The Government's strategy for POWER-TO-X

Danish Ministry of Climate,
Energy and Utilities

2021

Note that this is an English translation of the Danish strategy *Regeringens strategi for Power-to-X*. The content of the Danish version will be applicable at all times.

Contents of the Power-to-X strategy

Introduction

With the *Climate agreement for energy and industry, etc. of 22 June 2020,* the Government reached an agreement with a majority of the parties of the Folketing to prepare a Danish strategy for Power-to-X (PtX) and utilisation of carbonaceous products (Carbon Capture and Utilisation - CCU). Since then, developments have proceeded at an incredible pace. PtX projects have been announced across all of Denmark, with more on the way. The Government has launched initiatives that can contribute to the promotion of PtX through a number of agreements and proposals.

The adoption and utilisation of PtX technologies requires strategic planning, targeting and prioritisation. With this strategy for PtX and CCU, the Danish Government is now taking its first major holistic step to create the necessary framework conditions for PtX in Denmark. These framework conditions are intended to facilitate the contribution of these technologies to the objectives of the Danish Climate Act, the realisation of their commercial potential and their integration into the Danish energy system.

The PtX strategy is based on the Danish Energy Agency's analyses and running dialogue with the PtX industry. This has resulted in the establishment of the Government's four objectives for promoting PtX in Denmark:

1) Power-to-X must be able to contribute to the realisation of the objectives in the Danish Climate Act.
2) The regulatory framework and infrastructure must be in place to allow Denmark's
   strengths to be utilised and for the Power-to-X industry to operate on market terms in the long run.
3) The integration between Power-to-X and the Danish energy system must be improved.
4) Denmark must be able to export Power-to-X products and technologies.

These objectives are inextricably linked, and action will be required on all four fronts for PtX to become a new green utility sector in Denmark, thereby providing green solutions that benefit Danish consumers and the rest of the world.

With its electrification strategy, *Electrification of society - the road to an electric Denmark* - the Government has put forth a clear vision for the electrified society of the future. The strategy contains eight specific objectives that the Government believes are crucial in the transition phase from a fossil-fuelled to an electric-powered society. The scenarios of the strategy show a considerable electrification potential within a number of sectors, which can become even greater after 2030, provided that significant technological and market developments occur in relation to

indirect electrification in particular.

The Government has proposed that Denmark should aim to build upwards of 4 - 6 GW of electrolysis capacity by 2030. This expansion should occur on market terms to the greatest extent possible while also supporting the realisation of Denmark's export and commercial potential in the PtX area. This objective can also contribute to reducing Denmark's global climate footprint and achieving national and international climate objectives.

Additionally, the Government has proposed investing DKK 1.25 billion - through a PtX tender for operational support of the production of hydrogen and other PtX products - with a view to supporting the industrialisation and upscaling of PtX production in Denmark, thereby reducing costs associated with hydrogen production. This is envisaged to encourage growth and job creation as well as Denmark's commercial and export potential in the PtX area. By providing funding to the production of green hydrogen, we ensure that all PtX producers can in principle participate in the tender, as all known PtX technologies entail the production of hydrogen through electrolysis. This hydrogen can be further converted into other PtX products such as ammonia, methanol or e-kerosene.

Furthermore, the Government will earmark DKK 344 million for innovative green technologies via funds from the REACT-EU initiative and the Just Transition Fund. Additionally, the Government's strategy for investments in green research, technology and innovation - *Green solutions of the future* - presents four missions intended to accelerate the development of groundbreaking green solutions through a strategic and coherent green research effort, from basic research to commercialisation. One of the missions is focused on green fuels (including PtX) and contributing to the development of solutions to convert electricity from renewable energy into products that can be used to reduce emissions from parts of the transport and industrial sector where there are no cost-effective alternatives to fossil energy. Just under DKK 1 billion has been earmarked for the four missions of the strategy.

Together with a broad majority in the Folketing, the Government has also funded Danish value chain projects for hydrogen (IPCEI) with DKK 850 million, allocated roughly DKK 400 million to the development of PtX via the EUDP and Danish Energy Agency's energy storage funding pool and finally, allocated DKK 500 million from REACT-EU to act on the recommendations from the regional growth teams to establish eight local commercial beacons in Denmark, including a commercial beacon in South Jutland revolving around green energy and sectoral linking. The Government's proposed *Denmark can do more I (Danmark kan mere I)* reform envisages allocating an additional DKK 500 million in EU funds towards 2027, thereby reaching a total of DKK 1 billion for the development of the local commercial beacons, including the commercial beacon in South Jutland.

In addition, with its *Denmark can do more I* reform proposal, the Government has proposed a DKK 6 billion capital injection into the newly established Danish Investment Fund, of which 1.7 billion will be targeted for funding companies engaged in commercial large-scale demonstration projects in fields such as PtX.

What is Power-to-X?

PtX is a blanket term for a number of technologies that are all based on using electricity to produce hydrogen. This hydrogen can subsequently be used directly as a fuel for road transport or industrial purposes or further converted into other fuels, chemicals and materials.

This may sound quite advanced, but the idea behind the technology is in fact quite old. PtX is based on the lightest, simplest and most prevalent element we have: Hydrogen. Atomic number 1 on the periodic table.

Figure 1 shows the entire production chains from renewable energy to the production of fuels that can be used for transport and industry.

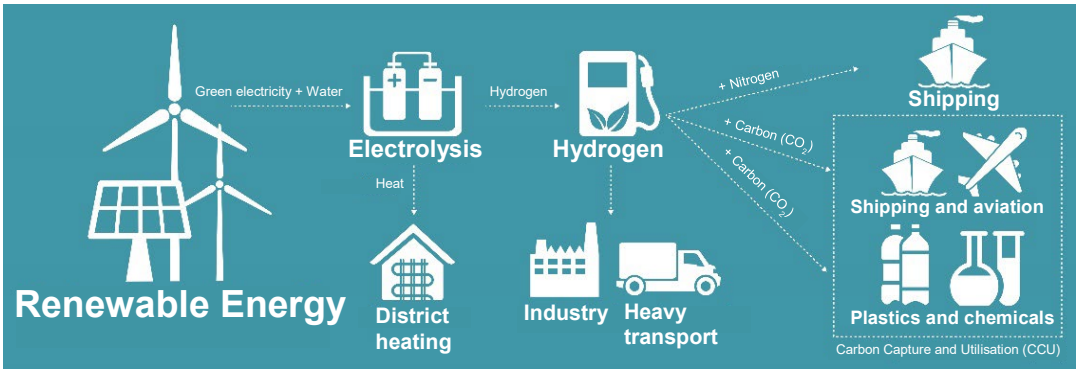
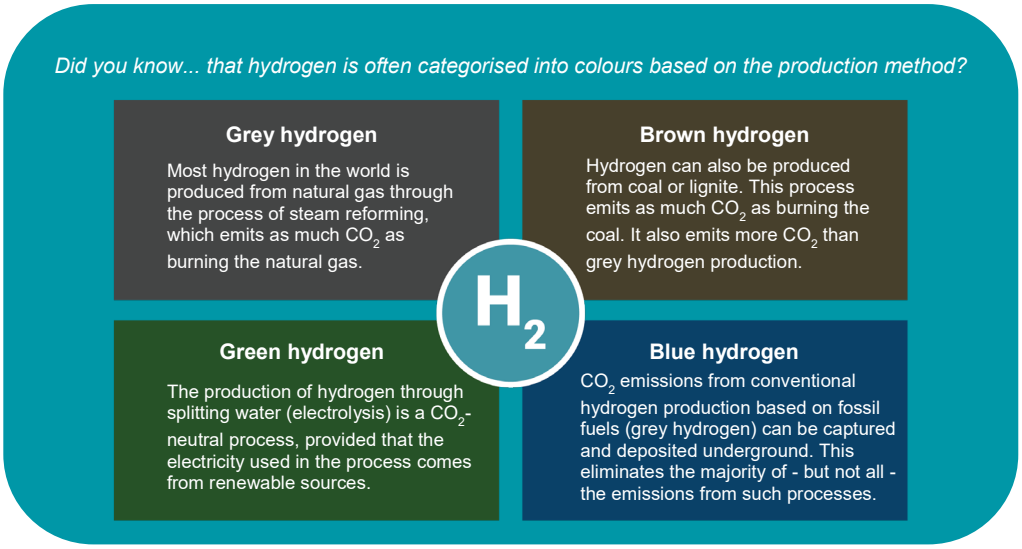


Figure 1. Renewable energy can be used to produce fuels and other products used for transport and industry. The figure shows how PtX can be used in Denmark.
Source: The Danish Energy Agency

Electrolysis uses electricity to split water into hydrogen and oxygen

The core technology behind PtX is called electrolysis, which uses electricity to split water into oxygen and hydrogen. The technique has been known for over 200 years. The hydrogen, which is considered 'green' when produced with renewable energy, can subsequently be directly used for industrial purposes or as a fuel for trucks and other vehicles. At present, Denmark's consumption of hydrogen is relatively modest and largely restricted to refineries where it is used to produce fossil fuels. The hydrogen can also be used as a building block for producing a wide range of other fuels and products.

Today, nearly all hydrogen production is based on fossil fuels such as coal (brown hydrogen) and natural gas (grey hydrogen). In Denmark, the focus is exclusively on producing green hydrogen. Several actors have already announced and launched plans for large-scale PtX projects that will produce large quantities of green hydrogen and fuels by 2030.



Ammonia can be made from hydrogen and nitrogen derived from air

Hydrogen can be combined with nitrogen to form ammonia. Being the most plentiful element in Earth's atmosphere, nitrogen is easily obtained from the air we breathe. The resulting ammonia can be used as fuel in diesel-like engines on ships in the future or for producing fertilisers and other chemicals.

Hydrogen and carbon can be synthesised into plastics, aviation fuel and much more

Hydrogen can be made to react chemically with carbon in large processing plants under high pressure and temperatures to form a number of fuels and other products such as methane, methanol, gasoline, diesel, aviation fuel and plastics with the same properties as the fossil-based products. This process is also called Carbon Capture and Utilisation (CCU).

For example, this carbon can be captured as CO_2 from flue gas stemming from incineration plants or biogas plants. When the carbon has a biogenic origin, i.e. when it originates from biomass, it is considered climate neutral in the energy sector according to the UN's calculation methods, as the emissions are included in the carbon balance for forests and soils (LULUCF). This means that if biogenic CO_2 is used to produce PtX fuels, these fuels can be considered CO_2-neutral overall.

CO_2 can also be captured directly from Earth's atmosphere through a process called *direct air capture* (DAC). In the long run, this process is expected to be able to contribute to the green transition, but the technology behind it still needs further development and to become more cost-effective. Biogenic carbon is a limited resource, while carbon captured from the atmosphere is essentially an unlimited resource.

Power-to-X in the energy system of the future

Power-to-X can help reduce greenhouse gas emissions

PtX technologies make it possible to use renewable sources of energy to produce fuels and chemicals that are currently produced from fossil sources. Thus, the utilisation of PtX fuels can contribute to CO_2 emission reductions if they replace the use of fossil fuels or materials (e.g. if e-methanol replaces oil in ships) or if the production of chemicals replaces conventional production that normally emits CO_2. An example of the latter could be the production of green ammonia for artificial fertilisers replacing the production of fossil-based ammonia, which emits large amounts of CO_2.

A prerequisite to considering PtX products as CO_2-neutral is that the electricity (and carbon) used can also be considered CO_2-neutral. In other words, the CO_2 must either stem from sustainable biomass or directly from the atmosphere. The CO_2 can also be captured from fossil sources and used for PtX, in which case either the fossil emissions or the PtX product can be considered CO_2-neutral, but not both. This means that if the CO_2 is captured from a factory that uses a fossil fuel, and the CO_2 is used for PtX, only one of the parts can be considered CO_2-neutral.

If PtX is to contribute to the achievement of Denmark's 70 percent target, PtX fuels - produced domestically or imported from abroad - will need to be adopted as a substitute for fossil fuels in the sectors in Denmark that are included in the country's national CO_2 balance. If the fuels are exported or used to replace biofuels, this will not impact the achievement of the 70 percent target, but may contribute to replacing fossil fuels elsewhere in the world, e.g. in international shipping and aviation. PtX can thereby contribute to reducing CO_2 emissions globally in different ways, as shown in Box 1. The Danish Energy Agency publishes an annual report called "Global Afrapportering"[1] ("Global Reporting") on the change in Denmark's global emissions.

Box 1

How Power-to-X can help reduce Denmark's global climate footprint

Fuel exports

Denmark can contribute to reducing global emissions of CO_2 if Danish PtX fuels are used to replace fossil fuels abroad.

Emissions in the value chain

Greenhouse gas emissions decline when CO_2-neutral PtX fuels replace fossil fuels. PtX can also contribute to reducing emissions in the value chain associated with the extraction of fossil fuels, land use, etc. for first-generation biofuels, refining, transport, etc. The latter are largely not included in the 70 percent target but included in European and global climate targets and make up part of Denmark's global climate footprint.

[1] Global afrapportering, Danish Energy Agency, 2021

International transport

Emissions from international aviation and shipping are not counted in the Danish national CO_2 balance, even when ships and aircraft refuel in Denmark. The use of PtX fuels in these sectors will accordingly contribute to reducing Denmark's global climate footprint and meeting climate targets at the European and global level.

Bringing home production of materials and chemicals

Today, Denmark only has a limited consumption of hydrogen for industrial purposes, as well as a limited production of chemicals and the like. The production of chemicals such as artificial fertiliser derived from ammonia based on PtX will therefore replace the production of ammonia and other chemicals abroad, thereby reducing emissions associated with foreign ammonia production.

The best use of electricity is direct electrification

The Danish Energy Agency's analyses have found that when transitioning transport and industry to fossil-free fuels, direct electrification - e.g. through battery-based electric cars - is in principle the most cost-effective and optimal way to use electricity generated from renewable sources. For example, the agency calculates that around 70 percent of wind energy is converted into propulsion of a battery-powered vehicle, while only around 30 percent of wind energy is converted into propulsion in a hydrogen-powered car. The technologies for replacing fossil-fuelled vehicles with electric/battery solutions are already well-established and becoming widespread. The production of fuels via PtX is energy-intensive, which is why PtX fuels should be prioritised for areas where direct electrification is not possible or associated with very high costs.

In the Government's electrification strategy, it is estimated that upwards of 80 percent of national transport can be directly electrified in the long run. This applies in particular to light road transport as well as large parts of heavy transport, e.g. passenger cars, vans and lorries driving short distances.

At the same time, however, the Danish Energy Agency's analyses have found that it will be difficult to electrify other types of transport such as long-distance flights, freight shipping and parts of the heavy road transport sector. It is in those areas where PtX and biofuels can be used to provide the green fuels of the future that can replace fossil fuels. There are also parts of the industrial sector that can use PtX to transition into sustainable energy consumption in cases where electrification or biogas are not possible or too costly to be a viable solution.

For example, this could include industrial high-temperature processes or particularly energy-intensive vehicles such as combine harvesters and large construction machinery. There are some industry processes where the emissions stem from the process itself and not from the energy consumed in the process, such as when producing ammonia for fertiliser. Naturally, it is not possible to

eliminate emissions through electrification of such processes. In some cases, however, PtX will be able to replace fossil-based alternatives.

Biogenic and sustainable carbon may become a limited resource

Carbonaceous fuels such as aviation fuel and methanol can be produced through the conversion of green hydrogen and carbon. For example, the carbon could stem from CO_2 from biogas plants, biomass-fuelled CHP plants or incineration of biological waste. Biogenic and sustainable carbon is, however, expected to become a limited resource, as the world's sustainable biomass resources are limited and biomass is also needed for food, feed and other purposes that contribute to CO_2 reductions in the transport, construction and energy sectors.

There will be enough carbon in 2030 - but likely not in the long run

The biogenic CO_2 can be used to produce CO_2-neutral fuels and materials (carbon capture and utilisation, CCU) as well as stored in the subsoil (carbon capture and storage, CCS). The Danish Climate Act states that negative emissions from technological processes such as CCS can contribute to meeting Denmark's reduction targets.

In June 2021, the Government presented the first part of its CCS strategy and on that basis, entered into a political agreement on the framework conditions for CO_2 storage in Denmark. On 14 December, a broad majority in the Folketing reached an agreement on the second part of the strategy, which establishes the principles for the first implementation of the CCUS funding pool and establishes the framework for capture and transport of CO_2.

