Green hydrogen is Danish hydrogen

How Denmark plans to speed up the fuel shift, and decarbonise global transport and energy-intensive industries

STATE OF GREEN

GREEN HYDROGEN IS DANISH HYDROGEN

How Denmark plans to speed up the fuel shift, and decarbonise global transport and energy-intensive industries

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Executive summary

With widespread adoption of green hydrogen across sectors, Denmark is committed to leveraging its experience, expertise, and partnerships to drive the production, distribution, and integration of green hydrogen into the energy system.

Denmark is blessed with an abundance of renewable energy resources, particularly in offshore wind. With firm governmental commitment to achieve climate neutrality by 2050, and nationwide expertise in integrating variable renewables into the energy system, the Danish stage is set to scale green hydrogen.

Green hydrogen and beyond
In Denmark, green hydrogen is seen as a catalyst to producing hydrogen derivatives like e-methanol, e-ammonia, and e-kerosene, which are crucial for decarbonising industry and transportation. The term 'Power-to-X' is widely used in Denmark to highlight that renewable electricity can produce any number of electro fuels. To ensure cost-effective, large-scale, and steady distribution of green hydrogen nationwide and beyond, Denmark aims to connect its hydrogen sector to Europe by establishing a pipeline infrastructure.

The Danish energy model is characterised by a holistic view of energy planning with a strong focus on sector integration. As such, efforts are invested in seeking out ways to utilise excess heat from hydrogen production in local district heating systems, or as process heat in the value chain and in industrial applications. Many hydrogen developers are also investigating alternatives to drinking water for electrolysis, such as wastewater and other types of water not suited for direct consumption.

Experiences across the value chain
Just as Denmark has played a pivotal role in the growth of the offshore wind industry, the country is well-positioned to apply its experience to propel the development of green hydrogen on a global scale. Denmark aims to become a frontrunner in the green hydrogen sector, utilising renewable energy sources like wind and solar to produce hydrogen and hydrogen-based products.

Denmark has experience across the whole green hydrogen value chain, from unparalleled experience within offshore wind, highly efficient electrolyser technologies, and a core focus on cross-industry energy efficiency, to a strong transport sector, district heating grids for utilising excess heat, and cutting-edge technology providers.

Denmark is also world-renowned for its research and development, helping new industries take root. This goes hand in hand with ensuring that the workforce's abilities align with the demands of the new hydrogen industry. To execute it all, great attention is put towards educating a skilled labour force, ensuring a transition that is both green and just.

About this white paper
This white paper takes the reader chronologically through the fundamental value chain for green hydrogen, spanning renewable energy production, electrolysis, and hydrogen derivatives, through to the utilisation of hydrogen and hydrogen-based products, and sector integration. It presents how and why Denmark is geared to accelerate the fuel shift and decarbonise global transport and energy-intensive industries.

FOREWORD

Advancing a sustainable energy future with green hydrogen

BY KADRI SIMSON, COMMISSIONER FOR ENERGY, EUROPEAN COMMISSION

In the face of the Russian invasion of Ukraine and the subsequent energy crisis, the European Union has doubled-down on its commitment to shape a sustainable and resilient energy future. Besides diversification and savings, the rapid development of clean and secure energy will improve our energy independence and mitigates geopolitical risks. In this context, green hydrogen is an innovative solution that will enable us to leverage substantial renewable energy potential and reduce and shift our dependence away from imports of fossil energy sources.

Green hydrogen will also be a crucial element in our efforts to achieve a carbon-neutral future. Already back in July 2020, the European Commission recognised the tremendous potential of hydrogen as a key enabler in our decarbonisation journey with the adoption of the EU Hydrogen Strategy. Since then, we set out a comprehensive regulatory framework to enable a rapid scale-up of green hydrogen into various sectors, such as industry and transport, and position Europe as a global leader in hydrogen technologies. This strategy serves as a guiding light for member states, businesses, and stakeholders in fostering a clean, secure and sustainable hydrogen economy across the EU.

The EU's REPowerEU plan has increased European ambitions on hydrogen. It accelerates the deployment of hydrogen infrastructure across Europe and aims to establish a robust hydrogen value chain through the Net-Zero Industry Act. Furthermore, the recent reform proposal for the Electricity Market Design will ensure an acceleration of renewables deployment at competitive prices and fostering cross-border collaboration to bring renewables to the end-consumers. In this way, we can reduce carbon emissions, create new jobs, and strengthen our energy security.

Moreover, the establishment of the European Hydrogen Bank marks a significant milestone in our pursuit of the creation of an early market for green hydrogen. It will play a crucial role in supporting the first off-take contracts for green hydrogen, mobilise public and private investments and facilitate the development of a full supply chain for the production, transport, storage and use of hydrogen.

As we confront the aftermath of the Russian invasion of Ukraine, it is imperative that we seize this moment to transform our energy landscape and enhance our resilience. By sharing knowledge and fostering collaboration, we can accelerate the transition towards a sustainable energy future.

Kadri Simson
Commissioner for Energy, European Commission

FOREWORD

Green fuels incoming

BY LARS AAGAARD, MINISTER FOR CLIMATE, ENERGY AND UTILITIES

The Danish adventure on green hydrogen and Power-to-X (PtX) has already left the harbour. The sails have been set, and in the coming years the key to our acceleration is clear sightlines for the future hydrogen market and infrastructure. Without the private sector, we are going nowhere. Industry actors need transparency and predictability, and Denmark is taking important steps to provide this. In April 2023, the Danish government opened a tender of DKK 1.25 billion (EUR 167 million) that will serve to kickstart the marketplace and get big players involved. The goal is a self-sustaining market, but a strong boost is needed for that to become reality.

Green hydrogen and PtX are not national endeavours either; they are a multinational ones requiring close cooperation across borders. That is why we have agreed to cooperate with our German neighbours on establishing a pipeline connecting our countries from 2028. Green hydrogen is essential to the green transition, not only in Denmark but across the continent. Therefore, we will continue to expand collaboration with nations and companies who share our vision.

Wind is key. Denmark has a storied legacy as a wind power nation, and we are in the midst of a historical expansion of our offshore capacity. This is an important prerequisite for our success within green hydrogen and PtX, as demands for green power will rise quickly when hydrogen factories start to spawn. This expansion will serve to establish Denmark as a green powerhouse in Europe and help us fulfil the promises made in Esbjerg and Ostend.

Our ambition is to reach an electrolysis capacity of 4-6 GW by 2030. That is an ambitious goal to pursue, and while we have come far, we still have a long journey ahead of us. For now, we will focus on the continued implementation of our national policies, as we are looking forward to realising our vision of Denmark as an important supplier of green fuels for the future. In this white paper, we have gathered some of the knowledge that we have acquired along the way, and I hope that it will inspire you to join us in our efforts. The possibilities are plentiful, and our planet needs them.

Lars Aagaard
Minister for Climate, Energy and Utilities

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CHAPTER 1

Why Danish hydrogen is green hydrogen

In Denmark, hydrogen will be produced using renewable energy sources like wind and solar with zero carbon emissions. This supports Denmark's commitment to clean energy, decarbonisation, and reaching climate neutrality in 2050.

Denmark has a long tradition of active energy policy, initiated as a reaction to the first oil crisis in 1973. Over the years, aggressive pursuit of energy efficiency, system integration, and renewable energy generation has moved Denmark close to a fossil-free energy system.

The next step is decarbonisation of heating, transportation, and industry through both direct and indirect electrification, taking advantage of the high level of renewable energy in the Danish energy system. Hydrogen is the natural conclusion of this journey. It holds considerable potential for reducing CO_2 emissions in hard-to-abate sectors, and offers further potential for system integration and deployment of renewable energy sources.

Power-to-X and green hydrogen
Power-to-X (PtX) is a blanket term that refers to a set of technologies that convert renewable electricity into other forms of energy products. The 'X' represents different energy carriers or products that can be generated through this process, including hydrogen, e-fuels, chemicals, and materials. In Denmark, the term is used to signal that the product is not necessarily hydrogen; it could also be methane, ammonia, or synthetic fuels.

Today, nearly all hydrogen production is based on fossil fuels such as coal (brown hydrogen) or natural gas (grey hydrogen). Using renewable energy instead of fossil fuels to produce fuels and chemicals can contribute to significant CO_2 emission reductions. In Denmark, the focus is on producing hydrogen and hydrogen derivatives using only renewable energy, making Danish hydrogen exclusively green hydrogen.

