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The emerging role of the Nordic region in a European hydrogen economy

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HYDROGEN FOR BREMEN'S INDUSTRIAL TRANSFORMATION

Hydrogen over the Horizon – The emerging role of the Nordic region in a European hydrogen economy

Report

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Summary

The emergence of a hydrogen economy in Europe and the Nordic region represents one important pathway to decarbonization of critical sectors. This development is and will be shaped by distinctive national strategies that do not fully converge around shared objectives. The landscape reveals a complex interplay of technological innovation, industrial policy, and environmental ambition.

Each Nordic country has developed a unique hydrogen strategy, although not formalized by all governments, reflective of its national capabilities and economic priorities. Denmark, Finland, and Sweden have predominantly oriented their approaches toward green hydrogen production through electrolysis, closely integrating hydrogen development with broader electrification strategies. Norway distinguishes itself through a more diversified approach, leveraging its substantial natural gas resources to explore both green and blue hydrogen. The national hydrogen initiatives concentrate on sectors where traditional electrification presents significant challenges. Synthetic fuels for maritime and aviation applications and energy-intensive industrial processes—particularly steel production—emerge as the primary target domains. This targeted approach underscores an understanding that hydrogen should not be viewed as a universal energy solution, but rather as a tool best deployed with precision where maximum economic and environmental benefits can be realized, and other options are scarce.

Governmental roles in this emerging ecosystem are characterized more by enablement than direct intervention. Policy frameworks are being carefully constructed to support research and innovation, build knowledge and capacity along key value chains, and facilitate cross-sector and international collaborations. The state is positioning itself as a facilitator, designing regulatory structures that can support private sector innovation. The emphasis on the export potential for hydrogen is a differentiating domain, with Denmark and Norway emerging as the countries most strongly viewing this as a central opportunity. However, the primary emphasis remains on domestic value creation, with hydrogen viewed as a mechanism for transforming domestic industrial sectors.

The current project landscape reveals both promise and complexity. Across the Nordic countries, 224 hydrogen projects have been identified, with 57 having reached final investment decision. Yet, significant uncertainty persists regarding project realization, as evidenced by recent delays and cancellations of high-profile initiatives. Critical challenges threaten to delay development further. Infrastructural limitations in electricity production and transmission, complex regulatory environments, inefficient distribution networks, and the absence of credible offtake agreements constitute substantial barriers. It is thus highly questionable if the envisioned potential for producing hydrogen in the Nordic region for export to continental Europe can be fulfilled, and in fact if there is even a matching interest in the Nordic countries to do so.

The Nordic hydrogen strategies reflect a pragmatic, incremental approach to energy transition. The region's hydrogen ambitions will ultimately depend on rapidly accelerating infrastructure development, streamlining regulatory processes, and maintaining competitive investment environments. While the region possesses significant renewable energy resources, technological capabilities, and strategic positioning, the path to a robust hydrogen economy remains complex and uncertain. The next few years will be crucial in determining whether the Nordic countries can transform their hydrogen potential into a meaningful low-carbon energy strategy.

1 Introduction

Hydrogen has for decades been discussed as a potential energy carrier for a sustainable society and several cycles of hope and hype around hydrogen technologies have passed (Bakker and Budde, 2012; Bockris, 2013). While hydrogen has played a role in EU policies for transforming the energy system for a longer time, it was not seen as a key solution to be aggressively supported (Bleischwitz and Bader, 2010). Several European countries, such as Germany, Norway and the Netherlands, have for decades supported hydrogen technology development, without it leading to significant breakthrough or wide adoption of these technologies in the key sectors (Godoe and Nygaard, 2006; Hekkert et al., 2005; Suurs et al., 2009). Yet hydrogen is now more salient as a real option for many applications in the energy transition (Kovač et al., 2021). Stronger climate ambitions targeting net zero emissions have led to the recognition that hydrogen can play a central role for contributing to mitigation especially in sectors where other forms of climate change mitigation are difficult, such as energy and emissions intensive industries (Wachsmuth et al., 2021). It is also seen as a potentially interesting technology for energy storage in the electricity system, something that is expected to be increasingly more important as intermittent renewable energy sources are gaining a more significant role in the electricity system (IEA, 2019). Hydrogen has thus come to play a much more prominent role in the discourse on energy system transformation, emphasized not least by the publication of an EU hydrogen strategy in 2020. Many other countries, in the EU and outside of the union, have also developed national strategies to support the development and deployment of hydrogen technologies.

The use of hydrogen as an energy carrier theoretically enables distributed production and use of renewable or low-carbon energy. However, as the scale of envisioned hydrogen production and use infrastructure has increased it has become apparent that regions with access to large volumes of low cost renewable electricity will have an advantaged position. A central aspect of an energy transition built on hydrogen for many applications is thus to develop the infrastructure that enables production of hydrogen in regions with a competitive advantage together with interregional and international trade of that hydrogen for use by actors elsewhere. Countries and regions with limited capacity to scale up production to meet local demand can thus import hydrogen or hydrogen derivatives from other regions, effectively creating a new map of energy trade (IEA, 2019). In this context, the Nordic region has been identified as an important potential supplier of hydrogen to users in other regions in Europe, if the countries in the region makes use of their joint capacity for innovation in the field (Wolf et al., 2010).

In this report we explore the envisioned role for the Nordic region as a supplier of hydrogen and key derivatives in European visions, map the strategies for hydrogen developed by the Nordic governments, and investigate recent market developments to analyze the prospects for hydrogen hubs in the Nordic region. We investigate the strategies of the Nordic countries (Denmark, Finland, Norway and Sweden) to identify the dominating perspectives in terms of what role hydrogen is expected to have in the energy transition and what measures that are proposed for reaching set targets, contrasting this with expectations expressed by EU institutions and in Germany.

2 Hydrogen in the EU energy transition

The European Green Deal (EGD) represents a comprehensive framework aimed at achieving climate neutrality in Europe by 2050, with hydrogen emerging as a pivotal component in this transition through its potential to enhance energy security, support the transition to renewable energy, and contribute to decarbonization efforts across multiple sectors. However, realizing this potential will require coordinated efforts in investment, regulatory reform, and technological advancement to overcome the existing barriers and fully integrate hydrogen into the European energy landscape. The EGD outlines ambitious targets, including a significant increase in the share of hydrogen in the EU energy mix. This shift is driven by the recognition of hydrogen as a versatile energy carrier capable of addressing various energy challenges, particularly in sectors that are difficult to decarbonize, such as transportation and heavy industry (Barnes and Yafimava, 2020).

However, the transition to a hydrogen economy is not without its challenges. The implementation of hydrogen strategies across EU member states necessitates substantial capital investments and modernization of existing infrastructure. For instance, Poland's Hydrogen Strategy aims to align with the EGD but faces hurdles related to funding and technological readiness (Bednarczyk et al., 2022). Additionally, the legal and regulatory frameworks governing hydrogen production, transportation, and storage are still evolving, requiring reforms to facilitate a cohesive approach across Europe (Chechel et al., 2022).

Importantly the EU hydrogen strategy is not supporting a particular category of hydrogen technologies but aims to include "a comprehensive terminology and European-wide criteria for the certification of renewable and low carbon hydrogen". It thus sets out to define the main types, mainly differentiated by the mode of production, as summarised by (Barnes and Yafimava, 2020):

- *Electricity based hydrogen* (often called green hydrogen when the electricity is from renewables) produced via electrolysis of water. The emissions lifecycle of the hydrogen mainly depends on how the electricity used for the electrolysis is produced.
- *Renewable hydrogen* (or *clean hydrogen*) produced from renewable electricity via electrolysis (often called green hydrogen), or via chemical conversion of biogas or other biomass resources.
- *Fossil based hydrogen with carbon capture* (often called blue hydrogen) where hydrogen is derived from fossil fuels such as coal or natural gas and where the CO2 is captured via CCS or as solid carbon via pyrolysis. The variable ability of the different processes to capture carbon needs to be taken into account.

- *Low carbon hydrogen* which includes fossil-based hydrogen with carbon capture, and also electricity-based hydrogen with 'significantly reduced' emissions for the lifecycle.
- *Hydrogen-derived synthetic fuels* (often called synfuels) are key derivatives of hydrogen and include fuels for both road vehicles, aviation, and shipping. The hydrogen component must be renewable for the synthetic fuel to be considered renewable.

The hydrogen strategy has been followed with more initiatives that also directly link to the development of a European hydrogen economy, with the RePowerEU identifying hydrogen as a key opportunity in the European energy transition to improve both sustainability and energy security. Several more detailed instruments have also been adopted as part of the hydrogen policy framework which is part of the Fit for 55 package, including delegated acts under the Renewable Energy Directive defining sustainability criteria for the use of hydrogen and hydrogen derivates as fuels in 2023 (European Commission, 2023a, 2023b), as well as new directives and regulations for hydrogen trade on the European gas market being adopted in 2024 (European Parliament and the Council, 2024a, 2024b).

To support the large need for investments that have been identified necessary to materialise the hydrogen economy (Cihlar et al., 2021) several support mechanisms have also been proposed, e.g. including hydrogen projects as important projects of common European interest (IPCEI), supporting innovative hydrogen projects through the Innovation Fund, as well as financing through the European Hydrogen Bank. There is thus a high ambition for hydrogen in current EU strategy and policy, but it has also been criticised for being unrealistic, fragmented, and in need of a reality check to ensure it can achieve its objectives by 2030 (ECA, 2024).

2.1 The envisioned role of the Nordic countries for supplying hydrogen to Europe

The EU and some specific European countries, in particular Germany, have high hopes for the Nordics' capacity to produce cheap and clean hydrogen at a scale large enough to buttress the decarbonisation of the region's hard-to-abate sectors and industries. The EU are keen to kickstart hydrogen's role in its low-carbon transition, implementing multiple incentivising schemes and programmes including the European Hydrogen Bank. Further incentivisation may be on the table, with discussions of implementing European-wide (Carbon) Contracts for Difference (CCfD) (Bouacida, 2023; Hoogsteyn et al., 2023). Major export opportunities from the Nordics have been identified in multiple analyses (Lenivova, 2022; Pedersen et al., 2022), touting the region to supply a significant portion of the EU's hydrogen demand via pipeline and ship as part of the ongoing mitigation measures being implemented on the road to net-zero. Hydrogen is envisaged to play a role in decarbonising hard-to-abate sectors but also to potentially make a contribution in other sectors by blending hydrogen into existing gas grids. A recent overview (European Hydrogen Observatory, 2024a) of the hydrogen market landscape identifies the 'emerging hydrogen applications' aligning with previously (Fuel Cells and Hydrogen 2 Joint Undertaking, 2019) envisaged end-use sectors, being the production of e-fuels, industrial heat, residential heat, power generation, mobility, and steel. The emerging application with the highest demand as of 2023 was industrial heat at 0.26 Mtpa. This demand, alongside low-carbon fuel alternatives, is envisaged to increase steadily over the coming decades as visualised in Figure 1. Decarbonisation of shipping fuels, for example, is high on the agenda with the use of ammonia and methanol as key hydrogen derivatives that can be used as fuels (IEA, 2024a). Ammonia bunkering capacity at ports will have to be constructed, further standards development is required to facilitate a large-scale implementation of integrated clusters that can host the large quantities of ammonia envisaged to meet the demands of the shipping industry.

