Policy brief, March 2022

Auctions for the support of green hydrogen

Applying RES auction expertise to green hydrogen

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Contents

Executive summary

Renewable hydrogen is seen as a key solution to achieving climate neutrality. The EU and its Member States have in the last years published hydrogen strategies to steer the ramp-up of the hydrogen market through frameworks and policy support. On its way to climate neutrality, the EU has set itself an intermediate target of minus 55% GHG emissions by 2030. To ensure the achievement of this target, the Fit for 55 package was published. It includes several proposals, some of which are of high importance for hydrogen. For example, the European Commission proposes that Member States ensure that the share of renewable fuels of non-biological origin (RFNBOs) of all hydrogen used for final energy and non-energy purposes in industry reaches 50 % by 2030. The fulfilment of this target requires support. Hydrogen auctions could be used to allocate the support to eligible parties.

This policy brief aims at informing the debate on hydrogen support policies by providing practical, near-term considerations on auctions for renewable hydrogen support allocation and discussing four basic auction models. We point out that any near-term policy needs to account for two main challenges – the missing market and infrastructure for RFNBOs. While electricity infrastructure is already today widely available, hydrogen infrastructure has yet to grow beyond dedicated industry clusters. The current market situation for hydrogen can best be explained as a chicken and egg problem. Currently, there is almost no demand for renewable hydrogen because it is very costly in comparison to alternatives. Hence, there is no supply of renewable hydrogen beyond pilot projects. The price of renewable hydrogen, however, can only drop if economies of scale and technological learning pick up.

Reflecting on these challenges, we discuss four auction models, each for a different purpose in the general market ramp up of hydrogen:

- Option 1: Demand-side auctions for hydrogen to support the ramp-up of hydrogen demand. Strategies at national and EU-level foresee a significant growth in the use of renewable hydrogen in industry in the future. This growth expectation has been underlined by the proposal for the RED II revision. It proposes a binding RFNBO target of 50% for hydrogen used in industry. If adopted as such, Member States are obliged to create the conditions for national fulfilment of this target. By bridging the cost gap to renewable hydrogen, the proposed auction model can encourage new hydrogen demand and ensure the simultaneous ramp-up of new supply.
- Option 2: Double-sided auctions for hydrogen derivatives to provide security to producers to invest in new electrolysers and industry offtakers to switch to green derivatives. This auction model could enable the import of derivatives for consumption by industry consumers in the EU. While the production and trade of derivatives based on fossil-based hydrogen is well-established, markets and new supply routes for green derivatives are still emerging and expected to grow in size. In this context, double-sided auctions would function as a platform to match supply and demand. The double-sided auction could fulfil this function while at the same time targeting large groups of actors on both sides, thereby enhancing competition, and lowering prices.
- Option 3: Supply-side auctions to help move towards the EU hydrogen strategy capacity target of 40 GW renewable hydrogen electrolysers by 2030. The large-scale production of renewable hydrogen is currently rather unattractive to investors, as the cost of producing renewable hydrogen is significantly higher than for fossil-based alternatives and consumers are not yet willing or able to pay a significant premium for renewable hydrogen. There is thus no demand market at the current production price. To reach the EU's capacity goal, renewable hydrogen production needs to be incentivized so that prices are reduced to a competitive level. This design option would be one way to do that.
- Option 4: A joint auction for hydrogen and renewable energy to support the joint deployment of RES and electrolysers. The joint auction can support the simultaneous deployment of hydrogen and a renewable energy source. The main conceptual rationale for jointly developing the two assets is that a project planner may be able to optimise both assets better than separate developers, streamlining the project development processes, improving the joint configuration and operation of the two assets, and reducing total investment costs.

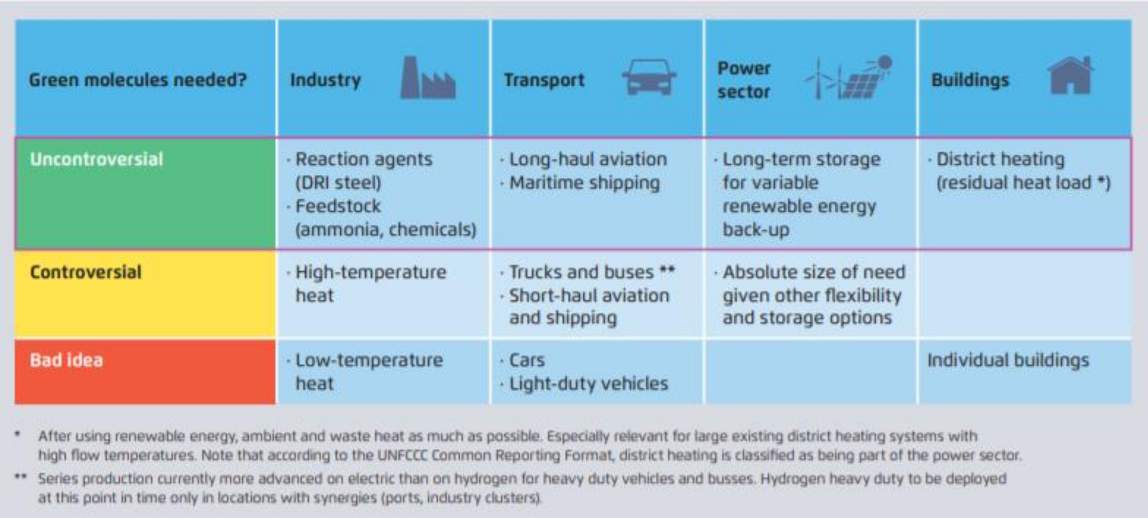
We conclude that the concept of auctions, widely used for the support of renewable energy sources, can be transferred to the hydrogen context. However, auction models must consider the different circumstances for hydrogen.

1 The opportunity for hydrogen auctions

By 2020, 116 countries have used auctions to allocate support for electricity from renewable energy sources (RES), with only five out of the 27 European Union (EU) Member States yet to introduce RES auctions. This vast uptake of auctions as an allocation mechanism in the RES sector has given us the opportunity to learn and study the advantages of auctions, as well as to identify instruments to counteract their challenges. On the other hand, hydrogen as an energy carrier is going to play a crucial role in the decarbonisation efforts of the EU and worldwide. IRENA already proposed that auctions can play a decisive role in this market update of hydrogen.[1] Thus, using the insights from RES auctions, the AURES II project aims to transfer the accumulated knowledge on the design of RES auctions to the increasingly important renewable hydrogen sector. In this policy brief, we present our first considerations on how auction-based support of renewable hydrogen could be designed in the EU.

1.1 Hydrogen developments

The EU wants to achieve climate neutrality by 2050. This effort requires decarbonisation in all sectors of the economy. While some sectors and applications such as passenger transport may use direct electrification to decarbonize, other sectors and applications cannot do so easily, quickly or within reasonable costs. Here, **renewable hydrogen**[2] (hydrogen) or derivatives[3] thereof may be used instead. Renewable hydrogen and its derivatives will be needed especially in industry (e.g. for steel and chemicals production), select modes of transportation (long-distance aviation, maritime shipping) and for flexible electricity generation (see Figure 1).[4]



Green molecules needed?	Industry	Transport	Power sector	Buildings
Uncontroversial	· Reaction agents (DRI steel) · Feedstock (ammonia, chemicals)	· Long-haul aviation · Maritime shipping	· Long-term storage for variable renewable energy back-up	· District heating (residual heat load *)
Controversial	· High-temperature heat	· Trucks and buses ** · Short-haul aviation and shipping	· Absolute size of need given other flexibility and storage options	
Bad idea	· Low-temperature heat	· Cars · Light-duty vehicles		Individual buildings

* After using renewable energy, ambient and waste heat as much as possible. Especially relevant for large existing district heating systems with high flow temperatures. Note that according to the UNFCCC Common Reporting Format, district heating is classified as being part of the power sector.

** Series production currently more advanced on electric than on hydrogen for heavy duty vehicles and busses. Hydrogen heavy duty to be deployed at this point in time only in locations with synergies (ports, industry clusters).

Figure 1 - Use cases for renewable hydrogen (Agora Energiewende and Guidehouse 2021)

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[1] https://www.irena.org/newsroom/expertinsights/2021/Sep/Auctions-for-Green-Hydrogen

[2] We refer to the EU's definition for renewable hydrogen: 'Renewable hydrogen' is hydrogen produced through the electrolysis of water (in an electrolyser, powered by electricity), and with the electricity stemming from renewable sources. The full life-cycle greenhouse gas emissions of the production of renewable hydrogen are close to zero. Renewable hydrogen may also be produced through the reforming of biogas (instead of natural gas) or biochemical conversion of biomass, if in compliance with sustainability requirements.' This type of hydrogen is often also referenced as "green" hydrogen.

[3] Derivatives may be ammonia, methane or methanol.

[4] Agora Energiewende and Guidehouse (2021). Making renewable hydrogen cost-competitive: Policy instruments for supporting green H_2. Retrieved from: https://static.agora-energiewende.de/fileadmin/Projekte/2020/2020_11_EU_hydrogen-Instruments/A-EW_223_hydrogen-Instruments_WEB_2.pdf

Today, the use of hydrogen in the EU is limited to industrial applications such as refining and the production of ammonia and methanol. The production of 150 billion m^3 (equivalent to 410 TWh) of hydrogen was reported in the EU in 2018.[5] Most of the hydrogen is fossil-based and produced from conventional steam methane reforming (SMR) or coal gasification, while only less than 4% is produced by the 300 electrolysers in operation. Hence, the vast majority of hydrogen used today is not renewable. **Fossil-based hydrogen** is in policy discussions often referred to as 'grey hydrogen'. It is produced mainly through SMR. A cleaner version is '**fossil-based hydrogen with carbon capture**' (also referred to as 'blue hydrogen'), which is also produced using fossil fuels, but the generated carbon emissions are captured and stored.[6] The most sustainable type of hydrogen is '**renewable hydrogen'** (or 'green hydrogen'), which is produced through electrolysis using electricity from renewable energy sources (RES).[7] In contrast to the previous types, renewable hydrogen does not emit any carbon emissions during hydrogen production.

1.2 Political context

The political and regulatory context for renewable hydrogen is currently seeing dynamic changes as policy makers aim for providing an enabling framework. Many countries have recently published **national hydrogen strategies** or other declarations of support, such as roadmaps or R&D programs.[8] In July 2020, the European Commission published its **hydrogen strategy for a climate-neutral Europe** setting out a target of at least 6 GW of renewable hydrogen electrolysers in the EU by 2024 and 40 GW by 2030.[9] The strategy acknowledges hydrogen as a key priority to achieve the European Green Deal and Europe's clean energy transition and emphasizes that the focus shall be on developing renewable hydrogen. A role for other forms of low-carbon hydrogen is limited to the rapid reduction of emissions from existing hydrogen production in the short – to medium term.