The Climate agreement for energy and industry, etc. of 2020 included a decision to allocate DKK 16 billion to a CCUS funding pool, which is expected to result in a reduction of approximately 0.4 million tonnes of CO_2 by 2025 and 0.9 million tonnes by 2030. In addition, the 2022 Finance Act allocates approximately DKK 2.5 billion to a funding pool for negative emissions, which is expected to result in a reduction of 0.5 million tonnes of CO_2e annually from 2025.

A full realisation of the potential for the use of PtX in Denmark presupposes the use of climate-neutral carbon corresponding to around 0.5-4.5 million tonnes of CO_2 in 2030 and around 1.5-6.5 million tonnes of CO_2 in 2050. The sizes of the estimate bounds depend on how much of the potential can be covered by PtX fuels that do not contain carbon, such as hydrogen and ammonia.

In comparison, the Danish Energy Agency estimates that there will be around 4.5-10 million tonnes of CO_2 at disposal from Danish point sources in 2030, of which 4-7 million tonnes will come from biogenic sources, as shown in Figure 2. This includes a certain reduction of biogas consumption in CHP plants compared to

present levels. This is being analysed more closely as part of the 2020 Climate agreement for energy and industry, etc.

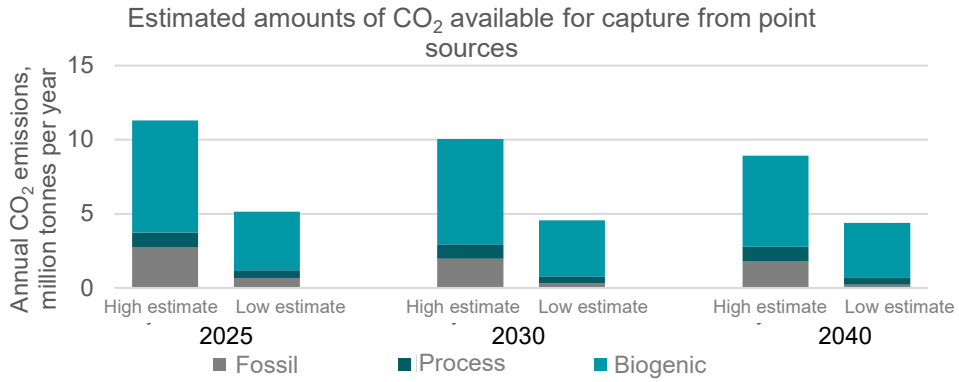


Figure 2: Estimated amounts of CO_2 emissions that can be captured and sequestered/used from Danish point sources within the waste sector, industrial sector, CHP plants and biogas upgrading plants. Source: The Danish Energy Agency

In the future, pyrolysis of degassed biomass, sewage sludge, straw and other material could provide additional carbon input for the PtX sector and negative emissions in the form of biochar for ploughing and carbonaceous gas or oil for fuel production.

Biogenic and sustainable CO_2 from point sources can thus become a limited resource in the long run, even though the Danish Energy Agency estimates that there will be enough to cover domestic needs in Denmark up to 2030.

Did you know... that the *Agreement on sustainability requirements for wood biomass for energy of 2 October 2020* provides greater guarantees that the biomass used in Denmark is as sustainable and climate-friendly as possible. The rules for sustainability criteria for biomass used for electricity and heat production entered into force on 30 June 2021. In addition, political agreements have been reached on the promotion of alternatives to the use of biomass for heating, such as heat pumps.

Power-to-X fuels without carbon may be the future-proof choice

Sustainable biomass is not an unlimited resource, and increasing demand for energy, fuels, food and building materials is estimated to put a significant future pressure on the world's biomass resources. In the long run, this is expected to lead to rising prices for biofuels and potentially also carbonaceous PtX fuels. The PtX fuels hydrogen and ammonia do not contain carbon and are therefore - all other things being equal - cheaper to produce than those containing carbon, as there is no need to pay for the carbon derived from sources such as capturing CO_2 from

flue gas. Accordingly, these types of fuels do not contribute to heightened demand on the world's biological resources.

Sustainability, carbon access and economical considerations would indicate that carbon-free fuels will potentially be a more future-proof solution for the sectors that do not need carbonaceous fuels, including shipping in particular. Hydrogen and especially ammonia are, however, subject to a number of stricter safety requirements in relation to other fuels, one of the reasons being that ammonia is toxic in even relatively small concentrations. In addition, ammonia engines are still in the developmental phase. If ammonia in particular is to become the cheapest fuel in the shipping sector, those issues will need to be addressed.

Although in the short term, there may still be uses for carbonaceous fuels in the shipping sector, for instance, this should be seen in light of the fact that engines that run on ammonia are still in development and that ammonia is toxic and therefore comes with a number of other challenges.

How much carbon can we use - and for what?

It is not only in the energy and transport sector that a growing pressure on biological resources is anticipated. Competing applications for food, building materials, chemicals, plastics negative emissions and last - but not least - wild nature and carbon storage in forests is also expected to entail a demand for growing amounts of biomass and land.

Green and sustainable biomass is, however, a limited resource worldwide. According to recommendations from the National Bioeconomy Panel, there is not enough biomass in the world to replace the large amounts of fossil resources currently used for producing products such as plastics, packaging, textiles and chemicals.

In the long run, the development of atmospheric carbon capture techniques - *direct air capture* (DAC) - can contribute to solving the challenge of this limited resource. Even though this technology is costly, partly due to the relatively high energy requirements it entails, the limited biomass potential is believed to entail that DAC will eventually be able to supply the remaining amount of carbon that biogenic sources cannot.

Did you know... that researchers are working on a method for capturing CO_2? The technology goes by the name *direct air capture* (DAC). The world's first DAC plant went into operation in Iceland in 2021 and is expected to capture 4,000 tonnes of CO_2 which will be deposited in the Icelandic subsoil. In addition, there are plans for at least three large-scale facilities in the USA, Scotland and Norway, each of which will capture and store 0.5-1 million tonnes of CO_2 annually.

Competitive relationship between Power-to-X and other fuels

At present, PtX production entails significantly higher costs than production of fossil fuels. This is especially due to the cost of hydrogen production through electrolysis. The majority of the costs for hydrogen production stem from the price of electricity, electricity grid payments (electricity tariffs) and investing in the electrolysis plant itself.

Direct electrification is therefore typically cheaper than using hydrogen and other PtX fuels, as only around two-thirds of the energy from the electricity ends up as energy stored in hydrogen. However, not all sectors will be able to be directly electrified, and in some sectors - such as aviation, shipping, heavy road transport and industry - there will still be a need for fuels.

Figure 3 shows the Danish Energy Agency's forecast for production costs of hydrogen and three PtX fuels within the coming decade. The market price forecasts of fossil fuels and biofuels are also shown for comparison. PtX fuels are expected to be remain more expensive than fossil fuels and 1st generation biofuels in the near future. Therefore, the use of PtX fuels will require regulation that creates incentives for using more climate-friendly fuels or contributes to evening out the price differences for consumers. This also applies to sectors where PtX fuels are anticipated to become a cost-effective tool for CO_2 reductions in the long term, either in the form of levies and subsidies or in the form of CO_2 displacement requirements or other regulation.

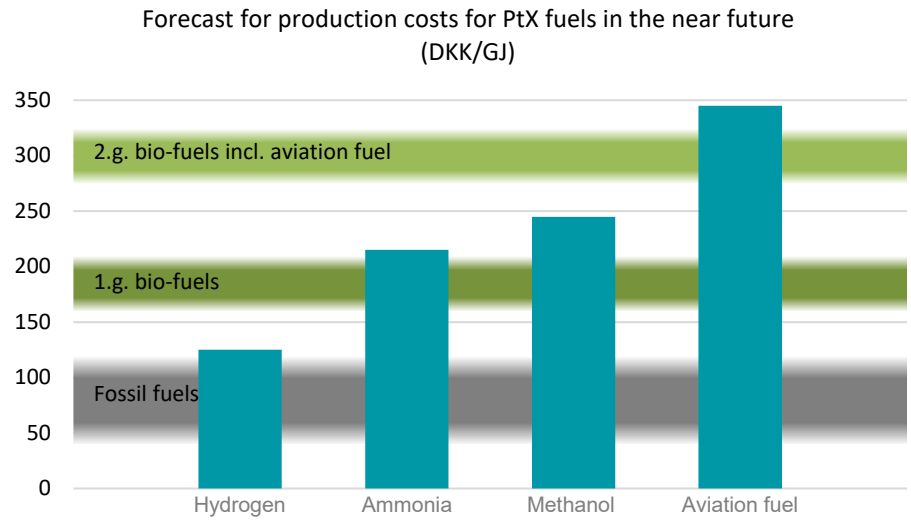


Figure 3. Forecast of production costs for Power-to-X fuels in the near future. Ranges for market prices of fossil fuels and biofuels are also shown, where ILUC effects on the price are not factored in. Source: The Danish Energy Agency

In the longer term, a global upscaling and industrialisation of PtX production can contribute to significantly reducing the price of green hydrogen and PtX fuels.

Box 2

When will Power-to-X become competitive?

The Danish Energy Agency's analyses have identified significant potential for reducing the cost of hydrogen production and PtX products, a conclusion which is echoed by several other actors. This potential lies especially in the upscaling and mass-production of electrolysis plants as well as adjusted framework conditions.

Predictions about technological development are subject to significant uncertainty, especially in terms of the speed and scope of the global rollout and mass-production of electrolysis plants.
Therefore, the strategy takes into account two different forecasts for production costs:

- Costs in the near future, which are expected to be achievable within this decade without a major adjustment of framework conditions to lower costs.
- The potential change in costs in the long term after significant upscaling and industrialisation of production as well as improved framework conditions and expansion of supporting infrastructure.

When and to what extent the costs for PtX will be reduced remain uncertain, however, and depend on national, regional and global developments, measures and regulations.

The Danish Energy Agency's analyses show that especially carbon-free PtX products - due to decreasing costs - are expected to eventually be able to compete with 2nd-generation biofuels. 2nd-generation biofuels will be the primary competitor to compare with in terms of sustainable fuels, as the use of 1st-generation biofuels is expected to be limited and potentially fall over the years as a consequence of national and international regulation. In some applications - the aviation industry in particular - there will still be a need for carbonaceous fuels. In that regard,

the Danish Energy Agency's analyses show that PtX fuels for the aviation sector (e-kerosene) will be able to compete with bio-kerosene, as long as there is enough biogenic CO_2 available, e.g. from upgrading biogas. This is shown in Figure 4, where the costs for PtX fuels is lower than in Figure 3 as a result of the aforementioned price reduction. A rising demand for biogenic carbon may push up prices, which the data in the figure does not account for.

In the long term, DAC is therefore anticipated to become a more widespread source of carbon. Carbon will be more expensive, but in spite of that, the e-kerosene produced from DAC-derived carbon is expected to be priced at around the same level as bio-kerosene or lower.

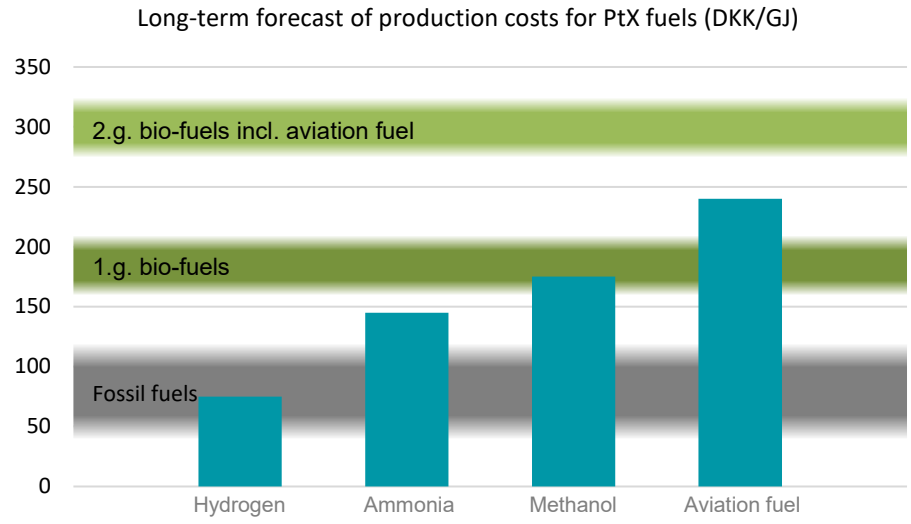


Figure 4. Long-term forecast of production costs for PtX fuels assuming significant upscaling of production, technology development, improved framework conditions and deployment of supporting infrastructure. Ranges for market prices of fossil fuels and biofuels are also shown, where ILUC effects are not factored in.
Source: The Danish Energy Agency

Denmark can become a global player in Power-to-X

Denmark has a number of strengths in relation to the production and use of PtX that create a solid starting point for the country being able to play an important role in the development of the green fuels of the future. At the time of writing, projects amounting to approximately 7 GW of electrolysis production by 2030 have been announced. A number of these are mapped in the figure on page 16.

Danish companies are strongly positioned throughout the value chain

There are about 70 companies operating in the PtX and CCUS area in Denmark, working with project development, research, technology development, consulting, production equipment and operation and maintenance. The value chain for PtX is larger, however, and includes other actors such as wind turbine manufacturers, plant owners and developers, producers of electrolysis and synthesis plants, suppliers of hydrogen infrastructure as well as consumers of green fuels in sectors such as shipping, aviation and heavy road transport.

A unique PtX knowledge and research environment

There is a generally high level of knowledge on green energy in Denmark, including PtX. Examples of this include the strong R&D environment for hydrogen and PtX solutions in Danish universities and knowledge institutions spread out across the country, from North Jutland to Zealand. The interaction between research and business in this area is crucial to ensuring that inventions and innovations from universities are brought to market.

Denmark has considerable offshore wind resources, access to biogenic CO_2 and a robust energy system

Denmark has considerable offshore wind resources and the potential to greatly expand its offshore wind capacity, particularly in the North Sea. Previous analyses from 2019 determined a capacity of 40 GW of offshore wind energy in Danish maritime territory, while the Danish Energy Agency's preliminary assessment is that - depending on the density of wind turbines - there is room for between 17 to 27 GW of offshore wind in the areas currently designated for renewable energy in Denmark's maritime spatial plan. Denmark already has a high proportion of renewable energy in its domestic electricity production, which is only expected to increase in the coming years.

A broad majority in the Folketing has decided to establish two energy islands, which in the first phase will supply 5 GW of electricity from offshore wind to the electricity system, rising to at least 12 GW once fully developed. This electricity can be transported to the mainland for normal electricity consumption or innovative activities such as PtX production or energy storage on the islands or close to the islands' grid connections to the mainland, as well as other purposes. The production from the energy islands will in itself sextuple offshore wind production in Denmark in relation to current production levels, thereby potentially constituting a major resource for future PtX production in Denmark and abroad. With the Agreement on the 2022 Finance Act, renewable energy production will be expanded by an additional 2 GW of offshore wind by 2030. This corresponds to the electricity consumption of roughly 2 million Danish households. It has also been agreed that in connection with its 2022 energy and utilities proposal, the Government will present analyses that can form the basis for the potential tendering of an additional 1 GW of offshore wind energy.

Overall, Denmark's offshore wind resources provide good conditions for the production of green hydrogen, which requires large amounts of green electricity. When it comes to the production of more advanced PtX products that require the use of carbon, Denmark also has the option to make use of biogas plants and biomass-fuelled CHP plants to produce biogenic CO_2. In addition to large and increasingly cheap renewable energy resources as well as access to biogenic CO_2, Denmark has a long tradition of coherent planning across the energy system, such as with the development of power planted heat and district heating in the 1980s, a well-developed gas infrastructure and a strategic geographical position in terms of exporting PtX products and technologies to countries such as Germany.

