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Market Assessment

Denmark's potential in a future hydrogen economy

March 2023

Preface

With this market assessment, the CIP Foundation intends to demonstrate how Denmark can contribute to Europe's green transition by joining the growing market for green hydrogen. With green energy being in short supply, Denmark is in a unique position to make a notable contribution to the energy independence and the transition of our nearest neighbours.

This is concluded by the CIP Foundation's market assessment, which estimates the extent of Denmark's green hydrogen potential as well as the significance of capturing this potential to Danish exports.

At the CIP Foundation we have set ourselves an ambitious target: We want to see to it that the next generation will experience a wealthy, sustainable Denmark with a 100% green agricultural and food sector; a public sector using intelligent, digital solutions; a future-proof infrastructure; and a coherent society.

In the autumn of 2022, the CIP Foundation launched a project with the ambition to present a plan for rolling out a coherent hydrogen and Power-to-X (PtX) infrastructure in Denmark. The intention of the plan is to support the expansion of renewable energy and Danish exports, strengthen Denmark's green lead and contribute to the reliability of supply and energy independence in Europe.

As part of the project, the CIP Foundation has produced this market assessment with the intention to qualify Denmark's options in a hastily growing hydrogen economy. Our assessment compares the demand of our neighbouring countries for green hydrogen and our own production options and expected consumption in order to provide an indication of the hydrogen market of the future and the role that Denmark might play – from a short-term as well as a long-term perspective.

The market assessment provides a unique insight into core features of the future Northern European hydrogen market. The market assessment should be understood as an evaluation of the future market for hydrogen and Denmark's possibilities for meeting the demands of this market.

According to the market assessment, Denmark has the potential to become a large exporter of hydrogen and to play a key role in the efforts to lower the CO2 footprint in our neighbouring countries. Achieving this will require timely action and expansion of both renewable energy and infrastructure.

In May 2023, the CIP Foundation will present a plan for a coherent hydrogen and PtX infrastructure in Denmark.

It is our hope that the market assessment will be read in the light of the intention with which it was written.

Enjoy the read.

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Chairman of the CIP Foundation

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Summary

Denmark will benefit from planning a hydrogen infrastructure with interconnectors to neighbouring countries

This is the main message from a market assessment conducted by the CIP Foundation. The market assessment concludes that there is a large, potentially unmet demand for green hydrogen from our closest neighbours and that Denmark has the potential to become a major hydrogen exporter. However, the potential may never materialise if action is not taken, and the necessary political decisions not made now. A hydrogen infrastructure connected to neighbouring countries will contribute to ensuring energy independence, making Europe greener and making Denmark richer.

HYDROGEN PLAYS A CENTRAL ROLE IN THE GREEN TRANSITION

European climate goals and desire for energy independence will drive a fundamental transformation of the energy system towards 2050. The expansion of volatile, renewable energy resources will be significant, and green hydrogen based on renewable energy will play a pivotal role in balancing the electricity system as well as in the transformation of European industry, agriculture, aviation, and shipping. Green hydrogen will replace traditional fossil fuels – either directly or refined as Power-to-X products.

THE EU WILL PRODUCE AND IMPORT HYDROGEN

With increased consumption of hydrogen from renewable sources, a new green energy market will emerge. The EU plans to produce 10 million tonnes of hydrogen per year by 2030 and has a goal of importing equivalent amounts from outside the EU, corresponding to a total EU consumption of up to 700 TWh. The next few years will be crucial in determining who gets to supply this market.

It will not only be up to private actors, but rather countries that create the best framework for the expansion of renewable energy and electrolysis capacity and ensure easy market access.

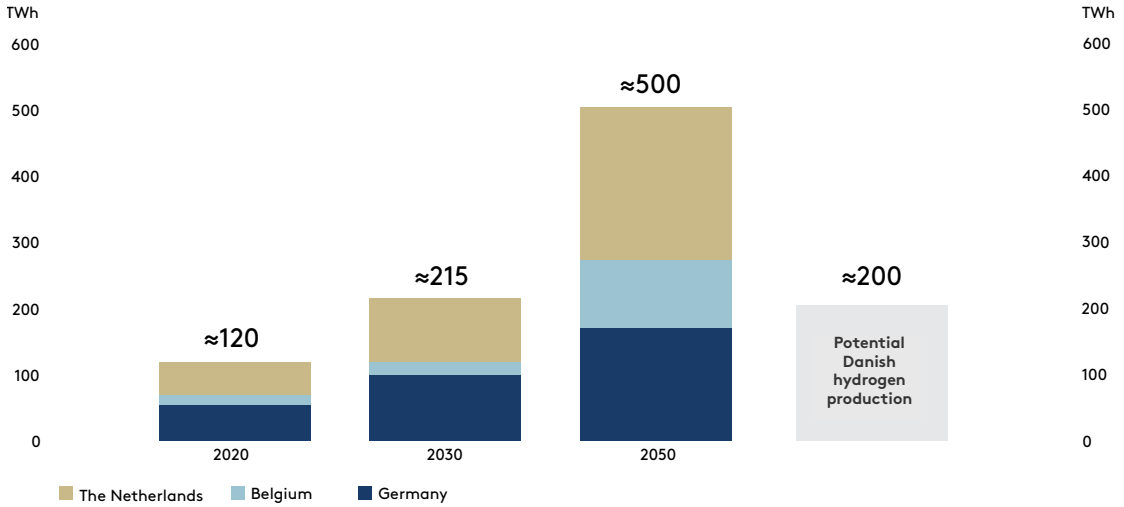
THE GREEN POTENTIAL OF DENMARK

Denmark has a large wind potential, and especially in the North Sea, we have large, good areas with a lot of wind resources in shallow waters. This gives Denmark the lowest production costs of large quantities of renewable electricity among all North Sea countries, and the expansion of renewable energy can be significantly cost-effective, especially if we also introduce offshore hydrogen production.

SURPLUS OF GREEN ELECTRICITY BEFORE OTHER COUNTRIES

According to the Danish Energy Agency, Denmark will become self-sufficient with green electricity by 2027, and when it comes to green hydrogen, we can become more than self-sufficient by 2030. At the same time, the hydrogen demand of Germany, the Netherlands, and Belgium will grow significantly. Hence, Denmark can from the outset sell our entire surplus of green hydrogen to neighbouring countries and much more over time. These countries are especially interesting because they have politically chosen a strategy to achieve their green transition resting on import of green hydrogen.

Figure 1: *The hydrogen demand forecast for Germany, the Netherlands and Belgium will exceed Denmark's potential hydrogen exports*



Sources: 2020: TNO PUBLIEK (2020) for the Netherlands; Deloitte (2021) for Belgium; and the Federal Ministry for Economic Affairs and Energy (2020) for Germany; 2030: Economie (2022) for Belgium; the Federal Ministry for Economic Affairs and Energy (2020) for Germany; and the Ministry of Economic Affairs and Climate Policy (2020) for the Netherlands; and 2050: estimated by COWI.
Note: Denmark's hydrogen exports are estimated to total 16 TWh by 2030, according to own calculations based on the Danish Energy Agency (2023) and the Danish Government's Climate Partnership for Energy and Utilities (2020).

By 2030, the three countries expect to consume around 215 TWh of hydrogen with an import of more than 140 TWh of hydrogen, even in a conservative scenario. Denmark may supply 16 TWh or just over 10% of the total import need of these countries with an increasing potential over time.

EXPORT POTENTIAL UP TO DKK 100 BILLION

The expected import of green hydrogen in Germany, the Netherlands, and Belgium correspond to a market value of DKK 70 billion by 2030, of which Denmark may take up to DKK 8 billion. The export market for green hydrogen will grow in line with the green transition in the years to come. If Denmark utilizes all its currently known and screened areas for renewable energy, there is an opportunity to export for around DKK 100 billion annually.

This corresponds to the current Danish export of energy technologies and services. In comparison, some of the largest Danish export industries, life science and the food cluster, correspond to around DKK 152 billion and DKK 164 billion, respectively.

The current fossil-based hydrogen market in Germany, the Netherlands and Belgium amounts to approximately 120 TWh and lends hope to a future green hydrogen export from Denmark (around 16 TWh by 2030) by its sheer size – much larger than Denmark's immediate production expectations.

INTERNATIONAL PIPELINES AND INTERCONNECTORS ARE CRUCIAL FOR EXPORT OPPORTUNITIES

Based on the export opportunities, Danish decision-makers may initiate the planning of a hydrogen infrastructure with connections to relevant countries and increase the expansion of renewable energy. Pipelines linked to demand markets are a prerequisite for Danish developers to invest in electrolysis capacity and the built-out of renewable energy giving crucial market access. A hydrogen pipeline infrastructure is necessary for the creation of a hydrogen market in Denmark and supporting the green transition of not only Denmark, but also our nearest neighbors.

The demand for green hydrogen from south of the border, combined with significant potential for production of renewable energy, create a unique position for Denmark in the green transition of Northern Europe, beneficial to both the climate, the European energy supply, and the Danish economy.

However, many others also compete for the green hydrogen market. While the hydrogen demand from the Netherlands, Germany, and Belgium constitutes a unique opportunity for Denmark, these countries also look elsewhere for hydrogen supply and have already entered into agreements for importing hydrogen from more distant countries.

OTHER COUNTRIES ARE ALREADY PLANNING AND DEVELOPING HYDROGEN INFRASTRUCTURE

Hydrogen infrastructure already exist in several central European countries due to their current use of fossil-based hydrogen for their industries. Furthermore, the countries have advanced their plans for further expansion and retrofitting of the gas infrastructure. These plans may bypass Denmark if we do not show that we are ready to enter the market.

By early 2023, German RWE and Norwegian Equinor entered into an agreement for an underwater hydrogen pipeline through Danish territorial waters. At first, the pipeline will supply Germany with blue hydrogen directly from Norway.

Similarly, there are several examples of countries entering into import agreements with Middle Eastern and Southern European countries for hydrogen supply. For every long-term purchase agreement that is signed, the market that can otherwise be covered from Denmark becomes smaller.

The situation requires action from Danish decision-makers. Therefore, based on the market assessment, the CIP Foundation provides three recommendations for Danish decision-makers:

- Plan for establishing a hydrogen infrastructure connected to other countries
- Accelerate the expansion of renewable energy
- Establish framework conditions to allow for the Danish part of the North Sea to be developed and utilized for the benefit of Europe's green transition

Contents

At the CIP Foundation we conceive and implement long-term projects that support the transformation of Danish society towards a more sustainable future. We are an independent and non-profit organisation that delivers tangible and implementable solutions for a long-term transformation of Danish society.

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> Hydrogen will play a pivotal role in achieving an affordable, clean and prosperous economy. Hydrogen allows for cost-efficient bulk transport and storage of renewable energy and can decarbonize energy use in all sectors.