The **EU hydrogen strategy** describes a gradual trajectory for the development of the hydrogen ecosystem in the EU. In a first phase until 2024, the focus is on decarbonizing existing hydrogen production by installing at least 6 GW of electrolyser capacity, producing up to 1 million tonnes of renewable hydrogen. Policies in that period should focus on establishing a regulatory framework incentivizing both supply and demand in lead markets. In a second phase until 2030, renewable hydrogen is expected to partially close the cost-gap with other forms of hydrogen production. At least 40 GW of electrolyser capacity should be installed, producing up to 10 million tonnes of renewable hydrogen. An EU-wide hydrogen infrastructure will need to emerge allowing hydrogen transport from areas with large renewable potential to demand centres. In a third phase from 2030 onwards and towards 2050, renewable hydrogen technologies should reach maturity and be deployed at large scale to reach all hard-to-decarbonise sectors. The EU strategy also describes the goal of technology leadership that allows the EU to benefit from a global development of clean hydrogen.

As part of its **'Fit for 55' package** published on 14th of July 2021, the European Commission has proposed substantial revisions to all relevant European legislation to put the EU on track to deliver the Green Deal.[10][11]

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[5] Eurostat (2021): Total production by PRODCOM list (NACE Rev. 2) - annual data (DS-066342) – 2021, Luxembourg, last updated 03.03.2021

[6] A novel alternative hydrogen produced through methane pyrolysis. It also uses methane as a feedstock, but the process is driven by heat produced with electricity rather than through the combustion of fossil fuels. The produced carbon is in solid form rather than CO_2, which can e.g. be used as a soil improver. Where the electricity driving the pyrolysis is renewable, the process is zero-carbon, or even carbon negative if the feedstock is biomethane rather than fossil methane (natural gas).

[7] Some lifecycle emissions for renewable emissions still occur related to upstream renewable electricity generation.

[8] https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Nov/IRENA_Green_hydrogen_policy_2020.pdf

[9] https://ec.europa.eu/energy/sites/ener/files/hydrogen_strategy.pdf

[10] The proposed revisions by the European Commission require agreement by the European Parliament and the EU Member States. Negotiations are expected to take at least until end of 2022.

[11] The basis of the 'Fit for 55' proposals are the new climate targets of the EU of climate neutrality by 2050 and the interim target of an emission reduction of 55% by 2030 compared to 1990. These climate targets are set by the Green Deal and are expected to be formally adopted in the second half of 2021 when the Council of the European Union adopts the European Climate Law.

Renewable hydrogen is a focus area of the 'Fit for 55' package. The European Commission proposes to streamline definitions and criteria for Renewable Fuels of Non-Biological Origin (RFNBOs), i.e. renewable hydrogen and its derivatives, across all end-use sectors.[12] If hydrogen used in industry shall be accounted as renewable hydrogen, it will therefore have to comply with the same criteria as renewable hydrogen used in the transport sector. Furthermore, the European Commission proposes to introduce new **targets for the use of RFNBOs**. By 2030, RFNBOs shall reach a binding share of 2.6% in final consumption of energy of the transport sector, including aviation and maritime shipping. 2.6% of the current (2018) energy demand of the transport sector of 3335 TWh[13] corresponds to ~87 TWh RFNBOs.

The European Commission also proposes a binding target share of 50% for RFNBOs in the total hydrogen use of the industry by 2030. At EU level, industrial hydrogen demand is projected to increase to 400-500 TWh.[14] This would imply a need for 200-250 TWh of RFNBOs. The European Commission's hydrogen strategy includes a strategic objective to install at least 40 GW of renewable hydrogen electrolysers by 2030 and the production of up to 10 million tonnes (equivalent to 330 TWh) of renewable hydrogen in the EU.[15] The added requirements for RFNBOs (287-337 TWh) of the RED thus align closely with the previous target from the hydrogen strategy. For the RFNBO target for industry, the target achievement responsibility rests with the Member States. They could theoretically use obligations, support schemes or rely on the EU ETS to ensure demand uptake. Due to the current high prices for renewable hydrogen and the concern for the international competitiveness of industry, obligations such as quotas are highly unlikely in the near term. Also, the ETS will not be sufficient to trigger switching from fossil-based to renewable hydrogen. Rather, Member States are likely to use support schemes in the short term. Hydrogen auctions could be used to allocate the support payments to offtakers in industry.

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[12] The European Commission is currently developing the criteria for renewable hydrogen and renewable hydrogen-based products in the transport sector, which will be adopted in a delegated act on the basis of Article 25 of the Renewable Energy Directive. The criteria relate inter alia to the additionality of the renewable electricity sourced for the hydrogen production, the (system-friendly) location of electrolyser capacities to avoid increasing grid congestion and to the temporal correlation between the production of hydrogen and the generation of renewable electricity. These rules will have a strong bearing on the amount of full load hours of an electrolyser and hence on its production volume and the costs of production.

[13] https://ec.europa.eu/eurostat/documents/3217494/11099022/KS-HB-20-001-EN-N.pdf/bf891880-1e3e-b4ba-0061-19810ebf2c64?t=1594715608000

[14] https://www.fch.europa.eu/sites/default/files/Hydrogen%20Roadmap%20Europe_Report.pdf

[15] https://ec.europa.eu/energy/sites/ener/files/hydrogen_strategy.pdf

2 Two short-term challenges: Missing infrastructure and market

The goal of this policy note is to provide considerations for short-term, auctions-based policy instruments. Before delving into the design of possible instruments, attention needs to be given to two short-term challenges – the missing hydrogen infrastructure and hydrogen market. Any policy instrument must account for these two key challenges.

2.1 Infrastructure for hydrogen and derivatives

To connect hydrogen supply to hydrogen demand, transport **infrastructure** is required.[16] With a view to transport, a differentiation between pure hydrogen and derivatives - also known as synthetic fuel produced from renewable hydrogen, such as methane, ammonia, methanol and synthetic liquid fuels – is needed. Derivatives can be shipped across large distance while hydrogen in its pure form requires transport via pipeline. Infrastructure becomes an important constraint in the short-term as it is mainly available at a small scale within industrial clusters. This is a crucial distinction between electricity and hydrogen. Electricity infrastructure is already today widely available, hydrogen infrastructure has yet to grow beyond those clusters. In the short term, the EU hydrogen strategy and the European Hydrogen Backbone, an initiative of European gas infrastructure companies,[17] foresee the development of so-called “hydrogen valleys”. Up to 2030, the European Commission expects a need for an EU-wide logistical infrastructure (a pan-European grid and a network of hydrogen refuelling stations).

Hence, in the short-term, the **constraint of limited infrastructure** needs to be taken into account in the design of support instruments for the market ramp-up.[18] Beyond 2030, this constraint becomes less binding.

2.2 Market for hydrogen

The current market situation for hydrogen can best be explained as a chicken and egg problem. Currently, there is no demand for renewable hydrogen, because it is very costly in comparison to alternatives. Hence, there is no market incentive to produce renewable hydrogen at large scale. The price of renewable hydrogen, however, can only drop if economies of scale and technological learning pick up.

To solve this chicken and egg problem and to accelerate a market ramp-up of renewable hydrogen, support is required. Support is required on both demand and supply side, to ensure that both sides of the market ramp-up in parallel.

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[16] To transport hydrogen, either existing pipelines can be retrofitted, or new ones built. On the challenges of transporting pure hydrogen by repurposing existing gas infrastructure please see the report by ACER (2021), http://s2.bl-1.com/h/dkxWoQK6?url=https://extranet.acer.europa.eu/Official_documents/Acts_of_the_Agency/Publication/Transporting%20Pure%20Hydrogen%20by%20Repurposing%20Existing%20Gas%20Infrastructure_Overview%20of%20studies.pdf

[17] The European Hydrogen Backbone initiative consists of a growing group of now 23 European gas infrastructure companies, working together to plan a pan-European dedicated hydrogen transport infrastructure. Participating companies are Creos, DESFA, Elering, Enagás, Energinet, Eustream, FGSZ, Fluxys, Gas Connect Austria, Gasgrid Finland, Gasunie, GAZ-SYSTEM, Gas Networks Ireland, GRTgaz, National Grid, NET4GAS, OGE, ONTRAS, Plinovodi, TAG, Teréga, Snam, Swedegas. The report can be found under this link: https://gasforclimate2050.eu/wp-content/uploads/2021/06/EHB_Analysing-the-future-demand-supply-and-transport-of-hydrogen_June-2021_v3.pdf

[18] Section 3.2 of the IRENA (2020) report mentions possible policy support instruments for infrastructure.

2.2.1 Demand

The demand for renewable hydrogen, in comparison to fossil-based hydrogen, is currently very small. In 2018, 410 TWh of fossil-based hydrogen[19] were produced in the EU, which were mainly consumed in the industry sector as feedstock.[20] Within the EU, the currently operating 300 electrolysers produce less than 4% of total hydrogen production.[21]

Figure 2 below provides an overview of the projected European renewable hydrogen demand in the different studies. The projected renewable hydrogen demand varies from 5 to 292 TWh in 2030, while the overall demand of hydrogen (mainly renewable and low-carbon hydrogen) will reach up to 665 TWh[20] in 2030. The projected overall hydrogen demand will reach up to 2,251 TWh in 2050[20]. The large variation on the demand projections mainly results from the different assumptions and boundary conditions (e.g. CO_2 price), the defined boundary of the model (e.g. inclusion of industrial feedstock) and the model itself.

The overview shows that a large portion of the renewable hydrogen demand comes from the transport and industry sectors. Besides the end-user sectors, hydrogen can in the long run also be used in the energy sector as dispatchable power.

