Decarbonising society with Power-to-X

A path to scaling production and uptake of renewable hydrogen and sustainable e-fuels

Ørsted

> **“ Renewable hydrogen and e-fuels are of critical importance to curb climate change. Without them, it will be impossible to achieve full decarbonisation — and the clock is ticking.**
>
> **Anders Christian Nordstrøm**
> Vice President, Hydrogen, Ørsted

Leveraging renewable hydrogen and power-to-X to achieve climate goals

In the quest to decarbonise the global economy, fossil fuel use in industry and transportation is one of the biggest obstacles. These two sectors account for more than a third of global greenhouse gas (GHG) emissions; without a rapid re-imagining of their feedstocks, it will be impossible to constrain global temperature increase to less than 1.5°C.

Over the past decade, significant cost reductions in renewable energy has enabled widespread penetration of power generation by renewable energy, which in turn is enabling decarbonisation of certain specific applications. For example, in cars and light transport battery-electric drives are replacing the internal combustion engine. In buildings, high-efficiency electric heat pumps are delivering cleaner and less costly space heating.

However, while these gains are valuable, the hard work of deep decarbonisation remains. Direct electrification is, quite simply, not feasible for many sectors such as heavy-duty road transport, deep-sea shipping and aviation.

And yet, large-scale and low-cost generation from wind and solar has enabled new pathways to decarbonisation. Renewable electrons can now be converted, through electrolysis, to renewable molecules in the form of hydrogen. Hydrogen, today almost exclusively produced from fossil fuels, is an important feedstock in industrial processes and, in its renewable variant, is increasingly attractive for powering fuel cell electric vehicles, such as buses, lorries and trains.

Renewable hydrogen can also be used to produce synthetic fuel ('e-fuels'), which can replace its fossil-derived counterpart across many applications, including aviation and deep-sea shipping.

At Ørsted, our vision is a world running entirely on green energy. Since commissioning the world's first offshore wind farm in 1991, we have been leaders in the quest to make this vast resource cost-competitive.

Now, building on renewable energy production from offshore wind, onshore wind and solar, we see a path to establish and scale up production of renewable hydrogen and e-fuels. In this way, power-to-X technologies can deliver 'indirect electrification'. And a good starting point is by converting existing hydrogen demand from heavy industry to demand for renewable hydrogen.

The 'renewable hydrogen economy' is not an end in itself. It is means to an end. We believe renewable hydrogen and e-fuels will be of critical importance to curb climate change. Without them, it will be impossible to achieve full decarbonisation – and the clock is ticking. From experience, we know that developing and deploying new technology comes with many unknowns and requires considerable, focused investment. But the only thing we know for certain is, if no-one tries, progress will not happen.

Renewable hydrogen and power-to-X face a unique challenge on their journey to commercialisation, as both supply and demand need to be developed in parallel. This entails uncertainty and hence makes it more difficult for developers to invest. To speed up deployment of power-to-X, we must overcome the 'chicken-and-egg' dilemma through industrial leadership, government support and regulation, and public-private partnerships.

Ultimately, societal demand for decarbonisation will be the driver for development of power-to-X technologies. To deliver this, policymakers – in Europe and around the world – must support this development by incentivising the shift to renewable hydrogen and e-fuels to help create and increase demand, by supporting the development of technology at scale, and by removing regulatory hurdles for power-to-X.

With this paper, Ørsted is presenting our vision for the scale-up and cost-out journey of renewable hydrogen and power- to-X technologies, to help inspire even greater efforts in developing the renewable feedstocks and fuels of tomorrow.

Anders Christian Nordstrøm
Vice President, Hydrogen, Ørsted

The “renewable molecule”: the potential of hydrogen from renewable energy

Renewable hydrogen and e-fuels at scale are critical to fully decarbonising our society. They are the only known route to decarbonizing large parts of our heavy industry and transportation which is essential if we are to constrain global temperature increase to 1.5°C by end-century.

Hydrogen is not a new fuel source: its characteristics as a potent and light energy carrier are well-established. Even before the first 19th century power grids, hydrogen was used for small scale lighting and early aeronautics.

Today, hydrogen is used widely as a feedstock for ammonia production (mainly for fertilizers), for refining and for other chemical processes. In 2018, the global market for pure hydrogen was app. 74Mt.[1] However, with future demand for hydrogen and hydrogen-based e-fuels to replace fossils, this is projected to increase by a factor of 10 or more towards 2050.[2]

Current production of hydrogen is emissions-intensive as it derives from fossil fuels. Steam reforming of natural gas, for example, involves producing hydrogen from methane while the carbon is released as CO_2. At present, fossil hydrogen production alone accounts for about 6% of global natural gas and 2% of global coal consumption, and approx. 2% of all global energy related GHG emissions is from production of hydrogen.

Renewable hydrogen is completely carbon free. It is produced by using renewable energy to split water into its elements in an electrolyser, with no GHG emissions as a byproduct.

Therefore, it can be swapped on a like-for-like basis with fossil hydrogen to deliver large emission reductions in chemical and other heavy industries in the immediate future.

Hydrogen has low volumetric energy density which makes it a challenging energy carrier for transportation – but in combination with either carbon or nitrogen, it can form e-fuels.

The density of e-fuels make them more suited to decarbonizing heavy transport – but how can they be made?

Renewable hydrogen, combined with carbon produces renewable methanol or kerosene. Sustainable, i.e. non-fossil, carbon can be sourced through carbon capture from a high concentration renewable source e.g. from gasification or burning of sustainably sourced biomass, bio-waste or biogas production. It could also be obtained from atmospheric CO_2 through direct air capture, but this technology is still experimental and too costly in the near-term future.

