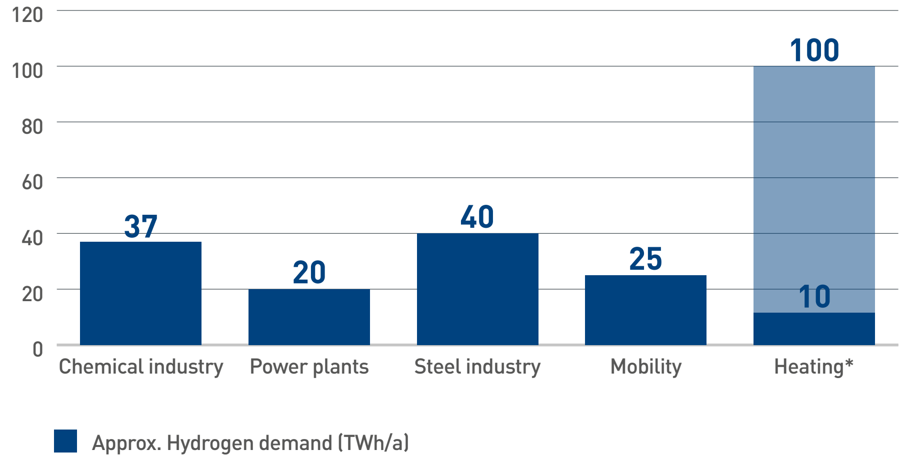
Demand for Green Hydrogen

Demand for hydrogen in Germany



Source:Koalitionsvertrag (bundesregierung.de), Nationales Reformprogramm 2020 - Die Nationale Wasserstoffstrategie (bmwi.de)

Industries expect higher demand until 2030



* Demand will increase in the future due to pipeline supply, heating sector took 53 % of final energy consumption in 2019

Source: Wasserstoff Aktionsplan Deutschland 2021–2025 (wasserstoffrat.de)

In order to meet its growing demand, Germany needs to import around 72 TWh by 2030 and around 208 TWh by 2050.

Scotland already offers clear benefits as a producer country and, with the expansion of offshore wind energy by a further 35 GW by 2030 and beyond, is an ideal partner for Germany.

Source: Nationales Reformprogramm 2020 - Die Nationale Wasserstoffstrategie (bmwk.de)

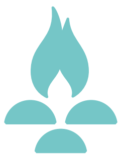
KPMG AG Germany: This part of the study was conducted by KPMG AG Germany and focussed on the German market and transport to and within Germany.

Use Cases Identified and Analysed

Use Case 1:

Demand for filling station infrastructure is 12 t/d.

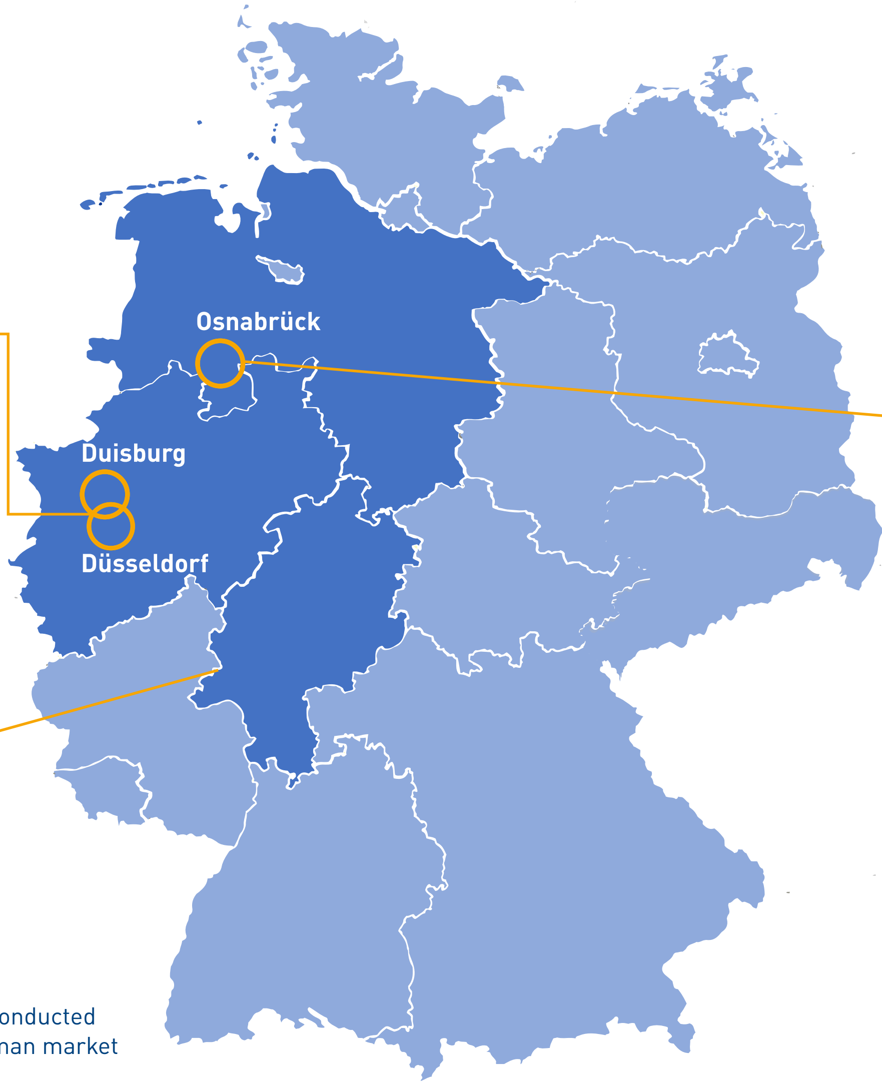
Demand of municipal utilities is 21 t/d.