Green Hydrogen for a European Green Deal (2020)

> ...we agree to explore joint cross-border renewable energy projects and identify infrastructure needs to enable the integration of renewable energy needed to ensure security of supply and affordable energy in our homes and businesses, while respecting Member States' national energy policy priorities and their choices of energy mix.

From Marienborgerklæringen (August 2022) signed by all the government leaders from countries around the Baltic Sea except from Russia

> ...to pave the way for the further expansion of offshore wind, we have decided to jointly develop The North Sea as a Green Power Plant of Europe, an offshore renewable energy system connecting Belgium, Denmark, Germany and the Netherlands and possibly other North Sea partners, including the members of the North Seas Energy Cooperation (NSEC).

From Esbjergerklæringen (May 2022) signed by the government leaders of Germany, the Netherlands, Belgium and Denmark

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Introduction

Climate demands and the desire for an independent supply of energy have really set Europe's green transition in motion.

Over the next years, the traditional demand for energy will see a fundamental change, and the transformation towards a greener society will give rise to new value chains and demand for a new energy infrastructure. By tradition, the countries with the best fossil fuel reserves embedded in the ground have been able to become wealthy by supplying the world around them with energy. In the future, the countries with the best access to renewable energy sources, such as wind and solar energy, will have the opportunity and the responsibility to be the catalysts of the green transition and to ensure reliability of supply and energy independence in these regions.

FROM FOSSIL TO GREEN FUELS

Fossil fuels have traditionally been the supporting pillars of our energy systems, where various types of fuel have been used to produce electricity or used directly in the heavy industry and for transportation purposes.

Renewable sources such as wind, sun and biomass have long been used to produce electricity, and today the transition from fossil-based to green electricity is very much a question of expansion. However, when it comes to the transition of the heavy industry and the transport sector where electrification is not an option, new green products must be added to the energy system.

Since fossil natural gas can to some extent be replaced by green biogas produced from sustainable biomass, this option can generate CO2e reductions for industry. Over time, however, biomass, which is also used directly for electricity production, will become a scarce resource, and the need for green fuels for both industry and heavy transport purposes will increase. Here, Power-to-X products based on green hydrogen present the solution.

In future, green electricity, biogas and green hydrogen will be key to the green transition and the reliability of supply. With a large number of fluctuating renewable energy sources, the importance of being linked to the energy systems of neighbouring countries and, in consequence, other energy sources, such as water and nuclear energy, becomes more apparent.

GREEN HYDROGEN AS A NEW ENERGY CARRIER

Of the three major energy carriers of the future, green hydrogen is set to become the new player on the block. Green hydrogen can be produced from renewable electricity and is necessary for the transition of the heavy industry, agriculture and the transport sector.

Green hydrogen can be used either directly in industrial processes or be converted to Power-to-X products which can be used as fertilisers in the agricultural sector or as a green fuel in the aviation and shipping industries.

Contrary to electricity, green hydrogen can be stored. And it can also be produced in a manner that will bring the power grid into balance and reduce the investments required for expansion of the grid over time; investments that would otherwise be necessary in order to handle the large and highly fluctuating quantities of renewable energy. The production of green hydrogen and PtX products can be increased at times with plenty of renewable energy and when the need for the electricity is limited.

Green hydrogen is widely and internationally recognised as a key component in the green transition process.

For this reason, the European Union has set up targets for both production and imports in order to meet the large demand facing EU Member States going forward. In addition, targets have also been set for how much of the technology used in the process the EU is to produce itself.

European countries also take their own steps to gain access to the green fuels of the future. Large consumers, such as Germany and the Netherlands, are now looking for possible suppliers by planning their infrastructures and establishing value chains to the Middle East and Southern Europe where the green hydrogen production potential is large due to the abundance of unexploited solar energy potentials.

The energy value chains are currently undergoing a transformation process; the large energy suppliers of the future will not be countries with oil and gas in the ground. They will be the countries with access to large quantities of low-cost renewable energy. And it will be those countries who assume responsibility for the green transition in their immediate vicinity and make an effort to promote the green progress.

The objective of this market assessment is to make an assessment of Denmark's possibilities to become an exporter of green hydrogen. The assessment is based on a qualification of the need for hydrogen of three of our nearest neighbours: Germany, the Netherlands and Belgium, and Denmark's production opportunities.

Green hydrogen and PtX

Green hydrogen is generated by splitting water molecules into hydrogen and oxygen through electrolysis using green electricity from renewable sources, such as wind turbines or photovoltaic cells.

Hydrogen can be used as is by industry or be converted into Power-to-X (PtX) products, such as e-methanol or e-ammonia. PtX products are for immediate use as fuel in the aviation and shipping industries or as green fertilisers for farming purposes.

The hydrogen colour scheme

Green hydrogen is based on renewable energy.

Grey hydrogen is based on fossil energy.

Blue hydrogen is based on fossil energy with a corresponding CO2e capture in order to compensate for the discharge of CO2e from the hydrogen. This combination is considered necessary during the interim period from grey to green hydrogen.

An emerging hydrogen market

At international level there is increased focus on the green agenda. The reduction targets are moving closer, and the desire to become independent of energy has induced countries in Europe to speed up the planning of their green transition in practice.

MORE EU MEMBER STATES TO IMPORT GREEN HYDROGEN
Most European countries have adopted a hydrogen strategy, and several countries, among these Germany, the Netherlands and Belgium, expect to become net importers of green hydrogen in keeping with their strategies[1].

The transition of the heavy industry and the transport sector creates a need which exceeds the countries' expectations for their domestic production. In terms of infrastructure, the countries surrounding Denmark have large-scale plans, also when it comes to imports.

Transporting hydrogen and PtX

The best and cheapest way of transporting hydrogen is through a pipeline hydrogen infrastructure. This can be dedicated hydrogen pipelines or retrofitted natural gas pipelines. Contrary to hydrogen, long distance transport of Power-to-X products is easier and less costly by ship.

NEW HYDROGEN INFRASTRUCTURE TO BYPASS DENMARK
At global level, the hydrogen infrastructure totals about 5,000 km. Most of this is located in the US followed by Belgium and Germany whose heavy industries use grey hydrogen.

By 2050, the hydrogen infrastructure is expected to extend more than 200,000 km with more than 50,000 km being located in Europe alone, according to Brinckmann (2023).

Germany is planning to have a hydrogen grid of more than 1,800 km before 2027[2], and Belgium is planning to build up to 160 km of hydrogen infrastructure by 2026 as part of establishing the European Hydrogen Backbone[3].

Dutch-German energy operator Gasunie is planning to develop a hydrogen infrastructure to interconnect countries, consumers and producers, see Figure 2. The purpose of this is to develop the hydrogen market as well as to create relevant import interconnections.

Figure 2: *The Netherlands and Germany plan a hydrogen infrastructure with interconnections to Denmark*

Source: Gasunie (2022a). See Gasunie (2023) for updates on the Dutch hydrogen infrastructure

1 Federal Ministry for Economic Affairs and Energy (2020) for Germany; Economie (2022) including Belgium's hydrogen strategy, Ministry of Economic Affairs and Climate Policy (2020) for the Netherlands.
2 Reuters (2022a)
3 Economie (2022) including Belgium's hydrogen strategy

The Dutch hydrogen infrastructure is expected to be a gradual process with the first stage connecting key industrial areas expected to be ready by 2025/2026. The second stage is expected to be completed by 2027/2028 and the final stage by 2030[4].

ALSO PLANS FOR IMPORT INTERCONNECTIONS

In addition to a land-based interconnection to Denmark from Hamburg, the Netherlands and Germany recently applied for EU funding to build a 400 km submarine pipeline, Aqua-Ductus. This pipeline will extend from Germany to relevant offshore wind farms and potential hydrogen production facilities via Helgoland and to Dogger Bank where the pipeline can be connected to pipelines from other countries, such as the UK and Denmark[5].

Meanwhile, Germany and France have entered into an agreement to extend the prospective H2Med interconnection from the Iberian peninsula via France to Germany[6].

Germany is expected to publish an actual hydrogen import strategy later in 2023, also addressing the need for piping and what is to be supplied by sea freight[7]. In comparison, Denmark has no specific plans to establish a hydrogen infrastructure.

EXISTING AND NEW PIPING

Between 60% and 80% of the hydrogen infrastructure in Europe is expected to consist of upgraded gas pipes – a cheaper and also faster solution compared with the establishment of new, dedicated hydrogen pipelines[8]. The Netherlands expect to reuse about 85% of the gas grid for hydrogen, according to Gasunie (2022b).

This option is only available to Denmark on a much smaller scale in view of the plans to use the Danish natural gas grid for many years to come, among other things for biogas. In the light of this, a much larger share of Denmark's hydrogen infrastructure will have to consist of new, dedicated hydrogen pipelines that will require approvals, new sites and a construction phase of some duration. Consequently, Denmark is off to a bad start compared with our neighbouring countries since we need more time to set up a hydrogen infrastructure.

SUPPLY CONTRACTS WITH OTHER COUNTRIES

As can be seen from the extensive plans to establish a hydrogen infrastructure, the countries envisage that the industrial transition process will consume large quantities. However, since their domestic production of hydrogen is unable to provide sufficient quantities, they are looking towards other countries who are able to meet their demand. At the beginning of 2023, German RWE and Norwegian Equinor entered into an agreement for the instalment of a submarine hydrogen pipeline – initially to provide blue hydrogen to Germany[9]. This interconnection passes through Danish territorial waters but has no connectors leading to/from Denmark.

BLUE HYDROGEN FROM FAR AND NEAR

There are multiple examples of countries entering into import agreements and joining forces with countries far away. The Netherlands and Germany have created value chains with the United Arab Emirates in order to secure a European interconnection for hydrogen from the Middle East[10], and as early as 2022 Germany received the first batch based on blue hydrogen[11].

Along the same lines, German E.ON has signed a Memorandum of Understanding (MoU) with an Australian supplier of green hydrogen starting in 2024 targeting the delivery of 5 million tons of hydrogen annually by 2030. In terms of energy, this accounts for about one third of Germany's previous imports from Russia for heating purposes . Such agreements serve to demonstrate that the countries are looking towards more remote areas to meet their future demand for hydrogen – towards new value chains and new dependencies[12].

PURCHASE AGREEMENTS REQUIRED FROM THE OUTSET BUT SALES ARE FIXED FOR A PERIOD

At the same time, the potential market for Danish involvement narrows down as long-term power purchase agreements (PPAs) are entered into with other countries. PPAs of a certain duration are expected to become the norm as the new hydrogen market evolves.

Hydrogen infrastructure – reused or new?

Some countries have already set up a hydrogen infrastructure dedicated to fossil-based hydrogen.

The natural gas grid can be retrofitted and used as a hydrogen infrastructure in many cases. The pipes will need to be inspected, however, and can only withstand a certain pressure. When reusing an existing grid instead of building an entirely new grid, the resulting hydrogen infrastructure is more extensive and the process is faster and cheaper. This will require that the natural gas grid is no longer needed, for example for biogas or CO2e.