Combined with nitrogen, which makes up about 78% of our atmosphere, renewable hydrogen can react to form renewable ammonia. These energy carriers offer significantly higher volumetric energy density compared to pure hydrogen.

As costs are reduced, synthesised e-fuels is a possible pathway for net-zero emissions deep-sea shipping and aviation, based on engines and fuel infrastructure very similar to what is used today.

E-fuels are less energy efficient than hydrogen which, in turn, is less energy efficient than electrification: so decarbonization pathways must focus on electrification first, renewable hydrogen second and thirdly using e-fuels in those sectors which cannot be directly electrified.

[1] IEA 2019, The Future of Hydrogen

[2] Energy Transitions Commission 2020, Making Mission Possible: Delivering a Net-Zero Economy

Examples of hydrogen production methods

There are many methods for producing hydrogen at industrial scale. Most common today is steam reforming of fossil feedstocks, where natural gas reacts with steam under high temperatures and pressure, ultimately yielding hydrogen and CO_2.

Another way is through high-temperature pyrolysis in the absence of oxygen, splitting hydrocarbons, e.g. methane, to produce hydrogen and solid carbon.

Hydrogen can also be produced through electrolysis, where direct electrical current is used to split water into its elements, hydrogen and oxygen.

Renewable hydrogen – where energy for the electrolysis is from renewable generation, e.g. from wind or solar, comes with no CO_2 emissions (0 kg CO_2e per kg hydrogen). Renewable energy can be sourced directly from onsite generation, by co-locating electrolysis with renewable assets. Or it can be sourced from the grid, provided it can be assured the energy used is sourced from renewables.

Hydrogen from electrolysis makes up some 2% of worldwide hydrogen supply. As it typically takes about 50 kWh of power to produce 1 kg of hydrogen, the carbon footprint is very dependent on the electricity used. Coal-based power, for instance, would result in extremely carbon intensive hydrogen. Using an average European electricity mix would emit app. 14 kg CO_2e per kg hydrogen, whereas electrolysis powered by renewable energy comes with no direct emissions.[3]

Steam reforming of natural gas is the most common production method for hydrogen, making up approx. 75% of global hydrogen supply. As the process is both highly energy intensive, and as fossil natural gas is used as feedstock, steam reforming of natural gas is estimated to emit 9 kg CO_2e per kg hydrogen.[4]

Coal gasification today contributes with approx. 23% of global hydrogen production. As with steam methane reforming, this is a highly carbon-intensive method, estimated at around 19 kg CO_2e per kg hydrogen.[5]

Fossil hydrogen with carbon capture and storage (CCS) e.g. steam reforming with CCS, is proposed as a future bridging technology for low carbon hydrogen at scale. CCS can generally be expected to catch up to 85% of CO_2 emissions, with 1.5-4 kg CO_2e released to the atmosphere per kg hydrogen, not indcluding fugtive emissions of methane in the supply chain.[6] CCS is still an immature technology at scale, and the cost advantage to other technologies is unproven. Furthermore, as steam methane reforming still requires natual gas, in a European context, large investments in CCS would uphold or even increase import dependence.

Pyrolysis is the process of breaking hydrocarbons apart using high temperature and pressure in a non-oxidative environment. This can be done with e.g. fossil methane or with biomass, yielding hydrogen and solid carbon. Pyrolysis adds the benefit of allowing further use of both carbon and hydrogen from the feedstock. Even so, as the process is energy intensive and comes with fugitive emissions, pyrolysis of methane is estimated to emit about 4 kg CO_2e. per kg hydrogen.[7]

3, 4. EU Commission, Hydrogen Strategy, 2020.

5. IEA, The Future of Hydrogen, 2019.

6. At 60% (for CCS only at process stream) and 85% (for both process and energy stream) capture rates. Cf C.E. Delft, 2019.

7. Parkinson et. al., Levelized cost of CO_2 mitigation from hydrogen, 2019 production routes

Decarbonising industry and transport with renewable hydrogen

There are at least three immediate uses for renewable hydrogen in the short term in the 'difficult-to-decarbonise' sectors of industry and transportation, with many more to come.

1. Replacing all uses of fossil based hydrogen with renewable hydrogen
Chemical industries and refineries are the right starting point for developing renewable hydrogen demand as they already have the hydrogen demand and virtually all necessary infrastructure is already in place. In 2018, the global market for pure hydrogen was app. 74Mt. Incentivising these industries to use renewable hydrogen in place of fossil-based sources will have immediate impact on GHG emissions.

At the same time, industrial applications where hydrogen today is not used, e.g. steel manufacturers, could be developed in parallel, which can grow in tandem with the scaling up of hydrogen production and industrialising electrolysers – and we make some suggestions as to how policymakers could incentivize this transfer on pp. 12-13. The resulting reduction in costs of renewable hydrogen would in turn incentivize additional industrial applications where hydrogen today is not used, creating new industrial centres, located near large sources of renewable energy and hydrogen production.

2. In medium to heavy-duty land transport, using renewable hydrogen in fuel cells
Diesel remains the primary fuel for the vast majority of medium- to heavy-duty land transport, e.g. buses, trucks and some trains and taxis. In many applications, direct electrification is not fit for purpose as energy requirements exceed the practical limits for batteries or frequent and time-consuming recharging is required, making batteries impractical.