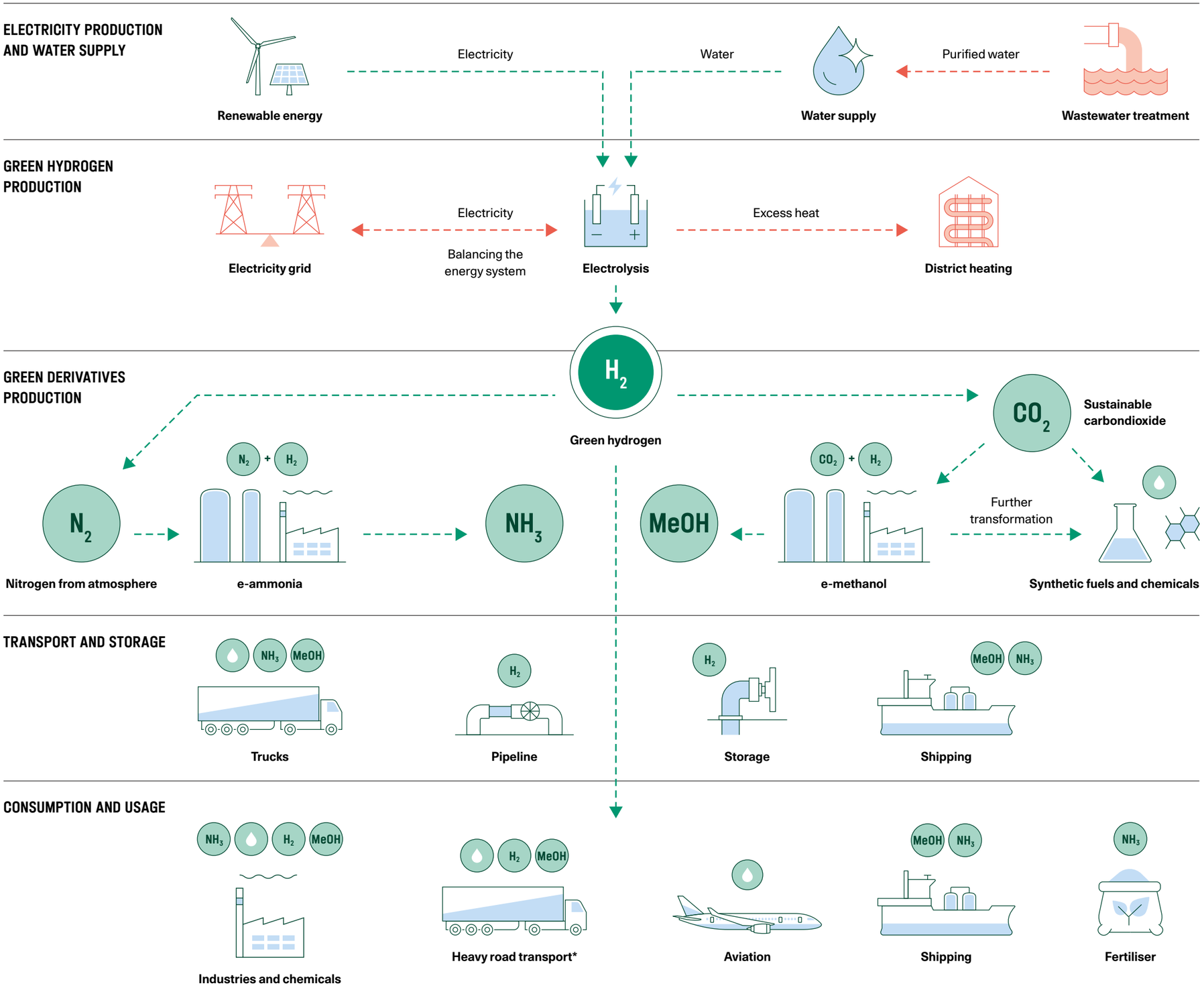
The best use of hydrogen
When decarbonising light transport and space heating, direct electrification through battery-powered vehicles, district heating or electric heat pumps is the most cost-effective and energy-efficient pathway. Due to their energy losses, e-fuels are more efficient for areas where direct electrification is not possible or is associated with very high costs, such as long-distance flights, freight shipping, industrial high-temperature processes, and energy-intensive vehicles in agriculture and construction.

The Danish principles for using hydrogen
Firstly, hydrogen production should be based on renewable electricity and should be fully integrated into the energy system. Secondly, hydrogen and hydrogen derivatives should only be used when direct electrification is not feasible. Thirdly, the development of the sector should be based on market terms. Finally, sectoral integration is key for the success of full deployment by, for example, utilising excess heat from electrolysis in the district heating system or using sources other than drinking water for electrolysis to create a circular process that protects drinking resources.

Basic principles of Power-to-X: renewable electricity is used to split water into oxygen and hydrogen. This technology is called electrolysis. The hydrogen can be used directly, or it can be further converted into other fuels, chemicals, and materials. The excess heat generated during the electrolysis process can be used in the district heating network, thus hydrogen can be integrated in the existing energy system.

GREEN HYDROGEN VALUE CHAIN

The figure illustrates the green hydrogen value chain from a Danish perspective where the energy source is derived from renewable sources like wind and solar. Hydrogen functions as an energy carrier, crucial for balancing the energy system, and is transported through pipelines and stored in underground salt caverns. Additionally, hydrogen serves as a building block for hydrogen-based products, where hydrogen can be combined with either nitrogen for e-ammonia or carbon dioxide (CO_2) for e-methanol and e-kerosene. The Danish approach sees sectoral integration as key for the success of the full deployment of green hydrogen. This includes utilising excess heat from electrolysis in the district heating system and purifying wastewater for electrolysis.



Power-to-X Sector integration

*While direct electrification will be the dominant solution for zero-emission road transport in Denmark, Danish companies are today producing green hydrogen for use in e.g. taxis domestically. EU legislation means green hydrogen will be an important part of decarbonising all sectors of European transport.

How do you start up a brand-new green energy sector? That is the question Danish policy-makers and industry had to answer as it became increasingly evident that hydrogen would play a key role in fulfilling the 2020 Climate Act to create of a greener future. Since then, several political milestones have been accomplished, most importantly the Power-to-X agreement of 2022, as well as the Joint Declaration with Germany, and the 2023 agreement on hydrogen infrastructure.

Photo credit: The Danish Parliament/Christoffer Regild

CHAPTER 2

Political framework to support an emerging green sector

With an ambitious political framework Denmark aims to become a frontrunner of green hydrogen. The 2022 Agreement on green hydrogen and green fuels sets a goal of 4-6 GW electrolyser capacity in 2030 and defines economic subsidies to kick-start the sector.

Green hydrogen plays an important part in fulfilling the 2020 Danish Climate Act's goal to decarbonise Danish society by 2050. As such, the Danish parliament has agreed ambitious targets for the roll-out of PtX in Denmark.

Establishing the framework: the PtX agreement
The PtX agreement builds on the visionary 2020 Climate Act and sets the ambition for Denmark to become a frontrunner in the production of green hydrogen. The agreement sets a target for building 4-6 GW of electrolyser capacity in 2030 with the goal to further Danish participation in the emerging European hydrogen market. It is a principle for the Danish approach that the roll-out of hydrogen and hydrogen derivatives should be market-based.

To kick-start the emerging hydrogen economy, the Danish state has initiated a tender to subsidise the production of green hydrogen, awarding DKK 1.25 billion (EUR 167 million) towards the end of 2023 to green hydrogen producers. The purpose of the tender is to support the industrialisation and scaling of Danish hydrogen production and prize discovery. Since 2019, more than DKK 3 billion (EUR 402 million) of public funding has been allocated to support the Danish hydrogen sector.

The Power-to-X-taskforce, which is anchored in the Danish Energy Agency, was also established to ensure smooth co-operation between government, municipalities, and private stakeholders, and to help identify and clear barriers to allow the growth of the Danish hydrogen sector.

The future of Danish hydrogen
The roll-out and success of the Danish hydrogen adventure hinges on an extensive planned build-out of renewable energy, mostly from North Sea wind farms. To ensure consistent efficiency, the Danish government allows for overplanting of offshore wind turbines.

The Danish government is working to ensure a framework that can acommodate smart regulation and cost-effective differentiated grid tariffs that can reward flexibility and interruptability to ensure that green hydrogen production is integrated in the national electricity grid, which will be dominated by wind and solar power in the future.

CHAPTER 3

Towards 100% renewable electricity production

Denmark is at the forefront of wind power and the integration of variable renewables. Abundant wind resources combined with hydrogen and hydrogen derivatives can secure a reliable, independent, and sustainable net-zero emissions energy system.

