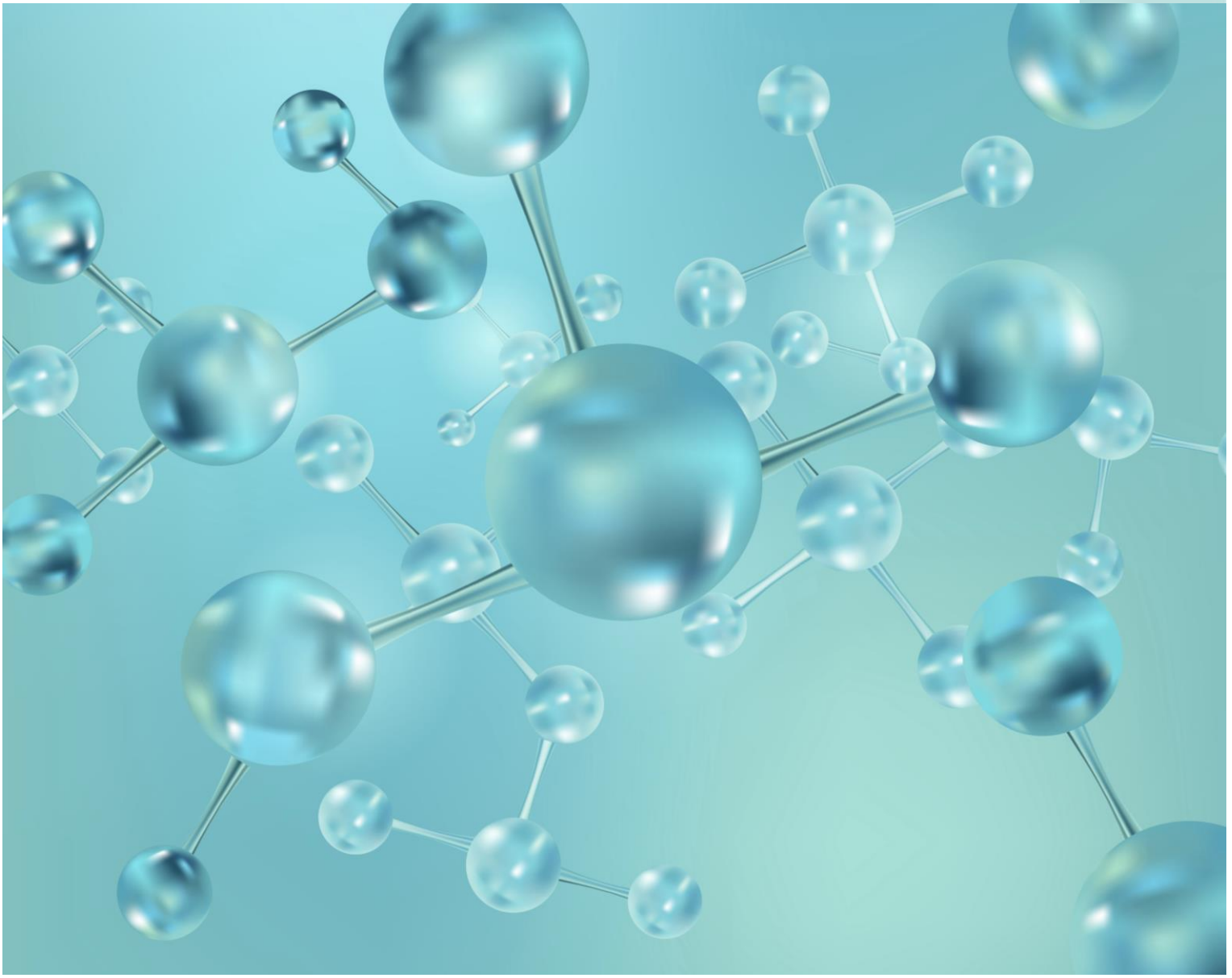
POSITION PAPER

The Northern European Hydrogen Opportunity

To capture the opportunity through co-operation

2022



By the partners of the Northern European Alliance for Sustainability

Executive Summary

Purpose of the Position Paper

This position paper is a collective effort by the partners of the Northern European Alliance for Sustainability where seven Northern European countries, *i.e.,* Denmark, Estonia, Finland, Iceland, Norway, Scotland/UK and Sweden are represented. The paper positions the Northern European countries towards fast implementation of the hydrogen strategies across Europe (and beyond) and suggests concrete actions to speed up the desired development.