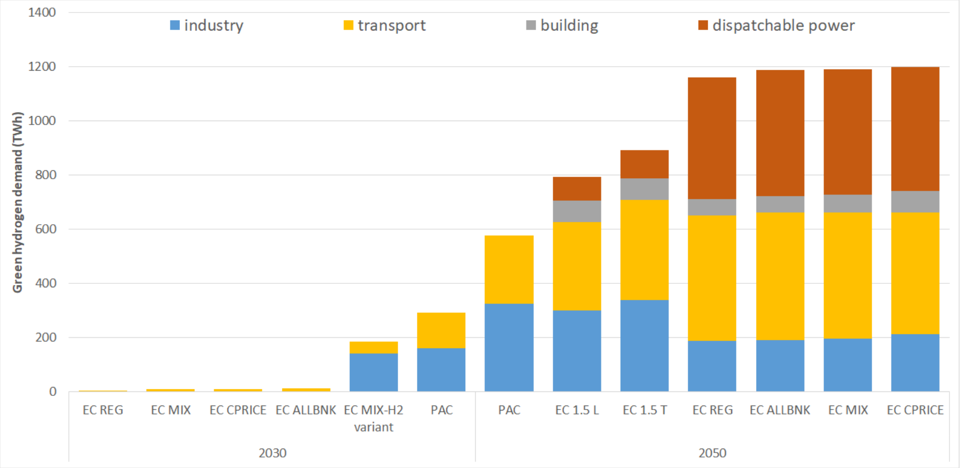

Figure 2 Renewable hydrogen demand in the energy system in the EU in the future (Source: Fraunhofer ISI (2021) based on European Commission (2018, 2020, 2021) and CAN Europe and EEB (2020))[22,23]

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[19] Eurostat (2021): Total production by PRODCOM list (NACE Rev. 2) - annual data (DS-066342) – 2021, Luxembourg, last updated 03.03.2021

[20] FCH 2 JU - Fuel Cells and Hydrogen 2 Joint Undertaking (2019): Hydrogen Roadmap Europe: A Sustainable Pathway for The European Energy Transition. Belgium.

[21] European Commission (2020): A hydrogen strategy for a climate-neutral Europe. URL: https://ec.europa.eu/energy/sites/ener/files/hydrogen_strategy.pdf

[22] Information regarding hydrogen demand for dispatchable power is not available for all studies; Industiral feedstocks are covered in part of the studies.

[23] European Commission (2018): A Clean Planet for all. A European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy. In-Depth Analysis in Support of the Commission Communication COM(2018) 773. Brussels. November 2018.
European Commission (2020): COMMISSION STAFF WORKING DOCUMENT – IMPACT ASSESSMENT. Accompanying the document: COMMUNICATION FROM THE COMMISSION TO THE ERUOPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS – Stepping up Europe´s 2030 climate ambition – Investing in a climate-neutral future for the benefit of our people. EUROPEAN COMMISSION. COM(2020) 562 final. Brussels.
European Commission (2021): COMMISSION STAFF WORKING DOCUMENT - IMPACT ASSESSMENT REPORT. Accompanying the Proposal for a Directive of the European Parliament and the Council, amending Directive (EU) 2018/2001 of the European Parliament and of the Council, Regulation (EU) 2018/1999 of the European Parliament and of the Council and Directive 98/70/EC of the European Parliament and of the Council as regards the promotion of energy

As for hydrogen derivatives, the current demand can be reflected indirectly through the hydrogen demand for their production. The FCHO data[24] shows that half of the hydrogen demand from the industry in 2019 was used for refineries (3.9 million Mt), followed by demand for ammonia production amounting to 2.4 million Mt. The rest of the hydrogen demand mainly comes from the chemical industry (e.g. for methanol production). Studies also project new demand for renewable hydrogen derivatives (Figure 3). The new demand of renewable hydrogen derivatives is projected to vary from 7 to 273 TWh in 2030, which consists mainly of synthetic liquid fuel and ammonia used in the transport sector and synthetic methane used in the industry. In 2050, the demand in all sectors is estimated to rise up to 1,159 TWh.

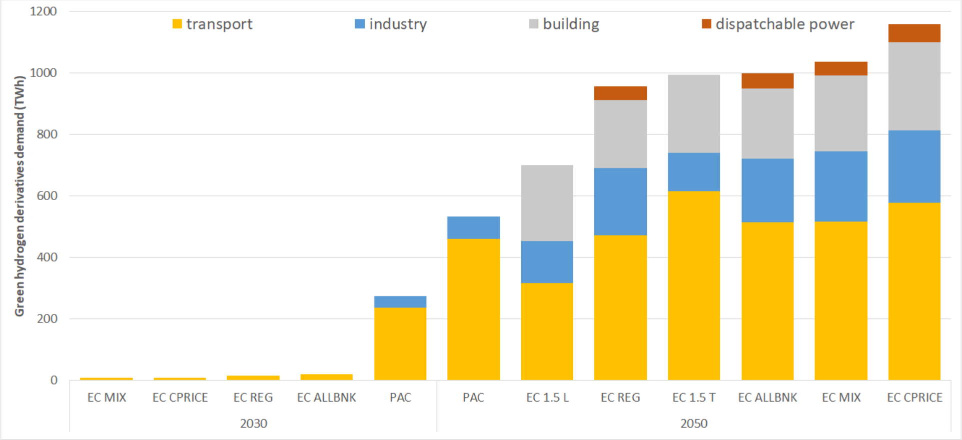

Figure 3 Renewable hydrogen derivatives demand in the energy system in the EU in the future (Source: Fraunhofer ISI (2021) based on European Commission (2018, 2020) and CAN Europe and EEB (2020)) [22,23]

2.2.2 Supply

On the **supply side**, the current market is also rather small. Within the EU there are less than a dozen companies that supply fossil-based hydrogen to the industry consumers mentioned above. Usually, these suppliers are in geographic proximity to the consumers, feeding into closed pipeline networks in industrial clusters.

However, looking ahead to 2030 and beyond, many companies (such as utilities or oil & gas companies) have already indicated interest to produce renewable hydrogen in the future. Thus, it can be expected that the supply market will become much more diverse. This is also reflected in studies modelling decarbonised energy system, where a total installed electrolyser capacity of 2 to 41 GW is estimated in the EU in 2030[25], while 40 GW inside the EU and 40 GW outside of the EU are targeted in the EU Hydrogen Strategy. According to the long-term projections in different studies, a rapid increase of installed capacity will appear after 2030 and the total capacity will reach 505 GW to 720 GW in 2050[26].

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from renewable sources, and repealing Council Directive (EU) 2015/652. COM(2021) 557 final. Brussels.
CAN Europe and EEB (2020): Building a Paris Agreement Compatible (PAC) energy scenario, URL: https://www.pac-scenarios.eu/fileadmin/user_upload/PAC_scenario_technical_summary_29jun20.pdf

[24] FCHO – Fuel Cells and Hydrogen Observatory (2021) Hydrogen Demand, URL: https://www.fchobservatory.eu/observatory/technology-and-market/hydrogen-demand

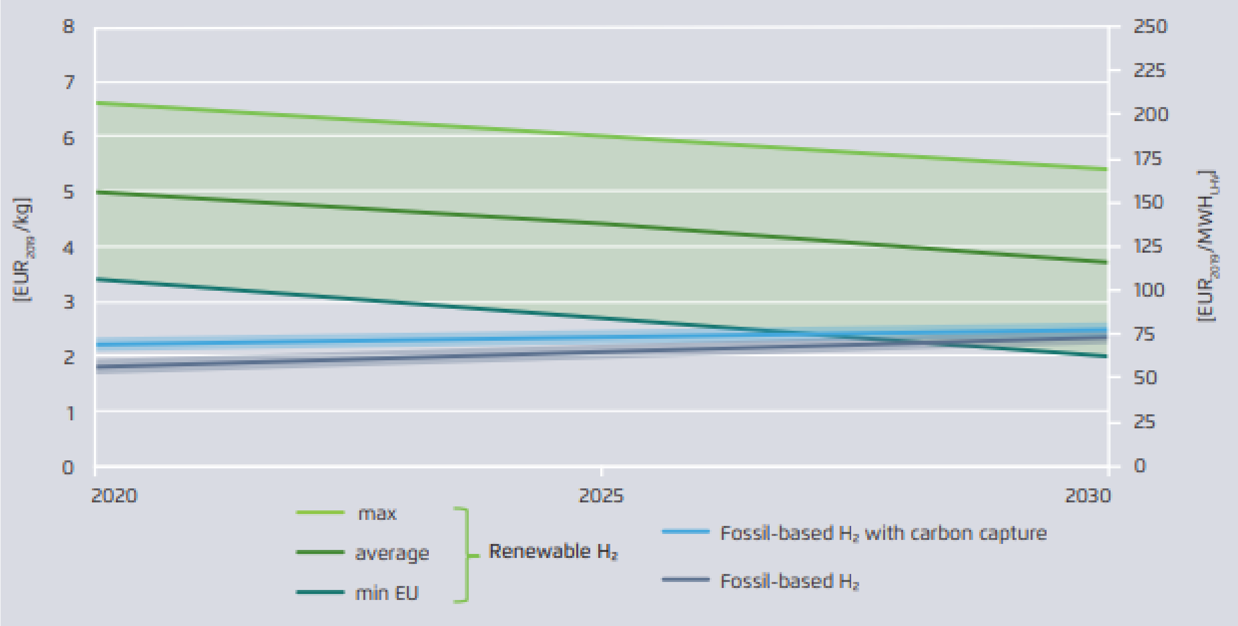
[25] Electrolyser capacity in 2030 ranges from 2 GW to 41 GW in different scenarios: the scenarios from “A Clean Planet for all” (EC, 2018) foresee only 2 GW, while the distributed energy scenario from “TYNDP 2020 Scenario report” (ENTSO, 2020) shows 41 GW.

[26] Electrolyser capacity in 2050 ranges from 505 GW to 720 GW in different scenarios: the 1.5 LIFE scenario from “A Clean Planet for all” (EC, 2018) foresees 505 GW, while the CPRICE scenario from “Impact Assessment” (EC, 2020) shows 720 GW.

2.2.3 Price

Currently, the large-scale production and use of renewable hydrogen is constrained. This is mostly due to the very **high costs of production.**[27] Renewable hydrogen production costs derive from the investment cost for the electrolyser, the cost of the renewable electricity used, the capacity factor, the efficiency of the electrolyser, and the cost of stack replacement. Renewable hydrogen is currently produced for around €5/kg, while fossil-based hydrogen with carbon capture can be produced at around €2/kg (see Figure 4).

Production cost of renewable H_2 compared to fossil-based H_2 with and without carbon capture Figure 3



Guidehouse based on BNEF (2021), Prognos et al. (2020), Hydrogen Europe (2020), Gas for Climate (2020), Agora Energiewende and AFRY Management Consulting (2021)

The price range for fossil-based H_2 reflects an implicit carbon price of €50/tCO_2 in 2020 increasing to €100/tCO_2 in 2030. For natural gas, a price of €20/MWh is assumed. The capture rate for fossil-based H_2 with carbon capture is assumed to be around 75%.

Figure 4 Production costs for renewable hydrogen compared to fossil-based hydrogen with and without carbon capture (Agora Energiewende and Guidehouse, 2021) [28]

The large price range shown for renewable H_2 in the figure is a reflection of divergent market expectations and variance in the underlying renewable energy potential. The cost for fossil-based hydrogen is based on the predicted natural gas price, the price for fossil-based hydrogen with carbon capture is a little higher, reflecting the small additional cost of installing a carbon capturing system. The shown **cost degression** for renewable hydrogen towards 2030 has several factors:

- Electrolyser costs are expected to reduce further, particularly with additional capacity additions,[29]
- Stacks are also expected to become very cheap as production gets automated, and,

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[27] The production cost of hydrogen depends on the investment cost of the electrolyser, the conversion efficiency, the capacity factor, the cost for stack replacement and the cost of renewable electricity used.