Since new hydrogen pipes are able to withstand larger differences in pressure, their capacity to store hydrogen is more flexible than for example reused gas pipes.

Sources: Evida, Energinet, Brinckmann (2023) and more

4 Vandoorne (2022), Ministry of Economic Affairs and Climate Policy (2022)
5 Fluxys (2023)
6 Hydrogen Central (2023)
7 Hydrogeninsight (2023)
8 Brinckmann (2023)
9 RWE (2023)
10 EU Observer (2023)
11 Golf Business (2022)
12 Reuters (2022b)

Denmark: Low energy consumption, huge production potential

Denmark is renowned for being a green first mover which has invested in renewable energy at an early stage.

Historically, biomass and onshore wind turbines have played a key role in the transition from fossil fuels; most recently, solar energy and offshore wind have been added, with offshore wind set to become an even more important player in our future energy production.

RENEWABLE ENERGY FROM OFFSHORE WIND OFFERS HUGE POTENTIAL

Today, the overall installed offshore wind capacity totals about 2.3 GW, whereas Denmark's offshore wind potential is slightly more than 40 GW[13]. This reflects that Denmark has large areas particularly in the North Sea offering good possibilities for installing offshore wind turbines.

The Danish Energy Agency estimates that solar energy combined with offshore wind energy will contribute with more or less the same quantity of renewable energy.

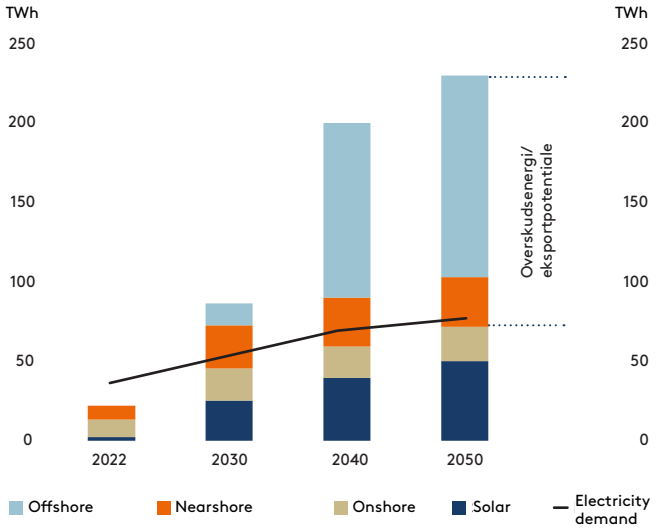
GW, TWh and hydrogen

Gigawatt (GW) is a unit for measuring electric power. The unit describes production capacity.

A terawatt hour (TWh) is a unit of measurement of the production and consumption of energy.

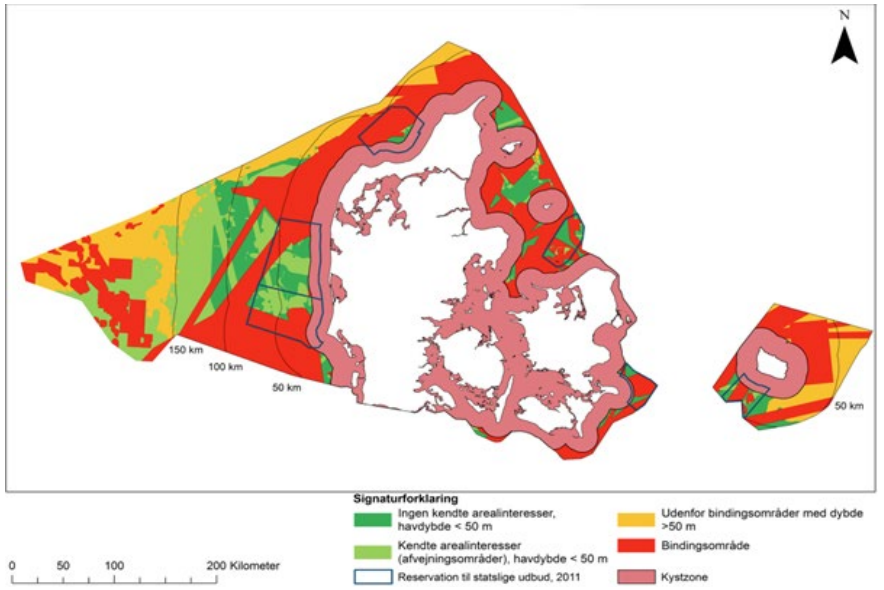
1 GW electrolysis capacity corresponds to about 4 TWh.
1 million tons of hydrogen corresponds to about 33 TWh.

***Figure 3:** Denmark will produce more energy than we need for direct electrification from 2030 onwards*



Source: The Danish Energy Agency (2023)
Note: Denmark's energy production from various sources and the power consumption is stated in TWh.

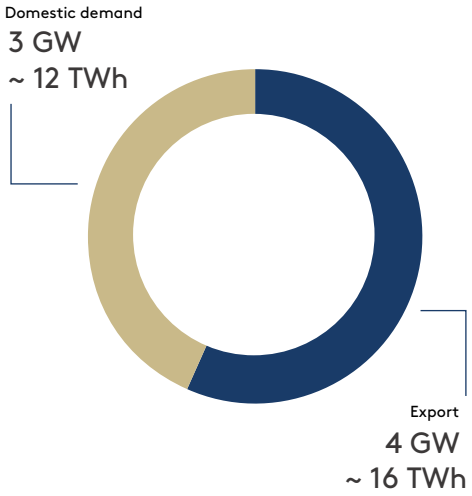
***Figure 4:** Multiple relevant sites exist for expansion of offshore wind*



Source: The Danish Energy Agency (2019)

13 The Danish Energy Agency (2019)

***Figure 5:** Denmark is expected to produce more than twice the quantity required to meet the domestic demand for hydrogen by 2030*



Source: Own calculations based on the Danish Energy Agency (2023) and the Danish Government's Climate Partnership for Energy and Utilities (2020)

Figure 3 shows Denmark's expected energy production today, in 2030, in 2040 and in 2050 compared with the Danish Energy Agency's expectations for the energy needed for the direct electrification. The figure shows that energy from renewable energy sources will generate a surplus of energy which can be converted into hydrogen and be either further refined to Power-to-X products or exported directly as hydrogen.

With this, Denmark can provide direct support for the green transition of Europe and the European reliability of supply.

DENMARK SOON TO BE SELF-SUFFICIENT IN GREEN ELECTRICITY

According to the Danish Energy Agency, Denmark is expected to become self-sufficient in green electricity for the direct electrification process as early as 2027[14].

The Danish Energy Agency expects that Denmark will also produce hydrogen and that the production will exceed domestic demand by 2030. Denmark will produce 16 TWh more hydrogen than needed to meet domestic demand, according to the Danish Energy Agency's forecast[15].

RENEWABLE ENERGY – AN OBVIOUS EXPORT CASE

After 2030, Denmark's energy production is expected to grow faster than the consumption, and by then energy will be an export case that can contribute to Europe's green transition.

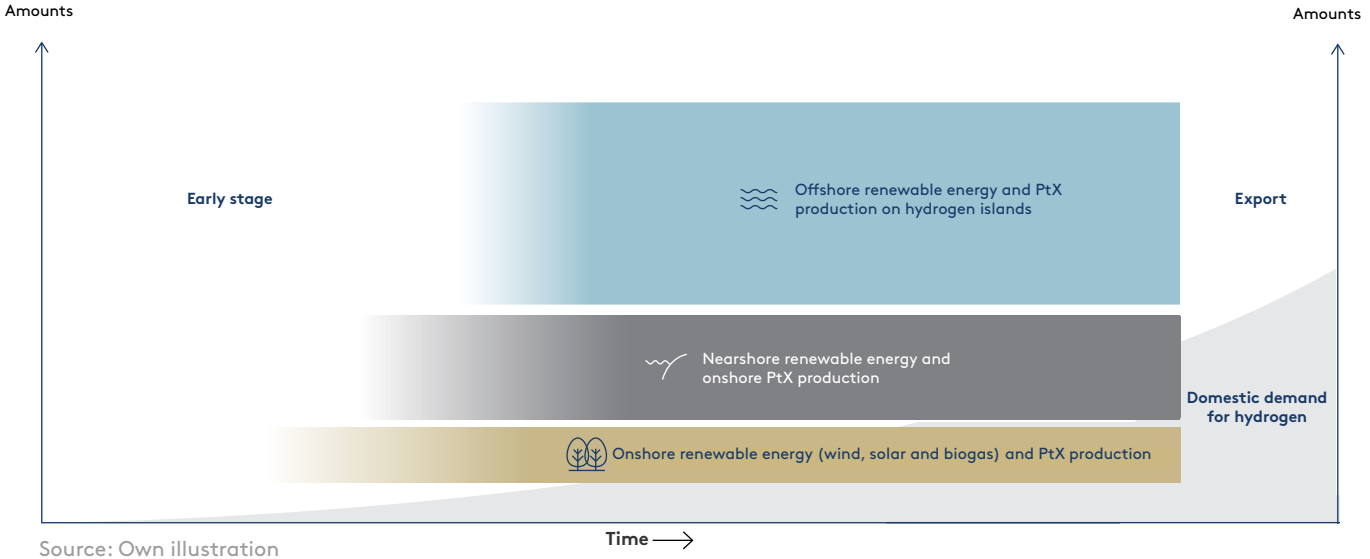
If Denmark exports the expected amount of surplus energy by 2030, the value of this could be in the vicinity of DKK 8 billion annually in the form of hydrogen exports[16]. However, Denmark has areas and resources available for renewable energy production which could yield twice the amount of energy needed to meet the domestic demand during the period up to 2050.

EXPORT POTENTIAL TO BE FUELLED BY EXPANSION

It is safe to assume that Denmark's exports can commence between 2027 and 2030 when the country will be producing more green power and more hydrogen than needed to meet domestic demand. The rate of export growth will depend on the regulatory framework, competition and the actual market access through a relevant infrastructure.

Initially, the Danish hydrogen production will most likely be onshore and meet the domestic demand, whereas especially the use of near shore and remote offshore wind resources will enable production at level that will allow exports, see Figure 6.

***Figure 6:** There are several stages and roles are at play in the expansion of Danish hydrogen production*



Source: Own illustration

14 The current analysis assumes that areas associated with applications under the Open Door process will be used for projects corresponding to 23 GW despite the current temporary suspension of the scheme.
15 Conservative estimate. According to the Danish Energy Agency's estimates (2023), Denmark's electrolysis capacity is expected to reach 6.9 GW in 2030 compared with domestic consumption of 2-3 GW, cf. the Danish Government's Climate Partnership for Energy and Utilities (2020). With domestic consumption of 3 GW, 3.9-4.9 GW of electrolysis capacity will be available for production.
16 According to Green Power Denmark (2020), a key estimate of the price of green hydrogen in 2030 is about DKK 17 per kg of hydrogen based on EA Energy Analyses' Balmorel model.

