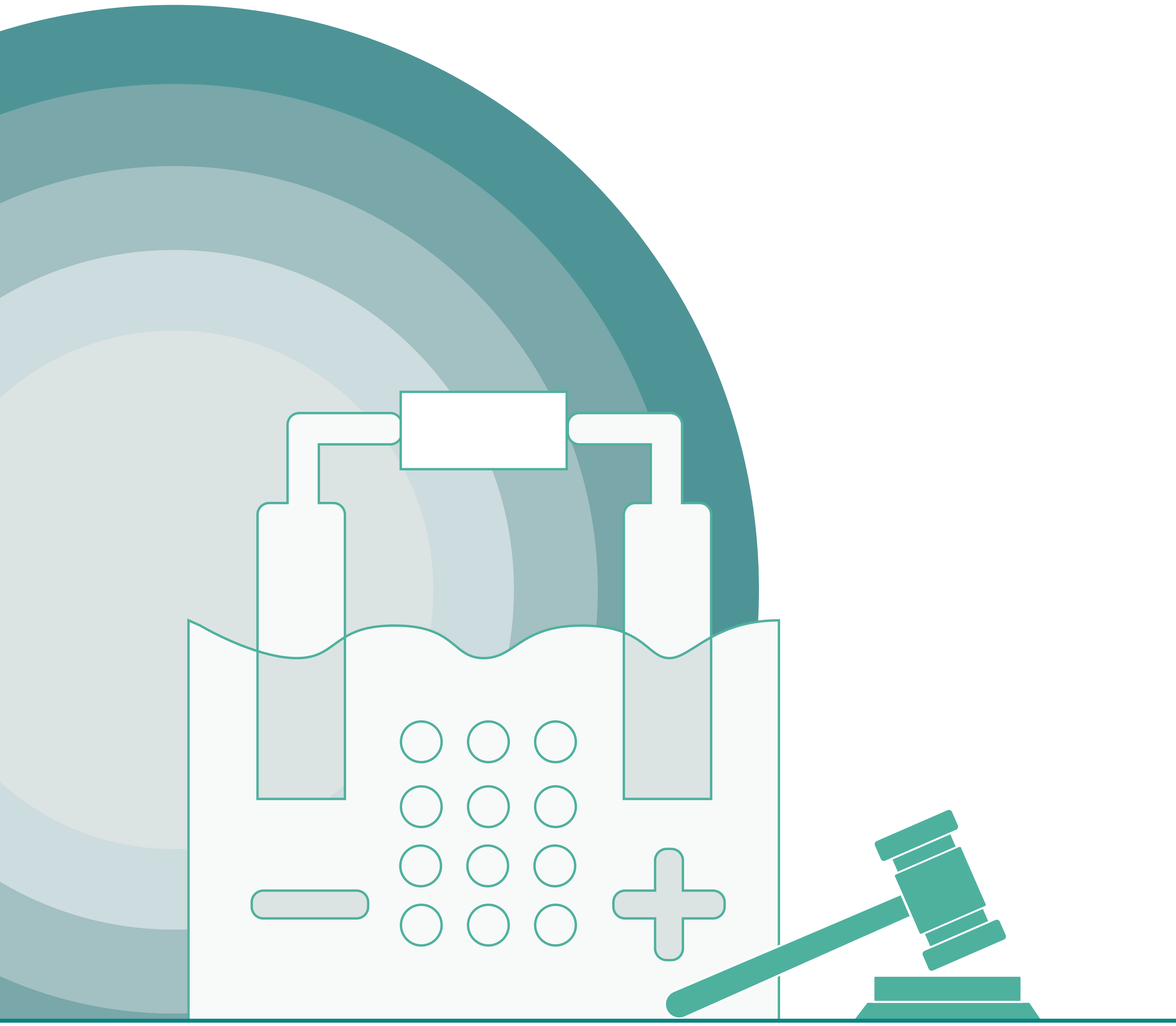
IRENA
International Renewable Energy Agency

Green hydrogen auctions

A guide to design



ISBN: 978-92-9260-617-6

Citation: IRENA (2024), *Green hydrogen auctions: A guide to design*, International Renewable Energy Agency, Abu Dhabi

About IRENA

The International Renewable Energy Agency (IRENA) serves as the principal platform for international co-operation, a centre of excellence, a repository of policy, technology, resource and financial knowledge, and a driver of action on the ground to advance the transformation of the global energy system. An intergovernmental organisation established in 2011, IRENA promotes the widespread adoption and sustainable use of all forms of renewable energy, including bioenergy, geothermal, hydropower, ocean, solar and wind energy, in the pursuit of sustainable development, energy access, energy security and low-carbon economic growth and prosperity.

www.irena.org

Acknowledgements

This report was developed under the guidance of Raul Alfaro Pelico (Director, IRENA Knowledge, Policy and Finance Centre), Ute Collier (IRENA) and Rabia Ferroukhi (ex-IRENA). It was authored by Diala Hawila, Emanuele Bianco and Abdullah Fahad (IRENA); Vasilios Anatolitis (IRENA consultant) and Fabian Wigand (Tetratech).