Hydrogen in many forms and applications

Hydrogen accounts for less than 2% of Europe's current energy consumption and is primarily used to produce chemical products, such as plastics and fertilisers. 96% of this hydrogen production is produced through natural gas, emitting significant amounts of CO2 emissions in the process. This form of hydrogen is labelled "grey", "brown" or "black" hydrogen based on which fossil raw material is being used (natural gas, coal or oil, respectively).

Renewable hydrogen ("green" hydrogen) is expected to play a key role in the clean energy transition for solving the climate challenge.

Hydrogen can, however, be also produced from renewable energy.

Green hydrogen allows the replacement of fossil fuels and raw materials with synthetic, sustainable alternatives derived from the use of clean electricity. This will help decarbonise transportation and industry and allow the replacement of coal in some hard-to-decarbonise energy-intensive industrial processes, such as steel making. Hydrogen also acts as an energy carrier as well as energy storage in integrated energy networks and so can help compensate for imbalances in weather-dependent power generation. Green hydrogen can also be produced from biomass and biogas sources.

In addition to green hydrogen, clean hydrogen can also be produced, *e.g.*, using nuclear electricity resulting in so-called "pink" hydrogen or by capturing and storing the CO_2 that is a by-product of fossil hydrogen (the result being "blue" hydrogen).

Our opportunity - Hydrogen from and for the North

The estimated current production capacity for renewable electricity in Northern Europe totals 100 GW. For wind power alone, the production capacity is estimated to be as high as 36 GW. In addition to wind energy, the other non-fossil fuel sources of energy in Northern

Europe include solar, hydropower, nuclear, geothermal and Bio CHP. The Northern European countries aim to add an additional wind power of 76 GW by the year 2030.

As full electrification of the industries and the society is difficult to achieve, some solutions are needed which enable full utilisation of the production capacities of renewable electricity. Otherwise, some potential from the additional electricity from renewable sources will evidently be lost. Production of green hydrogen provides a sustainable solution for this challenge. The estimated potential for green hydrogen production in Northern Europe is 22 GW by 2030.This figure needs to be updated in 2023 as new renewable energy projects are being announced. This potential is big enough to enable establishment of carbon-neutral societies in the Northern Europe and beyond.

Green hydrogen allows replacement of fossil fuels and raw materials with sustainable alternatives in industrial processes. Moreover, synthetic e-fuels produced from green hydrogen along with capture of CO_2 will help decarbonize transportation. Green hydrogen also acts as an energy carrier as well as energy storage in renewable-based energy networks that require balancing. Furthermore, green hydrogen enables increased decarbonisation of the agriculture sector through green ammonia.

For Northern Europe, the full utilisation of the clean hydrogen potential also introduces an opportunity to reduce imported carbon through coordinated use of local resources and the implementation of sector integration possibilities. Further, hydrogen transition enables maintaining or increasing jobs currently supported by fossil fuels in Northern European countries by coordinated hydrogen production.

How to capture the opportunity?