Denmark has a unique competitive advantage

The North Sea provides Denmark with favourable conditions for the production of renewable energy.

Of all the North Sea countries, Denmark not only boasts a sizeable area but also good sites with powerful winds and shallow waters which are among the most suitable sites for energy production.

THE NORTH SEA – THE BEST SOURCE IN NORTHERN EUROPE

Denmark's location makes it even more relevant to prepare the areas for harbouring energy production and with a geographic location close to the importing countries, Denmark's green power production costs are among the lowest among the North Sea countries[17].

With this in mind, it would be beneficial to both Denmark and our close neighbours, if Denmark makes good use of the areas with a view to exporting green energy.

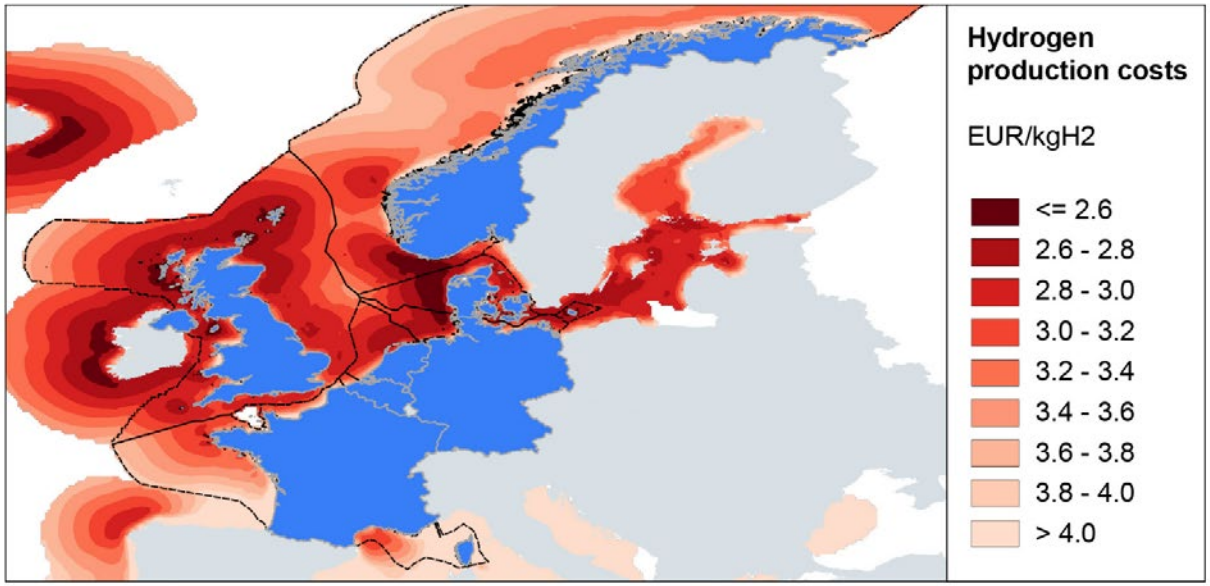
The Danish Energy Agency also finds that Denmark has the potential to become a significant net exporter of energy and that Germany, the Netherlands and Belgium will buy energy from Denmark[17]. According to the Danish Energy Agency, offshore hydrogen production will improve the opportunities for further expansion – and with this exports.

The reason is the relatively low cost of transporting hydrogen and, moreover, hydrogen production will generally increase efficiency since hydrogen can be produced during periods with low electricity demand, and it can be stored.

Figure 7 illustrates the cost advantages of hydrogen production for Denmark. This is a good starting point for Denmark for producing the green, low-cost energy which Europe has in scarce supply.

Figure 7: *The costs of producing hydrogen in the vicinity of Denmark are relatively low*

Hydrogen production costs from offshore wind in the Accelerated scenario, 2030



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Notes: This map is without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries and to the name of any territory, city or area. The analysis is based on hourly wind speed data from Copernicus Climate Change Service (2020).[56]

Assumptions: CAPEX for offshore wind EUR 1 700-1 800/kW; offshore hydrogen transport costs: EUR 0.27/kg H_2/100 km; other assumptions see notes of previous figure.

Source: IEA (2021b)

5 - 10%

This is how much cheaper the production of Danish hydrogen is expected to be on a Danish energy island compared with hydrogen from a German energy island.

Source: Brinckmann (2023)

17 The Danish Energy Agency (2022)

How come Denmark is able to compete on the production of green hydrogen?

- Some of the best wind resources in Europe are found in Denmark as are also shallow waters, which are ideal locations for offshore wind farms capable of producing large quantities of renewable energy.
- Denmark enjoys certain cost advantages in large-scale production of renewable energy and hydrogen.
- Since Denmark will soon be producing sufficient 100% green electricity to meet the domestic demand, surplus electricity will be available for hydrogen production. Other countries are in an earlier stage of generating sufficient capacity for their domestic electrification.
- Denmark has sufficient resources available for plentiful, reliable and stable supply to our nearest neighbours.
- The Danish concept of energy islands and hydrogen hubs facilitates large-scale production which is economically competitive with those of our neighbouring countries, and their remote offshore locations make them less exposed to competing requirements for the use of the locations.

Inflation Reduction Act (IRA)

In the summer of 2022, the US government announced the law package known as the Inflation Reduction Act (IRA) which includes USD 369 billion in climate and energy investments, the largest ever in US history. The IRA law package will entail renewable energy investments that are destined to help cut US CO2 emissions by 50% by 2030.

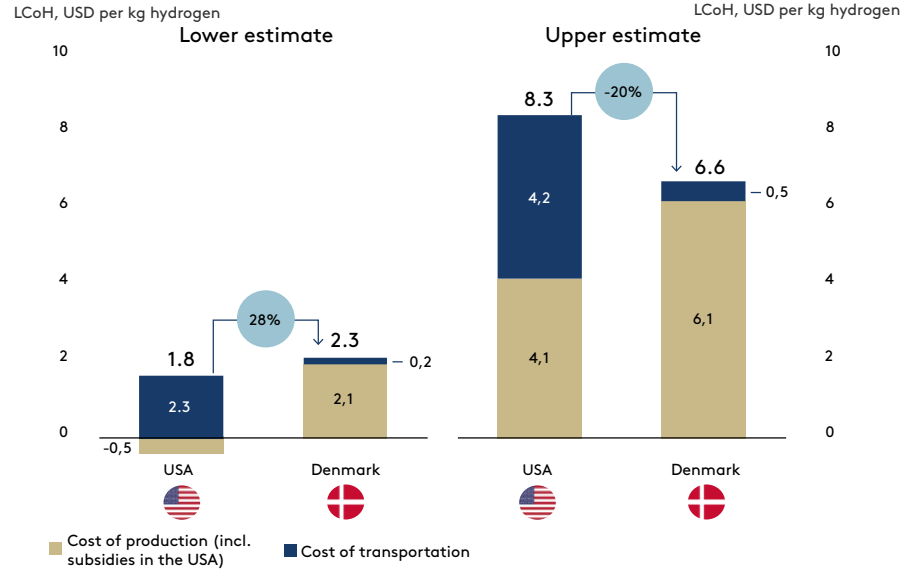
The IRA provides financial benefits to green hydrogen producers who will be granted tax credits over a 10-year period that are expected to cut production costs of green hydrogen by 50% in a short-term perspective. The tax credit is available to companies with financial activities in the US.

The EU has expressed concerns that the IRA might distort competition in the green market, also within hydrogen production. With the US hydrogen production tax credit, there is a risk of investments being transferred from Europe to the US to the detriment of European hydrogen production and green jobs.

Depending on the size of the tax credit, heavily subsidised green hydrogen from the US risk undercutting European green hydrogen, despite the added higher shipping freight costs and the potential conversion to other forms of energy (see the box about cracking).

Calculations from Copenhagen Economics demonstrate that the IRA has the potential to make US hydrogen more competitive than Danish hydrogen. Figure 2 shows the competition between hydrogen produced in Denmark and in the US, respectively, and sold on the German market. When US hydrogen is subsidised to an extent that cancels out or even more than neutralises production costs, it could end up competing with Danish hydrogen in the German market and with a small cost advantage. There are some uncertainties especially on the production side, but Danish hydrogen will be competitive at the upper end of the price range.

***Figure 8:** In some cases, subsidised US hydrogen can compete with Danish hydrogen*



Source: Calculations made by Copenhagen Economics [18]
Note: LCoH indicates the levelised cost of hydrogen, i.e. standardised production and transport costs to the same site by ship (from the US to Germany) and by hydrogen pipeline (from Denmark to Germany), respectively.

In view of the subsidies, there is no denial that US hydrogen might become cheaper than hydrogen produced in Europe.

At the beginning of 2023, the European Commission presented the Green Deal Industrial Plan with the intention to boost the competitiveness of the EU's green industries. The Green Deal Industrial Plan includes measures to generate predictable and simplified regulation and ensure speedier access to funding, for example in the form of fixed deadlines for application reviews, One Stop Shop procedures for essential technologies such as wind and solar energy, added targeting of already allocated funds etc.

The market assessment assumes that the EU will come up with a relevant response to the US subsidies for hydrogen, Power-to-X etc. Another EU objective is to ensure that half of the future green hydrogen demand is met by EU sources, and that the electrolysis capacity is developed and managed within the EU.

18 Copenhagen Economics on the basis of Fuel Cells and Hydrogen Observatory (2023), International Council on Clean Transportation (2023), ICCT (2023), Goldman Sachs (2022), national hydrogen strategies, AURES's database, The Inflation Reduction Act (IRA), IRENA (2022), IEA (2019), Agora (2021), EDISON (2021), McKinsey (2021), Johnston et. al (2022) and EWI (2020).

Cracking Power-to-X to generate hydrogen: a game changer?

Power-to-X products, such as ammonia and methanol, are the result of additional refinement of hydrogen. These can be converted back into hydrogen through cracking – a method which breaks up the molecules and enables re-splitting.

Despite being energy-intensive and very costly, the method can be used to generate ammonia and store this for later conversion back into hydrogen. In principle, this means that PtX products can be shipped to Europe and be converted back into hydrogen, generating a loss of energy.

If the price of a PtX product is sufficiently low, including freight and cracking costs, the product may be able to compete with hydrogen produced in Europe if, for example, the hydrogen production is subsidised in other countries (see box about IRA).

According to preliminary calculations, the costs of producing ammonia in for instance Morocco, shipping it to Denmark and cracking it into hydrogen do not differ that much from the costs of producing hydrogen in Denmark using renewable energy generated at Danish energy islands.

These costs are highly uncertain, however, but in some cases the Danish hydrogen will be cheaper. It is not obvious who stands to charge the lowest prices in 2030 and win markets. Also, other conditions will play role, such as reliability of supply, geopolitical circumstances and the overall framework conditions.