Use Case 2:

Demand of residential and industrial heating in the region of Hessen: 20t/d.

KPMG AG Germany: This part of the study was conducted by KPMG AG Germany and focussed on the German market and transport to and within Germany.



Use Case 3:

Demand in logistics sector – region of Osnabrück: 5 t/d hydrogen in form of LOHC.

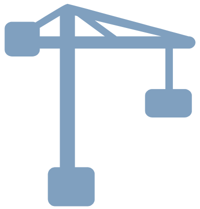
The use cases have been identified based on real discussions with several potential off-takers each with a different potential realisation timeline.

Optimal Transport Recommendations

Overseas transport

- Chartering container ships as the most competitive option:
  - Shortening and flexible transport times
  - Cost savings by avoiding downtime, reducing the number of containers and eliminating carriers' profit margins on individual containers
- The partial loading of hydrogen on a maritime-going vessel is less efficient

Ports



- Wilhelmshaven and Rotterdam are considered as interesting options as import ports for the identified use cases
  - Suitable infrastructure available
  - Options for using the imported green hydrogen also in the region of Wilhelmshaven

Inland transport

- Possible inconvenience in inland shipping make transport by rail recommended
- Advantages of transport by rail:
  - Short transport times
  - Independence from fluctuating and temporarily low water levels

German Supply Chain Outputs

01 **Feasibility**
As the feasibility study shows the import of green hydrogen to Germany is necessary and technically feasible in principle.

02 **Costs**
The Scot2Ger work shows that transport of hydrogen (or its derivatives) in liquid form is less than half the cost of transporting hydrogen in gaseous form, principally due to higher energy density.

03 **Hydrogen vectors**
Liquid hydrogen has proven to be the most attractive vector for this demonstrator. In addition, there are other attractive forms, such as ammonia and LOHC, which may become interesting in the future when dealing with different use cases and scales.

04 **Transport**
For the transport of hydrogen from Scotland to Germany the chartering of ships is recommended. For onward transport within Germany rail currently represents the best option.

05 **Ports**
The study identified the port of Rotterdam in the Netherlands and the port of Wilhelmshaven in Germany as interesting options for import ports for the identified use cases.

06 **Off-taker**
Use cases for the off-take of green hydrogen in the mobility, energy and heating markets were identified and the ramp-up of demand to 2030 was analysed.

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Next steps

During the course of the study the context for this project has changed radically. In addition to the challenges of climate change there is now a new focus on energy security as a matter of urgency. The energy crisis in Germany caused by the war in Ukraine has accelerated the need for low carbon solutions for Germany industry.

The concept for the production in Scotland of green hydrogen and derivatives such as ammonia will be further developed.

The maritime and overland options for the transport of hydrogen will be examined in terms of efficiency and cost.

Engagement with potential customers and investors will be intensified which will provide valuable feedback .

Government relations are a vital part of the ongoing project, particularly in relation to funding.

Marketing support will be essential to raise the profile of Scotland as a reliable and long term source of green hydrogen.

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