1 **H2RES (end of 2021)**
2 MW electrolysis plant, Avedøreværket
Project consortium: Ørsted, Everfuel Europe A/S, NEL Hydrogen A/S, GreenHydrogen A/S, DSV Panalpina A/S, Brintbranchen and Energinet Elsystemansvar A/S

2 **Green Fuels for Denmark (2023-2030)**
Electrolysis plant, Greater Copenhagen
10 MW in 2023, 250 MW in 2027 and 1.3 GW in 2030
Project consortium: Ørsted, Copenhagen Airport, A.P. Møller-Mærsk, DSV Panalpina A/S, DFDS, SAS, COWI

3 **Power2Met (opened June 2020)**
E-methanol plant, Aalborg University
10-30 MW, funded through EUDP
Project consortium: Green Hydrogen Systems, Re:Integrate, Aalborg University, Hydrogen Valley, E.ON, NGF Nature Energy, Drivkraft Denmark, Rockwool, Process Engineering, Holtec Automatic-Nord and Lillegaarden El

4 **Green CCU Hub (2024)**
120 MW electrolysis plant in Aalborg for producing e-methanol for heavy road transport and shipping
Project consortium: Re:Integrate, European Energy, Port of Aalborg, Blue World Technologies

5 **Green Hydrogen Hub (2025-2030)**
350 MW electrolysis + hydrogen storage facility in Hobro/Viborg
Up to 1 GW in the long term
Project consortium: Eurowind, Energinet, Corre Energy

6 **Blue Seal (commissioning date unknown)**
Electrolysis plant, Hobro 50 MW
Ballard Power Systems

7 **GreenLab Skive (2022)**
Electrolysis plant, Skive
12 MW in 2022 and potentially up to 250 MW in the long term. Hydrogen + methanol for heavy road transport.
Project consortium: GreenLab Skive A/S, Eurowind Energy, Everfuel, Eniig Holding, E.ON DK, GreenHydrogen, Re:Integrate, DTU, Energinet,

8 **HySynergy (2022-2030)**
Electrolysis plant, Crossbridge Energy Fredericia, 20 MW in 2022, 300 MW in 2025 and up to 1 GW in the long term
Project consortium: Everfuel Europe A/S, Crossbridge Energy Fredericia, Energinet Elsystemansvar, TVIS, TREFOR Elnet, EWII Energi A/S and Aktive Energi Anlæg A/S

9 **Høst (2025)**
1 GW plant by the Port of Esbjerg for ammonia production for agriculture and shipping
Project consortium: CIP, Din Forsyning, Esbjerg Havn, Arla, Danish Crown, Mærsk, DFDS

10 **REDDAP (2022)**
10 MW plant for ammonia production in Lemvig
Project consortium: Skovgaard Invest, Vestas, Haldor Topsøe

11 **Green HyScale (2024)**
100 MW electrolysis plant, Skive, funded by the EU (Horizon 2020)
Project consortium: GreenLab A/S, Green Hydrogen Systems A/S, Energy Cluster Denmark, Lhyfe, Siemens Gamesa, Equinor Energy A/S, DTU, Imperial College London, Quantafuel and Euroquality

12 **H2 Energy Europe (2024)**
1 GW electrolysis plant for producing hydrogen for heavy road transport and other sectors
Project consortium: H2Energy, Hyundai, Trafigura and others

13 **Eurowind Mariagerfjord (commissioning date unknown)**
Two 35-50 MW electrolysis plants
Project consortium: Eurowind

14 **European Energy (2023/24)**
6 MW hydrogen plant in Esbjerg. Capacity may be expanded to 12 MW

15 **The Port of Aabenraa (2025)**
100 MW electrolysis plant
Project consortium: Linde Gas A/S, Port of Aabenraa

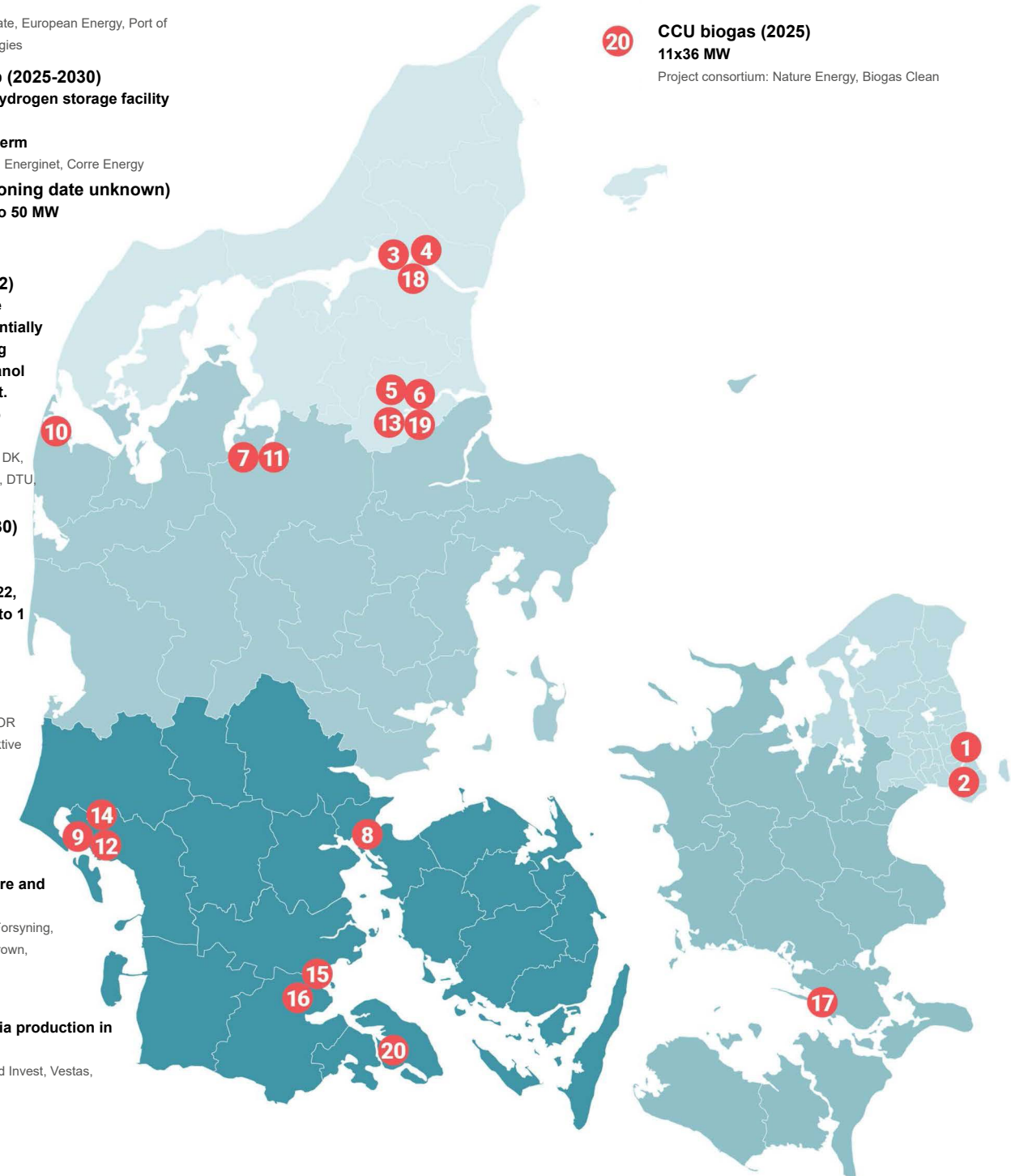
16 **The Port of Aabenraa (2023)**
10,000 tonnes of methanol per year
Project consortium: European Energy, Re:Integrate

17 **Vordingborg Biofuels (2024/25)**
100,000 tonnes of e-methanol per year in Vordingborg
Project consortium: Haldor Topsøe, Biofuel Technology, Vordingborg Havn

18 **Aalborg (2028)**
300-400 MW electrolysis for methanol production
Project consortium: CIP, RenoNord, Aalborg Forsyning

19 **HyBalance (opened September 2018)**
Electrolysis plant, Hobro 1.2 MW
Project consortium: Air Liquid, Hydrogenics, LBST, Neas Energy and Hydrogen Valley/CEMTEC

20 **CCU biogas (2025)**
11x36 MW
Project consortium: Nature Energy, Biogas Clean



The Government's four objectives lay the foundation for the development and expansion of Power-to-X

The green transition requires a fundamental transformation of our society. This will entail expanding the tools we already know and use. Accordingly, we will need more green electricity from wind turbines and solar panels, more electric cars on the roads and more heat pumps in Danish homes and companies.

With its electrification strategy, the Government plotted a course for the direct electrification of Denmark. With its PtX strategy, the Government aims to boost indirect electrification so that Denmark can become a climate-neutral society where sustainable transport by truck, ship and plane is possible.

Technological developments are proceeded at a rapid pace, and PtX is a crucial technology for a green, CO_2-neutral future. Large-scale PtX ambitions have been announced across Denmark, from the city of Esbjerg to the island of Bornholm, and more are expected in the coming years.

PtX holds considerable potential for reducing Denmark's - and the world's - CO_2 emissions and creating value for the Danish energy system while also providing significant commercial benefits. While Denmark is strongly positioned in this regard, there are a number of challenges that need to be addressed for PtX to be rolled out on a large scale and compete on market terms. This will require a holistic approach.

Accordingly, the Government has formulated four objectives (see Figure 6) that collectively contribute to overcoming the barriers for PtX and plot a course for the development and expansion of green hydrogen and green PtX products. The Government is thereby taking the first major holistic step towards a new utilities sector.

Objective 1: Power-to-X must be able to contribute to the realisation of the objectives in the Danish Climate Act

Partial conclusion: PtX can contribute to the green transition. PtX should primarily be promoted in sectors where direct electrification is not possible or associated with prohibitively high costs, such as parts of the industrial and heavy road transport sectors as well as the shipping and aviation sectors. PtX will be competing with biofuels for the same applications, but PtX is projected to eventually become more affordable than 2nd generation biofuels.

The Government aims to ensure that PtX can contribute to the achievement of Denmark's climate objectives, namely the 70 percent target by 2030, the long-term target of climate neutrality by 2050 at the latest and the reduction of Denmark's global climate footprint.

Objective 1.
Accordingly, the Government will:

- Push for ambitious, pan-European requirements for CO_2 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.
- Initiate an analysis of biological resources for the green transition.

Power-to-X must be able to contribute to cost-effective CO_2 reductions in Denmark and globally

The Government's climate programme notes a reduction potential of approximately 9 million tonnes of CO_2 if the transport sector transitions to using fuels derived from renewable energy. This potential is a technical gross potential and accordingly does not factor in competing technologies such as electrification.

In many cases, PtX fuels are more costly than direct electrification, although they are projected to become cheaper than most biofuels in the long run. Thus, PtX fuels can play an important role in those sectors where direct electrification is not possible or prohibitively expensive.

For some sectors such as shipping and aviation, liquid or gaseous fuels are also expected to make up the vast majority of energy consumption in the long term, as only a small proportion of the energy consumption in those sectors can be met through direct electrification. The extent to which PtX ought to be used for certain applications in road transport is less clear. The distribution between electrification and PtX fuels will depend on technological developments and the cost of direct electrification versus PtX fuels.

The Danish Energy Agency's analyses show that PtX fuels have the potential to provide the cheapest CO_2 reductions in certain parts of a number of sectors. This is illustrated in Figure 7, which shows the distribution of long-term potential between electrification and fuels derived from renewable energy, including PtX and biofuels, based among other things on the scenarios from the 2021 Climate Programme.

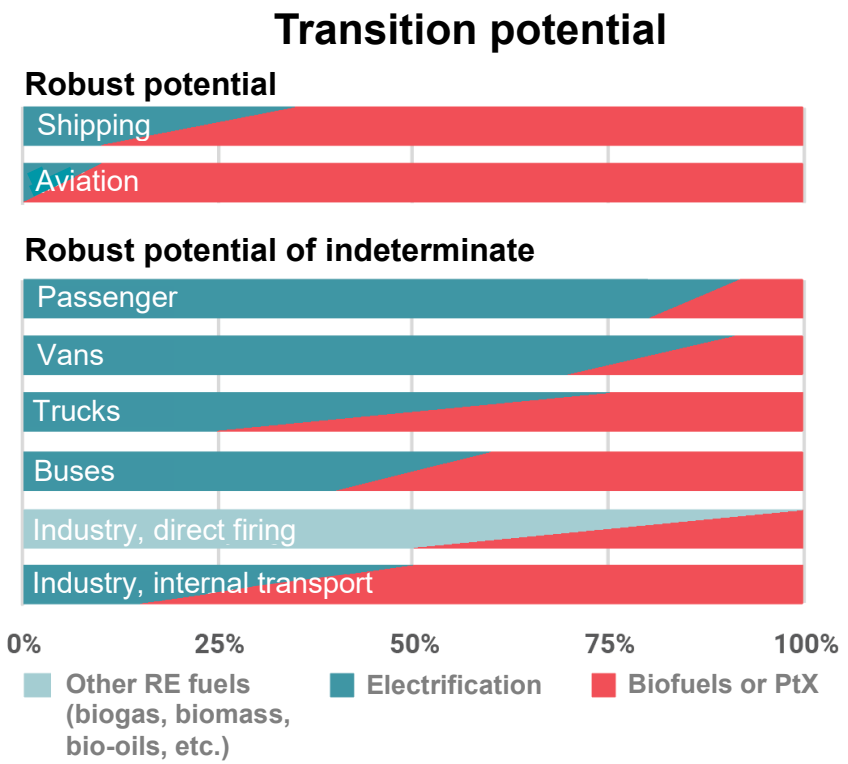


Figure 7: Long-term conversion potential of different segments through direct electrification, transitioning to biofuels or PtX or other fuels such as biogas, biomass or bio-oils. For process heat by direct firing, high-temperature process heat from solid and liquid fuels in direct firing processes is seen in isolation.
Source: The Danish Energy Agency

The Danish Energy Agency's analyses show that in the years between now and 2050, it is likely that PtX will have a significant role in aviation and most of shipping. In addition, PtX may have a significant role in the industrial sector's internal heavy road transport and high-temperature processes, parts of heavy road transport, refineries and a portion of the Danish Defence's emissions.

For these sectors, however, there is more uncertainty associated with the exact level of adoption of PtX due to uncertainties about the competitive factors with other technologies such as direct electrification. However, there is a robust likelihood that PtX can play a role in the sustainable transition of all the mentioned sectors.

The Danish Energy Agency has also assessed that it will be possible to increase the incorporation of PtX fuels such as methanol, e-gasoline and e-diesel in the remaining cars that use internal combustion engines until they are replaces by electric vehicles. This may prove cheaper in the short term compared to further promoting the electrification of passenger cars and vans beyond the normal replacement rate. However, this should be considered a potential transitional solution that is not the most cost-effective nor climate-friendly solution in the long term.

In addition, there is significant potential for the use of PtX products in relation to the production of materials and chemicals such as e-plastics and e-fertilisers, which can replace fossil-derived alternatives. The production of such products predominantly takes place outside of Denmark today, however. If the production is to be converted to PtX-based production and moved to Denmark, it will not contribute to Denmark's national reductions. Instead, it will help reduce Denmark's global footprint as well as global CO_2 emissions in general.

The Danish Energy Agency has assessed the potential for cost-effective CO_2 reductions within the transport and industry sectors by 2050. This potential is shown in Table 1. The table also shows the Danish Energy Agency's calculations of the potential in the same sectors by 2030. Whether these reductions will be cost-effective in 2030 depend on objectives, calculation prices, regulation, etc., as well as developments in the field of PtX, including which framework conditions the production and use of PtX fuels are subject to.

In the years between now and 2050, PtX has the potential to provide long-term, cost-effective CO_2 within specific sectors amounting to upwards of roughly 8 million tonnes of CO_2. The national reduction potential by 2050 is upwards of roughly 3.5 million tonnes of CO_2, while the remaining reduction potential stems from the green transition of international ships and flights refuelling in Danish (air)ports with destinations outside Denmark.

Already by 2030, PtX has a technical potential to provide CO_2 reductions in the same sectors where PtX is forecasted to eventually become cost-effective amounting to upwards of 4.5 million tonnes of CO_2. This includes reductions counted in Denmark's national CO_2 balance as well as reductions from international ships and flights refuelling in Danish (air)ports with destinations outside Denmark (and which are therefore not included in Denmark's national CO_2 balance.

In Denmark's national CO_2 balance, the use of PtX products can collectively contribute to a maximum of 2 million tonnes of CO_2 reductions by 2030, which counts towards the 70 percent target. Part of that (approx. 0.5 million tonnes) will come from transitional applications that will not necessarily be cost-effective in the long run.