[28] The renewable H_2 2020 range is based on Bloomberg New Energy Finance (2021), Prognos et al. (2021), Hydrogen Europe (2020) and Gas for Climate (2020). The 2030 range is based on Prognos et al. (2021) and Agora Energiewende and AFRY Management Consulting (2021). The price range for fossil-based H_2 reflects an implicit carbon price of €50/tCO_2 in 2020 increasing to €100/tCO_2 in 2030. For natural gas, a price of €20/MWh is assumed. The capture rate for fossil-based H_2 with carbon capture is assumed to be around 75%.

[29] According to the EU hydrogen strategy, electrolyser costs have already been reduced by 60% in the last ten years, and are expected to halve in 2030 compared to today with economies of scale.

- The costs of producing electricity from renewable sources have fallen steadily and are expected to decrease further in the future.

At the same time, the costs for fossil-based hydrogen without or, to a lesser extent, with carbon capture are expected to increase due to higher carbon prices. This favours the competitiveness of renewable hydrogen further.

Based on these trends, renewable hydrogen could become cost-competitive against fossil-based alternatives by 2030. However, this **break-even point** between fossil-based hydrogen and renewable hydrogen may only happen under optimal conditions and is certainly **not guaranteed**. Thus, policy makers need to target policies towards ensuring cost-competitiveness of renewable hydrogen.

2.3 Support instruments for market ramp-up and the role of auctions

To achieve the ramp up of renewable hydrogen production and consumption despite currently high production costs, numerous **supply- or demand-side instruments** are available.[30]

To increase the **demand**, governments could either opt for price- or quantity-based policy instruments. The first category aims at reducing the gap between the two prices of a commodity (in this case fossil-based vs. renewable hydrogen) and includes instruments like the Carbon Contracts for Difference (CCfDs), premiums for the use of renewable hydrogen, or subsidised prices via public procurement. The second category of support instruments consists of a mandatory quota for renewable hydrogen which ensures a certain demand for renewable hydrogen across the board or within sectors.

Support instruments on the **supply side** can be generally categorized into investment support or operating support. Renewable hydrogen production costs are driven by around 2/3 by the operating costs for the renewable electricity used. Only around 1/3 are the electrolyser investment costs. Thus, while a CAPEX instrument is helpful, it is not enough to make renewable hydrogen cost-competitive against fossil-based alternatives. The same rationale holds true for preferential loans. Operating support can take the form of a Feed-in-tariff or a Feed-in-premium on the produced renewable hydrogen or an exemption from a levy with a view to reducing the cost of electricity. Another option is to adapt the tax system, for example by increasing the energy tax on fossil fuels.

Some **Member States** have already set up or are in the process of setting up support instruments for renewable hydrogen. In the Netherlands, for example, the SDE++ scheme provides subsidies for the use of technologies for the generation of renewable energy and other CO_2-reducing technologies, including hydrogen electrolysers.[31] The German government published its national hydrogen strategy shortly before the European Commission in June 2020.[32] The strategy foresees CAPEX support for electrolysers as well as instruments to reduce operating costs and a support scheme to import renewable hydrogen from outside the EU[33]. Furthermore, operating costs for domestic electrolysers are reduced, through an exemption from the EEG-levy (Germany's renewable energy surcharge).[34] One support instrument that is widely discussed at national levels are Carbon Contracts for Difference (CCfDs). These have received significant support from industry, with Germany set to hold first auctions for CCfDs in 2022.

What the above review of policy instruments shows is that there are **several instruments which use auctions**. Auctions will likely be most relevant for the time frame up to 2030. During this time, significant support for demand and supply is required. The expectation is that after 2030, markets for renewable hydrogen have established and that instruments can focus on maintaining demand, e.g. through quotas on specific end use sectors. In line with these considerations, the auction-based options discussed in this policy report focus on

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[30] It should be noted that in some cases, demand and supply consist of the same actor, i.e. the same company.
[31] https://english.rvo.nl/subsidies-programmes/sde
[32] https://www.bmwi.de/Redaktion/EN/Publikationen/Energie/the-national-hydrogen-strategy.pdf?__blob=publicationFile&v=6
[33] https://h2-global.de/
[34] This exemption cannot be used in practice so far, as Germany is still awaiting state aid approval for this measure. The provision can be found Article 96b : https://www.gesetze-im-internet.de/eeg_2014/__69b.html.

the short-term.

An auction is a competitive process to allocate an incentive (e.g. support) based solely on the bids submitted by participating bidders according to transparent award rules. In an auction, the government sets the auction volume demanded, bidders offer a price for their project proposals, and the auctioneer ranks bids. The resulting price level is defined either at the level at which the auction volume is met by the ranked bids (uniform pricing) or by each bid (pay-as-bid).

There are two main **arguments in favour of using auctions**: First, they allow an efficient allocation of support at a support level that is competitively determined and timely updated. This is especially relevant when the technology and market develop rapidly. Secondly, they allow for non-discriminatory volume control and thus control of total support budgets. Another advantage is that competition between producers is created, which may lead to lower prices for consumers. The success of auctions depends on the competition levels in an auction, the design elements chosen and how well they address specific characteristics of a technology and market.

3 Practical, near-term auction models for hydrogen

This chapter discusses **four different auction models for the support of hydrogen**. Two options focus on auctions for the demand side, while the other two options focus on the supply side. All four options consider the two key challenges introduced above in chapter 2 – the missing infrastructure and market. The options were developed for short-term implementation. With developed markets and infrastructure, options may need to be adapted.

Each of the four options seeks to address a specific requirement we identified:

- **Option 1**: Demand-side auction for hydrogen to support the ramp-up hydrogen demand to help achieve targets for the use of hydrogen in the industry
- **Option 2**: Double-sided auction for hydrogen derivatives to provide security to producers to invest in new electrolysers and industry offtakers to switch to green derivatives
- **Option 3**: Supply-side auction to help move towards EU hydrogen strategy capacity target of 40 GW
- **Option 4**: Joint auction for hydrogen and renewable energy to support the joint deployment of RES and electrolysers

To make the options as concrete as possible, we made several assumptions:

- Auctions need sufficient competition to work properly. We assume that there will be enough actors interested in the demand and supply side of the hydrogen market in the short term (see section 82.2 on market developments).
- We also assume that policymakers take the potential number of participants and projects into account when setting the auction volumes to support.
- We assume that the political framework for hydrogen does not change fundamentally between the proposal for a RED II revision and the actually adopted revision. This implies that we assume a high demand for industry-focused support programs.
- We also assume that the sustainability criteria for renewable hydrogen are considered in all options.

One more consideration to mention here is that because of the limited infrastructure and the focus on short-term options, some options ask for offtake agreements. These can ensure that demand and supply are matched with bilateral transport arrangements. The following chapters describe the basic idea and functioning of each of the four models and touch upon auction design considerations. Further details will need to be elaborated for each of the four models.

3.1 Demand-side auction

3.1.1 Use case

The focus of this **demand-side auction for hydrogen**, which covers the cost gap between renewable hydrogen and fossil-based hydrogen from the perspective of an industrial consumer, is on enabling hydrogen use as a feedstock or energy carrier in industry. Today, hydrogen is particularly relevant in the industry for iron, steel, ammonia, and fuels (including high value chemicals) production. Hydrogen functions here primarily as a feedstock for industrial processes.[35] In the future, renewable hydrogen could be used to either substitute fossil-based hydrogen in industrial processes where hydrogen is already used today as a feedstock, or, as a decarbonisation solution in exchange for a fossil fuel such as natural gas. Likewise, derivatives can be used as decarbonisation solutions in exchange for fossil fuels such as kerosene.

The use of renewable hydrogen in industry is expected to grow significantly in the future. This growth

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[35] https://gasforclimate2050.eu/wp-content/uploads/2021/06/EHB_Analysing-the-future-demand-supply-and-transport-of-hydrogen_June-2021_v3.pdf

expectation has been underlined by the proposal for the **RED II revision**. It proposes a binding renewable hydrogen target of 50% for hydrogen used in industry.[36] If adopted as such, Member States are obliged to create the conditions for national fulfilment of this target.

One option to do so is to hold a demand-side auction for industry. By bridging the cost gap between renewable hydrogen and fossil-based hydrogen, the proposed auction model can encourage new demand for green hydrogen and ensure the simultaneous ramp-up of new supply. The participation of industrial consumers in the auction would be voluntary. **Incentives to participate** could emerge from corporate sustainability targets, the aim to "green" a product to appeal to a certain group of end-consumers or from the goal of ramping-up the corporate learning curve on the application of renewable hydrogen in production processes. A long-term strategy to avoid CO_2-costs in view of rising CO_2-prices in the EU ETS could also be a strong motivation to participate.

3.1.2 Auction model

The basic idea of this **auction model and its procedure** are shown in Figure 5. In the auction, the participating industrial consumers compete for support payments per unit (kg or kWh) of renewable hydrogen that cover the difference between their willingness to pay for hydrogen and the price at which hydrogen supply is offered to them in a bilateral offtake agreement. The bidder with the lowest bid would be awarded.