Source: IEA (2019), Copenhagen Economics (2022b) and more

The hydrogen market today

Hydrogen based on fossil energy, also known as grey hydrogen, is already used extensively today.

Europe's hydrogen consumption totals about 8.6 million tons of hydrogen annually, corresponding to 341 TWh[19], which is expected to double to about 700 TWh in the run-up to 2030[20]. Today, Germany is the largest producer of fossil hydrogen in Europe with considerable domestic consumption corresponding to one fifth of the total European consumption.

WHERE IS HYDROGEN USED TODAY?

Today, hydrogen is used mostly in the petrochemical industry and in the steel industry. The Netherlands are the second largest producer of fossil hydrogen in Europe and are also a heavy consumer of hydrogen for the production of steel and various chemicals.

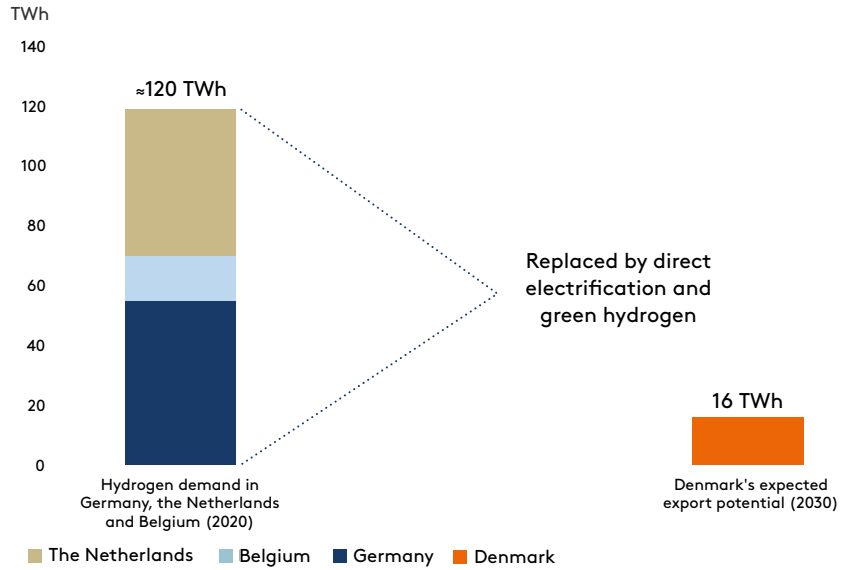
Belgium has a number of industrial clusters with large production of ammonia, petrochemicals and steel, also based on grey hydrogen.

The overall hydrogen consumption of the large industries in Germany, the Netherlands and Belgium today totals about 120 TWh annually (2020), see Figure 9. In comparison, Denmark is forecast to export 16 TWh to other countries by 2030. Put differently, the hydrogen markets in our neighbouring countries currently by far exceed Denmark's expected export potential in 2030. It is evident from the current hydrogen consumption in Germany, the Netherlands and Belgium that there is in fact a hydrogen market south of the Danish border even at this point in time. Right now, this market is saturated with grey hydrogen and needs conversion over time.

The solution to part of this consumption could be electrification, but this would definitely not cover all of it. Together with processes that today require other fossil fuels and will be difficult to convert, the consumption of grey hydrogen will constitute the green hydrogen market of the future, see Figure 10.

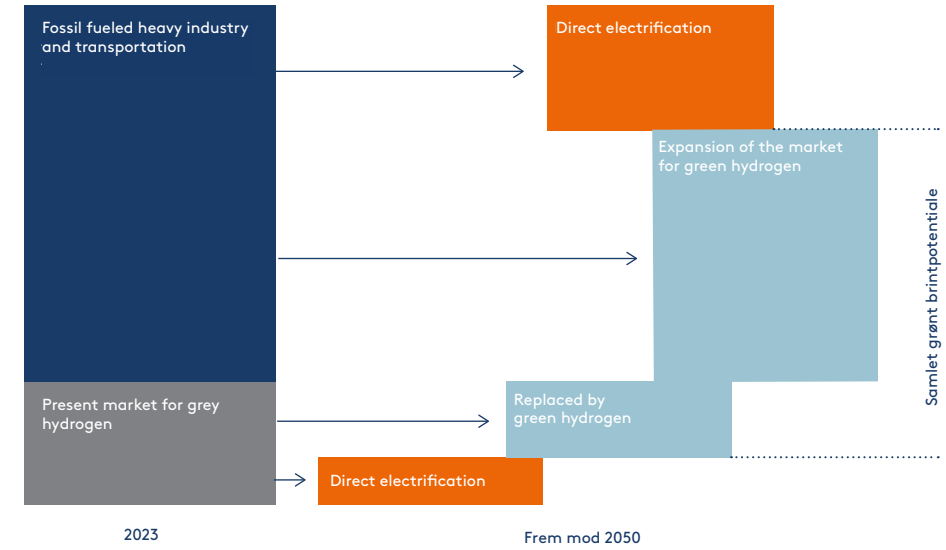
Other major consumers of grey hydrogen in Europe today are Poland, Italy, Spain, the UK and France.

***Figure 9:** Even today, hydrogen consumption in Germany, the Netherlands and Belgium makes up a considerable market for Danish hydrogen exports*



Sources: TNO PUBLIEK (2020) for the Netherlands; Deloitte (2021) for Belgium; and the Federal Ministry for Economic Affairs and Energy (2020) for Germany. Denmark's expected hydrogen consumption is based on own calculations based on the Danish Energy Agency (2023) and the Danish Government's Climate Partnership for Energy and Utilities (2020).

***Figure 10:** The transition of industries generates a green hydrogen potential*



Source: Own illustration

19 FCHO (2022)
20 European Commission (2022)

The hydrogen market of the future – huge export potential

The market – and the demand – for green hydrogen is expected to see substantial growth in the run-up to 2030. Germany, the Netherlands and Belgium expect their hydrogen consumption to outpace their domestic production, which will make them net importers.

Meanwhile, the hydrogen market will undergo changes. Parts of the industry that today use hydrogen will become electrified, while others will move from grey to green hydrogen. Over time, the hydrogen market will expand in step with the use of green hydrogen for the conversion of sectors that currently use fossil fuels. This will involve industries which replace oil, coal and gas with hydrogen, and it will involve the aviation and shipping industries which will replace fossil fuels with hydrogen-based Power-to-X products.

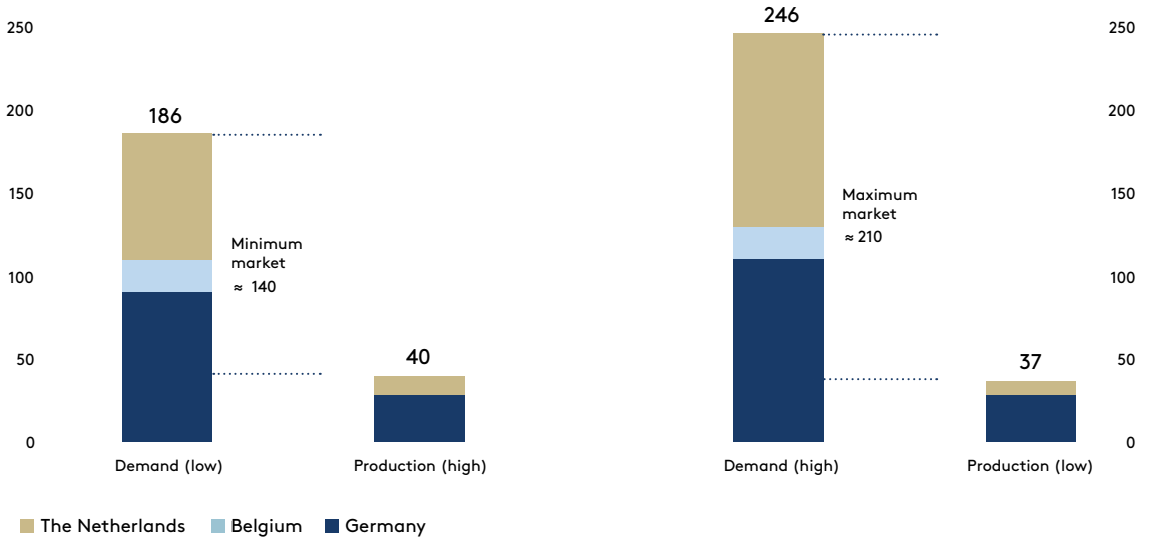
THE IMPORT DEMAND OF OUR NEAREST NEIGHBOURS

The national hydrogen strategies of Germany, the Netherlands and Belgium include estimates of the envisaged scenarios for their hydrogen demand and production by 2030. Based on these estimates, scenarios can be set up for the import demand of the three countries to give an idea of the scale of the hydrogen markets of the future. One scenario features a minimum market for Danish exports based on estimates predicting low consumption and high production in those three countries, whereas another scenario features a maximum market based on estimates featuring high consumption and low domestic production. Figure 11 shows that the overall import demand of Germany, the Netherlands and Belgium is expected to be somewhere between 140 and 210 TWh by 2030.

HYDROGEN EXPORTS COULD REPLACE 5 MILLION TONS OF CO2E

Denmark expects its exports to reach 16 TWh by 2030, unless the expansion process exceeds the expectations of the Danish Energy Agency. If the 16 TWh of hydrogen replaces grey hydrogen, this will correspond to an annual CO2e reduction of about 5 million tons of CO2e[21]. In view of the economic implications and climate considerations, Denmark is in the right position for speedy expansion of its capacity of renewable energy and electrolysis – also in a short-term perspective.

***Figure 11:** Germany, the Netherlands and Belgium expect to import 140-210 TWh of hydrogen in 2030*



Sources: Economie (2022), the Federal Ministry of Economic Affairs and Energy (2020), the Ministry of Economic Affairs and Climate Policy (2020)
Note: Assumptions from a German hydrogen strategy suggesting 4,000 full load hours annually for electrolysis and 70% efficiency are used across countries. The minimum market is made up of the lowest consumption estimates for the countries deducting the highest estimates for their domestic production, while the maximum market is made up of the highest consumption estimates deducting the lowest estimates for the domestic production of these countries.

21 Own calculations based on the assumption that grey hydrogen produces emissions of 11 kg of CO2 per kg of hydrogen (conservative estimate) and that 1 kg of hydrogen corresponds to 33.3 KWh

Even with a conservative estimate of the demand from these countries, the import expected for Denmark will satisfy only a small proportion of the market. The size of the market suggests that an expansion of the Danish production of renewable energy and hydrogen is expected to be sold south of the Danish border provided that the Danish production is cost-effective.

The value of the minimum market of 140 TWh is estimated to total DKK 70 billion, while the maximum market comprising our nearest neighbours is estimated to exceed DKK 100 billion by 2030[22].