Highly dependent on imported energy, the 1970s oil crises led to increased electricity costs in Denmark. As a solution towards energy independency, wind energy and other renewable energy sources gained public support and political goodwill.

The Danish wind power legacy
Despite renewables originally being more expensive than fossil fuels, continuous political commitment secured more and larger wind power projects onshore, and in 1991 Denmark established the world's first offshore wind farm, Vindeby.

Since then, the increasing scale of offshore wind and strong technological improvements from the Danish wind power industry have reduced costs throughout the whole supply chain — producing a lower Levelised Cost of Energy (LCOE) and increasing the competitiveness of offshore wind.

Today, renewables are among the cheapest forms of electricity production in Denmark and many other countries around the world, and costs are expected to further decrease as scale increases.

Gigantic potential for offshore wind
Geographically located between the North Sea and the Baltic Sea, Denmark has access to abundant offshore wind resources which provide the potential for Denmark to become Europe's green powerhouse.

With the Ostend Declaration, European politicians have set the ambitious target of 120 GW offshore wind capacity by 2030 in the North Sea, with the potential to increase capacity to at least 300 GW by 2050. Denmark can deliver a substantial amount of this.

Strong grid and flexibility from electrolysers
With a security of electricity supply of 99.99 percent, the Danish energy system has proven that it is possible to integrate large amounts of intermittent renewables. In the coming years, the need for a continued build-out of the electricity grid, as well as hydrogen pipelines across Denmark and to neighbouring countries, will grow as the volumes of intermittent, decentralised electricity production increase.

Electrolysers will play a key role in securing the balance between electricity supply and demand. They provide flexibility by being able to consume large amounts of electricity from the grid when renewables are producing abundantly and electricity prices are low, and by being easily turned off or ramped down when renewable production is low and prices are high. Renewable electricity and electrolysers thereby benefit each other towards securing the value creation and competitiveness of Danish renewables and hydrogen production.

From pioneering wind to pioneering net-zero energy systems
The potential for offshore wind energy in Denmark is high. Combined with hydrogen, Denmark can secure a reliable, independent, and sustainable net-zero emissions energy system. Denmark has a history of pioneering achievements, particularly in the refinement of skills within wind energy. Presently, the nation is poised to undertake a new pioneering initiative, with a specific emphasis on hydrogen.

FIGURE 1

Historical bid prices for offshore wind

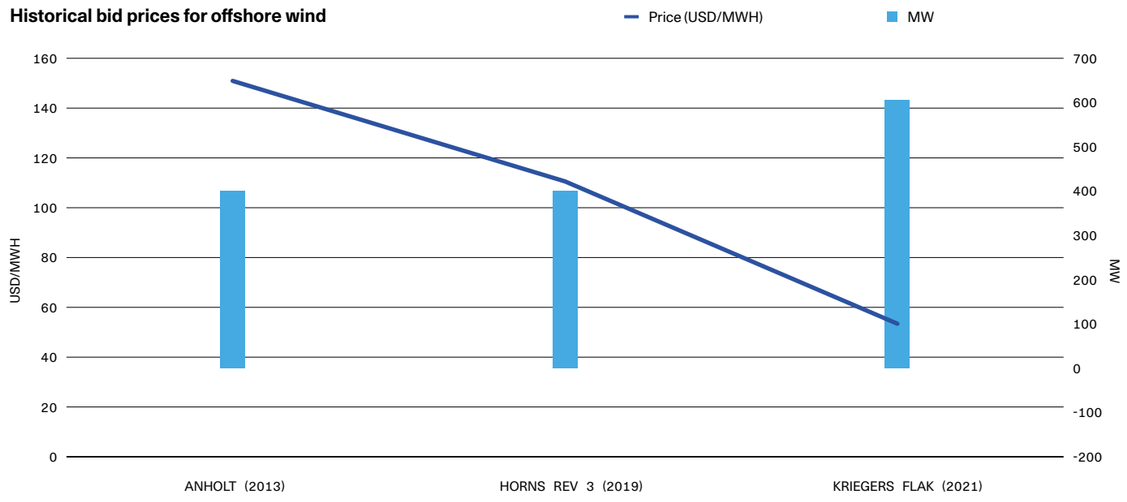
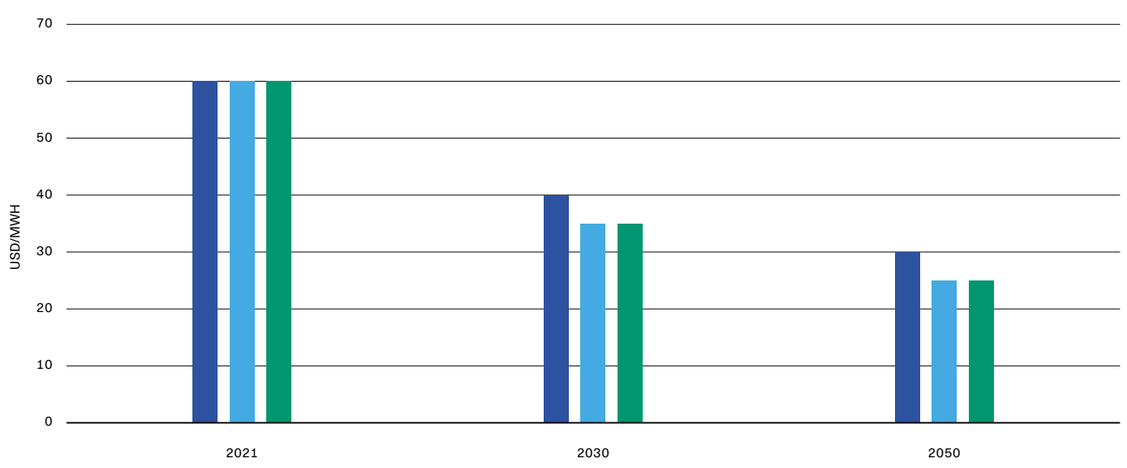


FIGURE 2

Forecasted LCOE in Denmark



The Ostend Declaration was signed in April 2023 in Ostend, Belgium. It highlights the collective commitment of participating countries to harness the vast potential of offshore wind in the North Sea region. It emphasises the need for increased collaboration, knowledge sharing, and investments to accelerate the deployment of offshore wind. The declaration also stresses the importance of sustainable development, environmental protection, and the integration of offshore wind into the broader energy system. Read the declaration here

kefm.dk/Media/638179241345565422/Declaration%20ENERGY_FINAL_21042023.pdf

CHAPTER 4

Electrolysis: the next phase of the green transition

Hydrogen and electrolysis are not new inventions. Hydrogen dates back 13 billion years to the Big Bang and has been used in industry for decades in the post-industrial world.

An electrolyser is a device that uses electricity to split water into oxygen gas and hydrogen gas. To keep the gases separate and prevent mixing, there is a special membrane in between called an electrolyte. It helps to balance the charges and keeps the gases from getting mixed up or contaminated. When using renewable energy for electrolysis the hydrogen produced is called green hydrogen.

Old technology given new life
There is nothing new about producing hydrogen from wind power — in Denmark, at least. Back in 1894, the inventor Poul la Cour used electricity from a wind turbine to split water into oxygen and hydrogen gas. The gases were separately collected in tanks, stored in bottles, and used to light buildings, such as the Askov Folk High School.

How green hydrogen can be utilised
While producing green hydrogen through electrolysis is not a new technology, the hydrogen currently used in industrial processes is predominantly fossil-based, being derived from gas and coal. Today's hydrogen supply accounts for 1.7 percent of the global annual energy consumption and emits 830 million tonnes of CO_2 annually. Only about 1 percent is based on renewable energy.

As global renewable energy continues to grow rapidly, the potential for substituting fossil-based hydrogen with green hydrogen represents vast opportunities for emissions reductions.

Green hydrogen can be utilised in many parts of the energy system, either in its pure form or as a building block in further refining processes. As a fuel, green hydrogen is completely free of harmful emissions; a vehicle fuelled by hydrogen, for example, only emits water vapor.

The importance of water
Water is the basis of electrolysis and presents its own challenges and opportunities. The purity of the water is essential, and this raises questions on how to supply the necessary quantities of sufficiently pure water.

As drinking water is a very scarce global resource, Danish efforts to develop suitable solutions for electrolysis focus on purifying wastewater, and using groundwater from areas where the water level is problematically high and cannot be used for consumption. In this way, electrolyser plants can contribute to a new water ecosystem which uses low-quality water from other sectors, including wastewater from private households. While technologies within wastewater treatment and water purification already exist in Denmark, the Danish water industry is also working on new technologies to solve these challenges.