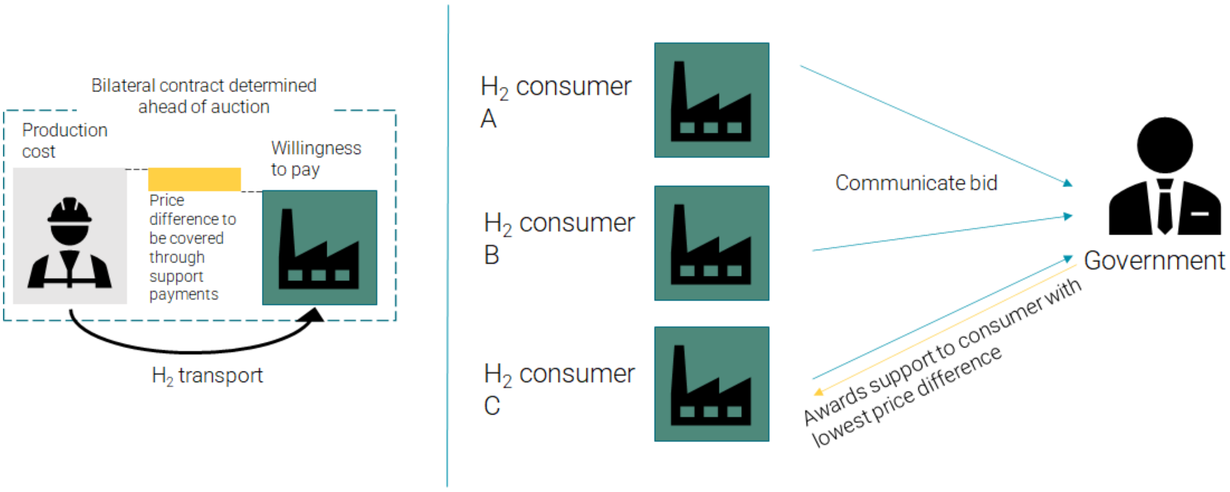

Figure 5 Demand-side auction model

The existence of the offtake contract between producer and consumer is a prequalification requirement for the auction. Thus, ahead of the auction, the industrial consumer that intends to place a bid in the auction would need to find a supplier for the hydrogen. Whether this company is only responsible for the construction of the electrolyser or also for the later operation can be decided between the parties. The parties would negotiate a **bilateral offtake agreement**. The offtaker has an incentive to negotiate well and keep the price difference as low as possible to allow for placing a competitive bid. The parties also need to organize the transport of the renewable hydrogen from the electrolyser to the industrial plant, which is therefore priced into the auction bid accordingly. Thereby, the auctioneer can ensure that the delivery of hydrogen is considered and accounted for and that supply and demand ramp-up in parallel.

Based on the bilateral negotiations, the offtaker can determine the **price difference between its willingness to pay and the costs of hydrogen supply to be covered by the auction**. It can be expected that participating industrial consumers will base their willingness to pay on the price of the current energy source/feedstock (and the related CO_2 price) that it will replace with renewable hydrogen. In addition, it may be willing to pay a

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[36] https://ec.europa.eu/info/sites/default/files/amendment-renewable-energy-directive-2030-climate-target-with-annexes_en.pdf

small premium based on the above benefits. In addition, in view of the proposed "labelling of green industrial products" in the RED II revision and the future emergence of green lead markets, industry consumers may have expectations about the price premiums they may add to their "green" products in the future, thereby lowering the overall required funding.[37]

Ceiling prices are implemented to ensure that bids are not overstated. There is currently no market price for renewable hydrogen that can be used as orientation, hence a proxy is needed to determine a feasible ceiling price. The calculation could be based on the level of abatement costs in different industry applications. Bidders are awarded up to a certain threshold which may either be installed capacity, cumulative production volumes or budget.

Regarding the **form of support**, we recommend that the auction should award either a fixed Feed-in-Premium or a Contract for Difference. The advantages of a fixed Feed-in-Premium are that it is relatively simple, provides high predictability on support payments for the auctioneer and high incentive for bidders to negotiate well with their hydrogen suppliers. The disadvantage is that it increases the risk of the winner's curse because long-term price forecasts are necessary but related to high uncertainties. A Contract for Difference on the other hand effectively reduces risks for the bidder. However, it provides lower predictability of the total support costs for the auctioneer.

In the auction, it may be necessary to **differentiate between industrial consumers** which already use (fossil-based) hydrogen in their processes today, e.g. as a feedstock, which would just need to change the type of hydrogen from fossil-based to renewable hydrogen and those consumers that do not use any hydrogen today by opening different support windows. For the latter, there can be significant costs related to the retrofitting of processes. These industrial consumers may need additional financial support.

3.2 Double-sided auction for derivatives

3.2.1 Use case

The focus of a double-sided auction for derivatives is to provide security to hydrogen producers to invest in new electrolyser capacities and for industry offtakers to switch to green derivatives. Derivatives have the benefit of being easier to transport than pure hydrogen. They can be transported by ship and truck and do not require a dedicated pipeline infrastructure. The electrolyser location is thus not bound to the location of the offtaker but can be further away, possible even outside the EU.[38] The auction model described below could thus enable the **import of derivatives** for consumption by industry consumers in the EU.

The double-sided auction would function as a **platform for matchmaking**. While the production and trade of derivatives based on fossil-based hydrogen is well-established, markets and new supply routes for green derivatives have not established yet. Hence, a coordination is required to ensure that demand and supply meet. The double-sided auction could fulfil this function while at the same time targeting large groups of actors on both sides, thereby enhancing competition, and lowering prices. This design of this double-sided auction is comparable to the German H2Global concept.[39]

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[37] The interplay between labelling and the emergence of green lead markets is described in more detail in this report by Agora Energiewende and Guidehouse (2021). Making renewable hydrogen cost-competitive: https://static.agora-energiewende.de/fileadmin/Projekte/2020/2020_11_EU_hydrogen-Instruments/A-EW_223_hydrogen-Instruments_WEB.pdf

[38] For example, countries such as Chile, Australia, Namibia, or the UAE have significant natural resource potential for renewable energy (e.g. high solar radiation, strong winds), enabling the cheap production of renewable electricity. In the future, this could enable the production of renewable hydrogen at low prices.

[39] https://h2-global.de/

3.2.2 Auction model

The double-sided auction would, as the name suggest, target both the supply and the demand side. By competitively selecting suppliers offering derivatives at the lowest price as well as those offtakers with the highest willingness to pay for derivatives, the price difference between supply and demand that needs to be covered through funds of the intermediary is minimised. On the supply side, the **derivative producers** have high CAPEX and OPEX as well as potential extra investment costs to fulfil the EU's sustainability criteria. The sum of these costs plus the cost of transporting the derivatives to a certain location determine the price at which producers can offer their derivatives to the intermediary. Producers compete for the lower supply price. Producers that can tap into cheap renewable electricity potential and/or into other support funds (e.g. investment support offered by the country in which they are located) have a competitive advantage over others as these producers can offer their product at a lower price.

On the **demand-side**, the offtakers communicate their willingness to pay to the intermediary. The intermediary closes contracts with both sides. No bilateral offtake agreement between supply and demand is required. The difference between the production price and the offtaker's willingness to pay is covered by intermediary through dedicated funds (see also Figure 6).

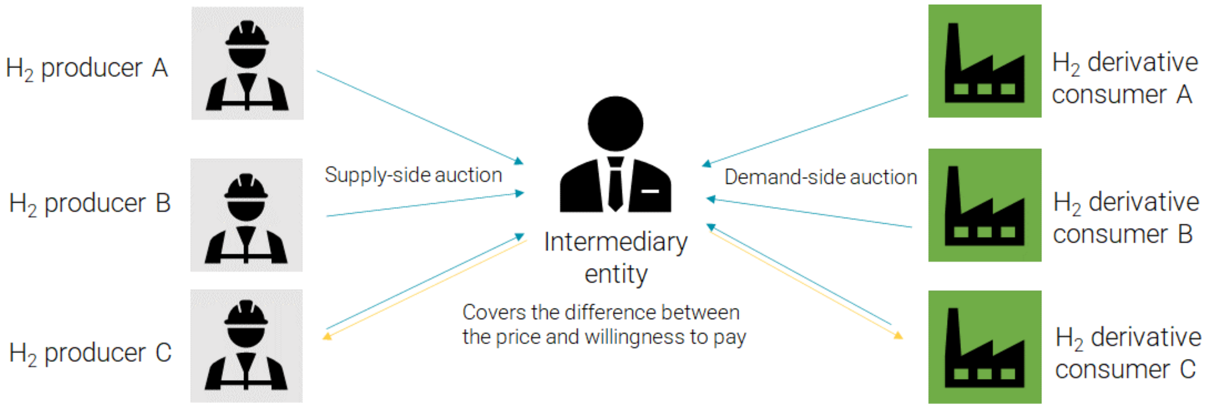

Figure 6 Double-sided auction model for derivatives

While we already make some implicit recommendations above, some design questions for the auction need to be further elaborated:

- How does the landing of derivatives work? Would the derivatives be shipped to a dedicated harbour or one of several industrial clusters? How is the landing point determined?
- What are feasible contract durations? Producers require long-term security which can be provided through the contracts, however offtakers may only want to be bound for e.g. 5 years to take advantage of expected price degressions.

3.3 Supply-side auction

3.3.1 Use case

The supply-side auction could be used to move towards the EU's strategic electrolyser capacity goal of 40GW by 2030. The large-scale production of renewable hydrogen is currently rather unattractive to investors, as the cost of producing renewable hydrogen is significantly higher than for fossil-based alternatives and consumers are not yet willing or able to pay a significant premium for renewable hydrogen. There is thus no market at the current production price. A supply-side auction model that allocates support to the production of renewable hydrogen can be applied to bring prices at which renewable hydrogen can be offered to certain offtakers down to a competitive level, therefore enabling investments in additional electrolyser capacities. The auctioneer can steer in which sectors the renewable hydrogen will be used by defining target demand sectors or even specific applications.

3.3.2 Auction model

In this model, suppliers that require the lowest amount of support to fulfil a supply contract are competitively selected. As in the demand-side auction, a **bilateral offtake contract** is required to ensure that transport is considered and that supply and demand ramp-up in parallel. In case the auctioneer has pre-defined eligible demand sectors/applications, the supplier needs to find an offtaker in this specific sector. As a result of this bilateral matchmaking, the electrolyser would most likely be constructed in close geographic proximity to the offtaker to reduce transport costs.[40]

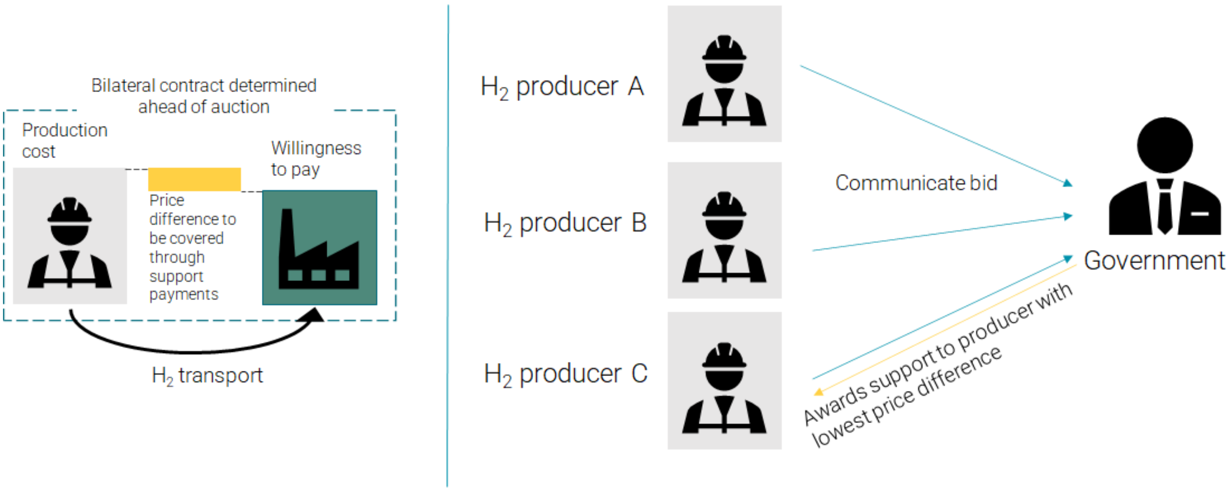

Figure 7 Supply-side auction model

As shown in Figure 7, in the auction, different hydrogen producers would enter their bids for support. The auctioneer would implement a ceiling price to ensure that bids are not overstated. The auction can award either investment support or operating aid. **Up-front investment support** entails a fixed upfront payment to the developer of the electrolyser which is related to installed capacity (i.e. x € per kW). The grants provided as investment support lower the equity and debt required, thus also lowering the costs of debt, which increases the cost-effectiveness of the support. Investors have up-front clarity about the level of support being paid to the project, as it is not dependent on production volumes. Furthermore, investment support is administratively relatively easy to implement. In principle, up-front investment support may be implemented without any additional (direct or indirect) operating support. However, given the cost of operation (i.e. the cost of renewable electricity), the provision of up-front investment support may not be sufficient to trigger hydrogen production.[41] In addition, the selection of projects according to a €/kW value does not reflect actual hydrogen production and may result in comparably higher support costs in terms of €/kg hydrogen. As a result, minimum generation requirements may be needed to make bids more comparable.