Table 1: Estimates for the use of PtX fuels in Denmark in sectors where they are forecasted to eventually become cost-effective

Application	Potential reduction (CO_2, million tonnes/year) 2030	2050
Robust potential		
Power-to-X for shipping	0.6 - 1.2	1.9 - 2.6
- Of which domestic transport	0.1 - 0.4	0.4 - 0.7
Power-to-X for aviation	0.3 - 2.5	1.5 - 3.0
- Of which domestic transport	0.02 - 0.13	0.08 - 0.15
Robust potential of indeterminate extent		
Hydrogen for light road transport, including vans	0.0 - 0.1	0.0 - 0.4
Hydrogen for trucks and buses	0.02 - 0.4	0.4 - 1.2
Hydrogen for industry, direct firing	0.0 - 0.1	0.0 - 0.5
Hydrogen or e-diesel for industry, internal transport	0.0 - 0.2	0.2 - 0.5
E-fuels for the Danish Defence (aircraft, ships, vehicles)	unknown	unknown
Hydrogen for biofuel production, etc. at refineries	unknown	unknown
Production of chemicals (fertiliser, plastics, etc.)	unknown	unknown
Uncertain potential for transitional solutions that are not cost-effective		
Methanol mixed with gasoline	0.03 - 0.05	0.00 - 0.01
Mixing e-fuels into diesel/gasoline	0.3 - 0.5	0.0 - 0.1
Sum	**1.3 - 5.1**	**4.1 - 8.2**
Of which contributes to the 70 percent target	**0.5 - 1.9**	**1.1 - 3.5**

Note:

1. 'Robust potential' is defined here as areas of application where direct electrification is not possible or expected to be more expensive than adopting PtX fuels.

2. 'Indeterminate extent' is defined as the degree of PtX adoption within the area of application being indeterminate/uncertain. This includes segments with significant electrification potential but where the use of PtX fuels will be the most cost-effective and practical solution in parts of the segment.

3. The technical gross reduction potential from the 2021 Climate Programme indicates that PtX has the potential to contribute with domestic CO_2 reductions amounting to approximately 9 million tonnes by 2030. This table shows the Danish Energy Agency's calculations of the cost-effective potential. The cost-effective potential is lower than the technical potential, which is partly due to an overlap between the use of PtX fuels and electrification, the latter of which is the more cost-effective choice in the indicated technical gross potential in the Climate Programme.

4. Blending e-fuels into diesel/gasoline is not believed to be cost-effective, as it is - albeit with considerable uncertainty - not likely to be competitive with 2nd generation fossil fuels.

Source: The Danish Energy Agency

Limited amounts of biogenic carbon for Power-to-X fuels

In certain sectors - mainly in aviation - the Danish Energy Agency believes that carbonaceous fuels will be a necessity for a number of years to come. In 2050, the realisation of the full potential in the table will require the use of 1.5-6.5 million tonnes of green CO_2 depending on the proportion that can be covered by PtX fuels that do not contain carbon. If CO_2 is to exclusively be used for the potential in the aviation sector, this will require around 3 million tonnes of CO_2 annually. In addition to this comes the need for fuels for export, chemical production, etc. As noted in the section on biogenic carbon, biomass and biogenic carbon are expected to become limited resources in the long term. Tackling this challenge will be crucial to meeting national and international targets (including Denmark's EU and UN obligations) as well as achieving the export-related potential of carbon-based PtX products in the long term.

Did you know...

that refineries have green ambitions? The refinery in Fredericia, Crossbridge Energy, aims to be CO_2-neutral before 2035 by replacing parts of its crude oil input with bio-oils and green hydrogen to produce biofuels. The refinery is already investing in green hydrogen via the HySynergy project, which has received funding from the Danish Energy Agency's energy storage funding pool. The project is also in the process of receiving funding through the IPCEI programme.

that hydrogen-fuelled taxis are already driving on Danish roads? The car manufacturer Toyota has, in collaboration with the taxi service DRIVR, rolled out over 100 hydrogen vehicles on the roads of Copenhagen. NEL, Circle K and Everfuel have also set up refuelling stations for these cars from Esbjerg to Copenhagen. Hydrogen can thereby supplement electric vehicles where special demands or considerations make it difficult to convert entirely to electricity.

that the Danish shipping company Maersk has ordered eight large container ships that can sail on climate-neutral methanol? The first container ship is scheduled to set

Regulation promotes the use of Power-to-X

As long as PtX fuels are more expensive than their fossil-based alternatives, the Danish Energy Agency believes that further CO_2 reductions driven by PtX will require regulatory measures. For example, this could include requirements such as the adopted national CO_2 displacement requirements for road transport (see *Agreement on the green transition of road transport from December 2020*) and the

upcoming EU regulations in *Fit-for-55*. At the same time, there is a need for more knowledge on the long-term challenge of limited amounts of biogenic carbon.

Fit-for-55 can have a major impact on the use of Power-to-X

In July 2021, the European Commission presented the *Fit-for-55 package*, which contains a number of proposals to support the EU's climate target of achieving at least a 55 percent reduction of greenhouse gas emissions by 2030, including proposals for a new European regulation of the transport sector (including shipping and aviation). The package will be subject to negotiations before the rules can enter into force, which is why the final contents of the Fit-for-55 package remain uncertain.

Box 3

The European Commission's proposal for regulating transport and industry in Fit-for-55

Generally for the transport sector (revision of the Renewable Energy Directive II)

With the revision of RED II, the European Commission has proposed setting a requirement for a 13 percent GHG intensity reduction target in the transport sector by 2030. The Commission has also proposed a specific blending requirement for advanced biofuels (2.2% in 2030) and PtX fuels (sub-target of 2.6% by 2030). It will be up to the Member States to enforce the directive to ensure the obligations are met. These are only minimum requirements, which can be raised at the national level and phased in by 2030.

Shipping in the EU (Fuel EU Maritime)

For the shipping sector, the Commission has proposed a new regulation which sets out a specific CO_2 intensity reduction target requirement that will rise to 6% towards 2030 and increase to 75% in 2050, where the targets can be achieved with renewable fuels (including PtX), but not traditional first-generation biofuels. The proposal will entail total harmonisation at the EU level, which means that stricter national requirements will generally not be possible.

Aviation in the EU (ReFuel EU Aviation)

With regards to the aviation sector, the European Commission has proposed a general requirement for blending in 2% renewable energy fuels into aircraft fuels by 2025, rising to 5% in 2030 and 63% by 2050, where 1st generation biofuels will no longer be counted towards the renewable percentage. The Commission has also proposed a specific requirement to blend 0.7% PtX fuels into aircraft fuels by 2030, rising to 28% in 2050. This proposal will entail total harmonisation at the EU level, which means that stricter national requirements will generally not be possible.

Additional elements (AFI regulation and CO_2 standards for passenger cars and vans)

In addition to the above, the package also contains new rules for establishing hydrogen filling stations as well as a further tightening of existing CO_2 standards for new passenger cars and vans. The effects of AFI are difficult to quantify, but the Danish Energy Agency expects that it may generally support the adoption of hydrogen fuels in heavy road transport.

Industry

The package contains a proposal for a national sub-target of at least 50% renewable energy in the industrial sector's hydrogen consumption by 2030. As Denmark's present hydrogen consumption is low, this will primarily contribute to reductions abroad, potentially with hydrogen produced in Denmark.

The Danish Energy Agency's analyses show that the proposals in *Fit-for-55* will create a major demand for PtX fuels in Denmark and the EU in general. Due to the *Fit-for-55* package, the consumption of PtX fuels by 2030 will be able to displace up to 0.5 million tonnes of CO_2 annually in the Danish transport sector, although this depends on whether the implementation of the requirement for PtX fuels will result in the displacement of fossil fuels or biofuels. If the requirement ends up primarily displacing 2nd generation biofuels, it will only result in minor emissions reductions in the value chain.

The requirements can also be met by reducing emissions from international maritime and aviation refuelling in Denmark, which will contribute to the achievement of international targets. However, these reductions are not included in the national CO_2 balance and do not count towards the 70 percent goal. The extent to which the reductions arising from *Fit-for-55* will contribute to Denmark's climate objectives is therefore uncertain.

The Government will push for ambitious requirements in the Fit-for-55 package, including in the aviation and shipping sectors. These requirements will result in a higher national and international demand for PtX products through fundamentally uniform framework conditions across the EU which will contribute to promoting the use of PtX where it has viable long-term applications.

National CO_2 displacement requirements for road transport promote green fuels

The Danish Energy Agency's analyses show that some of the bio-based fuels blended into gasoline and diesel in the Danish market can lead to significant CO_2 emissions in the value chain. The latter are not covered by the 70 percent target to the extent that they occur abroad, but they are part of Denmark's global climate footprint.

This is because first-generation biofuels are produced from crops which can require large tracts of agricultural land in Denmark or abroad. Increased consumption of these biofuels therefore increases the risk of claiming additional land that was previously uncultivated via deforestation and drainage. This is referred to as Indirect Land Use Change (ILUC) and impacts the climate through the removal of areas that store large amounts of carbon. New land being claimed for cultivation also comes with a high risk of negatively impacting biodiversity.

Denmark has introduced a new regulation of renewable energy fuels for vehicles starting from 2022, based on CO_2e-displacement requirements. This will help promote climate-friendly fuels. At the same time, a political decision has been made to incorporate ILUC values (or similar values) into the national fuel regulation by 2025 at the latest. The European Commission has also proposed that Member States should not be able to include first-generation biofuels in relation to meeting the specific Fit-for-55 requirements for shipping and aviation.

The use of PtX fuels as an alternative to biofuels could thereby help limit the overall consumption of biomass for energy as well as limit emissions associated with the production of biofuels which in a number of cases is located outside Denmark. The production of PtX fuels is better able to be scaled up than the production of biofuels, depending on the expansion of renewable energy and access to sustainable CO_2. The Danish Energy Agency accordingly expects that hydrogen and other PtX fuels will play a key role in the transition of the overall transport sector together with direct electrification.

A need for further analyses on biomass and biogenic carbon

With the *Agreement on a green transition of Danish agriculture*, the Government has laid the groundwork for pyrolysis technology being able to contribute negative emissions in the agricultural sector through carbon sequestration in the form of biochar. In addition, the agreement on the CCS strategy between the Government and Folketing includes conducting an analysis of the framework conditions for promoting DAC technologies and making them more affordable. In addition, the Government will initiate an analysis of biological resources for the green transition.

The aim of the analysis will be to create a comprehensive overview of the biological resources that are available to the green transition as well as synergies between primary production, different refining technologies and areas such as capture, storage and use of CO_2, pyrolysis, biogas, PtX, etc.

The Government will work to promote the green transition in the transport and industrial sectors. With the Roadmap for a green Denmark, the Government is planning to present a number of strategies and proposals in 2022 and 2023 for sectors in which PtX can potentially play a major role in the long term:

- A strategy for rolling out propellant infrastructure for heavy road transport
- A proposal for the green transition of air traffic
- A green industrial sector proposal
- A proposal for a green energy and utilities sector
- A proposal on sustainable fuels for road transport and shipping

The Government has already promoted the use of PtX fuels:

- Agreement on allocation of funding pool for green transport: A funding pool totalling DKK 50 million in 2022 for subsidising purchases of green trucks. The parties behind the agreement also agreed to allocate DKK 72 million in 2021 to co-financing of green fuel infrastructure for commercial transport. The funding pool is aimed at filling and charging infrastructure for vehicles such as taxis, vans, trucks and buses that run on alternative fuels such as hydrogen.

- Agreement on the green transition of road transport It is planned for ILUC values (or similar values) into national regulations by 2025 at the latest. In 2023, a political decision will be made on potentially tightening the CO_2 displacement requirement as well as specific requirements for renewable fuels such as PtX from 2025.

- Climate agreement for energy and industry, etc.: Approximately DKK 16 billion DKK has been earmarked for a CCUS pool, which via the agreement on the second part of an overall CCS strategy has been divided into two phases. The first phase aims to realise CO_2 reductions of 0.4 million tons annually starting in 2025. Experiences from the first implementation of funds along with market developments will allow funds to be implemented as appropriately as possible in the second phase, where reductions are expected to reach 0.9 million tonnes per year towards 2030. In connection with the second implementation of funds from the CCUS pool, the ways in which using CO□ can contribute to the climate objectives will also be reviewed.

- A roadmap for capture, transport and storage of CO□: With the second part of the CCS strategy, it was agreed to initiate an analysis of the framework conditions for promoting and cheapening DAC technologies. The captured CO_2 could also be used in carbon-based fuels produced via PtX.

- Agreement on the green transition of Danish agriculture: Among other things, the agreement earmarks DKK 196 million for pyrolysis in 2023-2024 in addition to the DKK 200 million in 2021-2022 earmarked via the Danish Finance Act of 2021, amounting to a total of DKK 396 million earmarked for developing brown bio-refining processes such as pyrolysis. The funds allocated via the *Agreement on the green transition of Danish agriculture* are planned to be provided through the Just Transition Fund.

Objective 2: The regulatory framework and infrastructure must be in place for Denmark to utilise its strengths and allow Power-to-X to perform on market terms in the long run

Partial conclusion: In the future, PtX will be able to compete with other fossil fuel alternatives. However, this will require establishing the right regulatory framework for PtX production, transport, storage and utilisation as well as a hydrogen infrastructure that allows PtX to perform on market terms. In addition, the Government plans to support technology development and upscaling as a way to significantly contribute to the industrialisation of PtX.

The Government will work to ensure that Danish hydrogen and PtX products can eventually compete with biofuels and foreign PtX products on the market. Accordingly, the Government will create the appropriate economic and regulatory framework for ensuring that the production and use of PtX products can eventually perform on market terms. The Government will also establish the framework conditions for a hydrogen infrastructure in Denmark that can support flexible operation of the PtX plants and transport hydrogen over long distances.

Objective 2.
Accordingly, the Government will:

- Invest DKK 1.25 billion towards operating support for the production of hydrogen and other PtX products. The purpose of the PtX tender is to support the industrialisation and upscaling of PtX production in Denmark and thereby reduce the costs associated with hydrogen production. This is envisaged to encourage growth and job creation as well as Denmark's commercial and export potential in the PtX area. These subsidies will be granted as a fixed price subsidy for a 10-year period.

- Enter into dialogue with the European Commission on allocating DKK 344 million 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, including green production and demonstration projects.

- 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.

Power-to-X must be able to perform on market terms in the future

The Danish Energy Agency's analyses show that Danish-produced PtX fuels can potentially become competitive alternatives to fossil fuels in a number of sectors. This applies to biofuels as well as PtX fuels produced in other countries.

The cost of PtX processes will have to be reduced before PtX can perform on market terms, as shown in Figure 8. The figure shows the forecasted production costs for four PtX products compared to the market prices for fossil fuels and biofuels. For PtX fuels, the forecasted production costs are shown for the near and long term with the assumption that the costs will be lowered as outlined in the section on competitive conditions. It will also be necessary to create the appropriate framework conditions for production, transport, storage and use of hydrogen and other PtX products, and to be able to document the green value of PtX products and have that value reflected in the market price.

This is underlined by the fact that the actors behind most of the PtX projects (amounting to up to 7 GW) announced so far are advocating for adjusted framework conditions and transparent regulation rather than public sector funding as a precondition for carrying out the projects.