Types of electrolysis:

1. **Alkaline**: a liquid electrolyte splits water with an electrical current. Free from costly metal materials and configurable in large stacks, it provides long-term stability and durability.
2. **Solid Oxide**: a ceramic electrolyte transfers oxygen ions to the anode at high temperatures. While complex, it offers high efficiency and good heat utilisation.
3. **Polymer Electrolyte Membrane (PEM)**: a solid polymer membrane conducts protons. Operating effectively at high current densities and variable power levels within seconds, it pairs well with renewable energy.

Photo credit: HyBalance

Cross-sector collaboration

Collaboration across sectors is a longstanding Danish tradition. Whether between industry actors, research institutes, and private businesses, or public-private initiatives to solve the greatest challenges facing society, cooperation lies at the heart of the efforts driving positive developments. The following three cases are great examples of this.

Partnerships paving the way

As part of the 2021 Finance Act, the Danish government allocated DKK 700 million to investments in mission-driven research and development within four areas. One of these 'InnoMissions' was the development of green fuels for transport and industry. To drive the innovation within this area, the public-private partnership MissionGreenFuels was formed.

The MissionGreenFuels partnership focuses on how to fulfil the Danish climate goals of 70 percent greenhouse gas reduction by 2030, and net-zero by 2050, by decarbonising the heavy road transport, aviation, and shipping sectors through green fuels. The partnership aims to support Danish research, innovation, growth, job creation, and export potential within the field of green fuels.

The MissionGreenFuels project portfolio is divided into three strategic research and innovation areas, called 'workstreams', where green fuels are essential for the green transition. Aalborg University leads the MissionGreenFuels' secretariat and is supported by Energy Cluster Denmark and the Danish Center for Energy Storage.

The project has received funding from The Innovation Fund Denmark.

CONTRIBUTORS

The Innovation Fund Denmark, Aalborg University, Energy Cluster Denmark, Danish Center for Energy Storage

LOCATION

Aalborg, Denmark

Green fuels for a brighter future

Green Fuels for Denmark is a unique partnership between Copenhagen Airports, A.P. Moller-Maersk, DSV, DFDS, SAS, and Ørsted, with COWI as a knowledge partner. It is focused on developing ground-breaking hydrogen and green fuel production facilities.

Green Fuels for Denmark will be a key project in developing sustainable fuels for aviation and shipping, while contributing significantly to Denmark's goal of reducing CO_2 emissions by 70 percent by 2030. The fully scaled facility will reduce annual CO_2 emissions by 850,000 tonnes.

The project aims to decarbonise heavy transportation by producing sustainable fuel and holds the potential to replace more than 270,000 tonnes per year of fossil fuel consumption in 2030, equivalent to a 1.77 percent reduction in Danish CO_2 emissions.

To do this, a 1.3 GW electrolyser powered by 2-3 GW offshore wind will be established. Once scaled, Green Fuels for Denmark can supply the transportation sector with more than 250,000 tonnes of green fuels each year, including enough e-kerosene to cover 30 percent of Copenhagen Airport's pre-pandemic fuel consumption.

CONTRIBUTORS

Ørsted, Copenhagen Airports, A.P. Moller-Maersk, DSV, DFDS, SAS, COWI

LOCATION

Avedøre Holme, Copenhagen, Denmark

Partnering on responsibilities

In 2019, the Danish government formed 14 climate partnerships representing the different sectors of the Danish economy. These partnerships build on the Danish tradition for public-private partnerships and recognise the private sector as a central actor in all climate efforts.

From energy and utility, maritime, and aviation, to industry, defence, and finance the partnerships were tasked with exploring how each sector could contribute to CO_2e reductions. This needed to be done in a just way, while supporting Danish competitiveness, export, jobs, welfare, and prosperity. Collectively the 14 partnerships present more than 400 recommendations for future initiatives.

Hydrogen and hydrogen-based fuels are seen as key components in the green transi-tion and for new job creation for a new green industry. The Climate Partnership for Energy and Utility recommended targeted initiatives for scaling up a hydrogen industry and focusing on sectorial integration, for example by utilising excess heat from electrolysis in district heating.

CONTRIBUTORS

Partners in the Climate Partnership for Energy and Utility: Ørsted, Vestas, Eurowind Energy, Andel, Topsoe, HOFOR, TotalEnergies, Norlys, Nature Energy, Energinet, Green Power Denmark, Confederation of Danish Industry, Danish Chamber of Commerce, Danish Waste Association, Danish District Heating Association, Free Energy Companies, Driving Force Denmark, Danish Agriculture & Food Council, Oil Gas Denmark, Danish Forest Association, Hydrogen Denmark, Danish Metalworkers' Union, Ministry of Climate, Energy and Utilities

LOCATION

Copenhagen, Denmark

Funding for research and development

Energy Technology Development and Demonstration Programme (EUDP)
EUDP funds work by enterprises and universities, which demonstrate new green energy technologies that support Denmark's goal of a 70 percent carbon reduction by 2030 and climate neutrality by 2050.

Independent Research Fund Denmark
The Independent Research Fund Denmark gives researchers the opportunity to test their best and most original ideas and creates fertile ground for innovation.

Innovation Fund Denmark
Innovation Fund Denmark supports researchers and businesses creating value for Denmark and providing new solutions to society's biggest challenges, including new climate mitigating solutions, cleaner environment, green transport, and beyond.

Danish National Research Foundation (DNRF)
DNRF is an independent organisation established by the Danish Parliament in 1991, and funds outstanding research of the highest international level at the frontiers of all research fields to strengthen the development of Danish research.

Wind to hydrogen production for the future

The Brande Hydrogen project demonstrates that green hydrogen can be produced without using any power from the grid and serves as an essential test bed for making large-scale, cost-efficient hydrogen production a reality.

With the Brande Hydrogen project, SiemensGamesa (Siemens Energy) is taking the first steps towards the large-scale production of green hydrogen. The production facility includes a 3 MW SiemensGamesa wind turbine owned by local partner Uhre Windpower, that will produce green electricity to power a 400-kW alkaline electrolyser delivered by the Danish electrolyser manufacturing company Green Hydrogen Systems. The plant can work in an 'Island Mode', meaning that the electricity comes directly from the turbine and bypasses the grid.

In 2021, Brande Hydrogen was granted status as a test zone, exempting it from certain regulations and thereby facilitating the project's aims of developing green energy solutions, and gathering valuable knowledge and experiences that can greatly benefit the upscaling of green hydrogen production.

To secure the offtake of hydrogen produced at the plant in Brande, SiemensGamesa has partnered with the Danish company Everfuel, which is responsible for operating a network of hydrogen refuelling stations in Denmark. Everfuel distributes the green hydrogen to their stations, suppling 100 percent green and emissions-free hydrogen for the hydrogen taxi fleet operational in Copenhagen.

Photo credit: Siemens Energy

CONTRIBUTORS

SiemensGamesa, Green Hydrogen Systems, Everfuel

LOCATION

Brande, Denmark

Hydrogen production for zero-emission transport

The H2RES-project, located at the Avedøre Holme powerplant close to Copenhagen, aims to demonstrate how large-scale offshore renewable production can be utilised in green hydrogen production. Large-scale conversion of renewable energy to hydrogen can ensure both an efficient energy utilisation, sectoral integration, and reduce the level of curtailment.

In the H2RES-project, a 2 MW electrolyser will produce upwards of 1 tonne of green hydrogen daily for the transportation sector in Greater Copenhagen and the island of Zealand. The application of green hydrogen for fuel-cell-based heavy-duty transport is a way of both utilising the Danish renewable energy resources and ensuring decarbonisation in the transport sector.

H2RES will showcase innovation and green technologies for global inspiration and application. Several of the project's 'state-of-the-art' elements will show ground-breaking, scalable green solutions developed and delivered by Danish companies.

The consortium behind the H2RES project consists of Ørsted, Everfuel, DSV, Green Hydrogen Systems, Hydrogen Denmark, Nel, and the Danish TSO Energinet. H2RES has been given funding for the demonstration of this set-up for hydrogen production by EUDP.

Photo credit: Ørsted

CONTRIBUTORS

Ørsted, Everfuel, DSV, Green Hydrogen Systems, Hydrogen Denmark, Nel, and Energinet

LOCATION

Copenhagen, Denmark

Balancing grid fluctuations with green hydrogen

HyBalance is a project demonstrating the use of hydrogen in energy systems. The hydrogen is produced from water electrolysis, enabling the storage of cheap renewable electricity from wind turbines to help balance the grid. The HyBalance facility produces hydrogen by leading power from the grid into a 1.2 MW Proton Exchange Membrane (PEM) electrolyser that splits water into hydrogen and oxygen.