Alternatively, the auction could pay **operating support** for every unit of renewable hydrogen produced. Generally speaking, operating support would incentivize plant output and could, depending on the form of operating support, effectively reduce risks related to costs and revenues for the project developer/operator. Furthermore, operating support would reduce the risk for governments of paying support without receiving benefits in case of unexpected project failure. However, on the flipside, operating support would also entail a certain administrative burden for the supporting entity since it must be paid over longer time.

Given the current high investment costs for electrolysers, up-front investment support could be helpful to incentivize investors by partially unloading the financial pressure from capital expenditure at the beginning

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[40] The RED II mentions in Recital 90 the requirement that there is a "temporal and geographical correlation between the electricity production unit with which the producer has a bilateral renewables power purchase agreement and the fuel production". A delegated act will specify the criteria further. The delegated act is expected to be published at the end of 2021.

[41] https://static.agora-energiewende.de/fileadmin/Projekte/2020/2020_11_EU_hydrogen-Instruments/A-EW_223_hydrogen-Instruments_WEB_2.pdf

of a project. However, currently, only 1/3 (possibly 1/6 in 2030) of renewable hydrogen production costs comes from investment, and the other 2/3 (possibly 5/6 in 2030) of them result from operating expenses (see section 2). Therefore, up-front investment support can lead to certain risks, such as project failure or discontinuance since it cannot provide financial and operational security throughout the lifetime of the production plant. Operating support, on the other hand, can ensure a secure financial income (for renewable hydrogen producers) or a stable and affordable price (for renewable hydrogen consumer) throughout the support period.

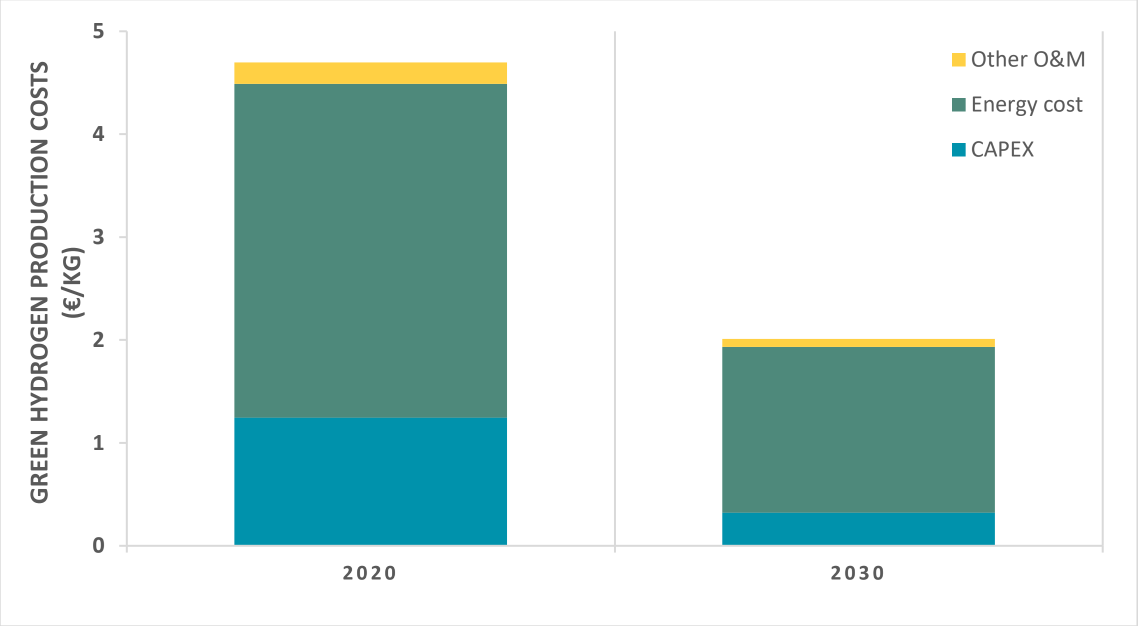

Figure 8 Breakdown of renewable hydrogen production cost for regions with average resources such as offshore, wind-based electrolysis in Central Europe (own compliant based on Hydrogen Council and McKinsey & Company (2021)[42])

3.4 Joint auctions for hydrogen and renewable energy

3.4.1 Use case

To be recognized as “renewable”, hydrogen production must adhere to the sustainability criteria that will be defined in a Delegated Act[43] by the European Commission. One option for producers of renewable hydrogen is to source renewable electricity from the grid. For this case, the Delegated Act will further clarify the criteria relating to the additionality of renewable electricity sourced, as well as geographical and temporal correlation between the electrolyser and the renewable electricity generation assets. Another option is to establish a direct connection between the electrolyser and new renewable electricity generation assets, which simplifies the proof of producing “renewable” hydrogen and ensures the additional deployment of renewables.

Joint auctions for hydrogen and renewable energy can ensure the simultaneous deployment of hydrogen and the renewable electricity required for the production of hydrogen. The main conceptual rationale for jointly developing the two assets is that a project planner can optimise both assets better than separate actors,

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[42] Hydrogen Council and McKinsey & Company (2021): Hydrogen Insights, A perspective on hydrogen investment, market development and cost competitiveness, URL: https://hydrogencouncil.com/wp-content/uploads/2021/02/Hydrogen-Insights-2021-Report.pdf

[43] The Delegated Act was due to be published by the end of 2021.

streamlining project development processes, improving the joint configuration and operation of the two assets, and reducing total investment costs. However, to what extent these efficiency gains materialise in practice is unclear. A likely use case is the combination with offshore wind, as currently discussed in e.g. the Netherlands, Denmark, and Germany. This option is investigated in more detail in chapter 4.

From the **perspective of a project operator**, the joint development and operation of both assets can hold many advantages. The project operator has higher flexibility to react to electricity wholesale market developments. At low electricity market prices, the electrolyser can produce hydrogen. At high electricity market prices, the electrolyser can be run at minimum baseload and the remaining electricity can be sold on the electricity wholesale market. Joint auctions can also enable technical optimization, which may be necessary to make use of grid optimization potential. It can also underline the additionality of the new hydrogen production. Since there will be a direct connection between the renewable electricity assets and the electrolyser, the realization of electrolysis is made dependent on the realization of renewable energy. This makes it easier to prove additionality, which then benefits the certification of renewable hydrogen. This dependency also reduces risks in project development - at least when compared to a situation where hydrogen producer is directly dependent on RE capacities that need to be developed in parallel but are auctioned separately.

From a **system level perspective** or the perspective of the auctioneer, joint auctions hold additional advantages: they support the ramp-up of both technologies, enable economies of scale, allow for better coordination of deployment, and reduce the need for grid expansion by demanding a direct connection between the electrolyser and the renewable energy source. Furthermore, the auctioneer can define suitable sites within the joint auction, based on integrated planning of renewable energy deployment, grid development, hydrogen infrastructure including natural storage possibilities and renewable hydrogen demand centres.

An important choice regarding the **technical set-up** of the joint project (RES + electrolyser) is the connection type of the electrolyser. It can be either on-grid or off-grid. Off-grid means that the electrolyser is restricted to the full load hours of the RES plant. The combination of different RE technologies (e.g. solar PV and onshore wind) or the combination with battery storage could increase the full load hours and predictability of operation for the electrolyser but comes at additional costs. On-grid means that the electrolyser can run independent of the full load hours of the renewable energy source as it can also source electricity from the grid. The choice thus has an impact on the operating hours and hence the hydrogen production costs, which decrease at large operating hours.[44] The preferred technical set-up of the new assets (i.e. ongrid or offgrid connection) would need to be defined as part of the auction.

3.4.2 Auction model

The joint auction can be designed in many regards like the supply-side auction described in section 3.3. Ahead of the auction, the hydrogen producer and hydrogen offtaker would need to align on costs, delivery period, transport, and other contractual elements. The considerations from the demand-side auction on the willingness to pay by the offtaker apply here as well. Like in the general supply-side auction, the existence of a business plan and offtake contracts are eligibility criteria for the auction. The transport between the electrolyser and the hydrogen offtaker would need to be organized between the two parties.

As shown in Figure 9, during the auction, different hydrogen producers would enter their bids, which are based on the price difference between the willingness to pay by the consumers and the hydrogen production price. The auctioneer would implement a **ceiling price** to ensure that bids are not overstated. The lowest bids are awarded in the auction (i.e. the auction criterion is price). Regarding the form of support, both investment or operating support are possible and already discussed above for the supply-side auction.