The emerging opportunity in hydrogen can be captured by cooperating actively in

- Connecting industries to introduce new demonstration and pilot projects and to strengthen the hydrogen ecosystem(s) in the region
- Utilising innovation capacities across borders to develop solutions that improve overall cost-efficiency and ensure safety in all parts of the hydrogen value network
- De-risking the investments that are inevitable for the transition through, *e.g.,* creating a common understanding of the needed standards and regulations, and by co-creating public acceptance and buy-in
- Conducting system-level studies to understand the role of hydrogen in the future energy and industrial systems, and in the climate transition
- Developing training programs for growing the skills and competences needed for the implementation of new technologies

Our strengths for building the hydrogen economy

DENMARK

Specific features of the energy system	Very high share of renewables in the electricity and gas systems and expected to be fully renewable in the near future (electricity already before 2030). Very high potentials for production of additional renewable electricity in the long term (e.g., offshore wind potential estimated to be at around 40 GW). These potentials are higher than the expected demand, which allows for significant amounts of export of renewable energy (either as electricity or in the form of Power-to-X fuels). High availability of biogenic CO_2.
Availability of renewable energy in the system today and going forward (for green H_2)	According to Wind Denmark in 2021, up to 47,2% of electricity consumption in Denmark in 2020, comes from renewable energy sources, especially solar and wind (onshore & offshore). According to Hydrogen Denmark, there is currently no specific capacity dedicated to renewable hydrogen.
Strong competence areas	Denmark possesses a high level of system stability with high shares of renewables integration. Denmark is well positioned in the development of Power-to-X technology, especially electrolysis production facilities, with large producers being Danish or based in Denmark, such as Green Hydrogen Systems, Nel, Siemens Gamesa Renewable Energy and others. See for example: Post | Feed | LinkedIn: https://www.linkedin.com/feed/update/urn:li:activity:6840909485414903808/
Strong industrial sectors	According to Hydrogen Denmark, latest study report Brint i tal 2021 Denmark is in the middle of a rapid development, as Power-to-X is now being widely recognized as key in the green transition in Denmark and globally. Currently, there are at least 21 hydrogen projects announced in Denmark, accounting for 6+ GW electrolysis capacity in 2030. The sector already generates 680 direct jobs and there is a clear potential to achieve additional 53000 jobs until 2030. The report is currently only available in Danish: https://brintbranchen.dk/wp-content/uploads/2021/12/Brint-i-tal-2021-1.pdf
National goals and policies in place	Newly published Power-to-X strategy aims at 4-6 GW of electrolysis capacity by 2030. Given the national target to reduce emissions by 70% in 2030, there is significant focus on Denmark's potential to export Power-to-X fuels and technology, besides reducing its own emissions with Power-to-X. Specific national hydrogen consumption targets have already been announced for national aviation: in 2025 one route of national aviation must fly on green fuels, and by 2030 all national flights must be carbon neutral. Other targets for use of Power-to-X fuels will be negotiated in subsequent sectoral strategies during 2022 (focus primarily on heavy transport segments).
	Yes. The Danish Government through the Ministry of Climate, Energy and Utilities have developed a National Power-to-X strategy in 2021 with strong

Industry Roadmap for implementation in place	ambitions to make Denmark a global player in Power-to-X. Denmark has number of strengths in relation to the production and use of P2X that create a solid starting point for the country being able to play an important role in the development of the green fuels of the future. The national strategy and background analysis including the English version, can be found here: Power-to-X og grøn brint | Energistyrelsen (ens.dk)

ESTONIA

Specific features of the energy system	The country has decades of experience as a net-exporter of electricity and is currently well interconnected to its neighbours via electricity and gas pipelines, providing a platform for energy security and market activity. The upcoming decade will see grid developments aimed towards increased uptake of renewable energy and finalising the process of merging the Baltic states into a single synchronous area with the mainland Europe.
Availability of renewable energy in the system today and going forward (for green H2)	Today, about a quarter of electricity demand is covered by renewable sources (ca 2.6 TWh). Going forward, this amount will be greatly increased due to the cost-effective uptake of wind energy both on mainland and in the shallow coastal waters in Western Estonia. After several pilot-scale H_2 projects, the scale-up of H_2 economy will become a reality once majority of the country's electricity demand is covered from renewable sources by around the end of decade.
Strong competence areas	Strong R&D competence in universities regarding H2 and other green energy technologies. Ambitious and diverse green tech start-up sector.
Strong industrial sectors	With limited examples of local energy-intensive industries for potential H_2 demand, the green hydrogen produced in renewable energy units will be utilised in (heavy) transport, P2X, etc. The local renewable energy is gearing up for the potential of future H_2 exports to Central Europe, relying on cost-effective wind energy developments in the region.
National goals and policies in place	The current national energy and climate plan for 2030 is up for revisal with ambitions set to increase. The energy sector development plan up to 2035 is currently being devised.
Industry Roadmap for implementation in place	The hydrogen roadmap for Estonia was put together at the end of 2021.