EXPORTS TO TOTAL DKK 8 BILLION BY 2030

Although Denmark's potential exports of 16 TWh of hydrogen only meets a small proportion of the demand, the value in 2030 could amount to DKK 8 billion measured at today's prices, see above.

From 2030 to 2050, the demand for green hydrogen is only expected to grow. According to their climate targets, many countries will be CO2 neutral by 2050, and green hydrogen will be an essential component in the conversion of the most difficult and heaviest energy-consuming industries. According to estimates developed by COWI, the forecast for the overall demand for hydrogen of Germany, the Netherlands and Belgium will reach about 500 TWh by 2050 when the green transition is supposed to be completed. The estimate is based on the economy, the size of the industries and the transition needs of each individual country and gives an idea of the quantity of green hydrogen expected to be consumed annually by those countries after a green transition.

According to their own hydrogen strategies, these countries will become net importers, and the imported quantities will depend on the domestic electrolysis capacity they will manage to develop and the prices at which neighbouring countries, such as Denmark, can produce hydrogen. For one thing, because the market is unable to meet its own demand but also, and even more so, because Denmark is able to deliver hydrogen at lower prices than what these countries are able to achieve in their domestic production.

COWI has analysed Denmark's long-term hydrogen export potential taking into account the extent to which well-known and accessible Danish areas for renewable energy can facilitate capacity and deducting the need for Denmark's direct electrification and domestic hydrogen demand. In other words, what the Danish resources, including Open Door areas, make possible, all things equal, corresponding to a sort of maximum estimate of the hydrogen export potential based on Danish resources.

If other relevant areas are included in the screening[23], or if Danish hydrogen production is linked to a neighbouring renewable energy production from, for instance, Germany, the production of hydrogen can be even higher. As a calculation example, if Denmark were to exploit all the screened areas in the country for the renewable energy expansion and produce hydrogen from the surplus energy after Denmark's domestic

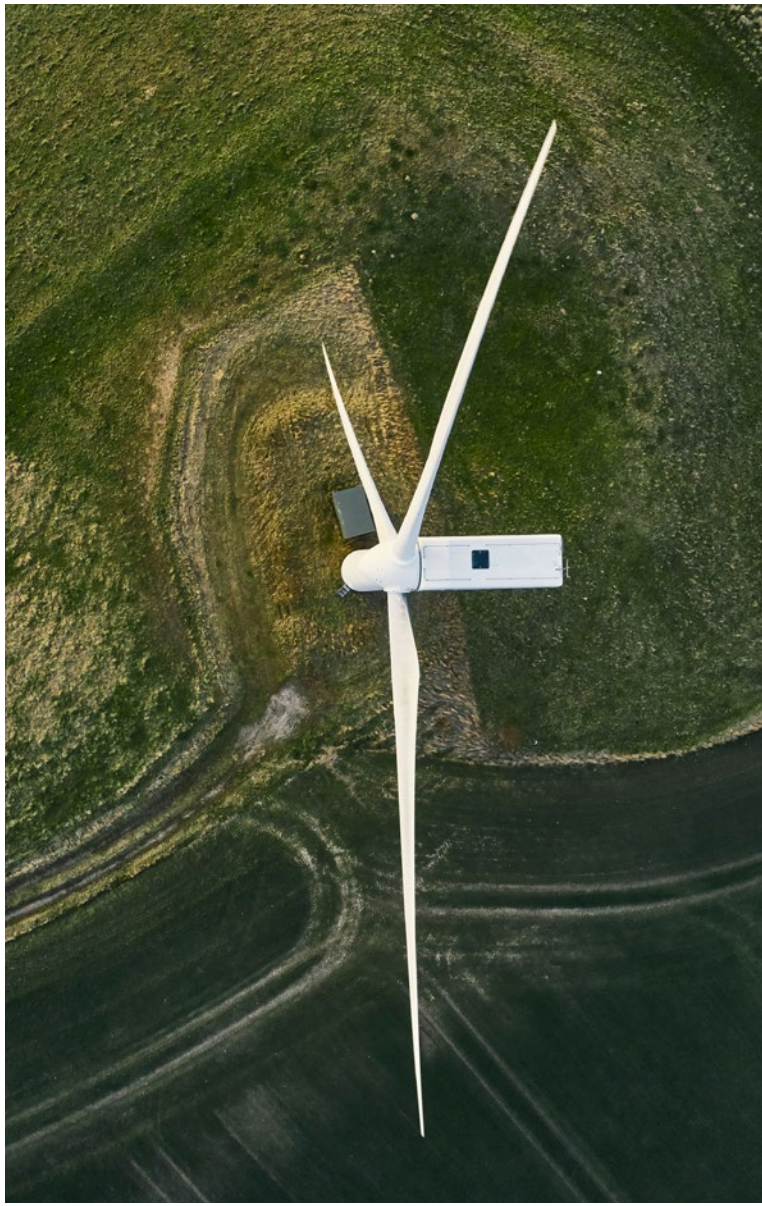
11%

of the demand from Germany, the Netherlands and Belgium can be met by exports from Denmark in 2030.

Source: CIP Foundation estimations

16 TWh

is expected to be exported by Denmark by 2030.



22 Same assumptions as in footnote 16.
23 Based on 15.6 GW of near shore wind energy, 6.2 GW of onshore wind energy, 30 GW of solar energy, 41 GW of offshore wind energy, cf. COWI (2023).

demand has been met, Denmark would be able to export about 200 TWh of hydrogen, all things equal.

Figure 12 shows the the Danish hydrogen export potential compared with the demand expected from Germany, the Netherlands and Belgium by 2050.

POTENTIAL OF UP TO DKK 100 BILLION

The figure illustrates that if Denmark expands its renewable energy production to its maximum potential, Denmark will be able to meet about 40% of the overall demand for hydrogen from Germany, the Netherlands and Belgium. This corresponds to annual exports of about DKK 100 billion at today's prices, according to COWI (2023).

Consequently, Denmark has the option to expand to full capacity and sell to buyers south of the Danish border provided the surplus energy is converted into hydrogen.

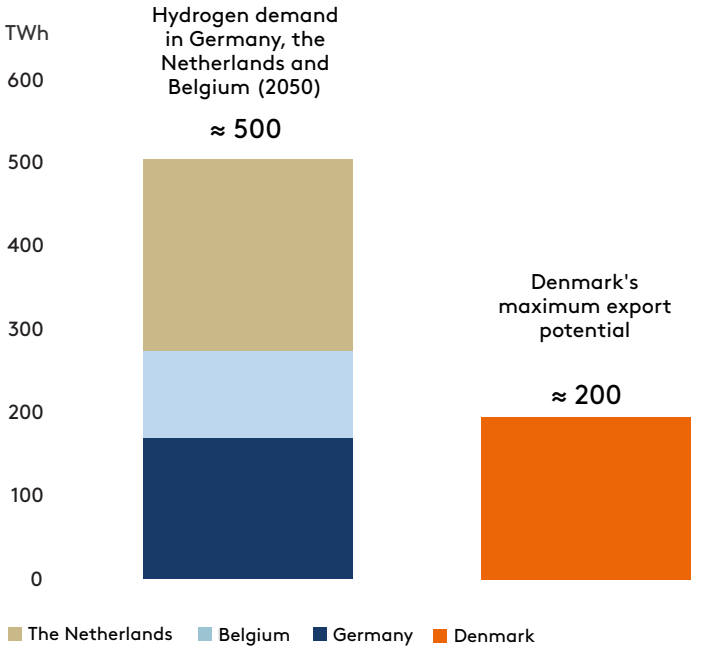
In comparison, the value of Danish exports of energy technologies and services totals about DKK 105 billion (2021), according to the Danish Energy Agency, which means that the value more or less matches the Danish-based hydrogen potential.

This compares with the Denmark's largest export sectors today which are the life science sectore exporting about DKK 152 billion and food industry sector exports (agriculture and processed products) exporting DKK 164 billion in 2020.

Accordingly, the green hydrogen export potential is significant and is based on a renewable energy source which cannot be depleted, unlike for example oil and natural gas.

Danish export of oil and natural gas peaked in 2012 at about DKK 62 billion (fixed prices), according to Statistics Denmark.

***Figure 12:** Long-term hydrogen demand compared with Denmark's maximum export potential*



Source: Calculations of estimates of demand and export potential are made by COWI (2023) on behalf of the CIP Foundation.
Note: The Danish export potential is calculated as the potential hydrogen production based on the largest possible expansion of renewable energy by screened areas in Denmark and electrolysis capacity deducting Denmark's expected domestic consumption in 2050. The hydrogen demand in Germany, the Netherlands and Belgium is calculated using the transition potential in these countries in view of their industry structures, expected economic developments etc.

Denmark's opportunities for large-scale exports

A large number of hydrogen-based projects are in the pipeline in Denmark – with the ambition to produce either hydrogen or hydrogen-based Power-to-X products.

Since these projects are in their infancy, their actual realisation is highly uncertain. And yet the projects suggest how hydrogen production can be established in Denmark in a short-term perspective. According to a market dialogue report, produced by KMPG for Danish transmission system operator Energinet and national gas distributor Evida, the electrolysis capacity in Denmark could exceed 14 GW as early as 2030.

LARGE CAPACITY PROJECTS ANNOUNCED

The capacity is considerable and larger than both the political target of 4-6 GW by 2030 and the ambition set by the Danish Energy Agency of 7 GW by 2030.

Despite the uncertainty linked to the realisation of all projects, the potential is huge and could pave the way for considerable Danish production of green hydrogen by 2030.

Since the need for hydrogen and Power-to-X products for domestic consumption is expected to be low in Denmark, many Danish hydrogen projects depend on a hydrogen infrastructure with international interconnections[24].

Without a hydrogen infrastructure, the projects will be left without sales channels and without international interconnections to a market characterised by huge demand, which is deemed to show significant growth.

A HYDROGEN INFRASTRUCTURE WITH INTERNATIONAL INTERCONNECTORS PROVIDES MARKET ACCESS

Consequently, international interconnections create market access. And considering the high level of activity in our neighbouring countries with import demand, it becomes relevant for Denmark to look towards their planned structures and consumption locations. Already at this stage, the Danish land-based hydrogen production is assumed to see considerable growth between 2027 and 2028 if an infrastructure is built with pipelines leading out of the country.

Evidently, access to renewable energy and a hydrogen infrastructure leading to especially Germany is absolutely critical for ensuring that Denmark will become a producer and exporter of hydrogen in the near term.

At the same time, Denmark is in an excellent position to top up with offshore hydrogen production. As discussed above, Denmark's many and very windy areas in the North Sea are well suited for the production of renewable hydrogen – even to the extent that compared with the other North Sea countries they generate a certain production advantage – about 5-10% – when comparing a potential Danish energy island with a German energy island.

If large-scale production is required, then offshore dedicated hydrogen production will present an advantage. The difference in costs is even more pronounced – approaching 15-20% – when compared with land-based hydrogen production, see Figure 13.