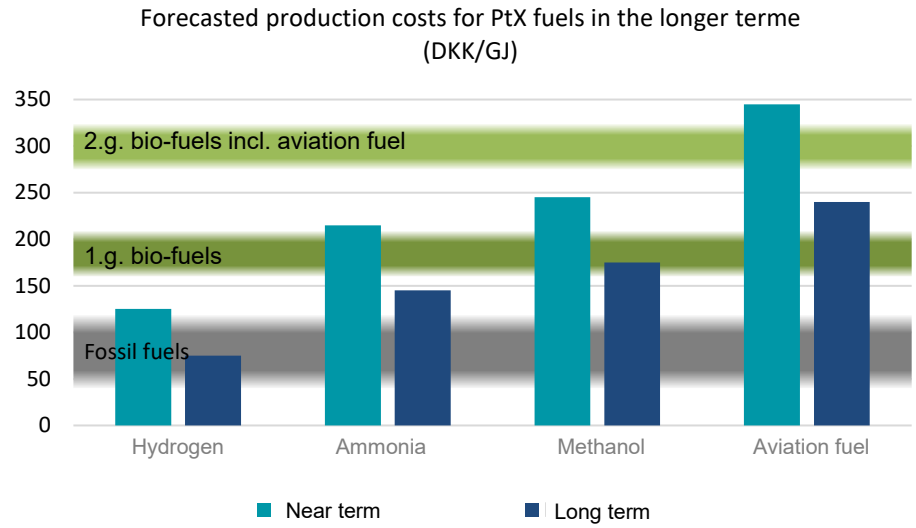
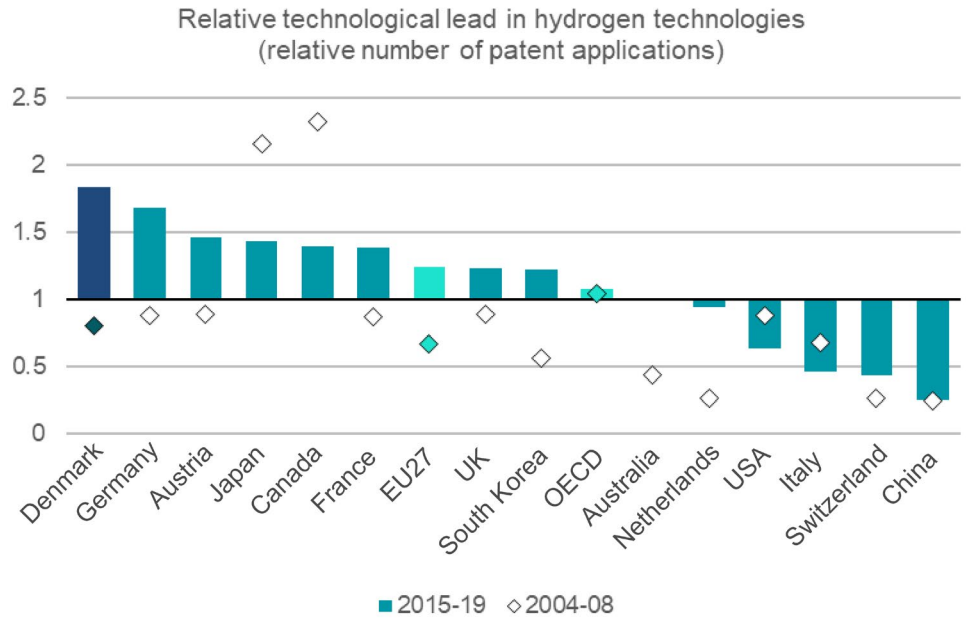


Figure 8. Forecasted production costs over this decade (near term) and the long term following upscaling of production, technology development, improved framework conditions and implementation of supporting infrastructure for each of the four PtX fuels. Ranges for market prices of fossil fuels and biofuels are also shown, where ILUC effects are not factored in.
Source: The Danish Energy Agency

Technological development and upscaling can lead to cheaper Power-to-X plants

Danish companies are primed to gain a strong market position in the industrial expansion of a global market for green fuels (PtX). According to the OECD, Denmark has a technological lead in the field of PtX, as Danish companies have developed and possess key technologies that are necessary for establishing large and efficient PtX production plants (see Figure 9, which shows a relative technological lead within hydrogen technologies, 2004-2008, compared to 2014-2018).



Note: The data shows patent applications submitted under the Patent Cooperation Treaty (PCT) in the field of green hydrogen technologies. The number of patents is based on the submission date and country of the patent submitter, indicated by fractional numbers. The tally only includes countries that have submitted more than 20 hydrogen technology patents in the period 2014-2018. Translated internally from the OECD's working paper "Innovation and Industrial Policies for Green Hydrogen" Source: OECD, STI Micro-data Lab: Intellectual Property Database, http://oe.cd/ipstats, Juni 2021.

If Danish companies are to succeed with developing large parts of the production of key technologies in Denmark, framework conditions for the companies' investments in development activities are needed that support the increased industrialisation of the entire production chain for innovative green key technologies for PtX production. Several actors have stated that upscaling and industrialisation of production facilities is the next step in further developing the technology and making PtX production less costly. Electrolysis plants, which make up a significant part of the costs for hydrogen production, are modular units comprised of many small elements (electrolysis cells) that are connected. As with solar panels and batteries, these cells can be mass-produced, and scaling up production is expected to have major potential in relation to lowering production costs. PtX plants will thereby not only become more affordable to build the bigger they get; they will also become more affordable to build as more get built.

Accordingly, the Government is already supporting research, development, innovation and major demonstration and scaling projects that can contribute to reducing the production costs of key technologies - e.g. electrolysis - that can, in turn, help make large-scale PtX plants more competitive. This strategy entails additional funding to a new investment support scheme focused on scaling up the necessary green key technologies.

In hydrogen production, the biggest cost comes from electricity consumption

In addition to the costs of the electrolysis plant itself, the costs of purchasing electricity and paying tariffs to the public electricity grid make up about 2/3 of the costs of producing green hydrogen in Denmark, according to the Danish Energy Agency's forecast. A potential reduction of these costs thereby offers significant potential for lowering the price of hydrogen and other PtX products.

The market prices for electricity - the so-called spot prices - fluctuate by the hour, depending among other things on the supply of cheap renewable electricity and the demand for electricity within the price range. If an electrolysis plant is sufficiently flexible, and the purchaser of the produced hydrogen can accept fluctuating production levels, electrolysis plants could simply choose to produce hydrogen during the hours of the year where electricity is cheapest. Often, however, hydrogen purchasers will want a steady supply of hydrogen. This challenge can be tackled with access to hydrogen infrastructure, including hydrogen storage facilities. Finally, hydrogen transport in pipes is an effective way of linking consumption to production. A hydrogen infrastructure system based on pipe transport and large-scale hydrogen storage could thereby prove valuable for PtX production in Denmark.

Expanding Power-to-X and renewable energy go hand-in-hand

It is generally expected that the green transition will give rise to increased demand for green electricity in the future, including for PtX production. There is already considerable interest in PtX in Denmark, and the announced projects - from private actors up to 2030 - have a collective electrolysis capacity of up to 7 GW. While there is some uncertainty about the actual production capacity that will be realised, the figure exceeds the level of capacity expansion upon which the Danish Energy Agency’s current projections are based. The announced projects and initiatives that further promote PtX can therefore be expected to contribute to an increased demand for green electricity in the future.

A need for robust and transparent regulation

Production, transport, storage and use of hydrogen and other PtX fuels require robust and transparent regulation in a large number of areas concerning safety, the environment, planning, market regulation, etc. For a future hydrogen market to function, especially across borders, it is necessary to ensure that the green value - i.e. climate neutrality - of both hydrogen and other PtX fuels can be documented. This documentation must be credible and harmonised across the EU. Finally, hydrogen pipe transport entails a monopoly in practice, and establishing a hydrogen infrastructure therefore requires effective and appropriate market regulation with a view to ensuring equal access to the system and low prices for consumers of PtX products.

Framework conditions, regulation, technological development and infrastructure must support Power-to-X on market terms

Since 2019, the Government has invested around DKK 400 million via the EUDP and Danish Energy Agency's energy storage funding pool. In 2021, the Government, together with other parties in the Folketing, also allocated DKK 850 million to the development of the green fuels of the future through the pan-European project on green hydrogen (IPCEI). The Government will also invest DKK 1.25 billion via a PtX tender, and in the agreements on the allocation of the research reserves for 2021 and 2022, the Government and parties of the Folketing prioritised just under DKK 1 billion to four green missions aimed at contributing to research and development of green technologies, including a mission on green fuels for transport and industry (PtX, etc.). These missions will be carried out by mission-driven partnerships that include relevant knowledge institutions, companies, public authorities and private actors collaborating on joint research and innovation efforts over several years. Innovation Fund Denmark is responsible for establishing these partnerships. These are important measures that support the technological maturation and industrialisation of hydrogen and PtX in Denmark, and which are thus expected to lower the costs of PtX production.

However, there are additional measures that can help make PtX more competitive: Coherent legislation in Denmark and the EU that establishes a clear framework and supports the green value of PtX, the establishment of a Danish hydrogen infrastructure that links production to consumption and facilitates storage, and finally, tariffs that better reflect real costs, which can help lower the costs of hydrogen production. The Government's approach to making PtX products less costly is illustrated in Figure 10.

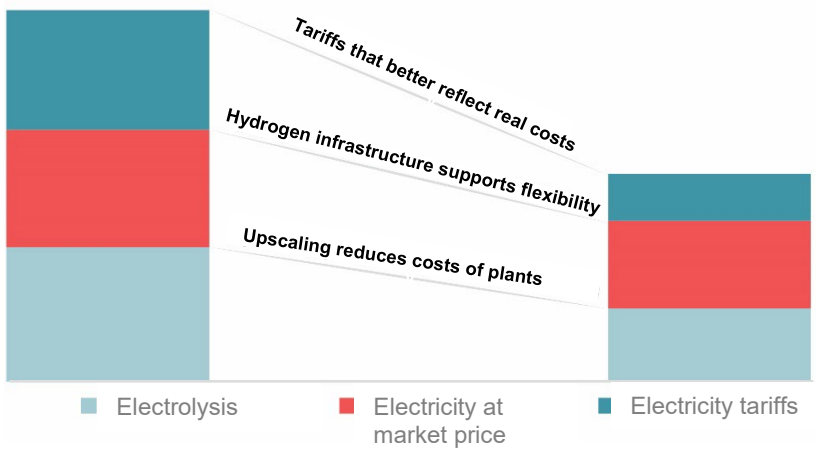


Figure 10: The three biggest elements in the production costs for green hydrogen can be reduced through the Government's proposed changes to framework conditions.
Source: The Danish Energy Agency

Robust regulatory framework that supports the expansion of Power-to-X

In recent years, there has been a marked development in the maturation of hydrogen and PtX technology. This means that current legislation is not presently able to accommodate the rapid developments taking place in the field of hydrogen production.

Approval procedures and safety approvals are complicated and can make it more difficult to establish PtX production plants as well as transport and storage facilities for hydrogen and other PtX products. The complex legislation also means that both PtX investors and authorities are uncertain about the framework. This can create further delays to the construction of PtX plants. When PtX actors are seeking to build PtX plants in Denmark, national regulations should make that process as simple and fast as possible. A clear and transparent regulation creates a secure framework for investors.

In addition, work is underway in the EU to determine how PtX producers that produce hydrogen for the transport sector through using electricity from the public electricity grid can document that the hydrogen they produce is based on renewables. A revision of the Renewable Energy Directive II (Art. 27 of the delegated act) is currently underway. The method, which must ensure that the production of green hydrogen does not result in greater electricity production based on fossil fuels, will be crucial to a future valuation of hydrogen produced in Denmark when it is traded across EU borders. Currently, there is also no documentation system for when carbon-containing PtX products can be categorised as green, depending on where the carbon used in the production comes from. In December, the European Commission will publish a communication on sustainable carbon cycles, which is expected to contain an action plan for promoting carbon farming and developing a legislative framework for a certification system for CO□ uptake. This will require a harmonised system that can document the origins of carbon with regard to storage and use.

Recent research suggests that hydrogen is a relatively potent greenhouse gas, and it is accordingly important to ensure that future hydrogen regulation also takes that aspect into account.

The Government will

- Enter into dialogue with the European Commission on allocating DKK 344 million 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, including green production and demonstration projects.

- Initiate a 360-degree review of legislation in relation to hydrogen with a view to identifying barriers to the development of a hydrogen market and establishment of a hydrogen infrastructure that can make it easier for Danish and international companies to produce and use PtX.

- Develop a national regulation in consultation with the PtX industry to ensure transparent market conditions for hydrogen infrastructure while also creating opportunities for existing methane gas pipes to be converted to transport hydrogen.

- Work nationally and at the EU level to create clear and uniform rules for certification of PtX products produced from renewable energy and sustainable carbon, thereby ensuring the green value of PtX while not delaying Danish and European projects.

A Danish hydrogen infrastructure must enable the transport and storage of hydrogen

Denmark has no pipeline infrastructure dedicated to transporting hydrogen over long distances. Parts of Denmark's existing gas system can, however, be converted to transporting hydrogen (see *the Green gas strategy)*. However, converting gas pipelines for new purposes will require extensive planning and strategic choices. At present, it also appears that there are only a few pipelines capable of being repurposed in the short term.

Box 4

Hydrogen infrastructure

Denmark does not currently have a hydrogen infrastructure, i.e. gas pipelines and gas storage facilities for transporting and storing hydrogen. Establishing the pipeline infrastructure will entail either converting and reusing parts of the existing gas system or establishing a dedicated hydrogen infrastructure.

The Danish gas system consists of a transmission system (owned and operated by Energinet), a distribution system (owned and operated by Evida) and Energinet's two underground gas storage facilities in Lille Torup (North Jutland) and Stenlille (Zealand). These storage facilities are used to store surplus gas and even out seasonal variations in gas consumption, thereby providing flexibility for the entire gas system and its actors.

From a socio-economic perspective, it can make good sense to convert electricity to hydrogen, which is subsequently handled in the gas system, where both transport and storage is simpler and cheaper than transporting and storing electricity. Storing hydrogen in pipes and gas storage facilities allows it to be stored for periods where renewable energy production is lower than electricity consumption.

Energinet and the Danish Energy Agency have been in dialogue with a total of 19 market actors based in Denmark and abroad who have expressed interest in Danish hydrogen infrastructure. This dialogue has provided more clarity on aspects such as the value of hydrogen infrastructure for the market actors as well as when it would be relevant to establish such infrastructure. Several market actors believe that they will initially be able to do without hydrogen infrastructure, but that it will eventually become a necessity to achieving full commercial scaling.

Energinet has determined that one of the two gas pipelines currently connecting the Danish and German gas system between Egtved and Ellund can be converted to export pure hydrogen, thereby contributing to linking Danish PtX producers to a European hydrogen infrastructure. Additionally, parts of the gas distribution system could potentially be reused as gas boilers for home heating are gradually phased out.

The majority of the gas system is able and likely to remain in service for many years to come, partly due to political decisions having been reached to expand biogas production. This means that the gas system will be used to transport and store biogas for at least another 20 years. In addition, the upcoming Baltic Pipe connection will transport large quantities of gas through Denmark to Poland until at least 2038. Accordingly, it would not appear possible to convert significant parts of the existing gas system to be used for other purposes such as hydrogen. This is shown in Figure 11.

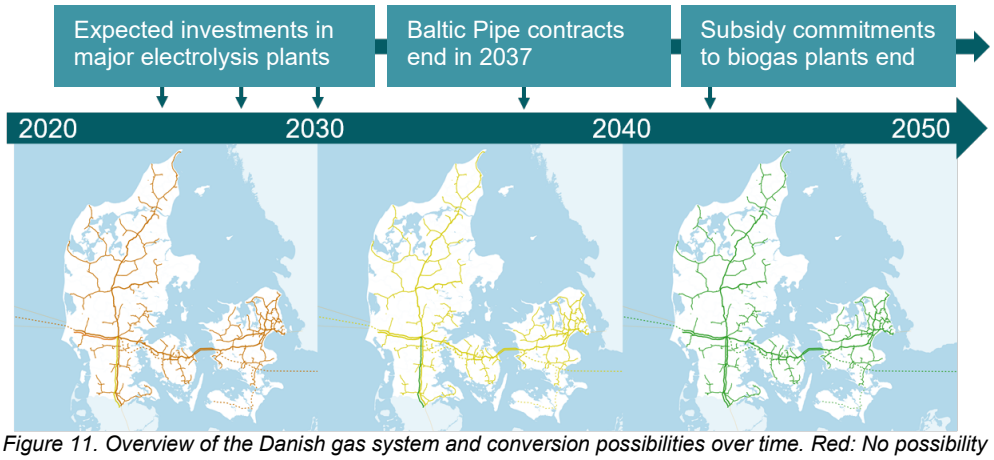


Figure 11. Overview of the Danish gas system and conversion possibilities over time. Red: No possibility for conversion, yellow: Some possibility for conversion, green: Good possibilities for conversion. Note the pipeline in South Jutland which can potentially be converted to hydrogen export in the medium term. Source: The Danish Energy Agency

In order to support the long-term establishment of a Danish hydrogen infrastructure, the Government will work towards removing the key barriers and ensuring that there are clear rules for the establishment of infrastructure, safety, etc.

In connection with the launch of its gas and hydrogen package in December 2021, the EU is presenting a proposal for how competition regulation for hydrogen should be designed at the European level. This means that pan-European rules for hydrogen will only be implemented in Danish law at the end of 2025. However, Denmark is already today in need of a form of competition regulation to ensure fair terms of competition in relation to hydrogen pipeline transport.