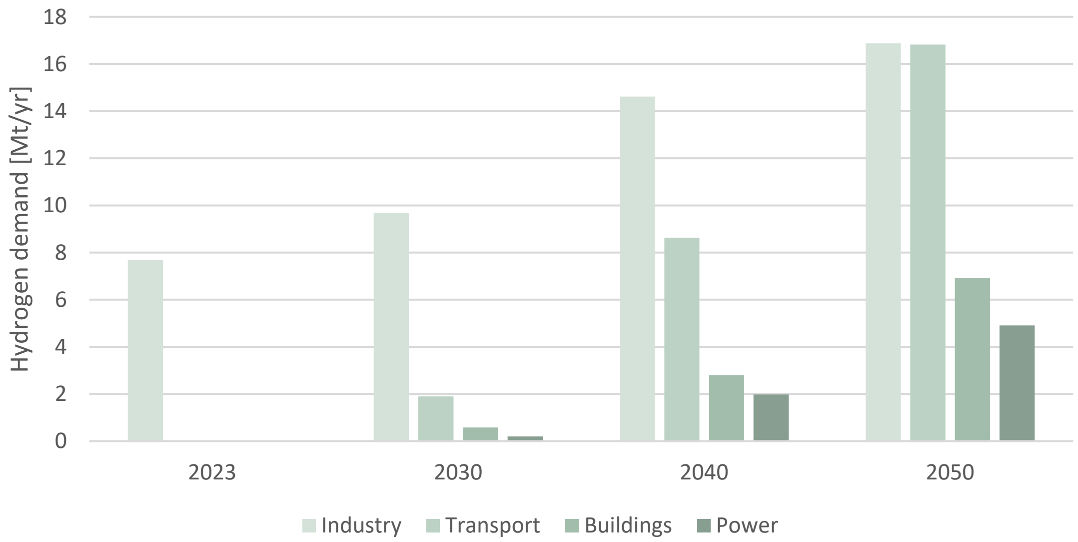

Figure 1 Anticipated EU hydrogen demand. Average projected demand of different scenarios by sector for the years 2030, 2040 and 2050. Based on data from European Hydrogen Observatory (2024a).

The EU and Germany share an expectation that there will be multiple transboundary pipelines linking up sources of hydrogen in the Nordics to end-users within Europe. A European hydrogen core network, envisioned by many European gas companies, has been titled the European Hydrogen Backbone (EHB) and the first phase, if it comes to fruition, will include 4,500km of pipeline, including connecting the Nordics with the rest of Europe. It will incorporate both repurposed gas lines and new bespoke infrastructure (Kountouris et al., 2024). Sections of the EHB have already received IPCEI support with other aspects still vying for the appropriate funding (German Federal Government, 2023).

Recent modelling scenarios assume that 25, 52, and 105TWh of Nordic-produced hydrogen will be exported to EU countries by 2030, 2040 and 2050, respectively (Rosendal et al., 2024). This level of export is predicated on the continuous expansion of renewable energy capacity in the Nordics, especially an envisaged supply of wind power that will far surpass domestic usage (Karlsson et al., 2024) and will thus be available for direct export as electricity or to produce hydrogen and its derivatives for export (Lenivova, 2022). The exported hydrogen includes applications for ammonia, liquid fuels and high-value chemicals, high-temperature industrial processes, and iron ore. Despite modelled increases in capacity, real-world issues can prove to be significant obstacles to overcome, such as local resistance to new renewable energy projects (Karlsson et al., 2024), safety concerns (Pedersen et al., 2022), and rising geopolitical tensions affecting decision-making (Quitzow and Zabanova, 2024)

2.2 The envisioned role of the Nordic countries for supplying hydrogen to Germany

Germany have released their Import Strategy for hydrogen and hydrogen derivates (German Federal Government, 2024). In this strategy, there is an explicit recognition of the limited domestic capacity for hydrogen production and thus, the majority of demand will have to be met by imports. The German Federal Government's analysis indicates that approximately 50-70% (45-90TWh) of the projected 2030 demand of 95-130TWh will be achieved via imports, both in the form of hydrogen and its derivatives. This proportion of Germany's hydrogen demand to be met by imports only looks to rise to between 70-80% by 2045 (Eriksen et al., 2023) when demand could reach between 290-440TWh for industry alone (German Federal Government, 2023). The industrial sector is central in the German hydrogen strategy, which aims to be a pathway to maintaining industrial leadership in a post-fossil world (Nunez and Quitzow, 2024). The share of this demand that will be supplied by the Nordic countries is not precisely calculated at this juncture, but given the anticipated EHB network, where Corridors C & D include linking up Nordic sites of production with Germany, the expectation looks to be substantial, and consequently a reliance is becoming embedded in policy pathways. The Nordics are characterised by a net oversupply of low-cost hydrogen resources with the region envisaged to benefit from vast renewable energy potential, high-capacity factors, and substantial land availability (EHB, 2023).

To meet the anticipated demand of German industry, there is also discussion of increased export of natural gas from Norway to facilitate blue hydrogen production on site with the necessary carbon capture capacity (European Hydrogen Observatory, 2024b). This demand is reflected in energy modelling where existing gas pipelines are expected to be utilised (Hanto et al., 2024). However, Equinor's recent decision to scrap their plans to export blue hydrogen to hydrogen-ready gas power plants in Germany have dampened expectations around a hydrogen supply chain from Norway (Reuters, 2024a). These signs suggest high costs, a current lack of CO_2 infrastructure, and insufficient demand in the near-term, will lead to a significant bottleneck in the coming decade, partly due to lengthy permitting processes and the early development stage of most projects. This indicates that fossil-based blue hydrogen production methods will likely be unable to bridge the immediate gap caused by a slower-than-anticipated scaling of renewable hydrogen (Agora Energiewende and Agora Industry, 2024).)

3 The future role of hydrogen in the Nordic energy system

Although the energy markets of the Nordic countries are in many ways closely integrated, the countries act in different historical, political and structural energy contexts which could impact how the countries view the role of hydrogen in the future energy system. Denmark, Finland and Sweden are full members of the EU, whereas Norway is not. However, through EEA (European Economic Area) agreement Norway follows various EU regulations of relevance for the energy sector. All four countries are part of the integrated European electricity market.

3.1 Energy system context in the Nordic countries

Norway is a main exporter of both oil and natural gas and the production of energy products is more than 10 times higher than energy use. In 2022 approximately 1270TWh of natural gas and 1075 TWh of oil was produced (Statistics Norway, 2024). Norway is also a net exporter of electricity. The domestic metal industries, oil refineries, and chemical industries have high energy demands.

Denmark has been a significant producer of fossil fuels, but both the production of oil and natural gas has declined significantly since 2010 and in 2020 the government decided that all fossil fuel extraction in the North Sea will be phased out by 2050 (Danish Government, 2020). In 2022 the production of oil (137 PJ/38 TWh) was just 25% of the level in 2010 and the production of natural gas (52 PJ/14 TWh) only approximately 17% of the level in 2010. On the other hand, the production of renewable energy has increased by 60% during the same period. Domestic oil production is significantly smaller than the domestic demand, whereas natural gas demand is of the same magnitude as production (Energistyrelsen, 2023a). Denmark was a net importer of electricity in 2022, but this varies from year to year. Norway and Denmark are also big shipping nations which could imply an interest in hydrogen for maritime transport.

Neither Sweden nor Finland has any fossil fuel resources. On the other hand, Norway, Sweden, and Finland have significant hydro power production, significant biomass resources and are sparsely populated which would potentially allow for the location of wind and solar power. However regardless of this, the localization of large wind and solar power generation projects is contested. For example, in Sweden there is local opposition both against land-based and offshore wind power and goal conflicts with defence interests have stalled offshore wind power in several locations.

Energy intensity and hydrogen use varies between the countries, see Table 1. Of special interest for hydrogen is the fact that both Sweden and Finland have a major iron and steel sector which is a potential consumer of hydrogen. So is petrochemical industry that is important in all countries.

Table 1 Energy intensities of the Nordic countries and current hydrogen and industrial energy use. Comprehensive statistics of hydrogen use is lacking. The presented data are estimates taken from various reports published in the beginning of the 2020s.

	Denmark	Finland	Norway	Sweden
Gross energy use/capita (2021)	100 GJ	250 GJ	230 GJ	190 GJ
Gross energy use/GDP at 2010 price level (2021)	2 500 GJ/MEUR	6 900 GJ/MEUR	3 300 GJ/MEUR	4 500 GJ/MEUR
Hydrogen use	2 200 TJ (18 000 ton)	20 000 TJ (170 000 ton)	27 000 TJ (225 000 ton)	22 000 TJ (180 000 ton)
Industrial energy use (2022)	100 000 TJ	410 000 TJ	270 000 TJ	470 000 TJ

3.2 Energy system scenarios for production and consumption of hydrogen

Scenarios for future hydrogen have been presented by some public actors in the different countries. They have not necessarily been developed by the same type of methodology and perspectives and are not easily comparable. However, they could provide an indication of what role hydrogen could play in the various countries.

3.2.1 Denmark

In recent projections from the Danish Energy Agency (2023) hydrogen production is estimated to approximately 10,7 PJ (3,0 TWh)/yr in 2030 and (5,5 TWh)19,9 PJ/yr in 2035, although a very high degree of uncertainty is noted for these estimates (Energistyrelsen, 2023b). In terms of demand, it is estimated to be significantly smaller and as a consequence most of the hydrogen being exported (export corresponds to 10 PJ/a in 2030 and 18,8 PJ/a in 2035).

In this scenario, only a fraction of the Danish electricity production is used for Power-to-X (less than 10% of total electricity production, 15% of wind power production in 2035). The net export of electricity from Denmark in 2035 is in these scenarios expected to be about 70% higher than the electricity used for Power-to-X production domestically. Thus, export of hydrogen seems relatively unimportant compared to electricity export in this scenario.

Other studies in Denmark have studied future potential hydrogen production and demand based on on-going projects. The Danish TSO Energinet has estimated that hydrogen production will be 2.5 times larger than demand around 2040 which also indicates the importance of export opportunities for motivating such level of production expansion (Energinet, 2023). The values in the scenarios are based on information gathered through a market dialogue (KPMG et al., 2022). Hydrogen production is in the scenarios estimated to be around 1.5 Mt (50 TWh) in 2035 and 1.8 Mt (60 TWh) in 2040 and demand around 0.7 Mton in 2040. These production figures are significantly higher than what was presented in the scenarios by the Energy Agency.

3.2.2 Finland

In 2022, five hydrogen economy scenarios were developed for the Finnish Government by the consulting firm AFRY (Sivill et al., 2022). The estimated production volumes vary significantly among the scenarios. The production volumes are estimated to 3.7-7.9 TWh/y in 2030 and between 6.2-132.9 TWh/y in 2050. For the upper levels, significant exports of hydrogen and e-fuels are assumed whereas the lower levels production is dimensioned for domestic demand. The maximum scenarios require, according to the authors, that Finland will be extremely competitive as producer and that the international demand corresponds or even exceeds the scenarios from the European Commission.

The domestic demand is in the scenarios expected to be mainly in the steel industry and in oil and biofuels refineries. The demand in the industrial sector excluding the fuel industry is, however, estimated to be less than 10 TWh/year in all scenarios. The domestic demand of hydrogen and e-fuels for transportation is expected to be small.

All scenarios take the Finnish target of carbon neutrality in 2035 for granted. The main growth-limiting factors with regard to hydrogen production are the availability of domestic onshore wind power, trends in domestic demand, the availability of international transmissions lines and the international demand of hydrogen and e-fuels.