Multiple factors make the production of hydrogen on a Danish energy island cost-effective, including 1) the electricity loss is reduced when the production of hydrogen shifts to a location closer to, for example, wind turbines; 2) the electrolysis

capacity utilisation is higher thanks to a higher number of full load hours; and 3) transport costs are lower since the cost of transporting energy in the form of hydrogen is lower than is the case for electricity.

HYDROGEN PRODUCTION ON ISLANDS IN THE NORTH SEA

As a result of efficiency, local conditions and large-scale benefits, a Danish hydrogen-based production island could operate competitive hydrogen production at slightly lower costs than a country such as Germany.

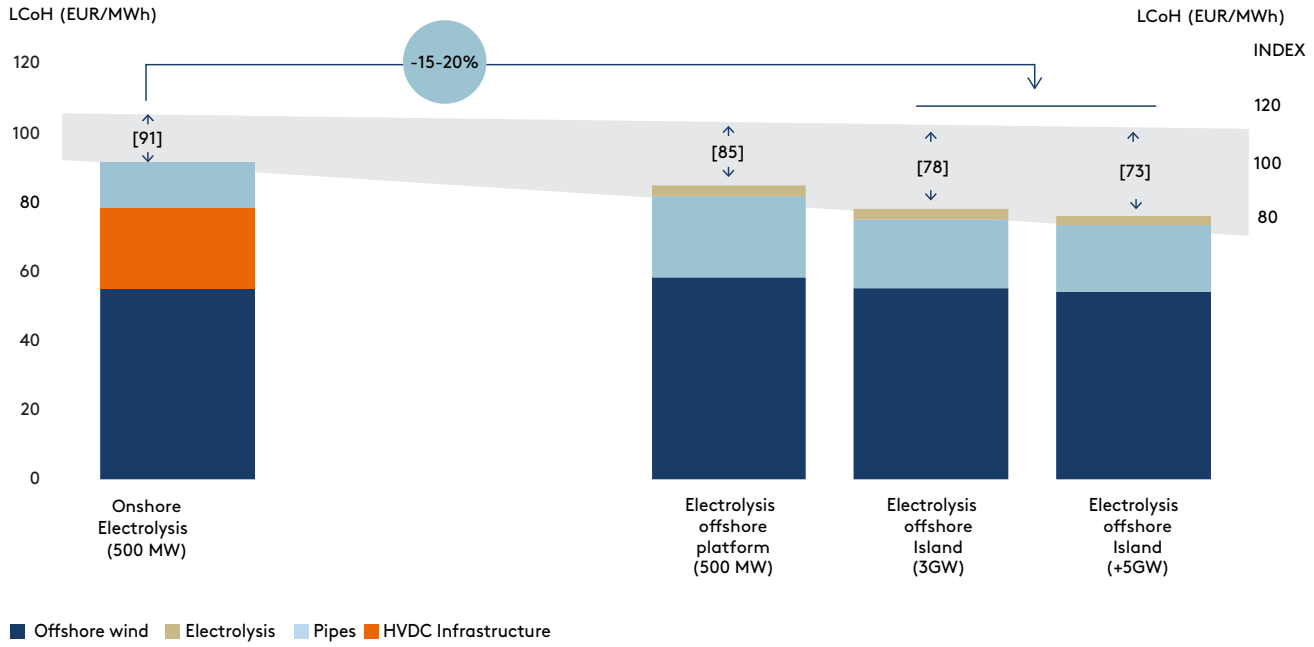
Due to the volume of the market, establishing multiple energy islands with the main objective of producing hydrogen – what you might call hydrogen islands – could prove to be a financial advantage. Evidently, there is a market for dedicated Danish hydrogen islands in the North Sea where the main objective will be to produce hydrogen for the market south of the Danish border once the Danish demand has been satisfied.

Such hydrogen islands can be built in parallel with the energy islands decided by politicy-makers and they can be built on commercial terms. While the Danish energy islands will play an important role in ensuring reliability of supply in Denmark and balancing the power grid, Denmark will not need energy from hydrogen islands to be self-sufficient.

The hydrogen islands can be built exclusively with export in mind, and they can be placed in the North Sea at locations that are strategically important to the renewable energy and infrastructure of other countries. The first ones to build the infrastructure will make their mark on the markets and the sales channels. And if Denmark sets a framework for the exploitation of the North Sea potential, the countries south of the border will gain access to low-cost green energy, while Denmark will see its export revenue grow. For these reasons, when planning the future energy infrastructure and to sell its surplus energy, it will make sense for Denmark to look towards markets where the plans for a hydrogen infrastructure are at an advanced stage.Denmark's costs benefits and opportunities to become a large-scale exporter of green hydrogen must be viewed in the context of how the countries around us are investing in renewable energy and infrastructure. Although the size of the market is convincing, and Denmark enjoys cost benefits in hydrogen production, the potential can only be realised if early action is taken.

The adoption of a Danish hydrogen infrastructure with international interconnections will improve the chance of realising the scenario of land-based hydrogen production in Denmark. Likewise a sound regulatory framework facilitating the establishment of hydrogen islands and a hydrogen infrastructure in the North Sea will generate a competitive advantage over other countries, whose plans will be even closer linked to Denmark's plans and their import strategies adjusted accordingly.

***Figure 13:** The cost benefits of hydrogen production are largest for offshore energy islands*



Source: Brinckmann (2023) on behalf of the CIP Foundation.

What does society stand to gain if Denmark becomes a producer and exporter of green hydrogen?

- Potential export revenues of up to DKK 100 billion – in line with the current export of energy technologies and services – and with additional tax revenue for society.
- Exports of energy that can replace oil and natural gas, for example, without depleting resources.
- Highly productive and relatively high paid jobs during the construction phase and subsequently in the hydrogen production – with geographical variations, typically outside the large cities.
- A balancing of the Danish power grid and a less imperative need to expand the power infrastructure for the transmission of the large quantities of renewable energy which can be applied in the production of hydrogen when more energy is produced than is required for the direct electrification process.
- Hydrogen and Power-to-X production will require a built out of renewable energy, which in itself will result in long periods of lower electricity prices but also periods of higher electricity prices than today (greater fluctuations) and overall lower energy prices for the benefit of the competitiveness of Danish trade and industry and also Danish consumers.
- Support of the green transition for a major region when Denmark becomes the best and cheapest producer of large quantities of green hydrogen in Northern Europe for the required transition of industry and transport.
- Support of the political intention to manage global climate issues in an area where Denmark has the opportunity to make a genuine difference, and which has the potential to make one of our biggest contributions to the international green transition.
- Greater energy independence and, hence, support of the EU safety and energy policy agenda.

Source: Based on input from COWI (2023), Copenhagen Economics (2022b), Green Power Denmark (2020), IRENA (2022) and EA Energy analysis (2020)

New infrastructure, new regulation

A new energy market calls for a new infrastructure and a relevant regulation mechanism.

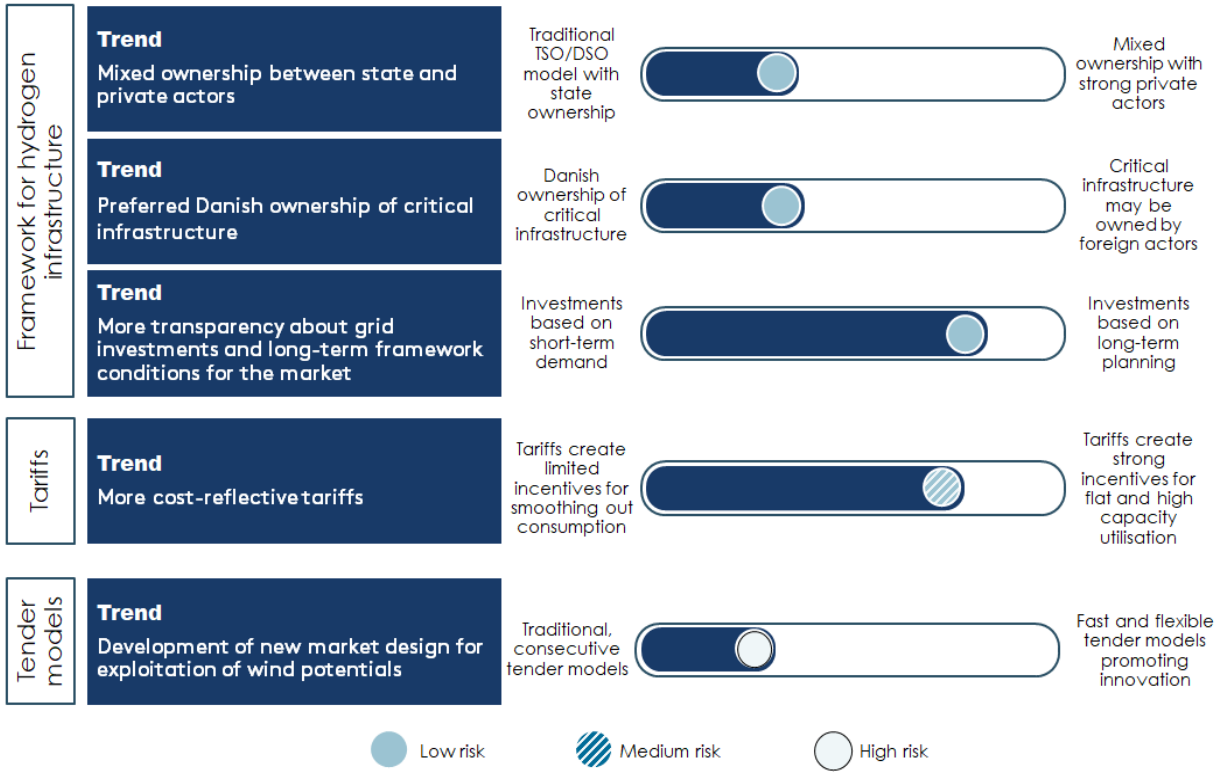
The organisation and regulation of the infrastructure is absolutely critical to a future hydrogen market. Issues such as ownership, operation, cost distribution and funding are – along with the physical infrastructure – critical to the development of a hydrogen market. The players need not only know the future pipelines and interconnections, they also need to know the conditions for their use and the relevant costs.

EXPERIENCE AND TRENDS FROM OTHER FORMS OF REGULATION

Denmark has considerable experience in energy infrastructure and its regulation but not yet any experience in the regulation of a hydrogen infrastructure. By drawing on previous energy infrastructure regulation, the future regulation of the hydrogen sector can take inspiration from the most useful trends and experience. However, a future hydrogen market will differ from, for example, the markets for electricity and natural gas in that it will feature only a few large producers and a few large buyers to be connected to the hydrogen grid. Fewer consumer will most likely result in a different price structure.