The Government will

- Create the necessary framework in legislation and the purpose provision to ensure that Energinet and Evida can own and operate hydrogen infrastructure. This will allow Energinet and Evida, which already have competencies in operating gas infrastructure, to allocate funds to develop hydrogen infrastructure projects such as market needs analyses and preliminary studies on par with other relevant market actors within the EU.

- In 2022, address the organisation of the Danish hydrogen market and how to ensure that relevant actors are brought into play in relation to ownership and operation in the hydrogen market

- Conduct an analysis on the availability of new fuels in Danish ports, based on the *2035 Infrastructure Plan*, as Danish ports can play a key role in the transition of Danish shipping towards sustainability. For example, the ports can rent out vacant areas to private companies that want to produce PtX, assuming the production requires a location close to a port or the areas cannot be rented out for port-related activities. Additionally, the Government considers the availability of electricity and infrastructure for refuelling at Danish ports a prerequisite to enabling the shipping sector's green transition from fossil fuels to green fuels.

Tariffs that better reflect real costs can help reduce costs for Power-to-X

With the current transmission tariffs, tariff payments amount to around 1/3 of the costs of hydrogen production. Tariffs that better reflect real costs, including geographically differentiated consumption tariffs, make it possible to reduce hydrogen production costs by making it attractive for PtX plants to be placed in appropriate locations in relation to the electricity grid's capacity. Tariffs that reflect real costs are aimed at ensuring more efficient use of the electricity grid and potentially reducing the need for grid investments, but they can also help make PtX more competitive and thereby able to perform better on market terms. The Government's specific proposal in relation to tariffs is described in more detail under objective 3.

Most large electrolysis plants are expected to be connected to the so-called transmission net, which is known for the large high-voltage lines that transport electricity around Denmark. This part of the electricity grid is owned and operated by Energinet, and payments include a network tariff and system tariff.

Energinet has developed two proposals for new tariff products that would better reflect the real cost of transporting electricity in the transmission grid and system operation. The first proposal is to revise the system tariff, which makes up around

half of Energinet's overall tariffs. The proposed revisal will entail a change from a tariff based entirely on consumption to a fixed subscription payment combined with a low consumption-dependent system tariff. This could benefit Denmark's biggest electricity consumers. The other proposal entails a reduced grid tariff for large flexible electricity consumers such as electrolysis plants. The condition for lower payments would be that the consumers can face electricity supply interruptions during times where the grid has insufficient capacity.
Overall, these tariff proposals could reduce the costs of hydrogen production in the Danish Energy Agency's forecast by up to around 25 percent. All changes of tariff methods must be approved by the Danish Utility Regulator. This would be in addition to any effects from the Government's further proposals, which are described under objective 3.

South Jutland could become a commercial beacon for green energy and sectoral linking

In May 2021, the Government's regional growth teams presented their proposals for how the Government can invest optimally in local strengths and potential around Denmark with a view to promoting future growth and employment across the country. The regional growth teams recommended the establishment of eight local commercial beacons that would build upon Denmark's strengths in the coming years.

South Jutland holds special potential for rapid transition and development in relation to PtX solutions. The region has especially favourable conditions due to its geographical location in the electricity grid, good infrastructural conditions with large gas pipelines going from west to east - and towards Germany - as well as the presence of a number of major green businesses. The growth team accordingly recommended the establishment of a national centre for green energy and sectoral linking in South Jutland, along with a push to adapt, attract and train workers for the future wave of green jobs.

PtX will also become important to the commercial beacon in North Jutland, which has ambitions for developing CCS and CCU solutions, as well as Bornholm, which is also pursuing PtX projects.

The Government has allocated DKK 500 million from the so-called REACT-EU initiative to acting upon the recommendations from the regional growth teams. All around Denmark, local and national actors have come together in local consortia to collaborate on applying for funds to develop the regional commercial beacons. As part of the *Denmark can do more I* reform proposal, the Government has allocated an additional DKK 500 million from the Just Transition Fund as well as the EU's Structural Funds, bringing the total up to DKK 1 billion allocated to the development of the local commercial beacons in the coming years. The Government will also enter into partnerships with the local consortia, inter-municipal business incubators

and Denmark's Business Promotion Board to support and further develop the potential of these regions.

The Government will

- As outlined in the *Denmark can do more I* reform proposal, allocate an additional DKK 500 million in EU funding to develop the eight local commercial beacons in addition to the DKK 500 million from REACT-EU funding which has already been allocated to act on the recommendations from the regional growth teams.

- Enter into partnerships with local consortia in Denmark's eight local commercial beacons, including in South Jutland, thereby contributing to the development of the local commercial beacons in the coming years. These partnerships will form the framework for the Government's running dialogue with actors in South Jutland on how PtX can function on market terms.

The Government has supported the market introduction of Power-to-X:

- With the agreement on Allocation of the research reserve, etc. in 2021, approximately DKK 700 million was allocated to the four green research missions, including the mission for green fuels for transport and industry. Innovation Fund Denmark will decide how the funds are to be allocated at the end of 2021. Approximately DKK 195 million has been allocated to the PtX mission.

- With the agreement on Allocation of the research reserve, etc. in 2022, an additional DKK 295 million has been allocated to the four missions from the Green Research Strategy, including the PtX mission.

- With the agreement on Danish participation in an "important project of common European interest" (IPCEI) regarding hydrogen, the Government has invested DKK 850 million in Denmark's participation in important projects of common European interest, which aims to support large, transnational development projects that can benefit the entire EU.

- PtX companies have become the first to qualify for a test scheme for green solutions: In May 2021, the Danish Energy Agency granted Greenlab Skive and Brande Brint the status of a regulatory test zone, exempting them from a number of rules and regulations in the field of energy. The companies, both of which focus on production and development of green hydrogen, are

thereby free to gain practical experience that may potentially be useful in improving legislation on the area.

- EUDP grants and the Energy Storage Funding Pool: In total, the Government has invested around DKK 400 million into research, development and demonstration of PtX solutions, including approximately DKK 300 million via the general EUDP grant and PtX special funding pool as well as DKK 128 into an energy storage funding pool, which the projects HySynergy and GreenLab Skive have received grants from.

Objective 3: The integration between Power-to-X and the Danish energy system must be improved

Partial conclusion: PtX can work alongside the electricity, heating and gas systems in an integrated energy system, where its integration with the electricity system in particular will be crucial. Electrolysis plants can play a key role in the electricity system by consuming large amounts of green electricity when the wind is blowing and electricity rates are typically low and shutting down when the wind isn't blowing and electricity rates are typically high. This would require the plants to be able to run flexibly. Flexible operation can result in a higher settlement price for renewable energy facilities during the hours the electrolysis plants are in operation, as well as during hours where there is a lot of renewable energy production and typically low electricity rates. Under special conditions, electrolysis plants that are flexible and appropriately located can help reduce or postpone the need for reinforcement and investments in the electricity grid and support the settlement price for renewable energy facilities during hours of overproduction.

The Government will work towards creating a framework that ensures that PtX can contribute to an integrated and flexible energy system where PtX is integrated into the system so that it works in harmony with the electricity, gas and heating sector. The Government will accordingly strengthen the basic conditions for ensuring that PtX plants are located in places around Denmark where they can create value for the electricity system by offering flexibility and reducing the need for grid expansion and reinforcement.

Objective 3.
Accordingly, the Government will:

- Provide the option for geographically differentiated consumption tariffs, giving Energinet and grid companies the option to differentiate consumption tariffs for large electricity consumers based on their geographical location and thereby ensuring that the tariffs reflect the true cost of electricity to a greater extent. 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.

- 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.

- Act on the recommendations from the South Jutland growth team to establish a commercial beacon for green energy and sectoral linking, including links between PtX and district heating.

Power-to-X must contribute to an integrated and flexible energy system

PtX plants consume large amounts of electricity to produce green gases or liquid fuels for the transport and industrial sectors. This process generates large amounts of surplus heat. PtX plants can thus contribute to a more integrated and flexible energy system, as illustrated in Figure 12.

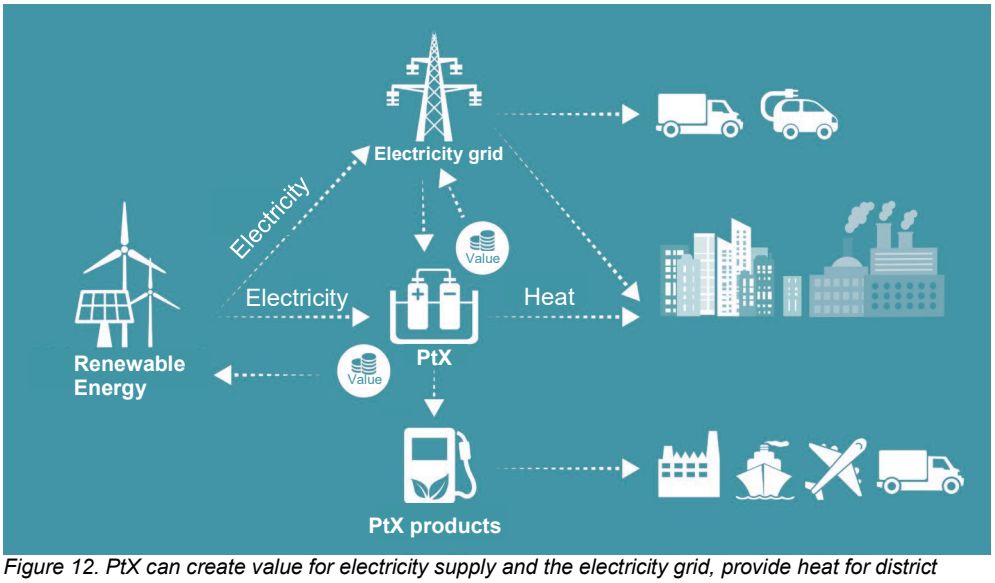


Figure 12. PtX can create value for electricity supply and the electricity grid, provide heat for district heating and produce green fuels for transport and industry.
Source: The Danish Energy Agency

Power-to-X and its interaction with the electricity system

Denmark's electricity supply is increasingly based on renewable energy, primarily wind energy. This places considerable demands on the development of the electricity grid as well as the rest of the electricity system.

Electrolysis plants, which are the core component of PtX, are able to run flexibly, and PtX plants can therefore to a great extent turn their production of hydrogen up, down, off and on as needed. This allows electrolysis plants to turn their electricity consumption up or down depending on electricity prices, which are largely contingent on how much renewable electricity is available in the grid. On an autumn day where the wind is blowing, the electrolysis plants will typically be in operation and producing green hydrogen. On windless days, where the electricity prices are typically higher, PtX plants can choose to reduce their production of hydrogen or shut it off entirely. This is illustrated in Figure 13, which shows the operation of an electrolysis plant over a month with fluctuating electricity prices. During periods where the electricity grid is near or over capacity, the PtX production can also be turned down or shut off entirely, lowering electricity consumption. Provided that the electrolysis plants are placed in appropriate geographic locations, they could

therefore contribute to effective use of the collective electricity grid and potentially reduce or postpone the need for grid reinforcement.

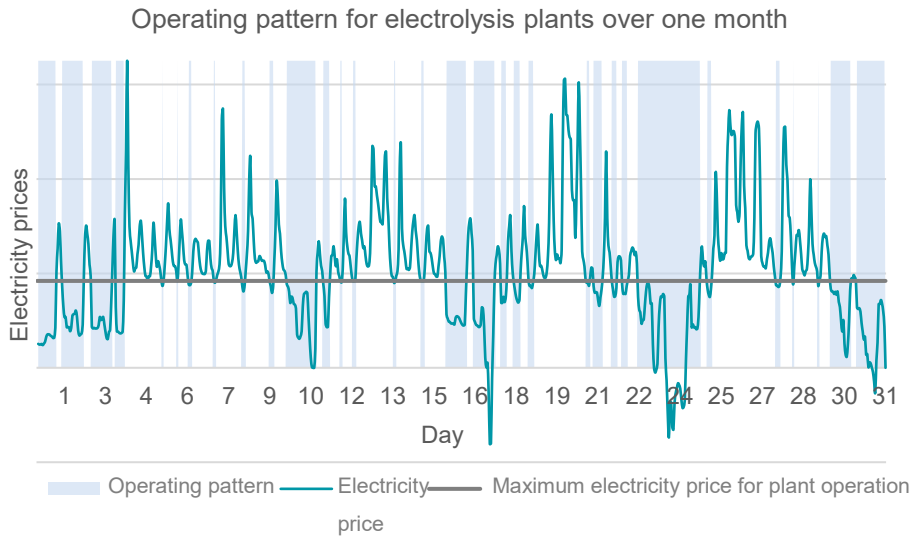


Figure 13. Illustration of the operation of an electrolysis plant over a month with fluctuating electricity prices (blue curve). The electrolysis plant will be in operation when the electricity price is below the grey line, and the blue fields show the periods where the plant is running and producing green hydrogen. The grey lines represent an electricity price that optimises the production cost of hydrogen.
Source: The Danish Energy Agency

Efficient use of renewable energy through Power-to-X

The expansion of renewable energy continues to increase as the years go by. This will lead to lower electricity prices during periods of high renewable energy production. These periods also lead to higher exports at very low electricity prices or even periodically forced shutdowns of production. Exporting electricity at low prices does not benefit the Danish market in isolation, although it may benefit the electrification and green transition of other countries. Periodically forced shutdowns of renewable energy production, however, does not benefit the electricity market nor the green transition.

Large electrolysis plants with flexible operation are excellent partners for large-scale renewable energy production. Electricity can be diverted to these plants, thereby increasing its value and settlement price during periods where there is a lot of electricity in the grid. This would allow PtX to support the continued expansion of renewable energy in Denmark without increased funding despite a rise in renewable energy capacity.

Utilising surplus heat

The surplus heat generated from PtX plants could, depending on local conditions, either be used in the local district heating grid or as process heat in the value chain and in industrial contexts. The value of surplus heat depends greatly on the

temperature of the heat and how often it is available. If the temperature is sufficiently high, the heat can be used directly. Otherwise, a heat pump is required to raise the temperature, which adds to the cost of heating. The temperature of the surplus heat depends considerable on the type of electrolysis technology, although with the technology at present, temperatures will typically not be high enough for the heat to be used directly. In addition, it depends on whether the hydrogen is to undergo further conversion, which requires higher temperatures. If the temperature is high enough, and the heat is available for a large part of the year, the plant may potentially be of value to a district heating grid. If, on the other hand, it is only available for a limited part of the year, the district heating company would need to establish other production plants anyway. This can often be the case for PtX plants, as it is expected that they will have a flexible operation that fluctuates with electricity prices.

The value of using the surplus heat therefore greatly depends on local factors. The socio-economic value of using the surplus heat will typically be lower than the socio-economic value of an appropriate geographical location in relation to the electricity grid. Therefore, the most sensible approach would be to set up the framework conditions to reflect that.

Did you know… that surplus heat from electrolysis under favourable conditions - and depending among other things on the type of electrolysis technology - can reduce the overall cost of hydrogen production by 5-10 percent? Copenhagen Infrastructure Partners expects that the surplus heat from the production of green ammonia and marine fuels based on 1 GW of electrolysis can supply up to 15,000 average homes in Esbjerg and Varde with green district heating.

The proper placement of electrolysis plants is crucial to efficient utilisation of the electricity grid and interaction with the overall energy system

Geographically differentiated consumption tariffs sends an important signal to major electricity consumers

The Danish Energy Agency's analyses show that a key precondition for electrolysis plants being able to work in harmony with the electricity grid is that the plants are constructed in geographically appropriate locations. It is crucial for electrolysis plants to be placed in locations where a new and major electricity consumption can be integrated into the existing grid. As a general rule, these are areas dominated by large amounts of electricity production and not areas already dominated by a high level of electricity consumption. Such areas are illustrated in Figure 14.

Did you know... that payment for the use of the public electricity grid is charged in the form of so-called consumption tariffs via the electricity bill? Energinet and the grid companies collect the tariffs within a framework set out in the Danish Electricity Supply Act. The Danish Utility Regulator must approve the tariffs beforehand. At present, it is not allowed to differentiate tariffs based on the geographical location of electricity consumption. If such differentiation is allowed, Energinet and the grid companies will have the possibility to charge lower tariffs from major consumers placed in areas with adequate grid capacity on the one hand, and charge higher tariffs from consumers based in areas where the grid capacity is under more pressure. This can reduce the need for

The figure shows the Danish electricity grid as it is expected to look in 2030. Provided that new and large renewable energy facilities are connected in consumption-dominating areas such as Zealand, transforming them from consumption-dominated to production-dominated areas, it would also be appropriate to place PtX plants in those areas.