Hydrogen-powered fuel cells offer a viable zero-carbon alternative to transport applications where direct electrification is unfeasible. Moreover, hydrogen fuel cell vehicles, as with battery-electric vehicles, have zero tail pipe emissions, which can significantly improve air quality.

3. In aviation and shipping, using e-fuels based on renewable hydrogen
The need to move loads over long distances leaves aviation and deep-sea cargo shipping reliant on energy-dense fuels, which today are almost exclusively oil-based.

Pure hydrogen is not an efficient solution here – but e-fuels derived from renewable hydrogen, are a possible pathway to decarbonisation. For aviation, e-kerosene that is produced from renewable hydrogen and carbon from sustainable CO_2 seems to be the only viable option at scale. For deep-sea shipping, different types of e-fuels may be the solution, and further feasibility studies and demonstration is required.

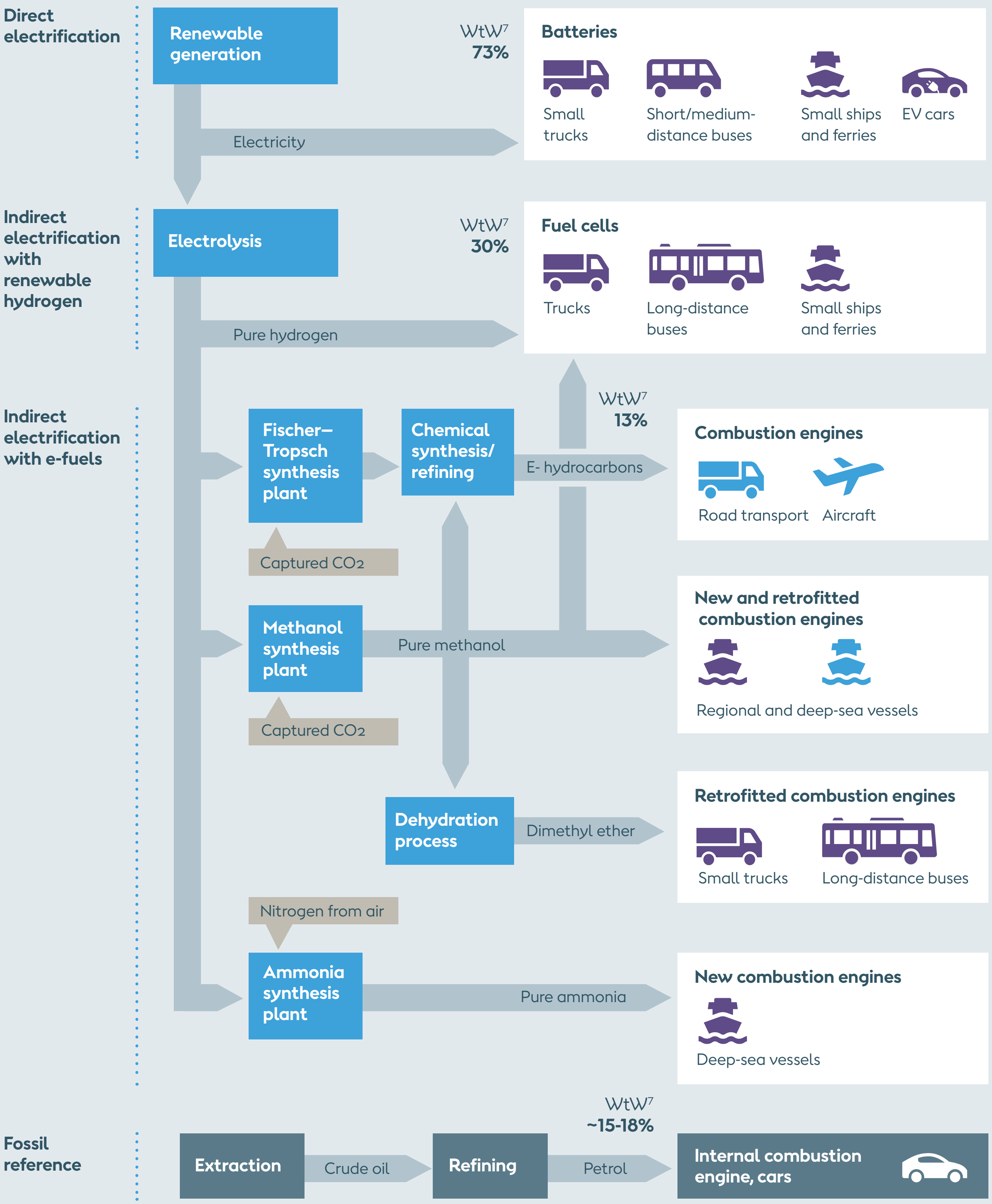
Industry and heavy transport are some of the hardest sectors to decarbonise. However, for the global economy to reach net-zero greenhouse gas emissions by 2050 (as required to stay below 1.5°C by end of this century), investment must begin today in the development of these green alternatives.

Policymakers, industry, and consumers and voters all have their part to play: while renewable fuels are significantly more expensive today than the fossil based alternative, to the end consumer, costs of e.g. sustainable shipment of a pair of shoes or an airline ticket using renewable fuels are relatively low. In fact, with ever growing consumer demand for sustainable options, green fuels can soon become a competitive advantage.