The consortium behind the HyBalance project consists of Hydrogen Valley, Air Liquide, Copenhagen Hydrogen Network (CHN), Hydrogenics, Centrica and Ludwig-Bölkow-Systemtechnik (LBST), with associated partners Energinet, Akzo Nobel, and Sintex.

Funded by the EU initiative Fuel Cell and Hydrogen Joint Undertaking (FCH JU), as well as the EUDP, the first soil was turned in 2017 at the site in Hobro. The plant was inaugurated in 2018, and the project was concluded in October 2020.

Project partner Air Liquide continues to operate the site and produce hydrogen to supply its customers. The hydrogen is used in both industrial processes and in transportation. One customer, the magnetic systems and powder metal components manufacture, Sintex, is supplied through a hydrogen pipeline linked directly to the facility. Another customer transports the hydrogen to Copenhagen, where it is used by hydrogen taxis, among others.

Photo credit: HyBalance

CONTRIBUTORS

Hydrogen Valley, Air Liquide, Copenhagen Hydrogen Network (CHN), Hydrogenics, Centrica and Ludwig-Bölkow-Systemtechnik (LBST), Energinet, Akzo Nobel and Sintex

LOCATION

Hobro, Denmark

World-leading electrolyser manufacturing facility

The Solid-Oxide Electrolysis Cell (SOEC) is a Topsoe electrolyser technology that enables high temperature electrolysis – a tested and proven process that facilitates large-scale green hydrogen production. In Herning, Denmark, the construction of the world's first industrial scale SOEC manufacturing facility is well under way.

Decarbonising hard-to-abate sectors requires finding viable ways of producing sustainable alternatives such as green hydrogen at scale. It is also essential to find ways of maximising energy efficiency across the value chain, from the way green hydrogen is produced, to the way it is industrially applied.

These efforts are at the centre of Topsoe's activities in Herning. Unique to this SOEC technology is the ability to utilise excess heat from the heavy industrial processes in which it is applied, making it extremely energy efficient. By coupling SOEC with excess heat-producing technologies, excess thermal energy from industry is repurposed and used to supplement the power needed to conduct the high temperature electrolysis.

The factory will have an initial manufacturing capacity of 500 MW with the potential to scale ten-fold to a 5 GW capacity. The first 500 MW of electrolysers have already been reserved by First Ammonia, and can displace almost 5 billion cubic meters of natural gas and eliminate 13 million tonnes of CO_2 emissions per year.

Photo credit: Topsoe

CONTRIBUTORS

Topsoe

LOCATION

Herning, Denmark

HYDROGEN PROJECTS IN DENMARK

Announced hydrogen and e-fuel projects

Over the past couple of years, the number of announced hydrogen projects has increased exponentially in Denmark. In 2020, the publicly announced electrolysis capacity was just around 40 MW.

In 2021, the industry really took off. Even without a national PtX strategy, a regulatory framework, or financial incentives, Danish industry players announced their plans to build 5-6 GW of hydrogen projects towards 2030.

2022 started on an even higher note with the Danish government presenting a DKK 1.25 billion hydrogen and PtX tender and agreement. The strategy pushes for production and use of green hydrogen in hard-to-abate sectors like shipping and aviation as well as heavy road transport and industry.

Currently, the total capacity of announced hydrogen amounts to 22 GW.

EXPLORE THE INTERACTIVE MAP

BRINTØ: 10 GW, GREEN HYDROGEN

HANSTHOLM HARBOUR: NOT SPECIFIED

EUROPEAN ENERGY FREDERIKSHAVN: 50 MW, GREEN METHANOL

EUROPEAN ENERGY BRØNDERSLEV: 20 MW, GREEN METHANOL

POWER2MET: 0.3 MW, GREEN METHANOL

AALBORG HARBOUR EUROPEAN ENERGY: 120 MW, GREEN METHANOL

NORTH JUTLAND POWER STATION: 350 MW, GREEN METHANOL

HYBALANCE: 1.2 MW, GREEN HYDROGEN

HFC MARINE: 0.5 MW, GREEN HYDROGEN

REDDAP: 10 MW, GREEN AMMONIA

HANDEST HEDE: 50 MW, NOT SPECIFIED

GREENHYSCALE: 400 MW, GREEN HYDROGEN

HEJRING: 35 MW, NOT SPECIFIED

GREEN HYDROGEN HUB: 1 GW, GREEN HYDROGEN

SKOVGAARD IDOMLUND: 3 GW, GREEN HYDROGEN

AARHUS HARBOUR

PTX HOLSTEBRO: 100 MW, GREEN HYDROGEN

BRANDE HYDROGEN: 0.4 MW, GREEN HYDROGEN

MEGATON: 2 GW, GREEN HYDROGEN

HYSYNERGY: 1 GW, GREEN HYDROGEN

PTX CLUSTER ZEALAND: 0.1 MW, GREEN HYDROGEN

EUROPEAN ENERGY JAMMERBUGT: 250 MW, GREEN METHANOL

DYNELECTRO, 0.03 MW, GREEN HYDROGEN

GREEN FUELS FOR DENMARK: 1.3 GW, GREEN HYDROGEN, METHANOL AND KEROSENE

GREENGUARD ESBJERG HARBOUR

H2RES: 2 MW, GREEN HYDROGEN

H2 ENERGY EUROPE: 1 GW, GREEN HYDROGEN

KRAGERUP GODS PTX: 6 MW, GREEN HYDROGEN

HØST: 1 GW, GREEN AMMONIA

EUROPEAN ENERGY MÅDE: 12 MW, GREEN HYDROGEN

STRANDMØLLEN: 0.5 MW, GREEN HYDROGEN

BIOGAS HOLSTED: 20 MW, GREEN HYDROGEN

LINDE AABENRAA HARBOUR: 100 MW, GREEN HYDROGEN

BORNHOLM BUNKER HUB

ESTECH: 5 MW, GREEN HYDROGEN

EUROPEAN ENERGY KASSØ: 50 MW, GREEN METHANOL

VORDINGBORG BIOFUEL: 240 MW, GREEN METHANOL

ARCADIA EFUELS: 254 MW, GREEN METHANOL

NAKSKOV HARBOUR: NOT SPECIFIED

EUROPEAN ENERGY SØNDERBORG: 150 MW, NOT SPECIFIED

BIOGAS CCU SØNDERBORG: NOT SPECIFIED, GREEN METHANOL

NATURE ENERGY GLANSAGER: 6 MW, GREEN HYDROGEN

CONSUMPTION HUB

ANNOUNCED PROJECT WITH LOCATION

PRODUCTION FACILITY

ANNOUNCED PROJECT PENDING LOCATION

Source: Hydrogen Denmark

CHAPTER 5

Connecting the Danish hydrogen sector to Europe

Establishing a Danish pipeline infrastructure for hydrogen will ensure a cost-effective, large-scale, and steady distribution of green hydrogen to users in both Denmark and Europe.

To ensure that the vast amounts of Danish-produced green hydrogen make it from producers to users, efficient means of transportation will be necessary. Initially, while the sector is still developing, hydrogen can be transported on trucks and ships. However, with the rapid scale-up of hydrogen projects throughout Denmark, pipeline infrastructure will be the cheapest, and for larger projects the only viable means of transportation.

Hydrogen infrastructure in Denmark
The Danish government is leading the way by working towards establishing the necessary framework for a market-based roll-out of hydrogen infrastructure. Recently, the government reached an agreement that ensures public ownership and operation of future hydrogen infrastructure in Denmark. The two state-owned gas system operators, Energinet and Evida, will build and operate the infrastructure based on the market demand for pipelines.

Energinet will connect cross-border hydrogen infrastructure, offshore infrastructure, and cross-border pipelines across Denmark to a storage facility. Evida will connect national hydrogen producers and users to the interconnected Danish hydrogen system. Building up hydrogen infrastructure can happen in part through retrofitting existing methane gas pipelines as they become redundant with the expected reduction of production and demand of methane in Denmark.

Hydrogen can solve the challenge of renewable energy storage
Hydrogen pipelines have an inherent capability to serve as storage by pressurising the pipeline. Additionally, parts of the Danish underground have unique properties which can be utilised to store hydrogen. Today, large natural underground chambers known as salt caverns are used to store pressurised methane gas. As the demand for natural gas decreases, the possibility for storing hydrogen could become relevant. Such large-scale storage would offer possibilities for flexible operation of electrolysers in coordination with electricity markets, while ensuring a stable, continuous supply of hydrogen to Danish consumers, producers of e-fuels, and neighbouring countries.