FINLAND

Specific features of the energy system	A robust, modern and clean electricity system as a basis for clean hydrogen expansion. The whole country forms one power market area. Extensive sector coupling opportunities to integrate hydrogen across industries and energy sectors for optimum cost efficiency • District Heating systems and CHP • Energy intensive industries • Bio-CO2 and clean water • Ports and zero-emission marine logistics
Availability of renewable energy in the system today and going forward (for green H2)	Potential for rapid and massive scaling of cost-effective onshore and offshore wind power
Strong competence areas	*Strong innovation system* that combines research at public universities and research institutes with active collaboration with industry. This is supported by public co-innovation programs and funding. *Effective public-private collaboration structures:* Finland has been at the forefront of European open-energy-market development.
Strong industrial sectors	*Technology industries cover the entire energy value chain*: the generation of clean electricity, power electronics and power conversion technologies, control and optimization of energy distribution systems, energy and process industry equipment, end-to-end digitalization and related consulting, and the design and engineering services required for turn-key project deliveries. *Strong and innovative process industries with capabilities for continuous renewal* *Energy industry* features both advanced local utilities engaged in local circular economy activities together with innovative local communities, as well as companies operating in several European countries and advancing the sustainable energy system transition on a European scale. In recent years, Finnish power transmission and distribution system operators have invested substantial capital in improving the resilience of the power distribution infrastructure, and the adoption of new technology.
National goals and policies in place	Preparation of a strategy in progress as part of the national climate and energy strategy The objective of the Finnish government for Finland is to be carbon-neutral and the first fossil-free welfare society by 2035.

Industry Roadmap for implementation in place	Yes. Hydrogen Cluster Finland has prepared a roadmap for the Finnish industry.

ICELAND

Specific features of the energy system	The Icelandic energy system builds predominantly upon renewable energy sources. Nearly 100% of electricity is derived from hydropower and geothermal energy plants across the country. With a strong use of geothermal energy for heating purposes in district heating systems and industries, 90% of all homes in Iceland are heated using this renewable energy source. In the overall primary energy supply, about 82% is derived from renewable energy. With limited industrial sector coupling opportunities, hydrogen use is predominantly being discussed for the transport sector (ships, air traffic, and truck) still depending on fossil fuels, as well as limited use e.g. for energy storage, back-up power and related applications.
Availability of renewable energy in the system today and going forward (for green H2)	Up to 100% of electricity produced in Iceland today comes from renewable energy sources, specifically hydropower and geothermal energy. The Ministry of the Environment, Energy and Climate published a *Greenbook* in March 2022 on the current situation regarding energy utilisation and main obstacles in that area. The Greenbook focuses, among other things, on energy transition and demand for energy for the growth of the economic sector. One of the findings is that to fulfil the Government's plans for energy transition in the transportation sector and climate goals, more electricity production is required as well as investments to strengthen the infrastructure, such as distribution and transmission system. The assessment of the country's need for electrical and geothermal energy for the next two or four decades is set in the form of numerical energy forecasts and calculations which need to be reviewed regularly. The Greenbook sets out six scenarios, of which four take Iceland's climate goals into account, with emphasis of energy transition, ranging from little to no addition to Iceland's electricity output, up to more than doubling it, or to a 124% increase by 2040. For a full energy transition, on land, sea and in air, the addition is 124% increase compared to the current output, which today is 19.127 GWh.
Strong competence areas	Iceland can build on a highly educated workforce and strong innovation collaboration between government, industry and the research community.
Strong industrial sectors	Iceland has a limited size manufacturing base, yet has a strong basis of heavy industry, such as aluminium smelters paired with an experienced internationally active engineering sector and players.