Hydrogen is exported in 3 out of 5 scenarios. In a moderate scenario Finland is expected to contribute with 4% of European e-fuels (not including hydrogen) in 2050 and in one maximum scenario the contribution is 10 %.[1] The restriction in this maximum scenario is not due to limits in transmission capacity but in the possibility to expand wind power production.

3.2.3 Norway

The Norwegian Statnett has provided scenarios for future electricity production and demand up to the year 2050 (Statnett, 2023). Statnett takes a European approach both in terms of t how the electricity market will develop and in its discussion of hydrogen demand. As focus is on electricity, less focus is on blue hydrogen, even though this alternative is highlighted as an alternative for Norwegian production. In its four electricity scenarios

[1] It can be noted that the current government has stated that Finland should produce hydrogen corresponding to 10% of European demand.

electricity demand is expected to increase from 140 TWh to 190-300 TWh/yr. In the base scenario, that is expected to be sufficient for securing a net zero emission society, including a green transformation of industry, demand reaches 220 TWh/a in 2050. The high demand scenarios are connected to an expansion of existing and new industries due to good availability of fossil free electricity. Statnett does not state how much of the electricity demand in Norway that is for hydrogen production but for the Nordic countries as a whole it is estimated that 25% of electricity demand in 2050 is for hydrogen production. In a previous report, which Statnett still regards as reasonable approximately 40 TWh/yr electricity is expected to be used for hydrogen needed in industry (Statnett, 2019). But blue hydrogen and import might also be needed.

Statnett also assumes that hydrogen is used for transportation. Their estimate is that 5 TWh/a electricity is used for domestic transport demand but also here blue hydrogen and import is expected to contribute.

The Statnett high and very high demand scenarios are based on a wind power expansion expected to contribute to global demand for green energy. Exactly how much of this is for hydrogen is difficult to see in the presentation of the results. In addition, the hydrogen market is presented from a European perspective. It is not clear to what degree green hydrogen will be produced in Norway and then exported or if wind energy is exported to Europe for hydrogen production (or other use) there.

Another set of scenarios were presented by a consortium, commissioned by the Norwegian Government. In 2023 then consortium presented three scenarios (low, medium, and high) for future hydrogen demand and production (Oslo Economics et al., 2023). The scenarios cover, in contrast to Statnett's scenarios, both blue and green hydrogen.

In the scenario "low" both the demand and supply of hydrogen is expected to be low. This is partly because blue hydrogen cannot be motivated from Norwegian demand only and that thed opportunities to expand renewable energy sources are limited. This is both a result of limited capacity in the transmission and distribution nets and long planning procedures for new production capacity. In this scenario, the demand is estimated to 14 000 tonnes/y in 2030 and 157 000 tonnes/y in 2050 (0,5 and 5 TWh/y, respectively). For 2030 the result is based on the assumption that only already decided projects will be put in production. In 2050, hydrogen demand is assumed to be dominated by maritime transport (55 000 tonne/yr, 30% of current energy demand for coastal maritime transport), road transport (50 000 tonne/yr 10% of current transportation energy) and existing industry (35 000 tonne/yr, 50% of the potential for decarbonisation in that sector).

In the middle scenario, it is possible to expand renewable electricity while insufficient electricity transmission capacity for electricity makes a case for hydrogen production in order to handle local and regional electricity surpluses. In this scenario, also blue hydrogen becomes an alternative but in the beginning of the period high demand for natural gas keeps natural gas prices high and blue hydrogen less competitive. The fractions of existing industry that substitutes fossil fuels with hydrogen increases compared to the previous scenario. This is also the case for maritime transport and road transport. New industries develop based on the availability of low carbon hydrogen. The demand in this scenario will be 34 000 tonne/y in 2030 and 455 000 tonne/y in 2050. Blue hydrogen totally dominates hydrogen supply and export dominates over domestic consumption. Total production is expected to be 600 000 tonne/y in 2030 and 5.4 Mton/year (180 TWh/y) in 2050.

In the high scenario, domestic demand increases slightly compared to the previous scenario, but the major change is that there will be no import restrictions for blue hydrogen to EU. Hydrogen production in this scenario will be 1.4 Mton/y in 2030 and 9.9 Mton/y in 2050. 9.9 Mton is equivalent to approximately 330 TWh/y which could be compared to the current export of natural gas. The hydrogen production in this scenario corresponds to approximately ¼ of current natural gas export.

3.2.4 Sweden

The Swedish Energy Agency has not provided any hydrogen scenarios of their own. In the background material to its proposal for a hydrogen strategy (see chapter 4), other scenarios are, however, summarised. In several electrification scenarios, flexible hydrogen production is expected to play a significant role. It is expected that industrial demand will be dominating. The production scenarios do not expect any export of hydrogen. In the most ambitious scenario from the Swedish TSO electricity demand for hydrogen production in Sweden is 47 TWh/y in 2035 and 87 TWh/y in 2045 (Svenska Kraftnät, 2024). This can be compared with current electricity production which is approximately 160TWh/y.

The most recent long-term (2050) scenarios by the Swedish Energy Agency for the energy system include some information on hydrogen (Energimyndigheten, 2023). In these scenarios, electricity demand increases significantly. It is to a large extent driven by the need for hydrogen in Swedish industrial projects especially in the iron and steel industry but also as feedstocks for producing electro-fuels and for use in the chemical industry. However, there are large uncertainties to what degree all the projects underlying these scenarios will materialise. Electricity for hydrogen demand for industry varies between 22 and 100 TWh/y in the 2050 scenarios.

No direct use of hydrogen is expected for transportation in the scenarios. The exact role of electro-fuels cannot be seen as it is not reported separately from other liquid fuels. The use of hydrogen in industry cannot be seen specifically as the demand is reported in the form of the electricity used. Import and export of hydrogen or electro fuels are not discussed at all in the scenario report.

4 Nordic hydrogen strategies – an overview

This chapter provides a short summary of the context in which the strategies have been developed and a brief description of on-going processes in which the governments and state agencies act in terms of hydrogen development. In the following sections we will in more detail present the content of the strategies including general perspectives, targets, as well as both proposed and initiated measures.

4.1 The potential role of government strategies for the transition towards hydrogen

Many member states have developed hydrogen strategies of their own, in parallel with or following the EU hydrogen strategy. Governmental hydrogen strategies could provide overall perspectives, approaches and goals that government and its related agencies are expected to follow in their everyday activities. The strategies may increase the political transparency and legitimacy of various policies and policy instruments showing how they would fit into a broader political narrative of the future role of hydrogen. The strategies can provide guidance to different public actors in terms of what goals they are expected to pursue. And finally, but not least importantly, they provide a guidance for private actors in terms of what they could expect in term of long-term policy direction, which may reduce the political risk for private investors (Lindner et al., 2016). For that to be the case, it is required that the strategies are really seen as something that is expected to have impact on policies and not something that is presented by the government only to gain politically. In addition, the actors need to see the strategic priorities as relatively stable over time to have an impact on long-term investment decisions in the private sector.

This perspective, on the role of strategies, follows a relatively rational view of policy making. However, it is an empirical question whether the strategies really play this role. Sometimes the presented strategies may just reflect and collect already existing policy initiatives rather than act as instruments that guide what initiatives to choose. The setting of policy goals, both quantitative and qualitative, would indicate directionality both for public and private actors. New policy initiatives could be initiated and evaluated in relation to these goals. Policy intentions manifested in the goals could also help private investors to find projects in line with expected policies. Various policy instruments can also support the introduction and diffusion of hydrogen in society. These can be both general economic instruments such as carbon taxation and subsidies to hydrogen for example to various forms of infrastructure, filling stations, pilot plants etc. The subsidies could consist of both direct funding and risk sharing. Funding of RD&D is usually not seen as a subsidy in the same way but can play an important role in enabling the development of new technology niches. Adaptation of legislation, standards, safety and market regulation is also required in order to enable a broader deployment of hydrogen (Kattel and Mazzucato, 2018).

Government policies have a role both domestically and as a part of on-going policy processes at the EU arena. Development of an intra-EU market is a clear strategy of the EU and is something the national governments can gain from or at least must relate to. EU policies can both act as support for the deployment of hydrogen, but certain market regulation rules can also act as hinders for the implementation of certain policy instruments (Mazzucato, 2016; Mazzucato and Penna, 2016). In many countries, gas infrastructures are publicly owned, and public agencies or publicly owned companies act as TSO:s in the field. These infrastructure owners are strategic actors for the development of a hydrogen system. Finally, public actors can play an important role in initiating and coordinating actor networks which would help creating the necessary environment for developing hydrogen clusters that would support the innovation system.

The private sector in the Nordic countries also identifies a need for cross-border collaboration to develop the hydrogen economy. A cooperation between business organisations and public agencies led to a report that presents recommendations in the fields of Nordic cooperation, exports from the Nordics and global investments in the Nordics (Business Sweden et al., 2023).

4.2 Introduction to country specific hydrogen strategies

In this section the national strategies are briefly introduced. A comparative analysis of the strategies will follow in section 4.3.

4.2.1 Denmark

The Danish hydrogen strategy, which is in fact a strategy for Power-to-X, was presented in 2021 (Danish Government, 2021a). An electrification strategy, which also referred to indirect electrification through hydrogen, was presented the same year (Danish Government, 2021b). In 2022, the Danish Power-to-X strategy was followed by an agreement on hydrogen between the government and several political parties in the Parliament, forming the foundation for continued work on the topic. Already in 2019, the state-owned transmission company Energinet presented a Power-to-X strategic action plan (Energinet, 2019). In 2022 it presented a new strategy for the green transition with a focus on energy infrastructure in which hydrogen was a significant part (Energinet, 2022). In the climate plan of the government from 2023 the potential for hydrogen to contribute to carbon mitigation was estimated and on-going activities summarised (Danish Government, 2023).

The Danish strategy has four main qualitative objectives for Power-to-X. These objectives aim to contribute to the Danish Climate Act's goals, create a robust regulatory framework and infrastructure that allows the Power-to-X industry to operate effectively, improve the integration of Power-to-X with the Danish energy system, and position Denmark as an exporter of Power-to-X products and technologies.

4.2.2 Finland

Finland does not have a specific hydrogen strategy. It is instead included as a part of Finland's energy- and climate strategy (Finnish Government, 2022). The strategy was presented in 2022 and included a separate chapter on hydrogen. In spring 2023, the Finnish government presented a short document on hydrogen that shows the intended direction of the Finnish hydrogen policy (Finnish Government, 2023). Finland has focused on the intentions of the government to create a competitive and predictable investment environment for hydrogen. The government is advocating for support of carbon-free refining industry solutions, such as hydrogen-based steel production, within the framework of the EU Net-Zero Industry Act.

Gasum Oy and Gasgrid Finland Oy are state-owned companies that are active in the hydrogen field. They are, for example, together with several private companies, members of Hydrogen Cluster Finland. The cluster presented a clean hydrogen economy strategy in 2023 in which recommendations were provided in how to contribute to the hydrogen targets set by the Finnish Government in June 2023. Gasgrid has also, together with the state-owned TSO-E Fingrid developed hydrogen economy scenarios which will be used for its work with the development of the hydrogen infrastructure and support future investment decisions (Fingrid and Gasgrid, 2023).