Regional interconnection of infrastructure: the key to a greener Europe
Hydrogen distribution plays a major part in ensuring a green future for Denmark as well as its neighbours. A border-crossing infrastructure along with Danish renewable energy resources will allow Denmark to export green hydrogen across Europe. The REPowerEU plan — with its target of 10 million tonnes of domestic hydrogen production and a further 10 million tonnes in imports by 2030 — highlights the need for an efficient infrastructure network across borders.

Joint Danish-German declaration of intent
The joint Danish-German declaration of intent, signed in Copenhagen on 24th March 2023, marks the first step towards a land-based cross-border pipeline for the export of Danish hydrogen to northern Germany and beyond. The pipeline could become a part of the larger 'European Hydrogen Backbone' project, which aims to connect hydrogen infrastructure throughout the EU.

At the Lille Thorup gas storage site in Denmark natural gas is currently stored in underground salt caverns. Gas Storage Denmark, the operator of the site, is exploring the conversion of sections of the existing storage facility from natural gas to hydrogen. As a start, one cavern will be repurposed. It is anticipated that two or more additional caverns will undergo repurposing to meet future supply and demand.

Photo credit: Gas Storage Denmark

CHAPTER 6

Green hydrogen derivatives for deep decarbonisation

Hydrogen is an important enabler for the production of hydrogen derivatives, such as e-methanol, e-ammonia, and e-kerosene, which can be used in industry and transport.

Green hydrogen in its pure form can be applied both in transport and industry, but there are areas where hydrogen is not suited for direct use. In these areas, green hydrogen can be utilised as a feedstock to produce products that can expand its application.

Energy carriers for hard-to-abate sectors
Green hydrogen can be converted or synthesised into other energy carriers or hydrogen-based products when refined with either nitrogen for e-ammonia, or carbon dioxide (CO_2) for e-methanol and e-kerosene.

Green ammonia
Green ammonia or e-ammonia is produced by combining green hydrogen with nitrogen captured from the atmosphere in a reactor, resulting in the synthesis of carbon-free ammonia. The production typically takes place through a chemical process known as Haber-Bosch. Green ammonia has various applications, such as a green fuel for shipping and a building block for fertilisers.

Green methanol
Green methanol or e-methanol is made from a combination of hydrogen and CO_2. Methanol offers storage benefits as it does not need cooling or storage under pressure. It is for example easily stored onboard ships.

Sustainable Aviation Fuel (SAF)
Sustainable Aviation Fuel (SAF) is almost exclusively produced in the form of kerosene. The production of e-kerosene, which requires CO_2 and green hydrogen as feedstocks, generally involves two main paths for converting them into aviation fuel: Fischer-Tropsch (FT) and Methanol (MeOH). E-kerosene is seen as a 'drop-in ready' fuel, as it can be blended directly with fossil jet fuel. It can, therefore, be used in the aviation industry without any major overhaul of infrastructure. Green kerosene stands to provide a more scalable source of renewable energy compared to biomass feedstocks used for biofuels.

The utilisation of CO_2
The use of CO_2 in the production of e-fuels addresses both environmental concerns and the demand for green fuels. The CO_2 can be captured directly from the atmosphere, from various industrial sources, such as power plants or as a biproduct in biogas production. It can then be combined with hydrogen. This process is called carbon capture and utilisation (CCU) and contributes to the reduction of greenhouse gas emissions and the transition towards a greener economy.

The demand for fuels and products based on CO_2 is growing across various sectors. In line with the global push for more sustainable solutions, the European Union is implementing regulations that will gradually require the use of biogeni CO_2 over time. This is a resource that Denmark is well geared to supply due to its large biogas production through the combustion of biomass and waste products.

Common hydrogen derivative production processes — such as Fischer-Tropsch, which produces methanol from hydrogen and carbon monoxide, or Haber-Bosch which produces ammonia from hydrogen and nitrogen — carry names from the scientists who first described them a century ago. This is an old and well-established industry about to be modernised.

Photo credit: Ørsted

The world's biggest commercial e-methanol plant

Through the world's first large-scale commercial green methanol plant, Danish developer European Energy will convert renewable electricity from solar panels into green methanol, aiming to deliver 32,000-40,000 metric tonnes of e-methanol in 2024.

The plant will utilise Siemens Energy electrolyser technology to produce green hydrogen for further synthesis with biogenic CO_2 sourced from a local biogas plant to produce e-methanol.

The facility will be supplied with power from the adjacent 300 MW solar farm owned by European Energy. It represents the first step in bringing e-methanol to market at scale to support the maritime and road transportation industries, as well as the chemical sector.

Half of the total plant output — 16,000 metric tonnes per annum — will be delivered to Danish global shipping company A.P. Moller-Maersk to fuel the company's first container ship capable of operating on green methanol.

In addition, Circle K, LEGO Group, and Novo Nordisk have signed offtake agreements. The LEGO Group and Novo Nordisk will utilise the methanol in the production of more sustainable plastic, while Circle K will make it available for road transport.

CONTRIBUTORS

European Energy, Siemens Energy, Maersk, LEGO, Novo Nordisk, Circle K

LOCATION

Denmark, Kassø

VISIT AN ANIMATED VERSION OF THE PLANT HERE

A path to decarbonise agriculture

Green Fertilizer Denmark, a consortium committed to advancing climate-friendly fertiliser production, is set to establish a state-of-the-art facility in Denmark. The primary objective is to enable the production of climate-friendly fertiliser based on green ammonia.

The green ammonia will be sourced from the Høst PtX Esbjerg plant (HØST), which is currently under development. The plant will leverage electrolysis technology on a gigawatt-scale to generate industrial-grade green ammonia. The plant will operate flexibly, adapting to the available power production from renewables.

The project will employ the conventional Haber-Bosch process, which is widely used in the industrial production of ammonia. The process involves the reaction of nitrogen with hydrogen, facilitated by a catalyst, under high temperature and pressure to yield ammonia.

The green ammonia supplied by the HØST project will have a carbon footprint amounting to a mere 10 percent of conventional ammonia. In this way, HØST will play a key role in the ambitious initiative by strengthening security of supply and contributing to the transition towards more environmentally-friendly practices.

CONTRIBUTORS

CIP, DLG, Danish Agro, Arla, and Danish Crown

LOCATION

Esbjerg, Denmark

Photo credit: Topsoe

Revolutionising green methanol production from biogas

Global methanol production is generally produced from natural gas or coal. Green methanol (or bio-methanol) can be produced via biological, thermo-chemical, or electrofuel pathways.

Danish projects are examining the production of green methanol based on biogas. The applied technology involves splitting biogas into CO_2 and hydrogen (H_2) using an electrically-driven catalytic reactor, with additional energy injection of hydrogen from electrolysis to convert the products into methanol.

The electrical reactor offers a ground-breaking approach to energy supply and revolutionises traditional methods by directly harnessing electrical power. Topsoe's eREACT™ technology enables capturing more than 99% of the CO_2 from the syngas generation process.

A pilot facility has been started with the capacity to produce synthesis gas of about 2000 kg per day. The experience and the technology developed can be translated into an industrial system to make the technology cost-effective at a scale suited to a large biogas plant. The results of the pilot plant operation will be forming the basis for the design and commercialisation for industrial-scale electrified reactors.

CONTRIBUTORS

Topsoe

LOCATION

Foulum, Denmark

The world’s first dynamic green ammonia plant

Green ammonia is seen as a promising sustainable alternative to fossil fuels, especially for international shipping which contributes 2 percent of global CO_2 emissions. However, the cost of green ammonia is higher than that of ammonia from fossil fuels.

To make green ammonia more attractive, a partnership of Danish industry leaders is working on the REDDAP-project, which aims to create a dynamic green ammonia plant at an industrial scale.

The plant will use renewable energy from wind turbines and solar panels to produce hydrogen, which will then be processed into ammonia. It is expected to be operational in 2023 and produce over 5,000 tonnes of green ammonia annually, preventing 8,200 tonnes of CO_2 emissions per year.

The project will provide valuable knowledge and operational experience to scale up dynamic ammonia plants in the future, and serve as a lighthouse project for larger projects. The project also has the potential to generate economic benefits by producing new markets for green ammonia, increasing demand for wind turbines, and creating jobs in the Danish economy.