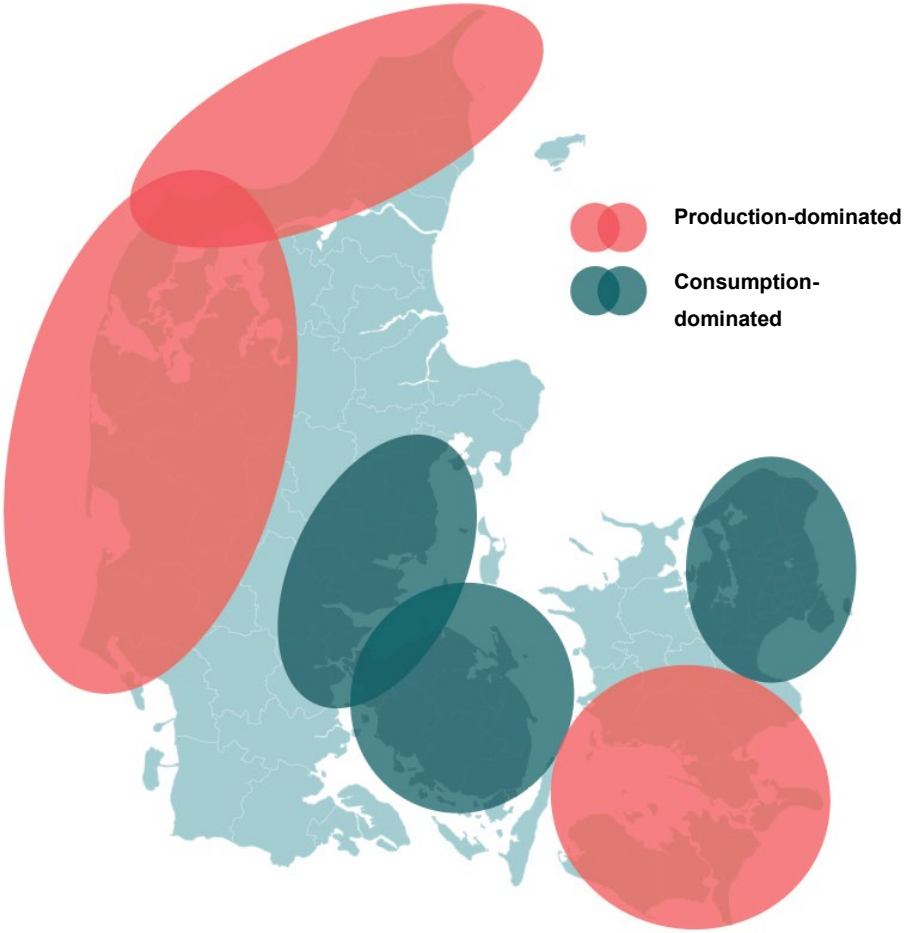


Figure 14. Capacity map of the Danish electricity grid. In order for the PtX plants to create value for the Danish electricity grid, large facilities would typically have to be placed in the production-dominated areas.
Source: Energinet

At present, it is not possible to make a geographical differentiation of consumption tariffs under the Danish Electricity Supply Act. This prevents tariffs that reflect the real geographically determined grid costs. The use of geographically differentiated consumption tariffs can create socio-economic value, as it would encourage new major electricity consumers to locate their operations appropriately in relation to the electricity grid and thereby help ensure the grid capacity is used more efficiently. This can reduce the need for investments in the electricity grid.

The Government wants to provide the option for geographically differentiated consumption tariffs for major electricity consumers such as electrolysis plants. It is expected that this measure would result in the development of new tariffs that could increase large electricity consumers' incentive to establish themselves in appropriate areas with respect to available capacity in the electricity grid. This will encourage greater co-location of electricity consumers and producers, benefiting the public electricity grid while also strengthening the integration between PtX and the energy system.

Geographically differentiated consumption tariffs also support the Government's objective that PtX must be able to perform om market terms, as tariffs that better reflect real costs - as determined by geographical locations - can make it cheaper to produce hydrogen via electrolysis.

Direct links can connect renewable energy facilities directly to Power-to-X plants

A direct link is an electricity connection between an electricity producer and an electricity consumer. For example, this could be a wind farm and a major electricity consumer - such as a PtX plant - that are directly connected without using the public electricity grid. Depending on the specific final formulation of the rules for establishing direct links, the electricity consumer can save on the tariff payments for the electricity supplied through a direct link from the producer to the consumer and which therefore do not put a load on the public grid. The reduced tariff payment can increase incentives for co-location of producers and consumers of electricity and reduce the need for expanding the electricity grid. Direct links can also lower the production costs for PtX plants that apply for and are granted permission to build a direct link according to the established criteria. The costs associated with establishing direct lines are paid by the constructor

The Government will grant major electricity consumers such as PtX plants

- The option for Energinet and the grid companies to use geographically differentiated consumption tariffs.

- The application-based opportunity to establish direct links between electricity producers and consumers, e.g. between a wind farm and PtX plant, when deemed socio-economically appropriate.

The possibilities for granting permission for geographically differentiated consumption tariffs and direct links have been analysed in more detail in a separate analysis. The specific tariff models will be developed by the grid companies and Energinet and subsequently undergo review for approval by the Danish Utility Regulator.

Utilisation of surplus heat can result in socio-economic benefits

The placement of PtX plants near a district heating grid is a prerequisite for utilising the surplus heat generated from the plants. The Danish Energy Agency's analyses note in this regard that the socio-economic value of appropriate placement of PtX plants in relation to the electricity grid will often be superior to the socio-economic value of utilising the surplus heat from the plants. This is because locations close to the district heating grid are often in consumption-dominated areas, which are not necessarily good locations to place a PtX plant.

If, however, the placement of a PtX plant makes it possible to utilise surplus heat in an economically sensible way, as may be the case in Esbjerg for example, it is important to ensure that the surplus heat can be used for the benefit of heating customers, the PtX operator and the green transition. The political agreement to promote the utilisation of surplus heat in the district heating, which the Government and a broad political majority in the Folketing entered into in September 2021, provides good opportunities for utilising surplus heat from PtX plants in the district heating sector.

The Government has supported flexibility and sectoral linking through:

- The agreement on utilisation of surplus heat and reduction of the electricity heating fee: In September 2021, the Government and a broad political majority in the Folketing reached a new agreement on promoting the utilisation of surplus heat in the district heating sector, which is expected to enter into force in 2022. Along with the relaxation of the electric heating levy and abolition of the surplus heating levy for electricity-based surplus heating, the new agreement provides good opportunities for utilising surplus heat from PtX plants in the district heating sector.

- The Just Transformation Fund: Denmark stands to receive DKK 663 million in a stream of awards in the period 2021-2027 from the EU's *Just Transformation Fund*. Part of the *Denmark can do more I* reform proposal entails prioritising at least DKK 100 million from the Just Transition Fund to act on the recommendations from the Government's regional growth teams as part of developing the local commercial beacons envisaged in the business development proposal.

- Agreement on stimuli and green recovery: A decision was made to establish seven regional growth teams as well as allocate DKK 500 million from the so-called REACT-EU initiative to act upon their recommendations to establish 8 local commercial beacons around Denmark. In addition, in connection with the allocation of the EU's Structural Funds from 23 June 2021, it was decided to prioritise DKK 400 million to the development of the recommended local commercial beacons. PtX plays a central role for the South Jutland commercial beacon. PtX will also become important to the commercial beacon in North Jutland, which has ambitions for developing CCS and CCU solutions, as well as Bornholm, which is also pursuing PtX projects.

Objective 4: Denmark must be able to export Power-to-X products and technologies

Partial conclusion: Exports of Power-to-X products and technologies made in Denmark can create growth and jobs, benefiting the country and its businesses while also contributing to CO_2 reductions beyond Denmark's borders.

The Government will work to ensure that Denmark contributes to the realisation of the EU's reduction targets for 2030 and 2050 as well as those of the Paris Agreements, while at the same time exploiting the commercial and export potential for Danish businesses by enabling an upscaling and development of the Danish PtX industry across the entire value chain. Foreign investors can make a significant contribution in that regard, and promoting investments can further help towards achieving that goal. At the same time, a focus on innovation can contribute to promoting future Danish exports and attracting foreign investment.

In addition to the investment support scheme that will contribute to the upscaling and development of PtX technologies (see objective 2), the Government will therefore strengthen the framework for 1) creating access to financing for major demonstration projects such as PtX plants, 2) ensuring that Danish companies can export certified green hydrogen and green PtX fuels and 3) establish a hydrogen infrastructure in Denmark that can eventually be used to export hydrogen to other European countries.

Objective 4.
Accordingly, the Government will:

- Propose that Denmark should aim to build upwards of 4 - 6 GW of electrolysis capacity by 2030.
- Support the export of hydrogen and PtX products by creating the framework for a hydrogen infrastructure that can eventually be linked to a common European hydrogen infrastructure.
- 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.
- Support Danish businesses' exports of hydrogen and PtX technology and work to attract foreign investment in Danish PtX projects.
- Work to create clear and uniform rules in connection with European certification for green hydrogen and biogenic sustainable CO_2.

Power-to-X can become a new export market for Denmark

Green hydrogen and other PtX products, including the technologies and plants that produce PtX, are expected to play a significant role in the green transition of transport and industry globally in the future. Accordingly, significant increases in global hydrogen consumption are expected along with the current consumption - which is almost exclusively sourced from fossil-based hydrogen - being converted to hydrogen produced with lower or zero emissions.

In July 2020, the European Commission presented the EU's hydrogen strategy. The strategy outlines three phases in the expansion of hydrogen production and infrastructure:

1) From 2020 to 2024, the EU's electrolysis capacity will grow to at least 6 GW.
2) From 2025 to 2030, the EU's electrolysis capacity will grow to at least 40 GW.
3) From 2030 to 2050, the goal is for the technologies for the production of green hydrogen to be mature and rolled out. In addition to this come parallel targets on the import of green hydrogen from third countries, amounting to as much as 40 GW by 2030.

In parallel with the launch of the EU's hydrogen strategy, a number of European countries have presented national hydrogen strategies that set national targets for the establishment of electrolysis capacity. As shown in Figure 15, the EU Member States have collectively announced an electrolysis capacity target of around 28 MW by 2030, 12 GW short of the EU's 40 GW target for 2030.

The EU's strategy - as well as most of the national strategies - identify green hydrogen as the ultimate goal, although certain national strategies identify blue hydrogen as a transitional technology. Blue hydrogen is based on natural gas, where most of the emitted CO_2 is captured and sequestered in the subsoil.

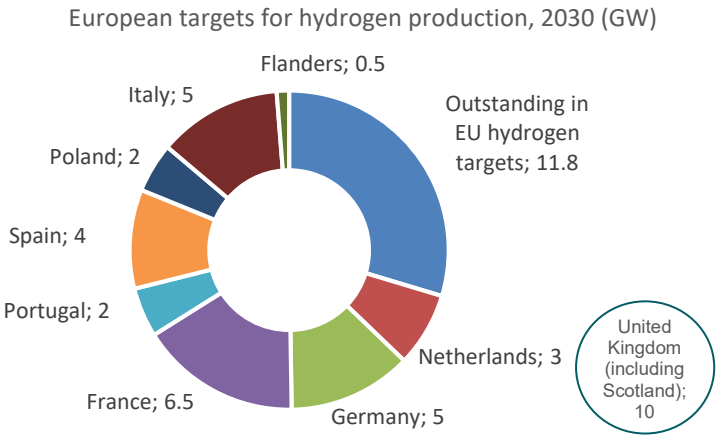


Figure 15 The EU's hydrogen strategy sets a target for 40 GW of electrolysis capacity among the EU Member States by 2030. A number of countries have announced national electrolysis capacity targets, leaving the current capacity shortfall at 12 GW in relation to the EU's target. In addition, the United Kingdom and Scotland have announced hydrogen production targets adding up to 10 GW.

In other words, there is considerable interest in PtX and especially green hydrogen abroad, and several countries in Europe such as Germany, the Netherlands and Belgium are aiming to import hydrogen and other PtX products and technologies. Germany, the Netherlands and Belgium already have a large consumption of fossil-derived hydrogen in their industrial sectors, which can be replaced by green hydrogen and thereby reduce the CO_2 emissions from their domestic industries. The export of Danish PtX products and technologies can prove valuable to Denmark while also contributing to the global green transition.

The Government has proposed that Denmark should aim to build upwards of 4 - 6 GW of electrolysis capacity by 2030. This expansion should occur on market terms to the greatest extent possible while also supporting the realisation of Denmark's export and commercial potential in the PtX area. This objective can also contribute to reducing Denmark's global climate footprint and achieving national and international climate objectives. A Danish electrolysis capacity of between 4 to 6 GW will, given a number of assumptions, be able to provide reductions amounting to 2.5-4.0 million tonnes of CO_2 by 2030, including up to 2 million tonnes that count towards the 70 percent target.

Did you know... that Germany's hydrogen strategy allocates DKK 15 billion to establishing energy partnerships for importing hydrogen and other PtX products? Among other national partners, the German hydrogen strategy mentions the North Sea countries as potential producers of green hydrogen for the German market. The German energy consultant Agora Energiwende expects that hydrogen will primarily be traded between neighbouring

Danish Power-to-X products can compete with foreign Power-to-X products

Denmark has large renewable energy resources, high security of supply and an electricity system that is well-connected to neighbouring countries. In addition, Danish companies possess expertise within all parts of the PtX value chain. In light of that, Denmark is potentially well-positioned to becoming an exporter of green hydrogen and PtX products at competitive prices.

Did you know... that Denmark is well-positioned to export green energy to our neighbouring countries? In 2020, Denmark's net export to Germany amounted to 3 TWh. Denmark will also in the future export electricity when prices abroad are high. Exporting electricity benefits the climate, as it reduces the need for power plants in other countries. However, there are major challenges in moving electricity further south in Europe. Exporting hydrogen would thereby make it possible for Denmark to export more green energy.

The Government will work towards ensuring that Denmark can export green energy in the

The Danish Energy Agency's analyses show that the short-term production costs for green hydrogen in Denmark are on par with production costs for green hydrogen in Morocco, a country which is often used as a benchmark for large hydrogen deliveries to markets in Northern Europe due to the country's considerable solar and wind power potential. When factoring in the transport costs for the hydrogen, Denmark has an advantage through its geographical proximity to markets such as Germany and the Netherlands, and the short-term costs are overall at a level that would be competitive with hydrogen from Morocco.

This development is illustrated in Figure 16. The figure shows a comparison of the costs for producing and transporting green hydrogen from Denmark to the markets in northwestern Europe as well as the corresponding costs for green hydrogen from Morocco. The costs of hydrogen production in Denmark as well as transporting it to countries in northwestern Europe can potentially be brought to a level below the production and transport costs for hydrogen produced in Morocco as a result of upscaling, industrialisation, adjustments to framework conditions, etc. (see objective 2).

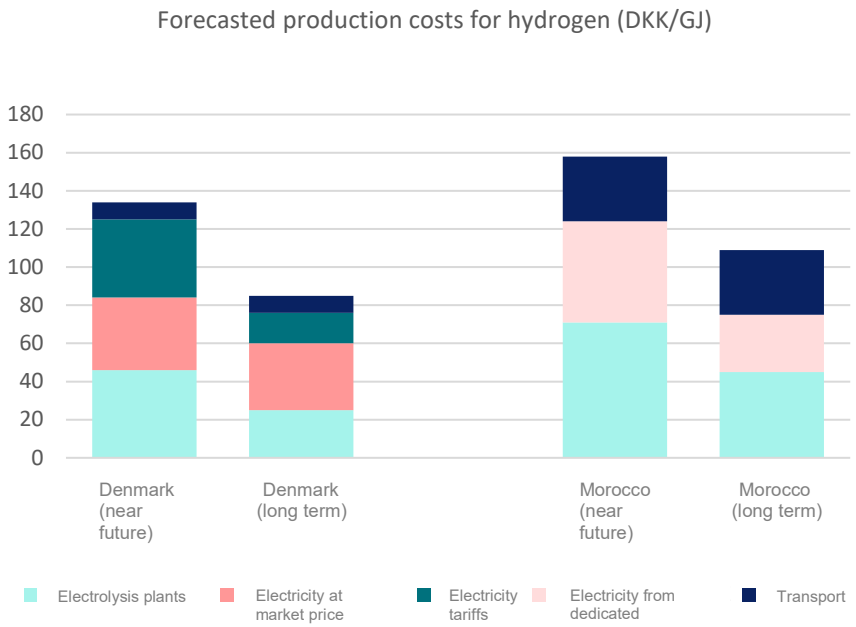


Figure 16. Forecasted production costs for green hydrogen in Denmark and Morocco as well as transport to northwestern Europe. The costs in Denmark are indicated for the near future as well as in the long-term, assuming a significant upscaling and mass-production of the technology, establishment of a hydrogen infrastructure, market regulation, etc. It is also assumed that electricity in Denmark would come from the electricity grid, while electricity in Morocco would come from dedicated renewable energy. The relative costs for electrolysis plants are higher in Morocco than Denmark due to fewer annual production hours from solar energy.
Source: The Danish Energy Agency

Large market for Power-to-X technology can benefit Danish companies

It is not only PtX products that can be exported. Danish companies possess expertise within PtX as well as CCUS, with approximately 70 major and small enterprises working with those technologies (see Figure 17).