Routes for renewable energy in transport

● Maintain existing hardware

● New hardware required



Direct electrification

Renewable generation

Electricity

WtW[7] 73%

Batteries

Small trucks

Short/medium-distance buses

Small ships and ferries

EV cars

Indirect electrification with renewable hydrogen

Electrolysis

Pure hydrogen

WtW[7] 30%

Fuel cells

Trucks

Long-distance buses

Small ships and ferries

Indirect electrification with e-fuels

Fischer–Tropsch synthesis plant

Captured CO2

Chemical synthesis/ refining

E- hydrocarbons

WtW[7] 13%

Combustion engines

Road transport

Aircraft

Methanol synthesis plant

Captured CO2

Pure methanol

New and retrofitted combustion engines

Regional and deep-sea vessels

Dehydration process

Dimethyl ether

Retrofitted combustion engines

Small trucks

Long-distance buses

Nitrogen from air

Ammonia synthesis plant

Pure ammonia

New combustion engines

Deep-sea vessels

Fossil reference

Extraction

Crude oil

Refining

Petrol

WtW[7] ~15-18%

Internal combustion engine, cars

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[7] Well-to-wheel (WtW) efficiencies. 77% efficiency of battery-electric drivetrain based on 95% grid efficiency, ~85% conversion and charge/discharge efficiency and 95% engine efficiency. 30% hydrogen fuel cell drivetrain efficiency based on 78% electrolysis efficiency, 78% efficiency for transport, storage and distribution of hydrogen, 54% fuel cell efficiency and 95% engine efficiency. 13% internal combustion engine drivetrain efficiency based on 78% electrolysis efficiency, 56% CO2 capture and synthetisation efficiency and 30% engine efficiency. Assumptions from T&E 'Roadmap to decarbonising European cars', 2018.

Strategic development of power-to-X infrastructure benefits the energy system

The new renewable hydrogen producers delivering hydrogen to industry and transport will be a new class of large-scale consumers connected to the power grid – and will have fundamentally different characteristics than current demand. The processes to produce e-fuels, especially electrolysis, are very electricity-intensive. In fact, power-to-X facilities connected directly to the transmission grid are likely to become some of the largest power consumers.

Unlike the majority of existing power consumers whose consumption is relatively inelastic, renewable hydrogen and power-to-X is able to deliver demand-side flexibility, ramping power consumption up or down depending on electricity price signals.

As industrialisation and innovation drive down the capital costs of renewable hydrogen production over the next decade, large-scale electrolysis is expected to be able to operate at lower overall capacity factors, while retaining a positive business case.

This allows them to optimise the operation of electrolysers to take advantage of the lowest possible electricity prices. It also enables power-to-X facilities to support grid operations through ramping, idling and sale of flexibility. In time, and with the right incentives, gigawatt-scale electrolysers and power-to-X facilities have the potential to contribute to an optimised operation of the power transmission grid.

These considerations raise questions of where, when and under what conditions to connect power-to-X facilities to the grid. While areas with high penetration of renewables and low cost of consuming power at large scale (such as in North West Europe) are a logical choice, many factors will come into play in decision-making.

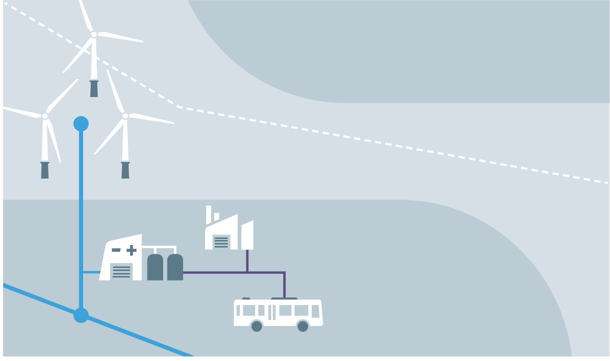
Coordinated plans for energy infrastructure development are critical to ensure the best climate- and socio-economic outcomes. Effective market signals can serve the dual purpose of incentivising optimised location and operation of power-to-X infrastructure and realising significant socio-economic savings for transmission infrastructure in connection with the continued build-out of renewables.

Vision for a renewable hydrogen pathway for Europe

Any vision for renewable hydrogen and power-to-X must start with an ambition for deep decarbonisation to drive the demand for climate neutral solutions in industry and transportation. To secure future supply of renewable hydrogen, it is necessary to achieve industrial scale for water electrolysis while driving down costs and, in parallel, incentivising demand for e-fuels. While the timeframe will depend on the growth rate of both supply and demand – and ultimately the political support and regulatory framework – the deployment of power-to-X can be envisaged in three general phases:

2020-2025: Peer-to-peer projects

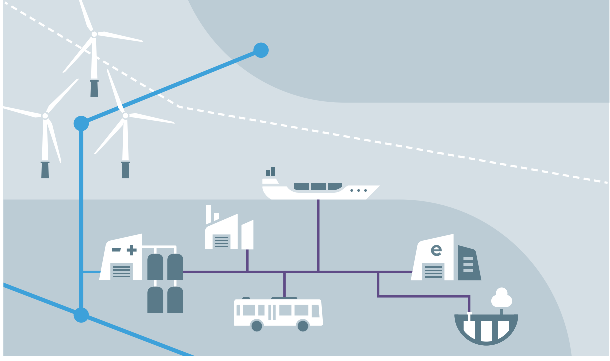
Develop renewable hydrogen to replace fossil hydrogen
Converting demand for fossil hydrogen into demand for renewable hydrogen is a good point of departure. This enables near term scale and industrialization of renewable hydrogen production, immediately driving down costs. Such facilities are best located close to large scale renewable assets and with strong connection points in the transmission grid, while also close to existing hydrogen demand. For instance, large scale offshore wind energy clusters, multi-connected to two or more markets, hold large potential as they offer high availability of renewable generation and can help to maximise the future role of power-to-X in grid operations and balancing.