At the request of the CIP Foundation, Copenhagen Economics (CE) has made an evaluation of what the future regulation of a hydrogen infrastructure could look like in Denmark. CE highlights that a hydrogen model with a Transmission System Operator (TSO) as the major player for the land-based production and piping is a highly likely solution, preferably under Danish ownership, see Figure 14. Commercial international pipelines and interconnections could also be established offshore directly from the renewable energy capacity.

Figure 14: *Five trends that are expected to occur to some extent in the Danish energy system, including the hydrogen infrastructure, in the years to come*



Source: Copenhagen Economics (2022a)

It is difficult to accommodate new industries and new needs based on identified demand, which has otherwise been a ruling principle for the energy infrastructure expansion so far. Here, Energinet, the TSO for gas and electricity in Denmark, has been given a wider range of options with the long-term development plan which allows for certain expansion in view of the envisaged market.

In CE's opinion, capacity-based, cost-reflective tariffs will – and should – become the dominant factor.

PAY-AS-YOU-USE RELATIVE TO CAPACITY

A capacity-based tariff system will encourage consumers to use the infrastructure at times when consumption is otherwise low. Conversely, the use of the infrastructure becomes

more costly in the regions and at times when production is high.

This reduces the costs of expansion of the infrastructure and provides the stakeholders with an incentive to take the dimensions of the infrastructure into account in respect of their use.

The principle of capacity-based tariffs is also the predominant approach in a number of our neighbouring countries when it comes to the electricity market. These countries also offer electricity tariffs which lend more support to the major electricity consumers, such as Power-to-X producers, see Figure 15. Differentiated tariffs based on geography could also be introduced in order to encourage optimal use of the electricity and hydrogen infrastructure.

Finally, CE finds that the market design and supply models for increasingly complex infrastructure projects in places such as the North Sea are fairly uncertain at this point.

UNCERTAINTY AND WAITING TIME ADD TO COSTS

The uncertainties relating to the future regulation are notable at all levels – whether the infrastructure will in fact be implemented, what the time frame will be, and, if implemented, its location, the cost of using it, the ownership and/or the funding of it.

As the uncertainties translate into higher costs for developers and users, it is relevant for the socioeconomic development and to support the green transition to make efforts to reduce these uncertainties where possible. Also with regards to regulatory measures.

The fact that green hydrogen offers huge export potential, all things equal, is an argument in favour of ensuring that the commercial players assume a large proportion of the risk and the funding, while the Government should focus especially on the overall planning and the timely organisation of the regulation and the regulatory framework.

The longer it takes to work out the regulation and the framework, the greater the risk that other stakeholders will set up their own infrastructures, which will define the frameworks for the market access and the long-term supply agreements for the future green hydrogen market. This can create a form of access barriers – an entry cost – for other players.

***Table 1:** Electricity tariff regulation trends across countries*

Country	Volumetric	Capacity focused	Time differentiated	Geographically differentiated	Electricity tariff for PtX/big customers
Denmark	✓	✗	✗	✗	~ 15 EUR/MWh
The Netherlands	✗	✓	✗	✗	~ 4 EUR/MWh*
Germany	✓	✓	✗	✗	~ 0 EUR/MWh After 20 yrs:
Belgium	✓ (~60%)	✓ (~40%)	✓	✗	
Sweden	✓ (~20%)	✓ (~80%)	✗	✓	~ 3 EUR/MWh After 20 yrs:

Source: Copenhagen Economics (2022a)
Note: Volumetric tariff means that consumers are charged for the volume taken from the grid, while capacity tariffs are based on the number of users of the infrastructure and whether the capacity load is high or not. Time and geographical differentiation are other ways to encourage consumers to use the infrastructure at times or in areas with less capacity pressures. Electricity tariffs charged from major customers affect the production costs of future producers of hydrogen and PtX products if the green power has used the electricity grid.

Conclusions and recommendations

Denmark has huge export potential which can be used to the benefit of Europe's green transition, energy independence and have a positive impact on Danish economy.

LARGE EXPORT MARKET SOUTH OF THE DANISH BORDER
South of the Danish border, Germany, the Netherlands and Belgium will have huge demand for green hydrogen for the transition of their heavy industries, among others. Denmark has the potential to export green hydrogen to Germany as early as 2030, and in the period up to 2050 the trade revenue from renewable sources could amount to more than DKK 100 billion annually.

However, in order to attain this potential, an infrastructure will have to be established, the expansion of renewable energy must be set in motion and a lucrative framework for the development of the Danish North Sea areas must be created.

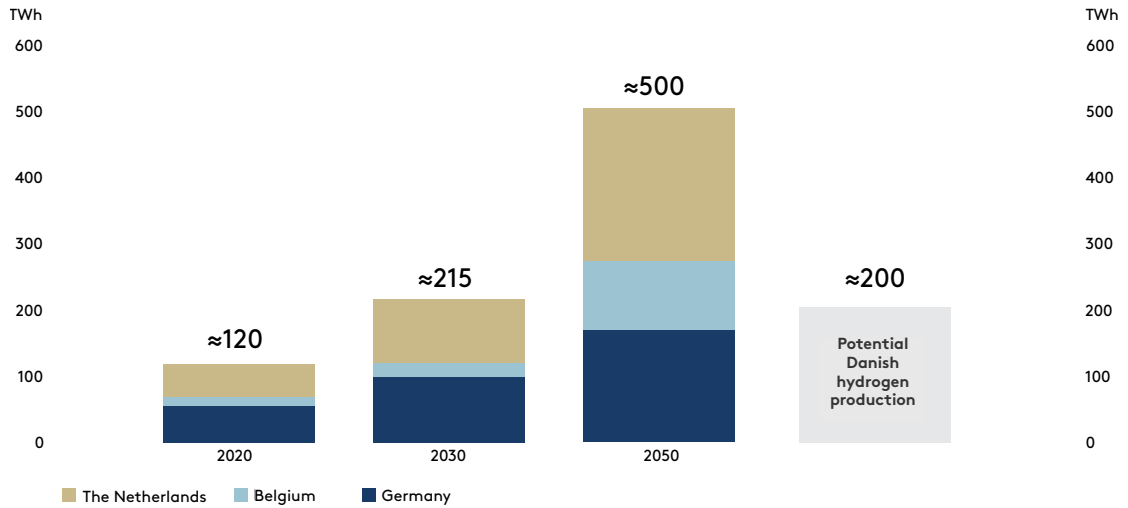
Green hydrogen is internationally recognised as an important component of the green transition process. Contrary to electricity, hydrogen can be stored and generate more efficient energy production and a balancing electricity grid.

In addition, hydrogen can also replace fossil alternatives in the heavy industry sector and it serves as the future base for Power-to-X products, which will ensure the transition of the aviation and shipping industries and enable the production of green fertilisers for agricultural use.

DENMARK TO JOIN INTERNATIONAL SCHEMES
The world is witnessing huge progress in this field, and hydrogen and Power-to-X projects are in the pipeline all over the planet. Players in countries with large industrial sectors, such as Germany and the Netherlands, are entering into agreements for the delivery of hydrogen from Southern Europe, the Middle East and Australia, and they are in the process of planning the relevant hydrogen infrastructures. Denmark has to target and tap into this market where possible.

According to forecasts, Denmark's own future demand for hydrogen will be limited, but sites in areas such as the North Sea hold potential for large-scale hydrogen production, and Denmark could reap the benefits from this export potential. The reason is that Germany, the Netherlands and Belgium will be deficient in large quantities of green hydrogen when their

***Figure 15:** The expected hydrogen demand for Germany, the Netherlands and Belgium will exceed Denmark's potential hydrogen exports*



Sources: 2020: TNO PUBLIEK (2020) for the Netherlands; Deloitte (2021) for Belgium; and the Federal Ministry for Economic Affairs and Energy (2020) for Germany; 2030: Economie (2022) for Belgium; the Federal Ministry for Economic Affairs and Energy (2020) for Germany; and the Ministry of Economic Affairs and Climate Policy (2020) for the Netherlands; and 2050: estimated by COWI.
Note: Denmark's hydrogen exports are estimated to total 16 TWh by 2030, according to own calculations based on the Danish Energy Agency (2023) and the Danish Government's Climate Partnership for Energy and Utilities (2020).

heavy industries and their transport sectors are to go through the transition process and, all things equal, Denmark will boast favourable conditions and the lowest hydrogen production costs in the immediate vicinity. Accordingly, Denmark is posed to exploit the possibility of exporting large quantities of green hydrogen to countries which will be unable to meet their own demand.

SURPLUS ENERGY FOR HYDROGEN SHORTLY

According to forecasts made by the Danish Energy Agency, Denmark will be able to produce more hydrogen than required to meet the domestic demand as early as 2030. By 2030, the surplus hydrogen will have an export value of DKK 8 billion, but it will meet only about 10% of the total demand from Germany, the Netherlands and Belgium.

LARGE POTENTIAL BUT…

The potential is much larger, and if Denmark expands the known capacity, exports of hydrogen could reach a value of DKK 100 billion annually, which is two thirds more than the value of Denmark's oil and gas exports when they peaked.

Denmark has the potential to make a significant contribution to the green transition, security of supply and energy independence in Europe.

However, the framework for the development of the new energy market will have to be elaborated if this potential is to be exploited. Otherwise, Denmark will miss out on possibilities when Germany, the Netherlands and Belgium enter into strategic partnerships and infrastructure agreements that do not include Denmark. Based on the market assessment, the CIP Foundation presents Danish decision-makers with three recommendations:

The CIP Foundation's three recommendations for Danish decision-makers:

- **Set the planning of a hydrogen infrastructure with interconnectors to neighbouring countries in motion.** The specific locations should be identified in view of the activities and import needs of our neighbouring countries. The plans should be announced as soon as possible to ensure that sales channels exist for the individual hydrogen projects and that import countries can incorporate Denmark into their supply strategies and their establishment of a hydrogen infrastructure on the receiver side. Decisions about issues such as ownership and operation of the infrastructure, cost splitting and funding should be made as soon as possible and in dialogue with the market.

- **Speed up the expansion of renewable energy.** The expansion of renewable energy must ensure that producers of hydrogen get access to the energy quantities they require and that Denmark makes the largest possible contribution to Europe's green transition when the opportunities are there. Ambitions, targets and political agreements are not enough – words must be accompanied by actions.

- **Create the framework for commercial large-scale production of hydrogen in the North Sea.** If Denmark is to make the most of its export potential and make the largest possible contribution to the European transition ensuring reliability of supply and energy independence, a framework is required that will allow expansion of renewable energy in the North Sea at a large scale with a view to exporting hydrogen. Hydrogen islands dedicated to exports is one option since Denmark's areas will be able to produce hydrogen at a scale that will exceed domestic demand and at the lowest costs.

On 30 May 2023, the CIP Foundation will present an overall plan for the hydrogen and Power-to-X infrastructure of the future. The plan will propose specific locations and pipelines for a future Danish hydrogen infrastructure and outline the investments required.

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