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[44] This interplay between full load hours and costs per kg of hydrogen is explained in more detail in the following publication: Agora Energiewende and Guidehouse (2021). Making renewable hydrogen cost-competitive: https://static.agora-energiewende.de/fileadmin/Projekte/2020/2020_11_EU_hydrogen-Instruments/A-EW_223_hydrogen-Instruments_WEB.pdf

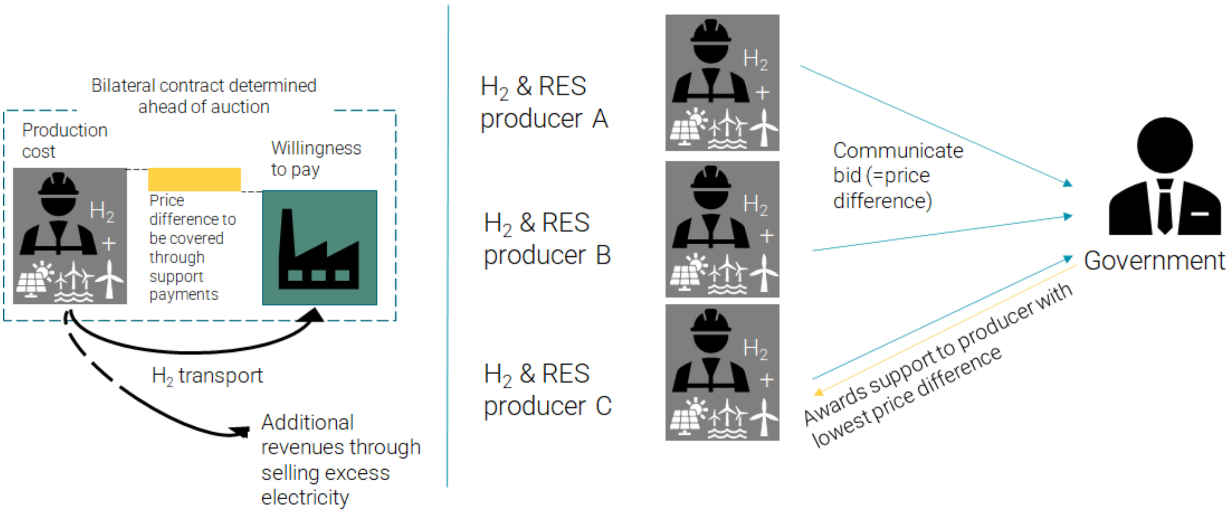

Figure 9 Joint auction for hydrogen and renewable energy

4 Auctions for offshore wind and hydrogen

As mentioned previously, offshore wind energy is often mentioned as an attractive renewable energy source for combination with hydrogen production. This chapter thus seeks to explore the joint deployment of both technologies more closely. This chapter provides a broad mapping of the topic, including an indication when offshore hydrogen electrolysers can be expected, why the discussion about them is relevant and what technical set-ups could look like. The analysis provided here is rather high-level and meant as an introduction into the topic. Further research will be required to discuss open questions and technical options.

The **combination of offshore wind power and the production of hydrogen** is increasingly discussed as it has the potential to produce large volumes of hydrogen. In addition, such a combination can support the integration of offshore wind power and reduce pressure on power transmission infrastructure. In the Netherlands, Denmark and Germany, first steps towards offshore hydrogen production are made. The Danish energy firm Orsted is developing a 2 MW demonstration project under the hydrogenRES scheme, which will be able to produce up to roughly 1,000 kilograms of renewable hydrogen per day.[45] The Danish energy island concept also foresees the production of renewable hydrogen based on offshore wind energy.[46] In the Netherlands, the PosHYdon project received €3.6 million funding to produce renewable hydrogen from renewable electricity.[47] In Germany, the national hydrogen strategy has clarified that offshore wind energy will play an important role and the maritime spatial plan includes two designate areas for offshore production of hydrogen.[48]

Potential benefits of using parts of the North Sea offshore wind power for hydrogen production are the reduced need of offshore and onshore transmission capacity and reduced congestion in the transmission system. By increasing the demand for offshore wind power and shifting parts of the offshore wind power to periods with higher prices on wholesale markets, hydrogen as well as other PtX and storage technologies may improve the business case for offshore wind. Offshore wind energy has very high full load hours compared to other RE technologies. This means that offshore wind can provide more baseload and thus plannability for the operation of the electrolyser. At the same time, the combination of offshore wind with hydrogen production is associated with significant costs (both CAPEX and OPEX) making additional financing necessary.

Combining offshore wind energy with hydrogen production has the potential to change the entire project setup significantly by impacting the infrastructure costs, the need for connection and transmission capacities (for electricity and hydrogen), the flow of electricity to the connected market areas, and the need for support payments. The magnitude of impacts on the offshore wind park, and hence the necessity to account for those in the support scheme and tender design, strongly depend on how the offshore wind assets are combined with the hydrogen assets.

There are two decisive aspects regarding the technical configuration of combining hydrogen production with offshore wind energy – firstly, the positioning of the electrolyser (onshore or offshore) and secondly the connection of the electrolyser (on-grid vs. off-grid, see section 3.4). Also, the ratio of capacities between the offshore wind park and the electrolyser determine the impact of the hydrogen production on the offshore wind park.

Hydrogen production combined with offshore wind energy can be done **onshore or offshore**. When producing hydrogen offshore several options exist for the placement of the electrolysers, including existing gas or oil platforms, dedicated new platforms or artificial islands, and in or on (e.g. on the gallery of) wind turbines.

When **producing hydrogen onshore**, electrolysers can be installed close to shore near the landing points of the offshore electricity transmission cables that connect the offshore wind park with the onshore electricity

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[45] https://www.cnbc.com/2021/01/20/denmark-to-trial-green-hydrogen-production-using-offshore-wind-power.html
[46] https://fuelcellsworks.com/news/denmark-decides-to-construct-the-worlds-first-windenergy-hub-as-an-artificial-island-in-the-north-sea-to-include-green-hydrogen/
[47] https://www.tno.nl/en/focus-areas/energy-transition/roadmaps/towards-co2-neutral-industry/hydrogen-for-a-sustainable-energy-supply/world-first-green-hydrogen-production-in-the-north-sea/
[48] https://www.bmwi.de/Redaktion/EN/Publikationen/Energie/the-national-hydrogen-strategy.pdf?__blob=publicationFile&v=6

transmission grid or deeper inland. Installing electrolysers close to the shore instead of deep inland is advantageous in that electrolysers can contribute significantly to the onshore grid integration challenge resulting from a large-scale deployment of offshore wind energy e.g. in the North Seas. Electrolysers at coastal regions can reduce grid congestion and curtailment of offshore wind energy significantly by converting electricity into hydrogen during periods when offshore wind generation exceeds the hosting capacity of the onshore electricity transmission grid. Therefore, the need for expanding the onshore transmission grid can be reduced. Another advantage is the lower cost for onshore electrolysers. Furthermore, production is technically easier as e.g. no saltwater desalination plants are required.

However, given certain circumstances, there are also major advantages of installing **electrolysers offshore**:

- There are potential overall cost advantages regarding the infrastructure. Analysis shows that this is especially the case when wind parks are located far offshore (>80 km), meaning expensive HVDC technology would be required for onshore grid connection. Instead, existing (retrofitted) offshore gas infrastructure can be used, which make the offshore production of hydrogen the cheaper option.[49,50,51]
- Electrolysers can be installed close to the intermittent renewable energy source (the offshore wind park). This avoids transport losses and helps stabilise the offshore electricity transmission grid, which reduces the need for expensive electricity transmission infrastructure offshore and onshore.
- The placement of electrolysers offshore may also eventually incur less public resistance due to lower spatial impact at shore and security concerns.

There are however also disadvantages to producing hydrogen offshore. The costs for the offshore electrolyser will likely be higher compared to onshore. However, as mentioned above, other costs can be reduced. Which effect is larger from a system level perspective cannot be answered conclusively (and is highly dependent on the concrete context). Further disadvantages are that the electrolysers are operated in a more challenging environment, which requires additional high investment costs for the electrolysers platforms that do not occur for onshore hydrogen production, and seawater desalination plants are required to supply electrolysers. With a view to infrastructure, the retrofitting of existing gas infrastructure or new dedicated hydrogen pipelines is required as well as infrastructure to enable the transport of other eventually produced chemicals, such as methanol, and the side products from the electrolysis process (oxygen, heat, etc.) to shore. Furthermore, space constraints for existing oil or gas platforms (mother platforms can host approximately 250 MW and satellite platforms can host approximately 60 MW electrolyser capacity)[52] need to be considered.

In the short term up to 2030, offshore hydrogen production is unlikely due to technical challenges. Pilot projects are required to assess the feasibility of potential solutions to these challenges. However, in the mid to long-term, it is generally expected that offshore hydrogen production will be an important pillar in the European hydrogen supply market.

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[49] World Energy Council (2017): Bringing North Sea energy ashore efficiently. https://www.weltenergierat.de/wp-content/uploads/2018/03/Bringing-North-Sea-Energy-Ashore-Efficiently.pdf

[50] DNV GL, 2018. Power-to-Hydrogen IJmuiden Ver. https://www.tennet.eu/fileadmin/user_upload/Company/Publications/Technical_Publications/Dutch/P2H_IJmuiden_Ver_-_Final_Report_-_Public.pdf

[51] Jepma et al. (2018): North Sea Energy - D3.6 - Towards sustainable energy production on the North Sea - Green hydrogen production and CO2 storage: onshore or offshore?

[52] World Energy Council (2017): Bringing North Sea energy ashore efficiently. https://www.weltenergierat.de/wp-content/uploads/2018/03/Bringing-North-Sea-Energy-Ashore-Efficiently.pdf

Illustrations of different technical set-ups for offshore hydrogen production

The following options outline the different basic technical set-ups for the joint development of offshore wind and hydrogen production, focusing purely on set-ups where the offshore wind park and the electrolyser are in close geographic proximity and directly connected. Each technical design entails specific advantages and disadvantages which are listed in the tables below each figure.

Option 1: Offshore wind park with offgrid electrolyser

In Figure 10, the electrolyser is placed offshore with the wind park. It is solely connected to the wind farm. Thus, all electricity for hydrogen production is sourced from the wind park itself. There is no connection to the general electrical grid, meaning that the electrolyser is off-grid. The wind park itself is also not connected to the general electricity grid, meaning again that all produced electricity is used for hydrogen production. The produced hydrogen is transported to shore via a pipeline or ship.