National goals and policies in place	A national roadmap is in final stages of creation, which is expected to provide direction for industry and stakeholders.
Industry Roadmap for implementation in place	There are various efforts and projects by energy companies and private sector players for the implementation of both production of hydrogen (e-fuels) and value chain development.

NORWAY

Specific features of the energy system	The generation of electricity is already almost completely based on renewables (in 2021 hydropower accounted for 91,5% of energy production and wind power for 7,5%). The installed capacity of solar energy was below 0,5% of the total installed capacity in 2021.The Norwegian energy system has a high storage capacity thanks to the installed hydropower capacity (half of Europe's reservoir storage capacity). More than 75% of the production capacity is flexible. The production is unequally distributed between different regions, but the country has a well-developed power grid. The Norwegian power system is closely integrated with other Nordic systems.
Availability of renewable energy in the system today and going forward (for green H2)	According to the Norwegian Ministry of Petroleum and Energy, in a normal year, the Norwegian hydropower plants produce 136.4 TWh, which is 90 % of Norway's total power production. At the beginning of 2021, a further 2.3 TWh was under construction. There is a great potential for further onshore and offshore wind power. Onshore wind has historically faced popular opposition, while offshore wind development is expected to accelerate to keep the pace of the European goals. The two areas currently identified by the Government for offshore wind development are 4,5 GW and fall short of the industry's ambitions.
Strong competence areas	Extensive experience in promotion of electric vehicles & projects to introduce hydrogen fuel cell vehicles for trucks and taxis Technical strongholds in key areas of the hydrogen value chain, (e.g., electrolyser, storage, safety, carbon capture, fuel cell, hydrogen ferries) Education
Strong industrial sectors	Oil and gas Hydropower Maritime and shipping
National goals and policies in place	Yes. **Short-term:** the government will seek to facilitate, in collaboration with the private sector, the establishment of five hydrogen hubs in the area of maritime transportation by 2025. It will also strive for the establishment of one or two industrial projects with associated production facilities, as well as five to ten pilot projects for the

	development and demonstration of new, more cost-effective hydrogen solutions and technologies. In its revised national budget (2021), the government proposed to strengthen financing for the development of infrastructure and markets for hydrogen, and to establish a research centre for environmentally friendly energy (FME) with a focus on hydrogen and ammonia. Finally, two FME's consortia were selected early 2022. **Medium term** (up to 2030): the government's ambition is that hydrogen will be established as a realistic alternative in the maritime sector, and that there will be the prospect of market-based development. **Long term**: the vision presented in the roadmap is that by 2050 a market for the production and use of hydrogen will have been established in Norway.
Industry Roadmap for implementation in place	Yes. The government launched a hydrogen strategy in June 2020, followed by the white paper "Energi til arbeid" (Eng. "energy to work") in June 2021, and an update on the paper in April 2022. Strong support to climate projects through Enova (e.g., three projects of 1 billion NOK selected in 2021, and accelerating support from Innovation Norway and the Norwegian Research Council.

SCOTLAND

Specific features of the energy system	Replacement of domestic gas transmission network with hydrogen ready polyethylene pipelines.
Availability of renewable energy in the system today and going forward (for green H_2)	Renewable potential in excess of indigenous demand, e.g. 25% of Europe's offshore wind resource. However, only a fraction of the wind energy potential in Scotland is used due to electricity transport issues.
Strong competence areas	Excellent engineering skill base from renewable and O&G industries, geological storage, Scotland's HEI's academic excellence.
Strong industrial sectors	Acorn blue hydrogen and CCUS, INEOS Grangemouth £1 billion commitment to reduce GHG emissions to net zero by 2045. SGN H100 supplying 100% green hydrogen to 300 homes Port of Cromarty Firth https://pocf.co.uk/hydrogen/ is looking at export by shipping.
National goals and policies in place	5GW of renewable and low-carbon hydrogen production by 2030 and 25GW by 2045.