CONTRIBUTORS

Topsoe, Vestas, Skovgaard Invest, EUPD

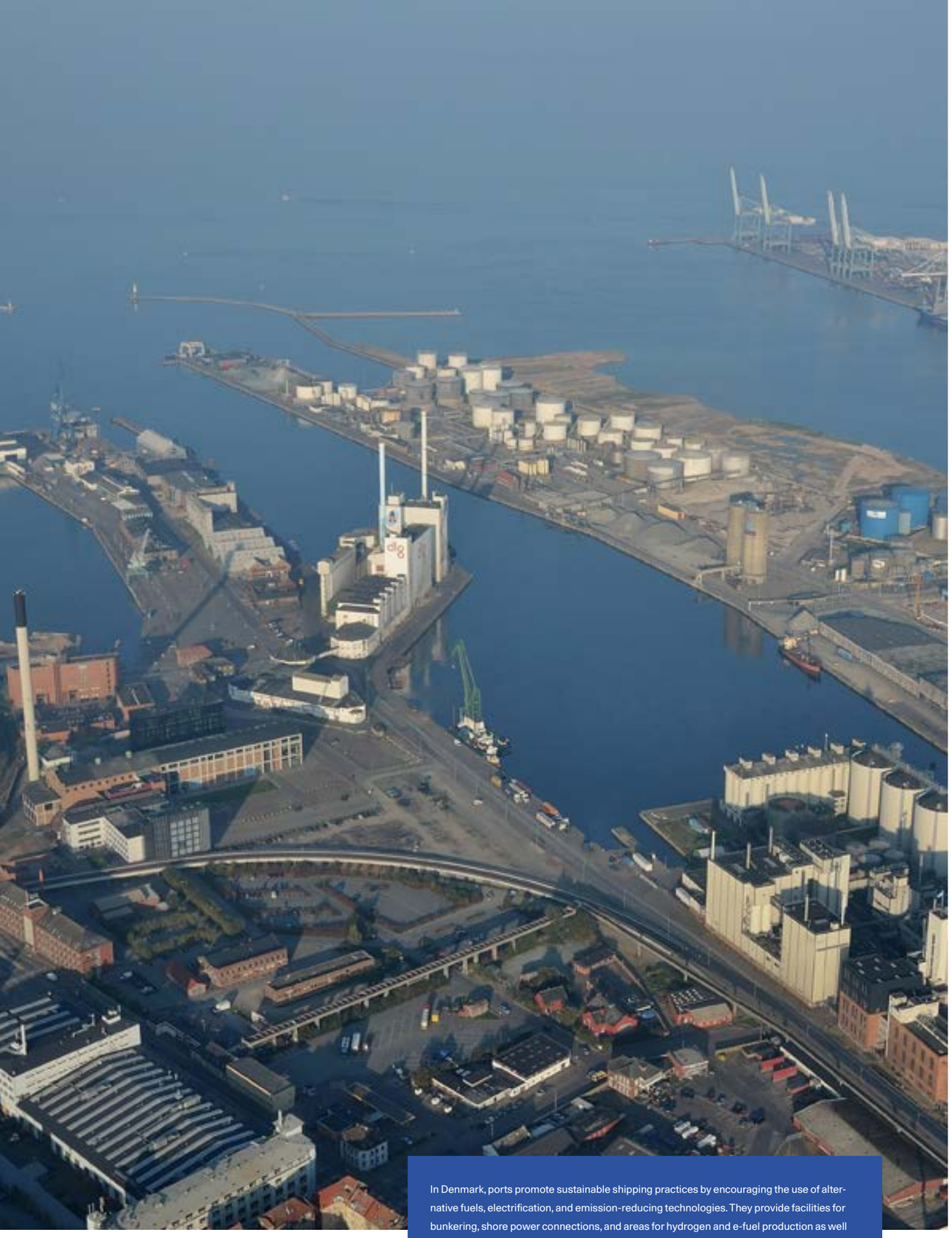
LOCATION

Lemvig, Denmark

CHAPTER 7

Utilising green hydrogen across sectors

Green hydrogen enables transport and industry sectors to greatly reduce their carbon footprint, paving the path to a more sustainable future.



In Denmark, ports promote sustainable shipping practices by encouraging the use of alternative fuels, electrification, and emission-reducing technologies. They provide facilities for bunkering, shore power connections, and areas for hydrogen and e-fuel production as well as CO2 storage.

Green hydrogen and its derivatives, such as e-methanol, e-ammonia, and e-kerosene, offer promising alternatives to traditional fossil fuels across many sectors. In agriculture, green ammonia can be used as fertiliser, lowering the carbon footprint of food production. In industry, green hydrogen can serve as a versatile energy source, replacing carbon-intensive processes with greener alternatives. In aviation and shipping, e-fuels can power engines to provide zero-emission mobility.

Visionaries within fuel cells
In Denmark, visionary companies are developing and manufacturing alternatives to combustion engines and diesel generators, demonstrating remarkable expertise both onshore and offshore. Denmark's competences within fuel cells are driven by a combination of R&D, technical expertise, and a strong focus on sustainability.

Capabilities range from Proton Exchange Membrane (PEM) fuel cells and methanol fuel cell systems, to high-temperature membrane solutions. The solutions can be applied to both mobile units for use in transportation and in a stationary state for industrial processes.

Technological strengths of the Danish maritime industry
Denmark has a strong maritime heritage. Combined with its commitment to renewable energy, Denmark is an ideal hub for offshore technology and innovation. In fact, the world's first two-stroke engine capable of running on methanol was designed in Denmark.

New developments in the industry go hand in hand with a great understanding of both ships and engines. This becomes important when retrofitting ships to run on methanol instead of diesel where the energy density is lower. Danish naval equipment manufacturers have processes and solutions which enable shipowners to meet regulatory requirements like the Carbon Intensity Indicator (CII) and the Energy Efficiency Existing Ship Index (EEXI).

Energy efficiency equals cost savings
Due to the energy loss in e-fuel production, maximising energy efficiency becomes important. To achieve energy efficiency, various measures can be implemented. In ships, for example, technological improvements like advanced propulsion and cooling systems, as well as optimised ventilation, can contribute to energy savings. Operational strategies like adjusted sailing speed, route planning, port waiting time, and space utilisation can also reduce energy use.

Energy efficiency plays a critical role in unlocking the full potential of e-fuels, as it directly translates into cost savings. Reducing the amount of energy needed to produce, store, and transport e-fuels minimises their production costs, which is crucial for promoting widespread adoption of e-fuels in industry and transport, and making them competitive alternatives to conventional fossil fuels.

Green transition of domestic aviation

The Danish government has an ambition to establish one green domestic flight route by 2025 and achieve completely green domestic air travel no later than 2030.

In the city of Vordingborg, companies have come together to make this a reality. Arcadia eFuels is working to achieve the goal of producing 80 million litres of eSAF fuel, or e-kerosene, a year by 2026. Since Danish domestic aviation uses around 40 million litres of fuel a year, Arcadia eFuels has the potential to cover the Danish domestic jet fuel consumption twice over.

The Arcadia eFuel project in Vordingborg will utilise renewable energy to produce green hydrogen. It will source biogenic CO_2 from a local biogas plant, built by Green2X, from where the CO_2 will be captured and synthesised with the hydrogen, ultimately making e-kerosene. The first e-kerosene is expected to be produced by 2026.

CONTRIBUTORS

Arcadia eFuel, Green 2X, Biofuel Technology, Kinetic Biofuel

LOCATION

Vordingborg, Denmark

A path to decarbonisation of shipping

The merchant marine sector consists of container carriers, tankers, and bulk carriers. It accounts for most of the shipping sector's CO_2 emissions.

The International Maritime Organisation (IMO), which, regulates the sector, significantly strengthened its greenhouse gas reduction targets in July 2023. The strategy is to reach net-zero emissions from international shipping by around 2050, with interim targets of 20-30 percent by 2030 and 70-80 percent by 2040.

At present, there are no huge technological blockers to these ambitions. Merchant marine ships have one thing in common: they are all propelled by a two-stroke engine, and the world's first methanol two-stroke engine has been in operation since 2016. Designed in Copenhagen, it is now implemented at engine builders across the world, particularly in Korea, China, and Japan.

The same team is currently designing the world's largest methanol engine suitable for container carriers and other very large merchant marine ships, which is expected to be sailing the seas in January 2024. When fed with sustainably produced methanol, this engine reduces CO_2 emissions by more than 95 percent compared to an engine running on heavy fuel oil.

Photo credit: MAN Energy Solution

CONTRIBUTORS

MAN Energy Solutions

LOCATION

The solution was developed, engineered, and tested in Copenhagen, Denmark.

Research centre will develop zero-carbon shipping

Today, the maritime transportation sector almost exclusively relies on fossil fuels. Addressing the climate impacts of the industry requires unprecedented collaboration across sectors, industries, and geographies.