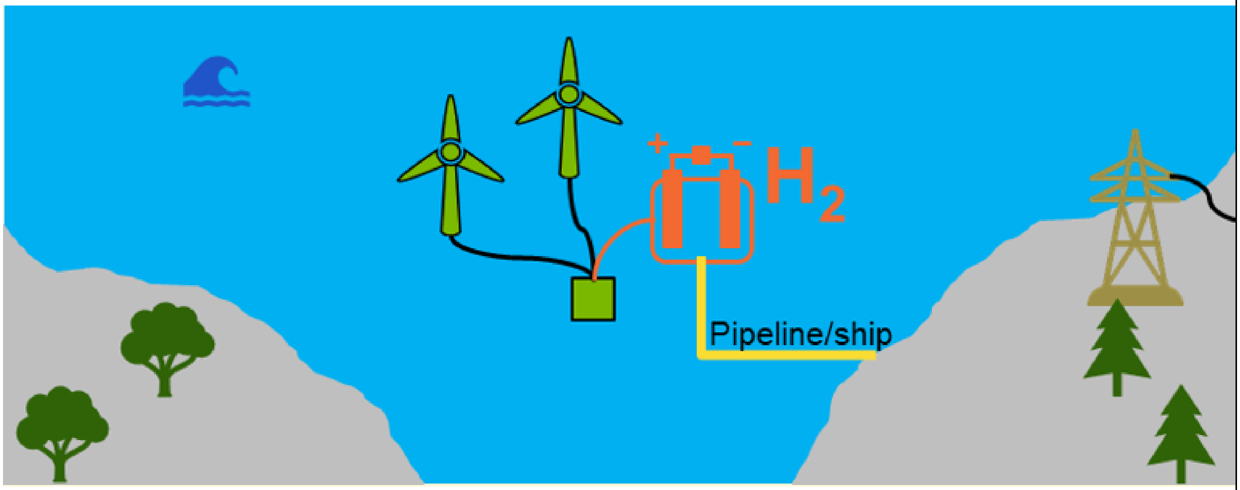

Figure 10 Offshore wind park with off-grid electrolyser

Advantages	Disadvantages
• Electrolyser operates with 100% renewable energy • Offshore wind park has no impact on onshore electricity grid • Electricity costs for electrolyser equals LCOE of offshore wind park • Less land use onshore • No electricity transmission infrastructure costs offshore and onshore	• Hydrogen production in challenging environment • Desalination plant required • Offshore wind park and electrolyser capacity must be aligned • Operating hours of electrolyser limited to full load hours of wind park • Wind park can participate on hydrogen market only

Option 2: Offshore wind park with off-grid electrolyser and electrical infrastructure to shore

In the next option illustrated in Figure 11, the electrolyser is placed offshore. It is off-grid, meaning that as before, it only receives electricity from the wind park, not from the general grid. In this instance, the wind park is not only connected to the electrolyser but also to the general grid, meaning that produced electricity can be sold to the market. The produced hydrogen from the electrolyser is transported to shore via ship or pipeline.

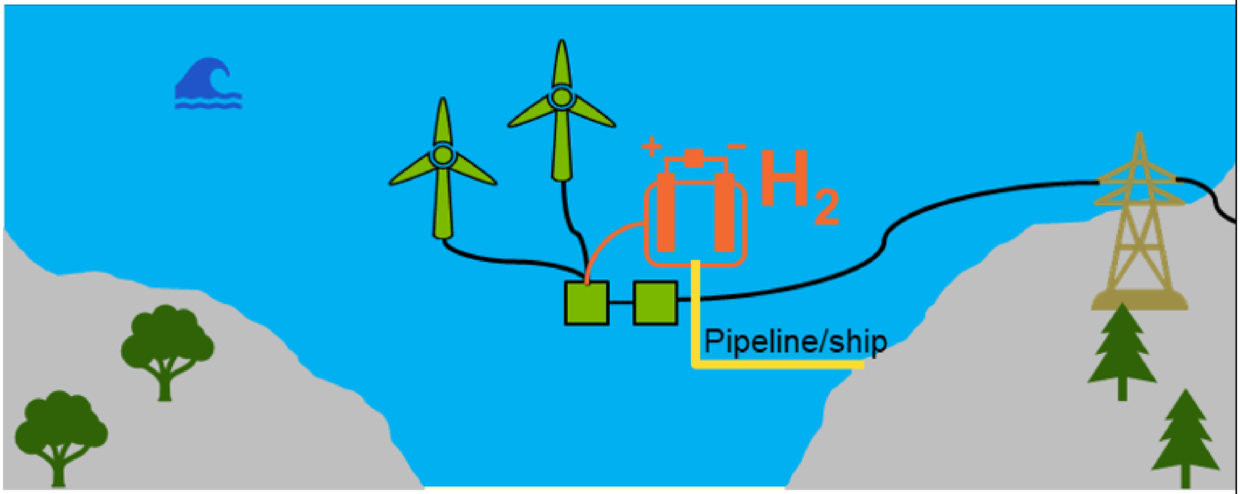

Figure 11 Offshore wind park with off-grid electrolyser and electrical infrastructure to shore

Advantages	Disadvantages
• Same advantages as above • Wind park can participate on electricity and hydrogen market • Offshore wind park and electrolyser capacity must not be aligned	• Hydrogen production in challenging environment • Desalination plant required • Operating hours of electrolyser limited to full load hours of wind park • Additional infrastructure costs compared to option above due to the additional electrical infrastructure

Option 3: Offshore wind park with hybrid connection electrolyser

In the third and last option, the electrolyser has a hybrid connection, meaning that it can source electricity from the wind park directly but also from the general grid. The wind park is connected to both the electrolyser and the general grid. The renewable hydrogen is transported to shore via pipeline or ship.

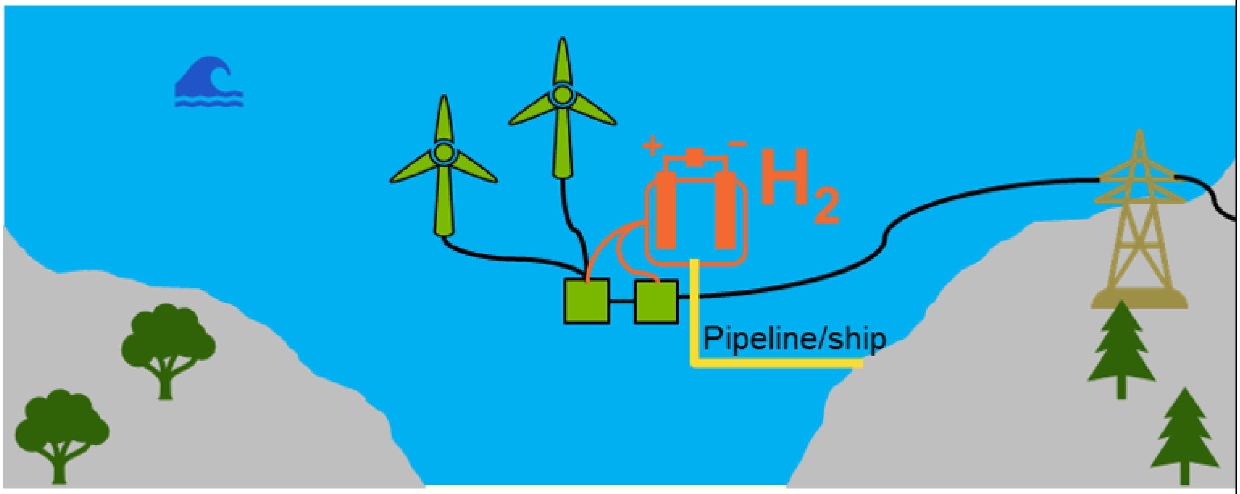

Figure 12 Offshore wind park with hybrid connection electrolyser

Advantages	Disadvantages
• Electrolyser can operate with electricity from offshore wind park and from the grid • Capacity factor of electrolyser not limited by offshore wind park capacity • Electrolyser can support onshore grid integration • Offshore wind park can participate at electricity and hydrogen market • Only limited additional infrastructure costs compared to option 2	• Hydrogen production in challenging environment • Desalination plant required

Which of the options illustrated above is the most sensible depends on the specific context. Generally, the last project configuration illustrated in Figure 12 has the most advantages. Project developers of the offshore wind park could participate on the electricity and hydrogen market and — due to the hybrid connection of the electrolyser — hydrogen production is not limited to the availability of offshore wind energy and it can be tracked if the electrolyser is operated by electricity provided by the offshore wind park or by the electricity grid. Furthermore, due to its connection to the electricity grid, the electrolyser could support the reliable grid operation offshore and onshore.

5 Conclusion and further considerations

Auctions can be used to competitively allocate available support funds to renewable hydrogen projects. To enable policymakers to implement such hydrogen auctions, this report introduced important considerations regarding challenges and sketched out possible near-term auction models for different policy needs. Six points are especially relevant:

First, in the near-term, policy instruments need to account for the fact that there is currently limited infrastructure and no market for renewable hydrogen. While electricity infrastructure is already today widely available, hydrogen infrastructure has yet to grow beyond dedicated industry clusters. With a view to the market, there is currently extremely limited demand for renewable hydrogen beyond pilot projects as it is very costly in comparison to alternatives.

Second, to support the uptake of hydrogen in industry, a demand-side auction could be implemented. The use of renewable hydrogen in industry is expected to grow significantly in the future. This growth expectation has been underlined by the proposal for the RED II revision. It proposes a binding renewable hydrogen target of 50% for hydrogen used in industry. By bridging the cost gap to renewable hydrogen, the proposed auction model can encourage new demand and ensure the simultaneous ramp-up of new supply.

Third, a double-sided auction for derivatives could be implemented to provide security to producers to invest in new electrolyser and to industry offtakers to switch to green derivatives. This auction model could enable the import of derivatives for consumption by industry consumers in the EU by functioning as a platform for matchmaking. While the production and trade of derivatives based on fossil-based hydrogen is well-established, markets and new supply routes for green derivatives have not established yet. Hence, a coordination is required to ensure that demand and supply meet.

Fourth, to move towards the EU's strategic electrolyser capacity goal of 40GW by 2030 a supply-side auction could be implemented. The large-scale production of renewable hydrogen is currently rather unattractive to investors, as the cost of producing renewable hydrogen is significantly higher than for fossil-based alternatives and consumers are not yet willing or able to pay a significant premium for renewable hydrogen. To move towards the EU's capacity goal, renewable hydrogen production needs to be supported so that prices are reduced to a competitive level.

Fifth, a joint auction could be implemented to support the simultaneous deployment of hydrogen electrolysers and renewable energy projects. The main conceptual rationale for jointly developing the two assets is that a project planner can optimise both assets better than separate developers, streamlining project development processes, improving the joint configuration and operation of the two assets, and reducing total investment costs.

Sixth, offshore wind is especially attractive for such joint auctions as it has the potential to enable large production volumes of hydrogen. In addition, a combination with hydrogen production can support the integration of offshore wind power and reduce pressure on power transmission infrastructure. By increasing the demand for offshore wind power and shifting parts of the power to periods with higher prices on wholesale markets, hydrogen as well as other PtX and storage technologies may improve the business case for offshore wind. Offshore wind energy has high full load hours compared to other RE technologies, providing for more operating hours and plannability for the electrolyser.

The AURES II project traditionally focuses on renewable energy sources. This policy brief was the first on hydrogen and intended as a high-level introduction into the topic of hydrogen auctions. There are many design considerations that require further analysis and considerations.

AURES II is a European research project on auction designs for renewable energy support (RES) in the EU Member States.

The general objective of the project is to promote an effective use and efficient implementation of auctions for RES to improve the performance of electricity from renewable energy sources in Europe.

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