Industry Roadmap for implementation in place	Yes

SWEDEN

Specific features of the energy system	An already climate friendly electricity system through hydro, nuclear, wind and bio-fueled CHP plants. A lot of hydropower and a well interconnected electricity system gives us lots of cheap balance power to balance wind and solar production.
Availability of renewable energy in the system today and going forward (for green H2)	Sweden is today a net exporter of green electricity. Potential for rapid and massive scaling of cost-effective onshore and offshore wind power. Also, a big biomass potential from forest waste products.
Strong competence areas	Like Finland a strong innovation system and a leading country within IT with many companies specialized in digitalized energy services.
Strong industrial sectors	Sweden will be the first country in the world to produce fossil-free steel in addition to being the first country to export fossil-free iron to the whole world. Forestry as well as chemical sector are also strong.
National goals and policies in place	Sweden has a goal of becoming the world's first fossil-free welfare state, reaching net zero emissions by 2045 at the latest. A sector target of 70% reduced emissions from the transport sector by 2030 (compared to 2010). A target of 100% renewable electricity by 2040 (not excluding nuclear power).
Industry Roadmap for implementation in place	Yes. 22 industrial roadmaps have been handed over to the government and a first follow-up was made in October 2021.

The way forward

Hydrogen from and for the North – how to seize the opportunity?

We call for action in building a tight co-operation in Northern Europe in the following:

- Implementation through, *e.g.,*
  - pushing for pilot and demonstration projects
  - mapping and connecting industries to strengthen the hydrogen ecosystem(s) in the region

- Utilising innovation capacities across borders to develop solutions that ensure safety in all parts of the hydrogen value network as well as to improve overall cost-efficiency through, *e.g.,*
  - expanding existing research collaborations into H_2-relevant topics and pairing new players into joint projects to strengthen each other
  - developing national and bilateral funding opportunities for collaborative research, development and innovation projects

- Shaping the operational environment in order to de-risk the investments that are inevitable for the transition through, *e.g.,*
  - creating a common understanding of the needed standards and regulations, and by
  - co-creating public acceptance and buy-in

- Conducting system-level studies to understand the role of hydrogen in the future energy and industrial systems, and in the climate transition

- Capacity building through, *e.g.,*
  - Developing training programs for growing the skills and competences needed for the implementation of new technologies

List of key stakeholders per country

Country	Name of stakeholder	Type
DENMARK	Brintbranchen (Hydrogen Denmark) https://brintbranchen.dk	Industry Association
	Hydrogen Valley https://hydrogenvalley.dk/hydrogen-valley-en/	Industry cluster
	CEMTEC https://hydrogenvalley.dk/cemtec-en/	Business incubator & Technology Park
	GreenLab https://www.greenlab.dk/about/	Business Incubator & Technology Park
	Confederation of Danish Industry https://www.danskindustri.dk/brancher/di-energi/	Industry Association
	Dansk Energi (Danish Energy) https://www.danskenergi.dk/about-danish-energy	non-commercial lobby organisation for Danish energy companies
	Danish Energy Agency https://ens.dk/ansvarsomraader/power-x-og-groen-brint	Public and National Authority
	Energinet https://en.energinet.dk/About-us	The Danish TSO
ESTONIA	Estonian Hydrogen Cluster www.vesinikuklaster.ee	Industry cluster for H2 economy
	Estonian Hydrogen Association www.h2est.ee	Industry association
FINLAND	**H2Cluster Finland** www.h2cluster.fi	Industry cluster for hydrogen economy coordinated by CLIC Innovation Ltd
	GreenE2 innovation ecosystem https://clicinnovation.fi/ecosystems/greene2/	RDI ecosystem between industries and academia operated by CLIC Innovation Ltd to boost clean energy transition and hydrogen economy