4.2.3 Norway

The Norwegian government presented its hydrogen strategy in 2020 (Norwegian Government, 2020). It was followed by an action plan in 2021 (Norwegian Government, 2021) and a roadmap for hydrogen (Norwegian Government, 2023). Both the action plan and the strategy were part of broader initiatives for greening the Norwegian industries, prioritizing hydrogen development in areas where the country has comparative advantages. The strategy concentrates on fields where Norwegian companies and technology developers can have a significant impact, with a particular focus on initiatives that can contribute to value creation and green growth. The Norwegian focus on blue hydrogen from natural gas with CCS indicates that continued exploitation of existing natural gas resources is a strong motivation for engaging in the hydrogen domain, although the strategy also presents opportunities for green hydrogen production in Norway.

4.2.4 Sweden

Sweden has no specific hydrogen strategy decided by the government. The Swedish Energy Agency has however presented a proposition for such a strategy (Swedish Energy Agency, 2021) but it has not led to any formal decision by the government. In 2022 the previous government presented an electrification strategy (Swedish Government, 2022). This is of special importance for hydrogen in Sweden, as a significant part of the projected increase in electricity demand is expected to be used for hydrogen production. It also refers specifically to the proposed hydrogen strategy and the government stated, as one of several proposals in the strategy, that it intends to clarify the political direction and remove obstacles for integrating hydrolysis and hydrogen storage in the energy system.

The role of hydrogen is not specifically stressed in the current climate plan presented by the Swedish Government (Government of Sweden, 2023), although it is expected to play a significant role for the decarbonisation of industry. Hydrogen is in this context presented as a part of the general vision of electrification. In the 2024 energy bill, Sweden refined its approach with four updated guiding principles. These principles emphasize using fossil-free hydrogen to transform energy systems and industrial processes, concentrating hydrogen use on socio-economically advantageous applications where more efficient alternatives are unavailable. The government also prioritizes effectively integrating hydrogen into electricity and heating systems to enhance energy security and developing hydrogen infrastructure in a way that supports climate transition while protecting competitive electricity prices.

The current Swedish Government in 2023 assigned the Swedish Energy Agency a role as a coordinator of hydrogen initiatives based on the principles in the agency's strategy proposal. The agency delivered a final report for this task in December 2024, summarising the need for interventions to support and enable the central role for hydrogen in industrial transformation (Swedish Energy Agency, 2024).

4.3 Comparative analysis

4.3.1 Motivation and focal areas

The EU hydrogen strategy is not seen as the main motivation for the national strategies although it is given as reference indicating the size of a future European market. Instead, it is the need for domestic decarbonization that is the main issue for Denmark, Sweden and Finland and a recognition that hydrogen will be an important part of the decarbonization. The importance of EU for enabling an integrated hydrogen market is also stressed in the strategies. The requirements of a hydrogen infrastructure for transportation in EU legislation has been driving the development of strategies for hydrogen infrastructure for transportation. And the importance of the Fit for 55 programme for future demand in Denmark and the EU is specifically mentioned in the Danish strategy.

In all countries, hydrogen is seen as an important part of the climate transition and closely connected to climate policy. The role of hydrogen is expected to be especially important in hard to abate industries, such as the steel industry, and in those parts of transport where direct use of electricity is less feasible. Hydrogen is presented as an important part of a green economic development both as enabling production of green products and the potential of exporting green technologies including power-to-X technologies. The role of companies that develop such technologies is stressed in several of the strategies.

In Denmark, Finland and Sweden focus is on hydrogen produced through electrolysis. Hydrogen is here seen as closely connected to a perspective of the electrification of society as a key climate strategy. The most recent energy bill from the Swedish government states that all fossil free electricity can contribute to hydrogen production through electrolysis, i.e. not only renewable electricity. This statement should be seen in the light of the pro-nuclear stance of the current government. In Norway, hydrogen from electrolysis is also a part of the strategy but here blue hydrogen (produced from natural gas with CCS) is also expected to be an important alternative.

4.3.2 Hydrogen applications and value chain connections

The Danish hydrogen strategy directly relates to an existing electrification strategy in which targets for electrolysis are presented. The same goes for the Swedish case. A commonly identified obstacle for hydrogen is the availability of electricity infrastructure but also institutional aspects are highlighted. However, in the Danish strategy it is explicitly stated that it is in general more efficient to use electricity directly than through hydrogen or hydrogen carriers. Nevertheless, it is noted that hydrogen can be advantageous for many applications.

In all countries, wind power is seen as a key part of increased electrification but nuclear is an alternative both in Sweden and Finland. Especially Denmark highlights its significant potential for offshore wind power production as a major advantage. Worth noting is that at the time the hydrogen strategy proposal was presented by the Swedish Energy Agency in 2021 the ruling government did not foresee a major expansion of nuclear as a relevant alternative. The new government that came into power in autumn 2022 on the other hand view new nuclear power plants as essential for a large-scale electrification and thus also for hydrogen production. Norway as a significant fossil fuel producer, differs from the other Nordic countries as it sees natural gas as an important source.

Electrification means a need for increased production, transmission, and distribution capacity in the electricity system. A major challenge highlighted in the strategies is the need for expansion of electricity production and transmission capacity. Denmark notes the need for reformations of pricing on the electricity market.

In the Danish strategy it is suggested that hydrogen production facilities should be localised close to electricity production. This is regarded to be more efficient than placing them close to the user. In the strategies of the other countries, localisation issues are not specifically stressed. In these countries where the distances are longer location close to significant consumers such as steel production plants could be seen as a more viable option. There is also a discussion whether the localisation strategy could differ between an initial phase with relatively low diffusion when more local production near consumption could be motivated also awaiting for the development of more large-scale distribution.

A general conclusion drawn in the strategies is that where electricity can be used directly, it is regarded as more efficient than going through hydrogen. Hydrogen's role for balancing the electricity system is also regarded an important option as it can support handling a large-scale expansion of variable electricity production. It is also noticed that storage and transportation is easier for hydrogen compared to electricity which could motivate hydrogen compared to direct use of electricity.

In the strategies not only direct use of hydrogen is discussed but also indirect use as e-fuels for example in the form of methanol and ammonium. The use for maritime transport is highlighted in several of the strategies. The reason for that is that liquid fuels are expected to be simpler to store and transport and liquid derivatives are therefore relevant for the transportation sector, especially for aviation, maritime transport, and heavy-duty vehicles.

The direct export of hydrogen does not play a predominant role in the strategies with the exception of Norway. Most focus is instead on domestic use. In Denmark the role of exporting fuels is highlighted but even more the role of Danish companies in the value chain and as a provider of key technologies. It is generally assumed that it is better that hydrogen is used domestically within industry in order to capture a large fraction of a low carbon value chain at home. Hydrogen would enable business actors to turn into competitive low carbon companies and thereby contribute to economic development and growth. In Finland focus is for use in industry, transport and electricity system. Domestic use is prioritized as it increases value added of hydrogen use and is seen as the most efficient way to contribute to a low carbon society. Export of hydrogen and electro-fuels is expected to be of secondary interest. In the Swedish energy bill it is explicitly mentioned that governmental support to production of hydrogen and electro-fuels should primarily be given where the use meets domestic demands and contributes to an industrial transition domestically.

4.3.3 Policy targets

The type of policy targets stressed in the strategies varies among the countries. Quantitative targets in terms of production or production capacity are presented in Denmark, Sweden and Finland, see Table 2. The Swedish and Danish target are of similar size and five times bigger than the Finnish target. The Swedish goals are presented as planning goals which does not necessarily imply that the targets are something that Sweden should strive to achieve, but that the Swedish policy should develop such conditions that would make it possible to achieve the targets *if* actors want to build such hydrogen production capacity in Sweden. In addition, the new Finnish government in its general strategy stated that Finland aims to account for 10 per cent of the EU's clean hydrogen production.

In the proposal for a Swedish hydrogen strategy the planning goals will correspond to an electricity demand of 22-42 TWh in 2030 and 66-126 TWh in 2045 depending on how they are used (Swedish Energy Agency, 2021). The lower level corresponds to a 50% utilisation factor and the higher to a 95% utilisation factor. These demands could be compared to current electricity demand that was 138 TWh in 2022.

Norway has not presented any quantitative targets in terms of hydrogen production or production capacity. It has, however, in its roadmap from 2021 (Norwegian Government, 2021) instead proposed targets in terms of number of facilities of different kinds, see table 2.

Table 2 Policy targets presented in the Nordic Hydrogen Strategies. The Swedish strategy refers to the proposal from the Swedish Energy Agency.

	2025	2030	2045	No date
Denmark		4-6 GW electrolysis capacity		
Finland	200 MW electrolyis capacity	1 GW electrolysis capacity 3% of transport fuels consist of electro fuels.		Contribute to 10% of EU hydrogen production and simliar level of use
Sweden		5 GW electrolysis capacity	15 GW electrolysis capacity	
Norway	5 hydrogen hubs for maritime transport 1-2 industrial projects combined with hydrogen production facilities 5-10 pilot plants for demonstration of new and more cost efficient hydrogen production.	Establishment of a network of hydrogen hubs Hydrogen should be a competitive alterantive for domestic shipping Realisation of full scale industrial hydrogen projects Hydrogen should be competitive with fossil fuels for energy purposes Norway should be connected to the European hydrogen market		

4.3.4 Policy interventions in the strategies

The strategies consist of several policy interventions, of which only some are concretely presented, summarised in Table 3. Many of the measures presented in the strategies are relatively vague in terms of exactly what the governments intend to do. Instead, they indicate fields that the governments judge to be important. The main approach seems to be that the role of the government is to create an environment that makes it attractive for various actors to develop hydrogen systems, whenever they see it would be commercially viable. The role of the state is not to drive transition but rather support it. One way to do this is by facilitating cooperation both at the EU and the national level. Another key approach is supporting research, development, and innovation.

Only the Danish and Finnish strategies specify domestic funding. The levels of funding are of the same magnitude. In addition, Denmark will try to allocate some EU-funding specifically to green technologies and especially to Power-to-X technologies. The Swedish strategy suggests that financial support should be given to actors that apply for EU funding.

Adaptations of existing regulation, policy instruments and standards are suggested in all strategies. Although many of them are formulated in rather general terms (that new instruments should be evaluated or that unspecified support should be given to hydrogen) there are also some concrete suggestions, for example to allow public actors to own and operate hydrogen infrastructure (DK), allow geographically differentiated consumption tariffs (DK), include synthetic fuels in fuel distribution obligation (FI), investigate the use of CCfD (FI), review and revise safety regulation (FI, SE), and develop a price regulation system for the hydrogen distribution network (SE). In addition, spatial planning and permitting processes have to be developed in order to allow for more hydrogen production. The problems are not always related to the hydrogen production itself but to the need for more electricity production, transmission and distribution networks.

Table 3 Main policy measures presented in the Nordic hydrogen strategies and/or related government positions.