PtX technology includes the export of physical elements such as electrolysis units, further conversion plants, hydrogen pipelines, ammonia engines for ships, hydrogen trucks and consulting services in sectoral linkage, infrastructure, etc. Danish companies can both export PtX technology as well as provide consulting services to PtX actors abroad.

A report published by Rambøll shows that Danish exports of PtX technology can accumulate to between DKK 100-410 billion up to 2035. This forecast is based on Rambøll's assumption that the Danish market can make up 3 percent of the expected global market. In addition, Danish exports of CCUS technology can accumulate to between DKK 90-190 billion up to 2035, if one assumes that the Danish market will make up 1 percent of the expected global market. Danish exports of PtX and CCUS technology can become an important export area for Danish companies and Danish business in general, creating value for Denmark.

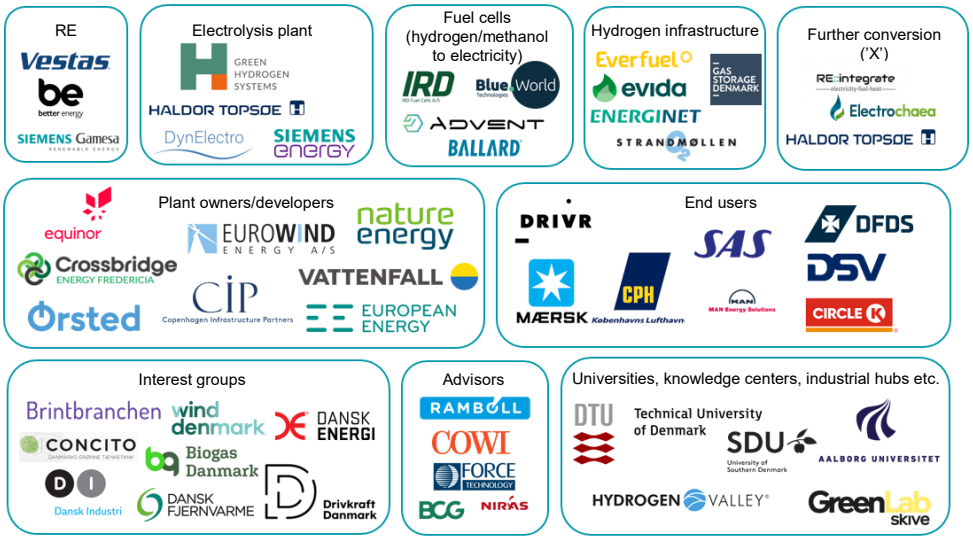


Figure 17. The PtX value chain in Denmark. This list is not exhaustive.

Did you know... that Danish PtX projects can apply for funding via the EU's Innovation Fund? In 2019, the European Commission set up an Innovation Fund to support large-scale demonstration projects of new groundbreaking energy technologies within the fields of renewable energy, energy storage, industrial processes as well as the capture, storage and use of CO_2. The Commission has estimated that the fund will have around EUR 25 billion at its disposal during the period 2020-2030[1]. The final amount depends on the quota price, which has increased significantly in recent years. From 2021-2030, the fund will be financed by proceeds from auctioning approximately 450 million emission allowances from the EU's emissions trading system as well as any excess funding from the NER300 programme.

The Government will improve opportunities to co-finance commercial large-scale demonstration plants within Power-to-X, among other technologies. The Government's *Denmark can do more I* reform proposal includes establishing the Danish Investment Fund (DIF) by merging the Danish Growth Fund, the Danish Export Credit Agency and the Danish Green Investment Fund into one. Furthermore, the Government has proposed a capital injection of DKK 1.7 billion to the fund, which can be used for funding companies engaged in commercial large-scale projects within fields such as PtX. With its *Denmark can do more I* reform proposal, the Government's aim is to scale up Danish PtX technology and plants, lower the cost of them and turn them into global exports.

The framework conditions for Power-to-X exports need to be established

Hydrogen infrastructure is a prerequisite to Danish exports of hydrogen

The Danish Energy Agency's analyses show that a key precondition for being able to competitively export Danish hydrogen to countries such as Germany is that Danish hydrogen infrastructure is connected to a planned and future European hydrogen infrastructure (see Figure 18). Parts of the existing infrastructure for gas transport in South Jutland may potentially be able to be used as a Danish export pipeline. This will make it possible to sell Danish-produced hydrogen in Germany and other importing countries in northwestern Europe.

Figure 18. Danish hydrogen pipeline connected to European hydrogen pipelines paves the way for hydrogen exports to Germany and other North European countries.
Source: The Danish Energy Agency

The Trans-European Networks for Energy (TEN-E) regulation opens up the possibility for cross-border projects for converting natural gas pipelines to transport green hydrogen to be financed through EU funding via the 'Connecting Europe Facility' (CEF). In the period 2021-2027, approximately DKK 44 billion has been allocated to support the development of European energy infrastructure.

The Government will create the framework conditions for allowing hydrogen infrastructure to play a key role in the export of hydrogen. With objective 2, the Government has put forward the ambition of a strong Danish hydrogen infrastructure that can be established either by laying new gas pipes or reusing existing gas pipes. However, the Government will also work to establish a common European hydrogen infrastructure so that Denmark can export green hydrogen to neighbouring countries via connections to countries such as Germany, Sweden, the Netherlands and Belgium.

Certification of hydrogen and carbon

It is expected that in the short and medium term, green hydrogen will coexist with fossil-derived hydrogen with or without carbon capture (so-called green and blue hydrogen). Even though blue and green hydrogen are sometimes placed in the same category as low-emission hydrogen, blue hydrogen production has higher CO_2 emissions. Therefore, the green added value of Danish-produced green hydrogen should be safeguarded through certification. Green hydrogen certification should reflect the climate benefit of using green hydrogen. The Danish Energy Agency's and Energinet's market dialogue indicates that there will be adeed value associated with a certification that hydrogen is based on renewable energy.

Did you know… that Energinet has launched ElOprindelse, a prototype system which can help provide better documentation of green electricity consumption? ElOprindelse is a new premium standard of documentation of green electricity consumption, where electricity consumption data is linked to offshore/onshore wind or solar energy production and thereby able to display how much green electricity one consumes on an hourly basis. This will solve one of the problems associated with the present guarantees of origin, namely that the electricity consumption calculation only occurs on an annual basis.

PtX processes rely on being able to document that they use green electricity in order for them to be considered genuinely sustainable and CO2-neutral. Thus, ElOprindelse offers potential benefits for green energy consumption, sectoral links and PtX.

Energinet has market-tested the prototype in 2020 with over 50 actors, which showed a demand and willingness to pay. Additionally, there has been considerable international interest in ElOprindelse, both in relation to forming the basis for an international standard under EnergyTag and in dialogue with the EU Commission.

Carbonaceous PtX fuels, such as methanol and aircraft fuel, require carbon. The overall CO_2 footprint of such fuels will, however, depend on the carbon source. Certification of carbon can therefore also become crucial to ensuring transparency

for buyers, which according to the Danish Energy Agency's market dialogue will become an increasingly important competitive factor for both producers and buyers of PtX fuels as the green transition progresses. Certification of green hydrogen and carbon is discussed under objective 2.

The Government will push for clear and uniform rules for the certification of green hydrogen and carbon across national borders. In connection with Article 27 of the Renewable Energy Directive II, the Government will push for fair pan-European rules for green hydrogen and PtX fuels so that green hydrogen and PtX fuels produced from renewable energy in Denmark get a high valuation when traded across European national borders, thereby benefiting Denmark and Danish companies.

Common EU rules and certification of green hydrogen are insufficient on their own, however. As the production of carbonaceous PtX products for aircraft and ships grows in the future, it will become necessary to ensure the carbon used is biogenic and sustainable. The European Commission is in the process of drafting a legislative proposal on a certification system for CO_2 emissions, which is expected to be presented by the end of 2022. The Government will work to ensure the development of a harmonised European system that can document the origin of carbon.

Green hydrogen based on renewable energy sources and sustainable carbon are key competition factors that the Government will support for the benefit of Danish companies.

Global climate targets and transnational cooperation

Some of the sectors where PtX has particularly high potential - shipping and aviation in particular - are subject to international competition. This means that we need ambitious and global climate targets and rules that can promote the decarbonisation of these sectors not only in Denmark, but in the rest of the world as well.

The Government will push for a climate-neutral shipping sector by 2050 at the latest. At COP26, the Danish Government, the Marshall Islands, USA, United Kingdom and a number of other countries presented a joint declaration on climate-neutral shipping by 2050 at the latest. The Danish shipping industry already has a goal to become climate-neutral by 2050, and the Government will work in collaboration with some of the world's other major maritime nations to support this ambition by pushing to make it a global target via the UN International Maritime Organisation (IMO). In so doing, the Government will contribute not only to achieving the objectives of the Paris Agreement, but also ensuring the best possible framework for commercial investments in green shipping both today and in the future.

A prerequisite to PtX becoming an important export market for Denmark and contributing to the European and global climate efforts is good collaboration with other countries. Denmark is involved in a number of partnerships in this area, including the international public-private Zero-Emission Shipping Mission, which also includes the USA and Norway as well as the Denmark-based Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping.

The Danish Energy Agency collaborates with authorities in a number of countries, including Germany, the UK, the Netherlands, the USA, Japan, China, South Korea and Australia, all of which are active within the field of hydrogen and PtX. One of the focus areas for these collaborations is to improve the framework conditions for green investments in more established technologies such as offshore wind, district heating and energy efficiency, boosting the green transition as well as Danish exports. There is also an increased demand for joint development and mutual knowledge exchanges between national authorities regarding regulation of new technologies such as PtX and CCUS, which is also included as a focus area in several bilateral cooperation agreements.

The Government is supporting the international promotion of Power-to-X through:

- Mission Innovation: Denmark has been the driving force behind the preparation of the Shipping Mission for climate-neutral shipping, which was selected as one of the missions of the new Mission Innovation 2.0. A Power Mission and Hydrogen Mission will be launched alongside the Shipping Mission. In June 2021, the Government launched the Zero-Emission Shipping Mission, a collaboration between Denmark, the USA, Norway and two major private sector actors, namely the Global Maritime Forum and Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping.

- The Danish Ministry of Foreign Affairs' Trade Council, innovation centres and Invest in Denmark The Government has a focus via the Trade Council to help Danish PtX companies enter new markets. Invest in Denmark is also engaged in attracting foreign PtX actors to Denmark. The Danish innovation centres prioritise collaborations on Power-to-X to gain new knowledge and thereby in the long run contribute to raising funds for PtX projects as well as further developing and commercialising PtX technologies.

- Green Hydrogen Compact Catalogue: The Green Hydrogen Compact Catalogue is a Danish initiative launched in connection with the UN Energy Summit in September 2021. The goal is to bring together a number of different actors, including governments, international organisations, private enterprises and other stakeholders to support

international and cross-sectoral collaboration on the development of green hydrogen.

- The Danish Energy Agency's bilateral collaboration with individual countries on PtX as part of its collaboration with other national authorities in the field of energy. The field is also included in several formal collaboration agreements.

- World Leader Summit Statement on the Breakthrough Agenda – Hydrogen. In connection with COP26, Denmark joined an initiative for global collaboration on developing green technologies, including hydrogen, with a view to making hydrogen affordable and available globally by 2030. This collaboration will fall under the Clean Energy Ministerial as well as under the auspices of Mission Innovation, LeadIT and Mission Possible, and the efforts will be based on status reports published by the IEA and IRENA.

- LeadIT Summit Statement. Danish endorsement of the declaration on industrial transition with a focus on national action plans that involve all public and private sector actors; a market for green hydrogen with a net-zero target for 2050, financing and infrastructure.

The Government's vision for Power-to-X

Today, Denmark produces large amounts of green electricity from wind turbines and solar panels, transported through cables across the country. Yet Denmark has the potential to produce even more green electricity in the future. This electricity will be used directly in households, companies and for transport, but will also be converted to hydrogen and other PtX products that can displace fossil fuels in the heaviest forms of transport and industry where electrification is not feasible.

The strategy sets a number of objectives for rolling out PtX in Denmark while also establishing key framework conditions for the Government's further work with PtX.

The Government's vision for Danish Power-to-X
Denmark has considerable PtX potential, and in the present strategy, the Government has presented four objectives that collectively set the course for its work with promoting the development, expansion and adoption of hydrogen and other PtX products.

The Government's Power-to-X strategy sets a course aimed at ensuring:

- **That Power-to-X can contribute to achieving the objectives of the Danish Climate Act**, including the 70 percent target in 2030 and the long-term climate-neutrality target by 2050 at the latest, as well as international climate targets that Denmark has committed to meeting within the EU and via the Paris Agreement. The Government will therefore push for ambitious requirements in the Fit-for-55 package (including within the aviation and shipping sector), initiate an analysis of biological resources for the green transition and invest DKK 1.25 billion through a PtX tender aimed at operating support for the production of hydrogen and other PtX products.

- **That the regulatory framework and infrastructure is in place for Denmark to utilise its strengths and allow Power-to-X to perform on market terms in the long run.** The Government will therefore initiate a 360-degree review of regulations related to hydrogen, create a regulation for a national hydrogen market and give Energinet and Evida the option to own and operate hydrogen infrastructure. The Government will also carry out an analysis of opportunities and needs in relation to the role of Danish ports as green transport hubs and act on the recommendations from the South Jutland growth team on establishing a commercial beacon for green energy and sectoral linking.

- **That the integration between Power-to-X and the Danish energy system is improved.** The Government will allow for geographically differentiated consumption tariffs for major electricity consumers (such as PtX plants),

incentivising them to seek geographically appropriate locations based on electricity grid loads. The Government will also provide the application-based option to establish direct links between actors such as major electricity consumers and renewable energy producers when deemed socio-economically appropriate, thereby allowing them to pay lower tariff payments to the public electricity grid or avoid them entirely.

- **That Denmark can export Power-to-X products and technologies.** The Government will therefore support the export of hydrogen and PtX products and technologies that can contribute to the achievement of international climate targets while also promoting Danish businesses' commercial opportunities by establishing the framework conditions for a hydrogen infrastructure, as well as increasing access to venture capital, including Danish companies' access to export financing. The Government will also propose that Denmark should aim to build upwards of 4 - 6 GW of electrolysis capacity by 2030. In addition, the Government will work with the Danish business community to revise the Energy Export Strategy from 2017 with a view to creating a partnership-based approach to supporting the export of PtX products and technologies.

Towards 2025, the Government will - as stated in the *Roadmap for a Green Denmark* - present several strategies and proposals that will detail the path towards the Danish Climate Act's objective to reduce Denmark's greenhouse gas emissions by 70 percent by 2030:

In 2022, the Government will present:

- An energy and utilities proposal
- A green industrial sector proposal
- A strategy for rolling out propellant infrastructure for heavy road transport
- A proposal for the green transition of air traffic, a green industry and a green energy and utilities sector

In 2023, the Government will present:

- A proposal on sustainable fuels for road transport and shipping

In 2024, the Government will:

- Consider future mission-driven research efforts as well as cross-cutting efforts to accelerate the development of green solutions, as well as how

the prioritisations can be optimised to support the goals of the Danish Climate Act.

In 2025, the Government will present:

- A proposal for a climate action plan

Danish Ministry of Climate,
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