Flagship projects, with developers of electrolyser facilities engaging with industrial consumers of hydrogen to realise 'peer-to-peer' hydrogen projects, can help create demand. To ensure adequate supply, actors should take steps to ensure offtake of renewable power.

2025-2030: Hydrogen clusters

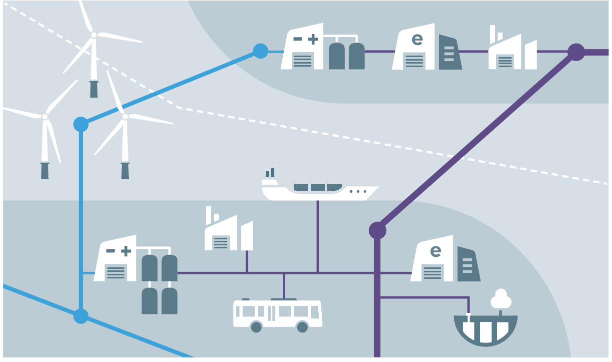
Optimise use of infrastructure, add storage
As electrolysis scales up, enabling distribution of hydrogen from large electrolysers to one or more designated consumers will become increasingly important. Electrolyser facilities could be sited near renewable power sources, to feed hydrogen into pipelines or co-located with e-fuel production. As larger volumes of renewable hydrogen are produced, infrastructure could include larger storage facilities e.g. in natural underground salt caverns. Such storage will absorb intermittency in production and ensure a steady supply of renewable hydrogen to consumers. Alternatively, hydrogen can be converted to other e-fuels, e.g. e-ammonia, e-methanol or e-kerosene, which can relatively easily be stored and transported using existing infrastructure.



Where feasible, segments of the current gas grid can be converted to dedicated hydrogen infrastructure. This should only be used for hydrogen, however, as blending with natural gas will decimate the value of the hydrogen and lock-in applications that will most likely not be relevant in a fully decarbonised economy.

2030-2040: Integrated hydrogen grid

A transnational hydrogen grid and market
In the longer term, further scaling of renewable generation and hydrogen production will transform the energy system and continue to drive down costs. Supplementary to expanded power transmission, a 'backbone' hydrogen grid will connect renewable hydrogen production – onshore and offshore – in regions with wind or solar resources to the industrial centres. This might leverage from existing infrastructure, where natural gas pipelines are retrofitted to hydrogen transport, or involve development of new pipelines designated for hydrogen.



Bringing down costs of power-to-X

Development of renewable hydrogen is ongoing, with more and larger electrolyser projects announced year by year. To maximise the decarbonisation potential of this fuel, costs must be brought down through industrialisation and scale. We know this is possible, with the right framework conditions – because we have done it for the offshore wind sector.

Achieving cost-competitiveness for renewable hydrogen production hinges on five factors:

- **Capital expenditure**, i.e. the price of the electrolyser and balance-of-plant
- **Efficiency of the electrolyser**
- **Renewable power costs**, i.e. the raw costs of energy
- **Utilisation rates** of the assets
- **Regulation** ensuring a 'level playing field'

Driving down costs of renewable hydrogen therefore requires investments into the electrolyser value chain to reduce capital cost; technology improvements to increase hydrogen output; low costs of power; cost-reflective transmission tariffs; and a high availability of renewable electricity to allow for higher operating rates.

As with all new technologies, scale and number of repeatable units sold are key to bringing down capital costs. Renewable hydrogen can be expected to follow the path of solar, on- and offshore wind generation, all of which saw costs decline rapidly over the past decade, as the global installation base multiplied exponentially.

The same will be the case with the entire power-to-X value chain. Costs of logistics, infrastructure, drivetrains, fuel cells, carbon capture (to obtain carbon) and catalytic reactors (to combine carbon or nitrogen with hydrogen) can be brought down through industrialisation and scale.

Yet, e-fuels based on renewable hydrogen face a unique challenge: whereas solar and wind generation could scale in an energy market with an existing demand and grid, neither demand nor infrastructure for renewable e-fuels are in place today.

Thus, investors on both the supply and demand sides face a dilemma. With future demand uncertain, developers of renewable hydrogen and power-to-X are reluctant to invest in building production facilities. And concerns of short supply and high prices make potential off-takers hesitate to commit.

In short, the overarching challenge is that power-to-X cost-out requires volume and continued developments in electrolyser efficiency. To scale beyond replacement of current fossil-based hydrogen consumption, parallel development of supply and demand is needed – this is especially the case for e-fuels.

Industrial partnerships to ensure demand and supply can grow in tandem

Action-based leadership that connects producers and users of renewable hydrogen and e-fuels can avert the potential supply-demand deadlock. This is already being demonstrated through several joint initiatives. Some initiatives work to facilitate dialogue and knowledge sharing between industries on demands, requirements, standards and barriers to emerging power-to-X applications. Others are concrete projects, in which renewable e-fuels developers work with off-takers to meet a specified need.

In Germany, for example, Ørsted is part of a consortium with the goal of substituting fossil-based hydrogen consumption at the Heide Refinery with renewable hydrogen, and creating large scale supply of renewable e-fuels. In Denmark, Ørsted is working with shipping, aviation and long-hauls land transport companies to develop industrial production of renewable hydrogen and e-fuels.