	Resarch, development, innovation	Domestic regulation	Investments and other economic incentives	International context	Value chain
Denmark	*Enter into dialogue with the European Commission on allocating DKK 344 million (44 million Euro) of REACT-EU funds and the Just Transition Fund to establish a national investment funding scheme for innovative green key technologies with a particular focus on PtX and hydrogen. *Improve access to venture capital, including Danish businesses' access to export financing, with a view to supporting the commercial development of PtX technologies and products both in Denmark and abroad.	*Initiate a 360-degree review of Denmark's legislation in relation to hydrogen. *Develop a national regulation for a Danish hydrogen market. *Give Energinet and Evida the possibility to own and operate hydrogen infrastructure. *Act on the recommendations from the South Jutland growth team to establish a commercial beacon for green energy and sectoral linking. *Provide the option for geographically differentiated consumption tariffs. This can provide a financial incentive to choose appropriate locations in the electricity grid for PtX plants and thereby contribute to more efficient use of the electricity grid.	*Invest DKK 1.25 billion (165 million Euro) towards operating support for the production of hydrogen and other PtX products.	*Push for ambitious, pan-European requirements for CO2 intensity reduction targets in the negotiations on the EU Commission's "Fit for 55" package, including in the shipping sector. *Push for higher pan-European sub-requirements for PtX fuels in aviation, as well as the option for individual Member States to set higher national requirements. * Work to create clear and uniform rules in connection with European certification for green hydrogen and biogenic sustainable CO2. *Support the export of hydrogen and PtX products by creating the framework for a	*Initiate an analysis of biological resources for the green transition. *Support Danish businesses' exports of hydrogen technologies and PtX technology and work to attract foreign investment in Danish PtX projects.

		*Create an application-based scheme for establishing direct links between major electricity consumers and electricity producers, e.g. between a PtX plant and a wind farm/solar park, when deemed socio-economically beneficial to do so.		hydrogen infrastructure that can eventually be linked to a common European hydrogen infrastructure.	
Finland	*150 million Euro allocated funding for hydrogen or CCU projects *Support for new solutions and demonstration projects for system integration. *Support for pilot project to test hydrogen for transport, especially in heavy road transport and maritime transport *Support technology development for CCS/CCU and regulation effort within the EU *RD&D Support *Arrange pilot project for CCS/CCU in waste combustion facilities	*Electrofuels included in distribution obligation for transport fuels from 2023 *Regulation supporting infrastructure development *Revision of safety regulation* Investigate a possible use for CCfD contracts * Develop safety regulation	*Support the development of hydrogen transmission and distribution infrastructure by utilising EU funding *Contribute to risk sharing	*Active participation in the development of an EU hydrogen market *Participation in the hydrogen cooperation of the IEA. *Assignatory to a hydrogen manifest to contribute to the hydrogen-IPCEI process.	*Comprehensive preparation along the value chain in order to implement hydrogen solutions when commercially feasible. *Prepare national, coordinated hydrogen networks
Norway	*Support necessary technology development	*Action plan for more climate and	*The government has the ambition to support	*Make it easier to participate in	*Broad support for zero emission vehicles

	through existing policy instruments. *Support for RD&D through relevant programmes *Develop technologies for carbon capture and storage *Strengthen research for low emission society	environmental friendlig public procurement. *Develop regulation and standards for hydrogen solutions *Ensure that the maritime agencies have competence to support green shipping. *Evaluate policy instruments for future hydrogen expansion	hydrogen production in order to meet 2030 demand *Support the establishment of blue hydrogen	international fora in order to support and establish low emission solutions *Contribute to a European market through participation in relevant fora. *Aim that Norwegian projects as soon as possible will be able to participate in the European tender within the Innovation Fund.	including hydrogen vehicles *Support for hydrogen in heavy duty vehicles and ships through the zero emisson fund. *Support for fueling infrastructure through ENOVA. *Mapping of ferry lines for identifying potential users of hydrogen. *The governemnt will contribute to build a coherent value chain for hydrogen *Map the market potential for hydrogen and the potential role for hydrogen export.
Sweden	*Mapping and dimensioning of existing tools for research and innovation *Long-term competence supply for fossil free hydrogen, electro fuels and ammonia. *Increased information and guidance for EU research and innovation for Swedish actors *Increased research cooperation with Nordic countries.	* Develop economic regulation for hydrogen pipelines *Investigation of a planning system for hydrogen in an integrated energy system *Regulation on hydrogen should be investigated and adapted with a focus on safety issues *Investigate how regulation can be adapted to encourage	*Economic support for Swedish actors that wants to apply for EU-funding *Mapping of overlaps between existing support systems	*Increase Nordic, EU, and international cooperation *Sweden shall participiate actively in standardisation work in EU and participate in negotiation in sustainability criteria and origin labelling of hydrogen	*Develop a dialogue platform between companies, trade organisations, *Easily accessible instructions for producers, installers, and users. *National guidance for hydrogen facilities have to be developed. *Start a working group of actors for investigating specific hydrogen projects.

		hydrogen as a flexibility resource for the electricity system. *Permitting process for hydrogen and electricity facilities have to be more efficient *Tools for better planning, co-existence, and local acceptance of new electricity production have to be developed. *Review the guidance for reserve power in order to enable the use of renewable sources and fuels cells for this purpose. *Investigation of the needs for new policy instruments			

4.3.5 Implementation

Since the presentation of the strategies several government activities have taken place in the different countries with most rapid developments taking place in Denmark, where the state-owned transmission and distribution companies carried out a market dialogue during 2022, in order to identify existing plans in terms of both future production capacity and demand. The result indicates that plans for production expansion were larger than the plans for increased demand which would indicate a significant export potential, see section 3.2.1.

The results of the market dialogue were used as input to an analysis of the need for transmission infrastructure in the future carried out by Energinet. To facilitate the expansion of Power-to-X the government presented a bill that includes two important revisions of the current electricity regulations. First, the reform includes to make it legal to build direct electric power lines between producers and consumers at power levels higher than 10 kV. That would support both Power-to-X and make the use of the public net more efficient. Second, the proposal will make it legal to have geographically differentiated transmission tariffs. The intention with that is to give incentives for localising Power-to-X facilities more efficiently considering the actual electricity balance in different geographical areas. In 2023, there was a broad agreement in the Danish parliament regarding the ownership of hydrogen infrastructure. It was concluded that it should be publicly owned by the companies Energinet and ENOVA.

The Danish and German energy ministers in March 2023 signed a letter of intention regarding hydrogen distribution infrastructure across the Danish-German border in the form of a pipeline. The intention was that the infrastructure should be in place in 2028. The letter of intention was followed up with a cooperation agreement between the Danish transmitter Energnet and the North German TSO Gasunie (Energinet, 2024).

In Sweden the Swedish Energy Agency has completed its task to coordinate the work with hydrogen, including an actor dialogue, cooperation and coordination among public agencies, information and knowledge diffusion. The future for strategic work in the hydrogen space is at the end of 2024 uncertain although other programs that support specific hydrogen initiatives continue. Filling stations for hydrogen will be financed through a variety of national and European subsidy systems such as Klimatklivet, regional pilots for electrification and EU-support through the Greater 4H and Nordic Hydrogen Corridor programmes. The Swedish and Finnish gas TSO:s (Nordion and Gasgrid Fi) are in turn planning an integrated hydrogen network in Northern Sweden and Northern Finland.

In Finland Gasgrid Finland has started a subsidiary company for the future hydrogen grid and hydrogen has also been included in the distribution obligation regulation for fuels from 2023. There is a temporary preferred treatment for green investments in permitting processes and allocations of funds to hydrogen from the ministerial group for civil preparedness.

In Norway a joint declaration on cooperation in the hydrogen field was made together with Germany in 2023. The intention is to secure hydrogen supply from Norway to Germany before 2030, although this now seems unlikely after the cancellation of key projects, see chapter 5. The declaration has been followed by a feasibility study carried out by the industry. An alternative to hydrogen supply would be to supply Germany with natural gas and then provide an opportunity to take care of CO2 from carbon capture and transport it as gas back to Norway and deposit it there.

The government has commissioned an external study regarding how the state can support the development of a hydrogen value chain and part of the budget settlement in 2022 was an agreement that the government should propose a CfD system for hydrogen – although this has not yet been presented.

4.3.6 Key Differences and Similarities

All countries see a connection between electrification and the expansion of hydrogen. Norway, however, stands out as it also highlights natural gas, combined with CCS, as an interesting option. This difference is not difficult to understand as Norway today is one of the main exporters of natural gas in Europe, a role that has grown in strategic importance following the Russian invasion of Ukraine. Whereas electricity-based hydrogen calls for measures supporting production, transmission and distribution of electricity (e.g. more efficient permitting processes), Norway stresses the need for improving the opportunities for utilising CCS.

All countries, except Norway, have set quantitative targets for increased electrolyser capacity. There are, however, no quantitative targets on the demand side, e.g. with regard to transport infrastructure, filling station for transport etc. Here, the countries are partly steered by the EU directive, see below.

As all strategies, except for the Finnish, are older than some of the revised EU directives they don't discuss how these should be implemented with regard to i) infrastructure or ii) the requirements for green hydrogen in industry (RED II).

All countries argue for the use of hydrogen mostly where it is most efficiently used. This is argued to be in hard-to-abate industries, vehicles where direct use of electricity is less feasible (heavy road transport, maritime transport and aviation) and as balancing power for the electricity system.

Whereas export is seen to be an interesting option for Norway, Finland and Denmark due to major natural gas resources (Norway) or wind (Denmark and Finland) export of hydrogen is not highlighted in the Swedish strategies. Although also Sweden sees a significant potential for fossil free electricity and hydrogen this is mainly expected to be used domestically as the potential demand in industry is expected to be very high and focus is on removing the obstacles for supplying this demand.

The economic value of hydrogen primarily comes, according to several of the countries, from producing high-value low carbon products, i.e. enabling the preservation of a competitive business sector in a carbon-restricted environment. That does not hinder that there might be some room for export also when the domestic demand has been fulfilled. The cooperation with Germany with regard to hydrogen infrastructure indicate that both Norway and Denmark see themselves as potential exporters in the future.

Much of the strategies are focusing on research, standardisation, etc. The state is mainly seen as an enabler making it possible for businesses, that regard it profitable, to develop hydrogen businesses. Ownership of hydrogen transmission is also seen as a role for publicly owned companies.

5 The emerging map of Nordic hydrogen initiatives

Denmark, Finland, Norway, and Sweden are often collated together as 'The Nordics' from outside the region, especially in the realm of governing a low-carbon transition. This is due to their well-established transboundary partnerships and pioneering progress in implementing renewable technologies and decarbonisation measures (Pedersen et al., 2022). However, this uniformity is not found in the context of hydrogen, where each country differs greatly in their scope of ambition, with high levels of uncertainty around production capacity and potential for export, in both hydrogen and its numerous derivatives.

5.1 Cumulative developments in the Nordic region

The IEA database on hydrogen projects identifies 224 entries accredited to the Nordic countries, across a wide range of project maturity (IEA, 2024b). Many of them are at the concept level or represent demonstration and feasibility studies. 57 of the projects have reached a final investment decision (FID) and are either near to breaking ground, are under construction, or are already operational. Based on the IEA's normalised calculations of potential output, these 57 projects could cumulatively amount to 346.8ktH2/yr of production. The vast majority of these projects are green hydrogen projects with only a miniscule 0.4ktH2/yr of the total classified as a blue hydrogen project, located in Norway.