	National Hydrogen Network https://raahenseudunkehitys.fi/index.php/kansallinen-vetyverkosto	Public-sector partnership coordinated by the city of Raahe to advance hydrogen economy
	BotH2nia initiative	Co-operation initiative, coordinated by the city of Raahe, to bring visibility to and to boost hydrogen-related demonstration and investment projects around the Gulf of Bothnia and the Baltic Sea
ICELAND	**Iceland New Energy** http://www.newenergy.is	Public-private partnership company/ R&D on hydrogen (since 1999)
	Iceland Renewable Energy Cluster http://www.energycluster.is	Energy industry cluster initiative
	Græna Orkan http://www.graenaorkan	Collaboration platform for the energy transition
	Samorka – Federation of Energy & Utility Companies http://www.samorka.is	Federation of energy and utility companies in Iceland, representation/ lobbying
	Association of Hydrogen & E-Fuel Producers http://www.si.is VOR Vetnis- og rafeldsneytis-samtökin	Working group with the Confederation of Icelandic Industries
	Green by Iceland http://www.greenbyiceland.com	Platform for cooperation on climate issues and green solutions for Iceland
NORWAY	**Energy Valley** https://energyvalley.no/	National industry cluster for energy. National Center of Expertise for Energy Technology
	H2 Cluster https://h2cluster.com/	National industry cluster for H2 economy
	Norsk Hydrogen Association https://www.hydrogen.no/	Members' association for conveying and promoting the advantages of hydrogen as an energy carrier in Norway.

	Ocean Hyway Cluster https://www.oceanhywaycluster.no	Norwegian hydrogen cluster to realize maritime use of hydrogen
	ENOVA SF https://www.enova.no/bedrift/hydrogen/	Norwegian government enterprise responsible for promotion of environmentally friendly production and consumption of energy
	SINTEF Energy https://www.sintef.no/en/sintef-energy/	Independent contract research organization (institute for applied research)
	Innovation Norway https://www.innovasjonnorge.no/en/start-page	Norwegian Government's instrument for innovation and development of Norwegian enterprises and industry
	Norwegian Research Council https://www.forskningsradet.no/en/	The Research Council works to promote research and innovation to deal with key challenges to society and the business sector
SCOTLAND	**Industrial Decarbonisation Research and Innovation Centre** (IDRIC UK) https://idric.org/	National (UK) focal point and international gateway for UK industrial decarbonisation research and innovation.
	Hydrogen Accelerator https://h2-accelerator.org/	Funded by Transport Scotland, connector between government and academic research base for hydrogen in transport.
	Scottish Hydrogen and Fuel Cell Association (SHFCA) http://www.shfca.org.uk/	Trade association
	H100 Fife https://www.sgn.co.uk/H100Fife	Green hydrogen-to-homes heating network
	Scottish Renewables https://www.scottishrenewables.com/	Trade association
	BigHit https://www.bighit.eu/	Integrated island hydrogen project
	Flotta Hydrogen Hub https://www.flottahydrogenhub.com/	Green hydrogen production and export facility on Orkney

	North of Scotland Hydrogen Programme/Green Hydrogen Hub https://opportunitycromartyfirth.co.uk/green-hydrogen/	Regional hydrogen programme based in Cromarty including electrolysis and whisky
	Aberdeen Hydrogen Hub including H2 Aberdeen https://www.aberdeencity.gov.uk/services/environment/aberdeen-hydrogen-hub	Regional hydrogen programme based in Aberdeen including hydrogen buses
	ReFLEX Orkney https://www.reflexorkney.co.uk/	Integrated energy system
SWEDEN	**Energiforsk**, the Swedish energy research centre www.energiforsk.se	Newley started broad Hydrogen R&D programme
	Rise, Research institutes of Sweden www.ri.se	SHDC, Swedish hydrogen development centre
	Production, Utilisation and Storage of Hydrogen (PUSH) **Center for Hydrogen Energy Systems Sweden** (CH2ESS) https://www.ltu.se/centres/CH2ESS **Hydrogen within the transportsector** (TechForH2)	Three academic centres for hydrogen research

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