A third example is the Getting to Zero Coalition, which is comprised of 80 global maritime, finance, energy and infrastructure actors. All are working together to overcome technological and other barriers, with the aim of developing commercially viable deep-sea vessels powered by zero-emission fuels by 2030.

Political ambition needed to unlock private sector capital
Unlocking private sector capital for the development of renewable hydrogen is critical to stimulate innovation and drive down costs. Policymakers must establish effective and ambitious regulatory frameworks that incentivises replacement of fossil-based hydrogen and scale up of renewable hydrogen and power-to-X. This could, for instance, be in the form of blending mandates requiring a certain amount of consumed hydrogen or e-fuels to be renewable. Support for development of the green alternatives, through subsidies and incentives is also important. The combination of regulatory framework, a clear demand pipeline and direct/indirect financial support boosts investor confidence in the merits of developing power-to-X at scale.

In Europe, strong political commitment for decarbonisation of economies has established a supportive environment for renewable hydrogen and power-to-X.

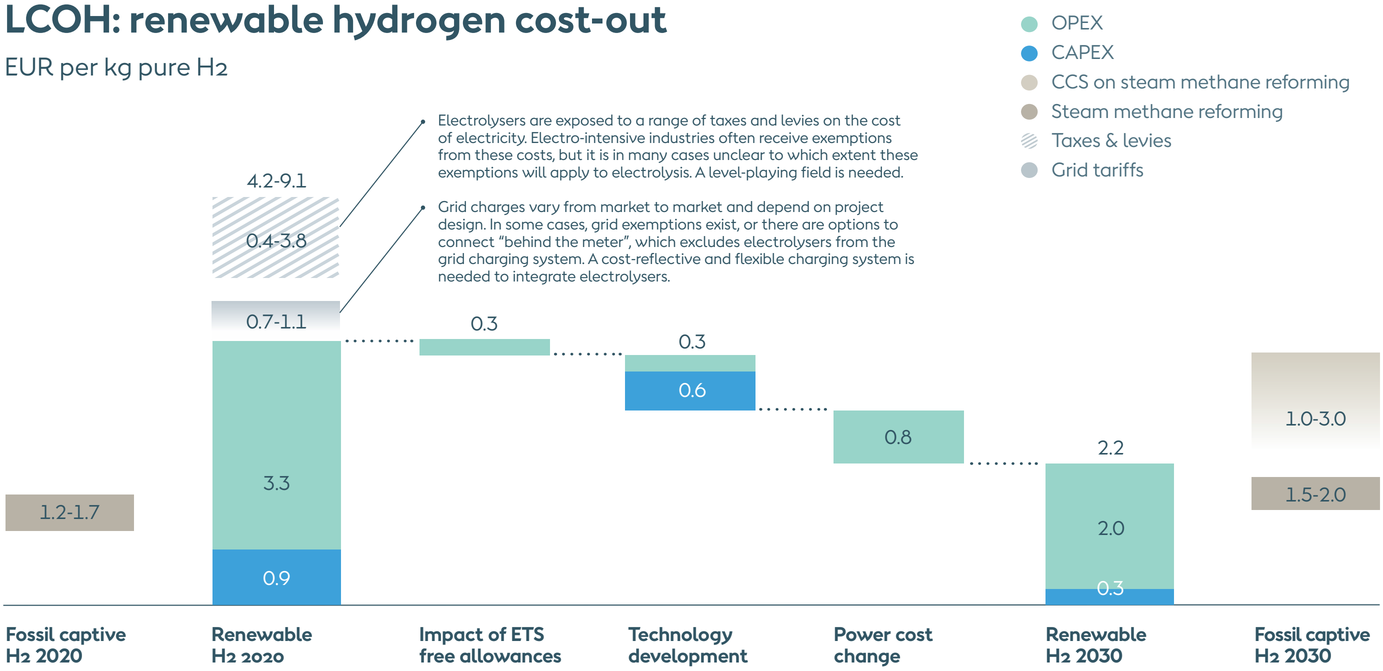
With its 'European Green Deal', the European Commission has made climate action a key priority, aiming towards 55% emissions reduction by 2030 and for Europe to become climate neutral by 2050. Individual nations, including the UK, Germany, Netherlands and Denmark, have also put national targets in place and formulated ambitious build-out strategies and support schemes for renewable hydrogen and power-to-X. Taken together, the European region offers:

- A high renewable share of power generation,
- Competitive power costs, and
- Political determination to achieve deep decarbonisation, resulting in explicit support for hydrogen and power-to-X technologies.

Just as Europe was the crucible for developing and maturing renewable technologies, such as offshore wind generation, as the replacement for fossil-based power generation, so it can foster a promising future for renewable hydrogen and e-fuel facilities.

LCOH: renewable hydrogen cost-out

EUR per kg pure H2



Electrolysers are exposed to a range of taxes and levies on the cost of electricity. Electro-intensive industries often receive exemptions from these costs, but it is in many cases unclear to which extent these exemptions will apply to electrolysis. A level-playing field is needed.

Grid charges vary from market to market and depend on project design. In some cases, grid exemptions exist, or there are options to connect "behind the meter", which excludes electrolysers from the grid charging system. A cost-reflective and flexible charging system is needed to integrate electrolysers.