When taking into account the projected output of the demonstrations and feasibility studies found on the IEA radar, it is clear that Norway has a strong preference for blue hydrogen uptake in comparison to the rest of the Nordics. Across 93 projects under consideration for rapid expansion that had at least 0.1ktH2/yr of production envisioned, there is a cumulative 4,022ktH2/yr of potential if all projects come to fruition. However, many feasibility studies and technological demonstrations do not result in a scaled-up operation (Leader Associates, 2024), and as has been witnessed in the realm of the hopeful hydrogen economy, even projects that have passed FID have been mothballed or have not reached their desired capacity, at least not within the projected timeframe as evidenced by the cancellations and delays of several hydrogen projects in the Nordic countries in 2024 (Gronholt-Pedersen, 2024; Reuters, 2024b, 2024c, 2024a). Nevertheless, by mapping the projected capacity from the demonstrations and feasibility studies across the Nordics, it is possible to identify trends and preferences between blue and green hydrogen and to look into which stakeholders are involved to give an indication of which end-use sectors are anticipating a hydrogen demand sufficient enough to warrant these studies and pilot programmes. An expectation for blue hydrogen is near non-existent across Denmark, Finland, and Sweden. However, in Norway, there is seemingly substantial appetite in ramping up production for the purposes of decarbonising industry, both within Norway and via export to the EU as clearly detailed in Figure 2, where Norway's interest in blue hydrogen is a clear outlier in the Nordics. Banking on blue hydrogen exports encounters offtake risks as there is still considerable scepticism throughout the EU, not least in Germany, although the resistance seems less rigid in the aftermath of the Russian invasion of Ukraine and subsequent efforts to reduce the dependence on Russian-supplied gas (Gehrung et al., 2023; Kurmayer, 2023).

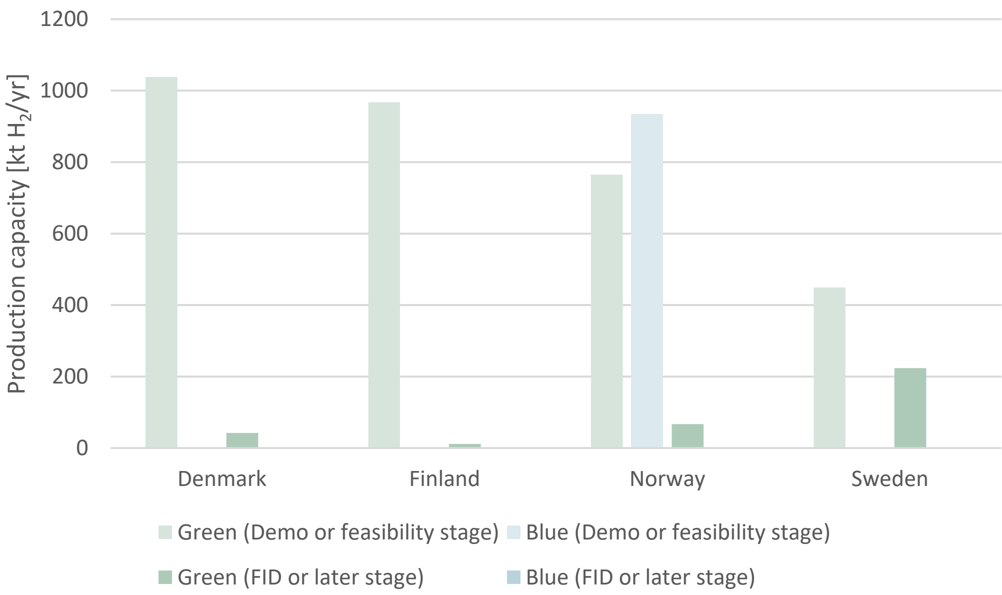

Figure 2 Hydrogen production in announced projects. The graph shows that there is a large volume of hydrogen production in projects currently at the demo or feasibility stage, whereas projects that have reached final investment decisions (FID) or later stages are scarce. Blue hydrogen projects are only announced in Norway. Based on data from (IEA, 2024b)

A mapping of the end-use sectors for green hydrogen based on present demonstrations and feasibility studies displays a more varied spread across countries and sectors, as shown in Figure 3. With the hydrogen economy still in its infancy, the majority of projects do not possess offtake agreements, nor the subsidiary steps such as letters of intent or memorandums of understanding. Due to this, the authors of this report have chosen to include three broad types of fuel, three variations of industry, and simply hydrogen as end-use sectors based on the publicly available information associated with each given project. Most of these products can be utilised in multiple sectors such as ammonia production being simultaneously considered as a valuable alternative in the decarbonisation of shipping and fertiliser production. Yara's green hydrogen plant at Herøya for example has started delivering the first tonnes of fertiliser made from green ammonia, declaring it a major step towards decarbonising fertiliser production as well as shipping fuel and energy intensive industries (Yara International, 2024).

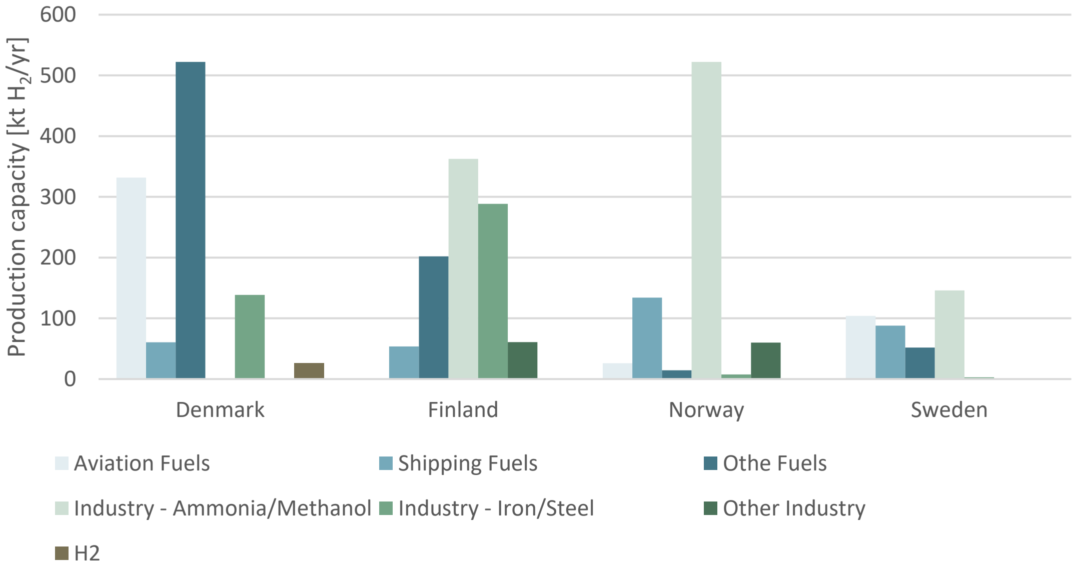

Figure 3 Green hydrogen production capacity from projects in demo or feasibility stage. Anticipated supply capacity from green hydrogen projects in the Nordic countries by end-use sector, as mapped by authors. Based on data from (IEA, 2024b).

As for green hydrogen projects that have surpassed FID, the take-off of fossil-free Swedish steel dominates the share of the figures, accounting for 64% of output across all countries combined. Although there are 57 projects that have now reached FID, the output of these projects is at a quantity not far ahead of prototype level, with the obvious exception of Swedish steel. Projects are often the first of multiple phases in a projected infrastructural pipeline, with more grandiose output expectations, as witnessable in the projects at concept or demonstration stage. The anticipated output from green hydrogen for the purposes of producing ammonia and methanol and across an assortment of fuels holds significant potential if these burgeoning projects come to the fore.

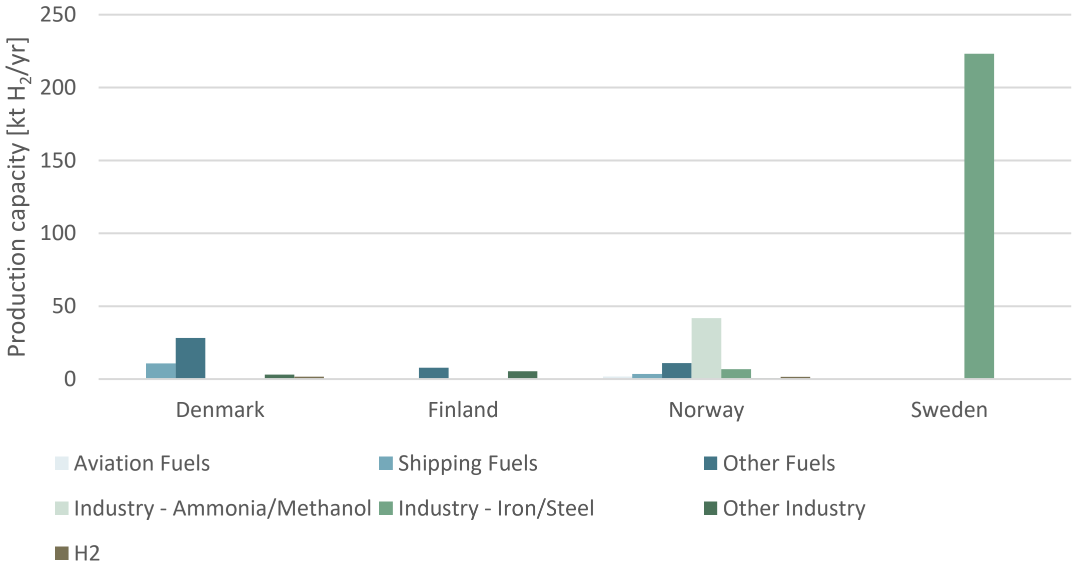

Figure 4 Green hydrogen production capacity from projects in FID or later stages. Anticipated supply capacity from green hydrogen projects in the Nordic countries by end-use sector, as mapped by authors. Based on data from (IEA, 2024b).

Hydrogen is certainly considered to be a component of decarbonising a slew of hard-to-abate sectors in the Nordics. Heavy industry, land transport, aviation, and shipping are all segments of the economy that can potentially reduce their emissions footprint with the help of low-carbon hydrogen. However, the extent of hydrogen production and its potential export from the Nordics to Europe is contingent on a rapid acceleration in bringing integrated infrastructure online with a fast-tracking of due diligence procedures coupled with sufficient commercial incentives for would-be investors to back the early movers in the industry.

5.2 Individual developments in the Nordic region

Here is a breakdown of hydrogen markets in individual Nordic countries based upon government strategies and policies.

5.2.1 Denmark

Much of the Danish-based projects look to be ‘green hydrogen’ predicated on an envisaged over-supply of renewable energy in the coming decades (Danish Government, 2021a) that will feasibly allow for large-scale production and consequently export of hydrogen (Energinet and Gasunie, 2023). According to the publicly owned national transmission system operator, Denmark could have an oversupply of green hydrogen to the extent that they could export 15TWh by 2030 increasing to 79TWh by 2050. Thus, being capable of making a significant contribution to meeting Germany’s projected demand. Depending on the scenarios in the demand forecast featured in Germany's Import Strategy for hydrogen and hydrogen derivates (German Federal Government, 2024), 2030 demand will necessitate between 45 – 90TWh of imported hydrogen.

The German-Danish collaboration agreement of 2023 might have indicated that the implementation of an EU-based Hydrogen roadmap is well-underway but this was dealt a blow when system operator Energinet postponed the planned commissioning date for the first cross-border hydrogen pipeline into Germany from 2028 to the end of 2031 (Energinet, 2024). Energinet declared that the land-based pipeline project is more complex than expected from a technical and market perspective, that more time is needed because of changes to the capacity bidding process, and that there are longer planning and environmental permit processes. In the near-term, Denmark looks to export the necessary expertise in connection with P2X as well as other physical elements such as electrolysis units, conversion plants, ammonia engines for ships, and hydrogen trucks (Danish Government, 2021a).