Headquartered in Copenhagen and established in 2020 with funding from the A.P. Moller Foundation, the Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping (MMMCZCS) is an independent, not-for-profit research and development centre that works with companies, governments, and organisations from across the globe to decarbonise the maritime industry.

The centre delivers independent analyses on how the green shipping transition is progressing and clear, data-driven recommendations for accelerating maritime decarbonisation. Drawing on knowledge and data from partners across the maritime value chain, the centre is working to mature solutions for zero-carbon shipping, from fuel production to onboard solutions, regulations, and financing.

You can read more about the centre's work and download its latest publications at www.zerocarbonshipping.com

Photo credit: Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping

CONTRIBUTORS

Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping

LOCATION

Copenhagen, Denmark

The world's first net-zero fueled container vessel

With shipping accounting for around 3 percent of energy-related CO_2 emissions, the potential and impact of decarbonising international shipping is great. The Danish shipping industry has set ambitious targets for the green transition, aiming for all Danish-operated ships to be CO_2-neutral by 2050, and for 5 percent of ships to be ready to use e-fuels by 2030.

Already in 2023, the global shipping company, Maersk, will start operating the world's first container vessel sailing on green fuel. The launch is part of Maersk plans to achieve net-zero greenhouse gas emissions across its business by 2040. The goal encompasses both direct emissions from its vessels and indirect emissions from its supply chain, including container handling and transport. Committed to reducing its carbon footprint, Maersk has placed a total order of 19 green methanol vessels.

The vessels will operate on green fuel, utilising green methanol produced from renewable sources. By introducing the vessels, Maersk sets a new benchmark for environmentally responsible shipping, inspiring the industry to embrace greener practices and paving the way towards a more sustainable future.

Photo credit: Maersk

CONTRIBUTORS

Maersk

LOCATION

Global

CHAPTER 8

Creating value across the energy sector

Green hydrogen and hydrogen derivatives can support the integration of renewables into the energy system, create value for electricity supply, provide excess heat for district heating and industry, and produce green fuels for transport and industry.

The Danish energy model is characterised by a holistic view of energy planning. Combined heat and power generation has been a key component in the development of the Danish energy sector, creating a cost-efficient heat and power supply. Today, more than 60 percent of Danish households are heated by the district heating network, which has been one of the key drivers of reductions in gross energy consumption and CO_2 emissions from the energy sector.

Integrating hydrogen in the energy system
Hydrogen and hydrogen derivatives can work alongside electricity, heating, and gas systems in an integrated energy system. Large, flexible electrolyser facilities are excellent partners for large-scale renewable electricity production, as they can balance their consumption depending on the availability of renewable electricity in the grid.

Provided that electrolysis plants are placed close to renewable energy production sites like wind farms, they could potentially reduce or postpone the need for building new power lines and support integration of more renewable electricity in the system, bolstering security of supply.

Utilising excess heat
The excess heat generated from hydrogen production holds great potential for cheap, green district heating in the future. It can be used in local district heating systems, or as process heat in the value chain and in industrial applications.

Its value depends on its temperature, its fluctuating availability, and the distance between the hydrogen facility and the district heating net. If the temperature is sufficiently high, the heat can be used directly. Otherwise, a heat pump is required to raise the temperature.

The close location of electrolyser facilities to district heating grid or industries is a prerequisite for utilising hydrogen plant waste heat. This introduces a trade-off between the location of large sources of renewable energy and areas with a large district heating system. In many cases these locations overlap, as in Esbjerg, Denmark's fifth-largest city on the west coast of Jutland. Here, access to wind power from the North Sea coincides with a large district heating system, allowing utilisation of green excess heat for Esbjerg and Varde citizens.

A new water ecosystem
Electrolysis requires large amounts of high-purity water. To ensure a sufficient quality, the water source needs dedicated purification systems, even if the source is drinking water. This means that sources other than drinking water can be utilised, and many hydrogen developers are investigating the use of alternatives including wastewater and other types of water not suited for direct consumption. This means that electrolysers can contribute to a new water ecosystem, where they can offtake low quality water from other sectors, including wastewater from private households.

Green hydrogen is often labelled as the Swiss army knife of energy transition. Hydrogen can produce green fuels for transport and industry, create value for electricity supply and the electricity grid, and deliver heat for district heating – provided the input is green energy.

Photo credit: GreenLab

Photo credit: Everfuel

Utilising electrolyser heat in the heating network

In Fredericia, Denmark, the HySynergy project is revolutionising the energy landscape through an innovative collaboration between the green hydrogen producer Everfuel and the local district heating company TVIS. The project aims to harness the excess heat generated from Everfuel's green hydrogen production and supply it to local households.

To achieve this, TVIS has established a 1.2 km transmission line connecting their district heating network to Everfuel's 20 MW electrolysis plant. This enables the transfer of excess heat from the hydrogen production, which would otherwise be wasted, to be utilised in district heating.

The project is a win-win scenario for both parties. By repurposing the heat, the energy efficiency of Everfuel's hydrogen facility is significantly improved, increasing it to the highest standard of approx. 87 percent plant efficiency. TVIS also benefits by providing clean heating solutions to 1,800 households in the area, and helping local businesses reduce their carbon footprint. The collaboration demonstrates the power of synergistic partnerships in driving the energy transition.

CONTRIBUTORS

Everfuel, TVIS, Rambøll

LOCATION

Fredericia, Denmark

Photo credit: GreenLab

GreenLab: The industrial park of the future

GreenLab is a green and circular industrial park located in a rural area by the city of Skive, Denmark. Here, the focus is on finding new ways to generate, store, and share energy. GreenLab connects industrial production facilities to renewable energy from its own solar and wind park via a direct connection. It also has a unique network of energy and data connecting the companies in the industrial park. This so-called SymbiosisiNet allows companies to share their excess resources with each other, so one company's waste becomes another company's energy source. The integration of sectors within the industry cluster shows the way for new energy systems.

GreenLab's green industrial park also hosts GreenHyScale, an EU-funded 100 MW green hydrogen project. This project is building an electrolyser from 6 MW modules using a design that can be replicated across the world, thus paving the way for global green hydrogen production. The green hydrogen facility will be fully integrated with GreenLab's SymbiosisNet to utilise the hydrogen in the green industrial cluster, and the excess heat from the production will be utilised in district heating locally.

CONTRIBUTORS

Green Hydrogen Systems, Euroquality, Energy Cluster Denmark, Imperial College London, Lhyfe, Quantafuel, Everfuel, Equinor, DTU, Siemens Gamesa, Evida, Vestjyllands Andel, Organic Fuel Technology

LOCATION

Skive, Denmark

CHAPTER 9

Skills and support: ensuring public acceptance

The green transition and the fundamental recalibration of both energy systems and society make great demands on citizens.

The growth of a hydrogen industry brings entirely new requirements for workforce development and safety. To ensure that the skills of the workforce keep pace with demands of the labour market, new initiatives have been introduced to encourage lifelong learning, as well as re- and upskilling in Denmark.

Measures to foster lifelong learning
Firstly, it is important that young people are introduced to educational opportunities within green industries and technologies. The green transition requires that important skills are integrated into the Danish education system. This is already a focus area for Danish higher education institutions. A recent analysis shows that 65 percent of Danish higher education programmes provide students with important skills for the green transition, including those critical for producing hydrogen.

Furthermore, Denmark has a well-established adult education, training and lifelong learning system. Reskilling and upskilling the workforce helps to ensure that employees possess the skills that are in demand in the labour market, and to enable people to make career changes during their working life.

Safety as standard
The rise of an entirely new industry requires safety and standardisation across all areas of implementation. Safety is a Danish stronghold, and both public authorities and private companies alike work hard to secure the safe industrywide application of new hydrogen technologies, certification, and standardisation. This is a testament to the Danish focus on health and safety in industrial development in both a Danish and global context.

Community support for societal changes
As the green transition offers new opportunities for all citizens it also requires cooperation and support from the public. Climate and energy rank highly among the political priorities of the population, which means that there is general support for new, green initiatives. Even so, securing public acceptance of the concrete measures that will bring about the green transition is imperative for its success. This is why public consultations, town hall meetings with local communities, and constructive dialogues are central to the expansion of big infrastructure projects like wind farms. These kinds of community contracts ensure that local communities are heard and can impact project develop-ments. Transparent communication, green responsibility, and creating local beneficial growth are at the core of the transitional shift.

Learn more about Danish energy solutions, find more cases from around the world and connect with Danish experts:

www.stateofgreen.com

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Ministry of Environment of Denmark

Ministry of Foreign Affairs of Denmark