	Fossil captive H2 2020	Renewable H2 2020	Impact of ETS free allowances	Technology development	Power cost change	Renewable H2 2030	Fossil captive H2 2030
CAPEX		Electrolyser production capacity today is small and not automatized		Mass production, larger systems, improved performance			
OPEX		Cost of electricity is the main cost driver; Particularly affected by significant grid charges, tariffs and levies	Fossil hydrogen producers receive free allowances; We advocate for an "equal product, equal incentives" principle in EU-ETS	Increased efficiency	Reflects offshore wind cost reductions and operational optimisations		

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8. Assumed electricity price is the same for all markets, based on BNEF LCOEs forecasts for offshore wind, with FID 2020 and 2030 (1H 2020 update; we assume 4 years from FID to COD). A faster cost-out of offshore wind would therefore show lower costs of renewable hydrogen.
9. Cost ranges for fossil hydrogen with CCS based on independent, external studies and Ørsted's own estimates. Estimates vary significantly across external publications, and current costs are highly uncertain. We therefore only include a cost range for 2030.

Recommendations for policymakers

Power-to-X is key to decarbonising important economic sectors that are difficult to electrify directly; but this is only viable if the hydrogen is 100% renewable; continued use of fossil-based hydrogen will undermine climate mitigation efforts and risks locking the economy in to costly solutions and import dependence.

Given the unique potential of a low cost renewable molecule to address the decarbonization challenges faced by society, in the near-term policymakers committed to climate action should pursue and support the cost-out and scale-up pathways for renewable hydrogen and power-to-X outlined in this paper. They can help facilitate the development by establishing regulatory frameworks to:

Incentivise consumers to decarbonise
As noted, replacing substantial existing fossil-based hydrogen demand with renewable hydrogen is a point of departure for industrialising production of renewable hydrogen and e-fuels. As long as fossil-based hydrogen remains significantly cheaper to source, however, the desired shift to renewable hydrogen will be negligible.

Measures to incentivise and support use of renewable hydrogen and e-fuels could include renewable mandates and carbon pricing. In parallel, incentives to deliver e.g. steel or ammonia based on renewable hydrogen should support the growth of demand for such products to ensure that early industrial adopters are rewarded, not disincentivized.

Promote flagship projects to overcome uncertainties
In some sectors such as aviation and deep-sea cargo shipping, the technology to run on renewable e-fuels is not yet commercialised. This creates uncertainty for future suppliers and consumers. To produce more complex e-fuels, several new technologies must be deployed and scaled simultaneously, e.g. hydrogen electrolysers, carbon capture and e-fuel synthesis. In parallel, new infrastructure must be put in place for distribution and bunkering.

Flagship projects create a means to manage and overcome such uncertainties, ideally with both developers and consumers collaborating to develop solutions across the entire value chain. By nurturing new demand, flagship projects help industrialise production while also driving development of infrastructure and key off-taking technologies.

Policymakers can facilitate such projects through grants for initial establishment and scale up of production, distribution and consumption assets as well as support to bridge the initial cost gap of renewable hydrogen and e-fuels.

Integrate power-to-X in infrastructure planning
Strategically locating power-to-X facilities close to renewable energy sources – and co-locating energy-intensive industries – is important. Regulators can help by designating dedicated 'infeed zones', situated near strong points in the transmission grid. For example, at the connection points for large offshore wind generation assets. By carefully designing transmission tariffs to be cost-reflective, electrolysers and power-to-X facilities can be incentivised to locate and operate in a way that can save large costs for the surrounding transmission grid. This will also be a critical part of the business case for power-to-X, as regular transmission tariffs represent a considerable share of total electricity costs to industrial consumers. Policymakers can also help by acknowleding hydrogen electrolysis as an energy intensive industry in terms of taxes and levies on power consumption, further reducing costs.

Policies that encourage locating large electrolysers in close proximity to large-scale renewable generation enable immediate consumption of a significant share of the power, thereby avoiding costs associated with extensive build-out of onshore transmission. Ultimately, this development strategy can also help stabilise the grid by providing flexible demand services once dedicated hydrogen grid and storage infrastructure is in place.

Eventually, infrastructure planning should include options for establishing hydrogen transmission grids to connect consumption and supply, as the market for renewable hydrogen scales.

Accelerate deployment of renewable energy
Today, costs of generating power from solar, on- and offshore wind are lower than from new coal, gas or nuclear power plants. This is a game-changing enabler, making decarbonisation feasible through either direct or indirect electrification.

Access to stable and low-cost renewable energy is a prerequisite for sustainable production of renewable hydrogen or e-fuels. Hence, to enable power-to-X to expand, policymakers must ensure that renewable power generation can scale further as well. Specific actions should include taking steps to align policy targets, maritime spatial planning and long-term infrastructure development with the build-out rates needed to achieve decarbonisation.

Commit to an ambitious and strategic policy pathway
Historically, political ambition and certainty have set in place a sufficient safety net to prompt the offshore wind industry to 'take the leap'. Clear signs of sustained ambition gradually unlocked larger investments to support industrialisation of supply chains, technology and operations, in turn allowing the industry to mature and achieve ever-higher efficiency at lower costs.

Electrolysis and power-to-X is unique and will require customised regulation and incentives. As was the case for offshore wind, renewable hydrogen and e-fuels require an environment of high political ambition. To kick-start development and unlock private investment, clear evidence is needed that policy support, subsidies and favourable framework conditions will be in place over the years it takes to complete the cost-out journey.

On the other hand, countries moving early may stand to gain a significant economic upside. As power-to-X technologies will be a crucial part of any realistic global climate mitigation effort to reach net-zero emissions by 2050, one way or another, they must eventually be developed and deployed. Early action to set a supportive policy framework will translate into early opportunities for companies, countries and regions willing to take bold steps towards becoming suppliers of green fuels to global markets.