5.2.2 Sweden

Sweden finds itself in a similar context as Finland where ramped up green hydrogen capacity is sought but is mostly predicated on the production of high-value derivatives, namely steel (Ćetković and Stockburger, 2024). HYBRIT has amassed great excitement with the prototyping of carbon-neutral steel, as well as significant streams of financing from public and corporate actors alike. The caveat to this is that the renewable energy demand for producing hydrogen is huge given that producing hydrogen from electricity has an efficiency of between 38-55% (Agora Energiewende and Agora Industry, 2024) and thus the envisioned production of derivatives such as steel and synfuels carries a weighty energy penalty and will require a historic grid-capacity addition (Kushnir et al., 2020).

Ørsted cancelled the FlagshipONE 50ktpa e-methanol project in Sweden, which it had acquired from Liquid Wind, citing a lack of long-term offtake agreements (Gronholt-Pedersen, 2024). Liquid Wind is developing two other similar projects, FlagshipTWO and FlagshipTHREE, each targeting an annual production of 100kt of e-methanol, with operations expected to commence before 2030. However, as the company shifts its focus toward hydrogen, the successful completion of these projects remains uncertain (IEA, 2024a). Sweden's HySkies SAF project has taken a blow with Shell retreating from the collaboration with Vattenfall and returning the funds received from the EU Innovation Fund (Sjöberg, 2024), leaving the project's future uncertain.

It remains unlikely that Sweden will pursue additional green hydrogen capacity to warrant transboundary transport and storage infrastructure necessary for export. Therefore, its focus looks set to remain on refining industrial processes within its own borders, as is also expressed in the hydrogen strategy proposal developed by Swedish industries in the public-private partnership initiative Fossil free Sweden (Fossilfritt Sverige, 2021).

5.2.3 Norway

Norway identified blue hydrogen as relevant in several sectors as part of the transition to a low-emission society in its hydrogen strategy (Norwegian Government, 2020). This preference for blue hydrogen is driven by the possibility to utilise existing gas reserves and infrastructure. It is recognised that envisioned markets capable of large offtakes in Europe, particularly Germany, have a strong preference for green hydrogen rather than blue. However, recent volatility in gas markets has led to a cautious acceptance of blue hydrogen as a temporary solution (DNV, 2023). Temporary is the key term in this context as we will investigate here.

Norway has an opportunity to supply blue hydrogen to Europe by the mid-2030s, switching to green hydrogen by the 2040s. The European demand for low-carbon hydrogen coupled with existing natural gas pipeline infrastructure which may be repurposed for transporting hydrogen acts as a strong incentivisation for Norway to ramp up its blue hydrogen capacity, followed by green hydrogen when an oversupply of electricity generation is envisaged (DNV, 2023).

The short to medium-term focus is on blue hydrogen accounting for 56% of Norway's hydrogen production by 2035. Another 20% will still come from unabated natural gas-based hydrogen production (DNV, 2023). It is not until around 2050 that the ratio for green versus blue hydrogen export changes drastically for Norway, where 70% will be grid-based, i.e. renewables, with 14% being blue hydrogen, 13% from dedicated wind, and a lingering 2% supplied by grey hydrogen.

A concern for rapid blue hydrogen implementation is that it will not be available in the short-term, not even based on Norwegian gas, given the absence of infrastructure for transporting and permanently storing the captured carbon, and highly efficient carbon capture technologies at scale and reasonable cost are not showing signs of being available soon, thus potentially causing a bottleneck in the industry. These limitations and concerns for the sustainability credentials for blue hydrogen are echoed by RIFS Potsdam's review of Norway's Hydrogen Strategy (Skjærseth et al., 2023).

Thus, Norway finds itself in a paradoxical scenario concerning hydrogen. It purports to be using blue hydrogen as a temporary bridging measure until green hydrogen capacity becomes scalable to outstrip the efficiencies of blue hydrogen. There has been virtually no blue hydrogen production in Norway to date (Skjærseth et al., 2023) and with numerous bottlenecks in the industry being apparent, the temporality of blue hydrogen looks set to be more extensive than perhaps envisaged from a German and European perspective. This merging of short-term and long-term planning with blue hydrogen is exemplified by Norway investing heavily in their Longship and Northern Lights CCS projects (Gassnova, 2024), both of which demand large CAPEX outlays in comparison to the comparably smaller economies of scale associated with the production of green hydrogen.

In the aviation sector, Norwegian Air and Cargolux committed to purchase 140kt of synfuels from Norsk e-Fuel in early 2024 (Norsk e-fuel, 2024). Signalling to the market that there is sufficient appetite for alternatives to conventional jet fuel, this will be seen as a positive step that will bolster the hopes for the second and third phase of the Norsk e-fuel project.

5.2.4 Finland

While hydrogen has not played a significant role in Finnish industry to date, industry actors in the Hydrogen Cluster Finland are optimistic about Finland becoming a European forerunner in the hydrogen economy (Hydrogen Cluster Finland, 2023). Finland currently imports ~40% of all energy used, thus if they are to follow a hydrogen-based pathway to meet net-zero commitments and replace where fossil fuels currently meet demand, there is a gap to fill domestically before production capacity can be ramped up to the stage where exports become commercially viable.

Similar to Sweden, it looks increasingly likely that Finland will focus on green hydrogen technology and derivatives as their primary forms of hydrogen-related export rather than supplying Europe with hydrogen itself (Finnish Government, 2023; Hydrogen Cluster Finland, 2023). The transformation of clean hydrogen into higher-value commodities domestically provides a more lucrative option than large capital investments in the infrastructure required to export pure hydrogen at scale. However, it is notable that even these potentially high-value derivatives are struggling to maintain commercial viability as exemplified by the early conclusion of the FEED study to produce hydrogen-reduced fossil-free sponge iron in Raahe (Fortum, 2023) and Neste scrapping their investment in to renewable hydrogen production at its plant in Porvoo, citing “challenging market conditions” (Reuters, 2024d).

5.3 EU support for hydrogen in the Nordic region

European thinktanks are all optimistic for the role of the Nordics in producing hydrogen with the potential of export but with the careful consideration that there is currently more of a domestic use prioritisation rather than producing for export (European Hydrogen Observatory, 2024b), while the market continues to wait for early-movers (Hydrogen Europe, 2023).

The EU Commission and its financial subsidiaries have been direct with their support in making hydrogen part of the EU’s low-carbon transition. Via the EU’s Clean Hydrogen Partnership (CHP), there are 36 projects in the Nordic countries that have been receiving funding since 2010, with Norway receiving the majority of the funds, receiving over €110m across 21 projects. Funding has been steadily increasing with a large uptick in recent years, as featured in Figure 5, condensing fifteen years into three aggregated five-year periods.

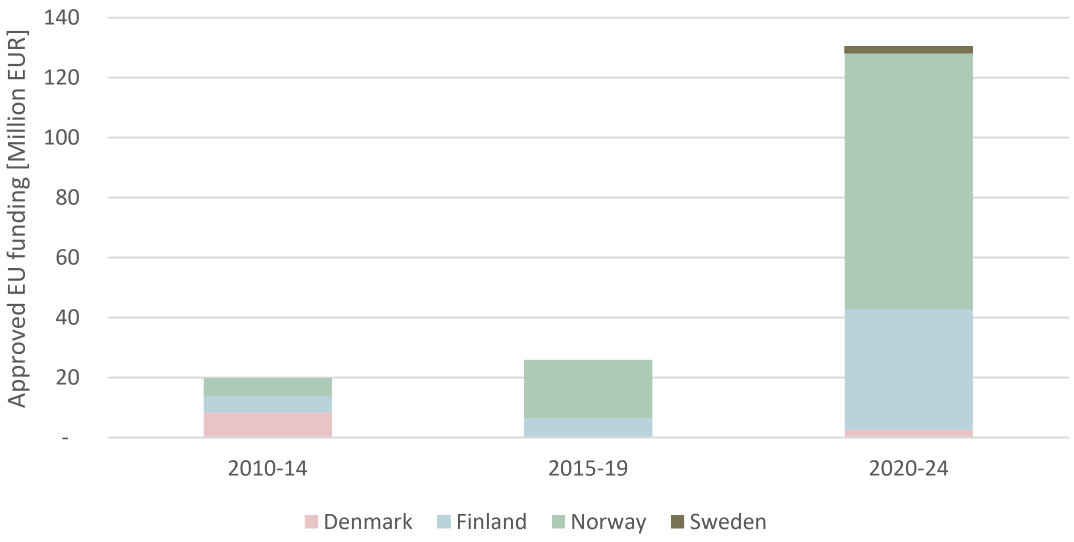

Figure 5 EU Clean Hydrogen Partnership funding to the Nordic countries.

The 36 Nordic CHP projects represent plans that are in the early levels of maturity, dominated by research and development, demonstrations, and feasibility studies. These fledgling projects require extensive external capital, hence the proportionally large input from the EU scheme with a provision of more than two thirds of the projects' overall CAPEX being commonplace, as detailed in Table 4 below.

Table 4 Overview of Nordic hydrogen projects receiving EU funding via the Clean Hydrogen Partnership.

	No. Projects	**EU Funding (M EUR)**	**Contribution to Budget**
Denmark	6	10.94	64 %
Finland	8	51.91	70 %
Norway	21	111.00	76 %
Sweden	1	2.50	71 %

Denmark, Finland, Norway, and Sweden are all signatories to the Important Project of Common European Interest (IPCEI) process for hydrogen, which they are already starting to benefit from in their implementation of preliminary infrastructure necessary to facilitate a hydrogen network. IPCEI Hydrogen consists of four combined clusters of projects from more than half of the European Union member states and Norway. The projects take place in the complete value chain of hydrogen: production, import, transportation as well as end use. This support for accelerating hydrogen is reflected in the growing interest in using Carbon Contracts for Difference (CCfD) as a potential finance mechanism across the Nordic countries.

There are five IPCEI hydrogen-linked projects that are based in one of the Nordics as featured in Table 5. Two of the five projects have already received significant funding from the EU Innovation Fund, with Neste's e-fuels project being awarded 88 M EUR and HYBRIT's novel approach to decarbonising steel production receiving 143 M EUR (European Commission, 2024a).

Table 5 Nordic based hydrogen-linked IPCEI projects.

	Project Name	**Green/Blue**	**IPCEI Funding**	**End use**
Denmark	Ørsted - Green Fuels for Denmark (GFDK) (DK10)	Green	86 M EUR	e-fuels
Finland	P2X Solutions - Green Reindeer (FI08)	Green	Unknown	e-fuels
Finland	Neste (FI05)	Green/Blue	28 M EUR	e-fuels
Norway	Barents Blue Project (NO01)	Blue	48 M EUR	Ammonia
Sweden	HYBRIT Demonstration Project (SE12)	Green	Unknown	Steel

In 2022, the Commission launched the European Hydrogen Bank to create investment security and business opportunities for European and global renewable hydrogen production. It is not designed to be a physical institution, but is a financing instrument, run internally by European Commission service. The first competitive auction awarded more than 700 M EUR to 7 renewable hydrogen projects across Europe under the Innovation Fund (European Commission, 2024b). The successful projects have the ambition of producing 1.58Mt of renewable hydrogen over ten years, potentially avoiding >10Mt of CO_2 emissions compared to conventional practices. The first auction awarded funding to seven projects, two of them located in the Nordics, as featured in Table 6.

Table 6 European Hydrogen Bank Funding awarded to Nordic projects in 2024.

	Project	Coordinator	Production (kt/yr)	Expected GHG avoidance (kt_CO_2/10yrs)	EU Contribution (M EUR)	Output
Finland	eNRG Lahti	Nordic Ren-Gas	12H_2	836	45	Synthetic Methane / Green Hydrogen / District Heating
Norway	SKIGA	Skiga -Fuella	100NH_3	1,159	81	Green Ammonia

These examples display the seed funding being provided by the EU to kickstart the hydrogen economy, with the Nordics being no exception to that. However, despite repeated initial examples of public funding alongside hydrogen pathway conceptualisation from corporate actors , there are few projects that are actually coming to the fore and reaching a level that is deemed commercially attractive.

5.4 The central role of export-enabling infrastructure

For the Nordics, or a portion thereof, to be a reliable source of low-carbon hydrogen for Germany and elsewhere in Europe there must be an integrated infrastructural network to facilitate that. Conceptually, this is more-than-delivered with six hydrogen pipeline projects as featured in Figure 6 below mapped with multiple other hydrogen distribution projects. These six projects are envisaged to link up Nordic points of production with Germany and beyond. However, none of these projects have reached a Final Investment Decision (FID) at the time of writing. Further incentives will be required for suppliers, distributors, and downstream users to sign-up to binding offtake agreements according to industry actors (Hydrogen Europe, 2023).

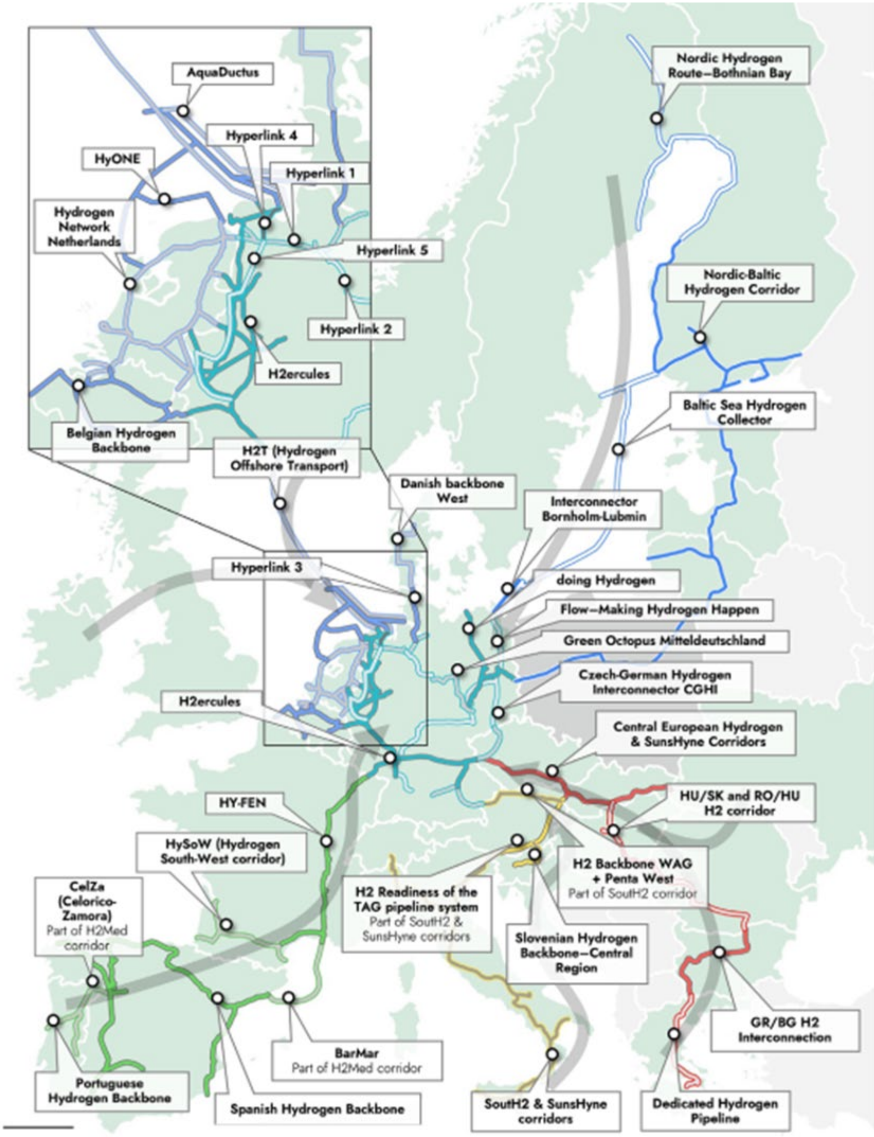

Figure 6 A selection of EHB-affiliated hydrogen transmission projects. Several projects affiliated with the European Hydrogen Backbone initiative are relevant for the Nordic countries and their potential exports, including the Baltic Sea Hydrogen Collector, Danish backbone West and Hyperlink 3, H2T (Hydrogen Offshore Transport), Nordic-Baltic Hydrogen

Corridor, and the Nordic Hydrogen Route-Bothnian Bay. Reprinted with permission from Gas Infrastructure Europe. **All rights reserved.**

The Danish Backbone West, the Hyperlink 3, the Baltic Sea Hydrogen Collector, the Nordic-Baltic Hydrogen Corridor, and the Nordic Hydrogen Route – Bothnian Bay projects have been confirmed as Projects of Common Interest by the European Commission (European Commission, 2023c), exemplifying the faith that the EU Commission holds in the emerging Nordic hydrogen economy. This status provides eligibility for benefiting from streamlined permit-granting, regulatory support, and possible EU financing from the Connecting Europe Facility (CEF). Given the paradoxical finding that Sweden and Finland have not released any figures for anticipated hydrogen export in their hydrogen strategies, or equivalent, it is somewhat surprising to see the Baltic Sea Hydrogen Collector project being a forerunner of the Nordic-related projects.

As of November 2024 the remainder of the Nordic-related pipeline projects are awaiting further incentives to move beyond the stage of conceptualisation and to conduct feasibility and FEED studies and arrange the appropriate permissions and licenses before infrastructural implementation (European Hydrogen Backbone and Gas Infrastructure Europe, 2024).

There is certainly an expectation shared by Germany and the EU that at least Norway and Denmark will be equipped with the capacity to export both blue and green hydrogen at scale. However, there are several caveats that will have to be overcome in order to fulfil Germany's import expectations, as we will explicitly outline here.

5.5 Summary of Nordic Export Potential

Sufficient incentives are required for Nordic countries to think beyond domestic hydrogen usage and to export directly to the rest of Europe, even for Denmark and Norway that are more well-positioned for export potential than Finland and Sweden. Hydrogen derivatives such as steel, synfuels, fertilisers and chemicals possess significant market value and do not require a high level of infrastructural reconfiguration to facilitate their distribution, as would be the case for upscaling hydrogen transport and storage capacity. Memorandums of Understanding and Letters of Intent can provide legitimacy to envisaged hydrogen projects but confirmed offtake agreements are a stronger bet in minimising financial risk for the public and private actors involved.

For blue hydrogen to be a viable export for Germany's industrial needs, it will have to be classified as low-carbon. However, the EU Commission states that low-carbon hydrogen defined as resulting in "at least" 70 percent less greenhouse gas than the liquid fossil fuel benchmark (ECA, 2024), meaning a maximum of 3.38kg CO_2-eq per kg of hydrogen. Only Norway controls upstream methane leaks sufficiently enough to be able to pass the 70% threshold (IEA, 2024a). To adhere to the staggered measures of decarbonisation towards the EU's target of climate neutrality by 2050, modelling suggests that the maximum-emissions threshold for 'low-carbon' hydrogen should be progressively lowered over time from 3kg by 2030, to 2kg by 2040 and 1kg by 2050 (Agora Energiewende and Agora Industry, 2024). This may prove to be an insurmountable target for blue hydrogen given the opportunity for leaks across a protracted value chain as from a life-cycle perspective, it has been contended that 'blue' hydrogen cannot be considered low-carbon unless the release of fugitive methane in the production process is adequately dealt with (Howarth and Jacobson, 2021).

To stave off the threat of 'carbon leakage' and the subsequent threat of stranded assets, there are multiple financial instruments required to protect both suppliers and downstream users of low-carbon hydrogen (German Federal Government, 2024). Carbon Contracts for Difference (CCfD) and the Carbon Border Adjustment Mechanism (CBAM) can work in conjunction with one another to protect domestic and interregional hydrogen value chains. Germany has implemented a CCfD but remains alone in the commitment to ambition as the Nordics have simply considered the idea at present.

6 Concluding discussion

The Nordic hydrogen landscape presents an emerging picture of the low-carbon energy transformation. Current developments reveal both promising opportunities and significant challenges in establishing a robust hydrogen ecosystem. The hydrogen (or hydrogen relevant) governmental strategies reveal a nuanced and strategically diverse approach to low-carbon energy transformation, reflecting distinct national priorities while sharing overarching decarbonization goals.

Each Nordic country demonstrates a unique hydrogen strategy, with common threads of domestic decarbonization and industrial transformation. Denmark, Finland, and Sweden predominantly focus on green hydrogen through electrolysis, closely linking hydrogen development to broader electrification strategies. Norway stands out with its dual approach, embracing both electrolysis and blue hydrogen production, strategically leveraging its natural gas resources.

Hydrogen is primarily viewed as a critical solution for hard-to-abate industries, particularly in sectors where direct electrification is challenging. Maritime transport, heavy-duty vehicles, and industrial processes like steel production are identified as key application areas. The strategies unanimously emphasize that hydrogen should be deployed where it provides the most significant decarbonization and economic value, rather than as a universal energy solution.

Governments are positioning themselves as enablers rather than direct drivers of the hydrogen economy. The primary policy interventions focus on creating attractive investment environments, supporting research, development, and innovation, facilitating cross-sector and international collaborations, and developing supportive regulatory frameworks.

While direct hydrogen export is not a primary objective for most countries, there is recognition of potential export opportunities, particularly for Denmark and Norway. The strategies prioritize domestic value creation, viewing hydrogen as a mechanism to transform domestic industries into competitive, low-carbon enterprises. An important difference is the focus on green hydrogen in Denmark, whereas Norway sees a greater export potential for blue hydrogen.

The International Energy Agency's database identifies 224 hydrogen projects across Nordic countries, with 57 projects having reached final investment decision (FID). A very high uncertainty remains regarding the realisation of all announced projects, as evidenced by the delay or cancellation of several high-profile projects in 2024.

The hydrogen economy is emerging as a critical pathway for decarbonizing hard-to-abate sectors, including heavy industry, transportation, and maritime applications. Swedish fossil-free steel production represents a very large share of the downstream use of planned hydrogen in the region. The versatility of hydrogen derivatives—such as ammonia, methanol, and synthetic fuels—further underscores its potential across multiple industries.

While European stakeholders are optimistic about the Nordic region's hydrogen production potential, substantial infrastructural and regulatory challenges remain. Critical factors include expanding electricity production and transmission capacities, developing efficient hydrogen distribution networks, establishing credible offtake agreements, creating sufficient commercial incentives for investors and addressing complex spatial planning, permitting processes, and other regulatory barriers. It is thus highly questionable if the envisioned potential for producing hydrogen in the Nordic region for export to continental Europe can be fulfilled, and in fact if there is even a matching interest in the Nordic countries to do so.

The Nordic hydrogen strategies reflect a pragmatic, incremental approach to energy transition. The region's hydrogen ambitions will ultimately depend on rapidly accelerating infrastructure development, streamlining regulatory processes, and maintaining competitive investment environments. The next few years will be crucial in determining whether the Nordic countries can transform their hydrogen potential into a meaningful low-carbon energy strategy able to deliver in the 2030s.

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