Power-to-X is essential to stay within 1.5°C

By 2030, global greenhouse gas emissions need to be halved in order to limit global temperature increase to 1.5°C by 2100. And by mid-century, global emissions must essentially be brought down to net-zero.

Getting there will require an ambitious 'all-of-the-above' mitigation policy, using all relevant means to decarbonise energy use. It cannot be achieved without large scale power-to-X technologies. We're in a hurry to develop and deploy renewable hydrogen and e-fuels production at scale. And even if all this is implemented at once, it will take around a decade before renewable hydrogen can become cost- competitive to its fossil alternatives.

Still, we expect this to happen. We have seen costs of renewable power generation decline rapidly to the point where renewable generation from solar and on- and offshore wind is now cheaper than coal or gas-based power generation. This presents a unique opportunity to leverage renewable energy in decarbonising other sectors. And today, just as with renewable power years ago, we see both future producers and consumers of renewable hydrogen flocking to invest, to set the development in motion. Once the ball starts rolling, we might even be surprised by the speed of the development – as has been the case for wind, solar and battery technology.

Much remains to be done. And the effort required is staggering. The EU Commission estimates, for example, that for Europe to reach its target of becoming climate-neutral by 2050 will increase power demand by up to 150% compared to today. While some of this new demand will be driven by direct electrification and some of it by general economic development, production of renewable hydrogen and e-fuels will drive more than half of Europe's growing power demand towards 2050.[1]

For power-to-X – and the green transformation at large – to succeed will require effort from policymakers, investors, producers of renewable energy and industrial consumers. At Ørsted, we're committed to doing our part in scaling up renewable hydrogen and e-fuels. With this paper, we have outlined a way forward towards deep decarbonisation.

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[1] European Commission 2018, A Clean Planet for all, COM(2018) 773, 1.5TECH Scenario

Examples of Ørsted's hydrogen projects

At Ørsted, we develop and construct renewable energy projects across the globe, with large-scale renewable electricity projects operating or underway in North-western Europe, the United States and the Asia-Pacific region. Building on these experiences, we have ambitious plans to accelerate deployment of renewable hydrogen production and power-to-X, with a current focus on North-western Europe, and an eye on other parts of the world.

Green fuels for Denmark

The Green Fuels for Denmark project unites leading Danish companies to develop industrial-scale production of renewable hydrogen and sustainable e-fuels for road, maritime and air transport. By combining both supply and consumer side actors, the project seeks to develop 10MW electrolyser capacity by 2023, 250MW electrolyser capacity with e-fuel production by 2027, and a vision to scale up to 1.3GW by 2030. The electricity is to be sourced from offshore wind farms off the coast of Bornholm in the Baltic Sea. By then, the main part of renewable hydrogen will be combined with sustainably sourced carbon, to produce 250,000 tons of e-kerosene and e-methanol per year.

Copenhagen Airports CPH
DFDS
MAERSK
SAS Scandinavian Airlines
DSV
City of Copenhagen
Everfuel
HALDOR TOPSØE
COWI
nel

Westküste 100

Westküste 100 in Germany sets out to contribute in making industrial processes, aviation, construction and heating more sustainable, using renewable hydrogen at scale. The project consortium works to develop, build and operate a regional hydrogen economy at industrial scale, including a 30MW electrolyser system and with the goal of scaling up to 700MW hydrogen electrolysis. In the first step, renewable hydrogen from a 30MW electrolyser will replace current fossil hydrogen at the Heide Refinery in Schleswig-Holstein. Other elements in the project is the test of cavern-storage of hydrogen, test of a pipeline system and feasibility study of future e-fuel synthesis, including large-scale electrolysis. It is the first large-scale hydrogen project to receive funding from the German Reallabor funding program.

EDF
Holcim
REGION HEIDE Vielfalt im Nordseewind
FH Westküste Wirtschaft und Technik
OGE
RAFFINERIE HEIDE
thyssenkrupp
STADTWERKE HEIDE GmbH
thüga Das große Plus der Gemeinschaft

Gigastack

The partners of the Gigastack project in the UK work to optimise production and deployment of large-scale electrolysers. As manufacturing costs of electrolysers are an important cost-driver for renewable hydrogen, the project involves development and test of a new modular 5MW stack design, a semi-automated manufacturing facility and different operational innovations to facilitate cost savings. The project also includes a front end engineering and design (FEED) study of a 100MW electrolyser system at the Phillips 66 Humber Refinery, powered by energy from Ørsted's Hornsea 2 offshore wind farm, currently under construction in the British North Sea. The project has secured funding from the UK BEIS Hydrogen Supply Competition.

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About Ørsted

Ørsted is driven by its vision of a world that runs entirely on green energy. It is the global market-leader in offshore wind power, and supplies large-scale and cost-competitive offshore wind energy, onshore wind energy, and solar energy solutions. In parallel, Ørsted operates sustainable bioenergy plants, offers green power purchase agreements, and explores renewable hydrogen and battery solutions.

All business lines support Ørsted's mission to reduce emissions, improve air quality, and create local jobs. Ørsted has reduced its own greenhouse gas emissions by 86% since 2006, and will be essentially carbon-neutral by 2025.

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Get in touch

Get in touch if you have any enquiries about this paper.

Magnus Hornø Gottlieb
Global Public Affairs
mahog@orsted.com
grouppublicaffairs@orsted.com

Version 1.0, October 2020