IRENA colleagues Ann-Kathrin Lipponer, Arno van den Bos, James Walker and Patricia Wild provided valuable contributions.

Inputs were also provided by: Cristian Carraetto (EBRD), Joseph Cordonnier (OECD), Jazaeer Dawody (Energimyndigheten), Pablo Del Rio Gonzalez (IRENA consultant), Daniele Di Nepi (DESNZ), Javier García Fernández (European Commission), Dolf Gielen (World Bank), Michelle Hallack (World Bank), Emanuel Henrich (H2Global), Leandro Janke (Agora Energiewende), Jan Klenke (H2Global), Paul Komor (IRENA Technical Reviewer), Yury Melnikov (Mylonastar), Susana Moreira (H2Global), Roland Schulze (EIB), Eisuke Tachibana (AfDB), Moeketsi Thobela (AfDB) and Miguel Vazquez (Bocconi).

Publication and editorial support was provided by Francis Field and Stephanie Clarke. The report was edited by Erin Crum, with design by Strategic Agenda.

For further information or to provide feedback: publications@irena.org

This report is available for download: www.irena.org/publications

Disclaimer

Contents

Figures

Tables

Boxes

Abbreviations

AaaS	Auctions-as-a-Service
BOO	build-own-operate
BOOT	build-own-operate-transfer
CAPEX	capital expenditures
CfD	contract for difference
CO_2eq/kg	carbon dioxide equivalent per kilogram
COP28	28th Conference of the Parties
DBFOM	design-build-finance-operate-maintain
DKK	Danish kroner
EHB	European Hydrogen Bank
EPC	engineering, procurement and construction
ESIA	environmental and social impact assessment
ETS	emissions trading system
EU	European Union
FID	final investment decision
GHG	greenhouse gas
GHPA	green hydrogen purchase agreements
GJ	gigajoule
GW	gigawatt
H2	hydrogen
HAR1	Hydrogen Allocation Round
HBPM	Hydrogen Business Production Model
HPA	hydrogen purchase agreement
HSA	hydrogen sale agreement
IGHP	independent green hydrogen producer
IMF	International Monetary Fund
INR	Indian rupees
IRA	Inflation Reduction Act
IRENA	International Renewable Energy Agency
ITC	investment tax credits
kg	kilogram
kt	kilotonne
LCOE	levelised cost of electricity
LCOH	levelised cost of hydrogen
LCR	local content requirement
Mt	million tonnes
MW	megawatt
NZHF	Net Zero Hydrogen Fund
OPEX	operating expenses
PEM	polymer electrolyte membrane
PPA	power purchase agreement
PTC	production tax credit
PV	photovoltaic
R&D	research and development
RES	renewable energy source
SDE++	Stimulation of Sustainable Energy Production and Climate Transition
OWE	Subsidieregeling Opschaling volledig hernieuwbare waterstofproductie via elektrolyse
SIGHT	Strategic Interventions for Green Hydrogen Transition
TSO	transmission system operator
UAE	United Arab Emirates
UK	United Kingdom
US	United States
VRE	variable renewable energy

Executive summary

Green hydrogen will play a big part in decarbonising hard-to-abate sectors, but its deployment and development require policy support. Competition-based tariffs, or auctions, can be considered, taking into account their strengths and limitations.

Clean hydrogen[1] accounts for about 12% of greenhouse gas (GHG) emissions abatement in 2050 under the International Renewable Energy Agency's (IRENA's) 1.5°C Scenario to decarbonise hard-to-abate sectors and to be used as feedstock for industrial applications. The benefits of green hydrogen go beyond reducing GHG emissions. Green hydrogen can enable green industrialisation, energy independence, increased participation in global trade and markets, and job creation. Driven by these potential benefits, policy makers are increasingly embarking on ambitious plans to support the development of green hydrogen in their jurisdictions. As of May 2024, 52 countries had a hydrogen strategy or roadmap in place, 52% of which are emerging and developing economies.

Competitive public procurement – or auctions – is emerging as a tool to promote green hydrogen production and use. Auctions – like all tariff-based support schemes – offer long-term revenue certainty, allow for long-term budgetary planning and enable moving forward on the technology learning curve. In addition, the competitive nature of auctions can enable true price discovery and the revelation of a feasible remuneration for the producers and the willingness to pay of the consumers, thereby minimising the overall cost of public support. Auctions also provide a clear pipeline of future projects, provide transparency in the selection of projects and the level of support they receive; they can ensure timely delivery of what is promised in the bids, and they can be designed to achieve broader policy objectives for green hydrogen deployment or to address specific barriers.

1 For the purpose of this report, "clean hydrogen" refers to both "blue" and "green" hydrogen. For the color-coding meaning, please refer to Figure 1

However, auctions are successful in bringing down prices only if there is sufficient competition. In addition, the price pressure resulting from auctions can lead to projects not being realised, the sector being compressed, and potentially an inability to invest in innovation and technological improvement. For smaller producers, the upfront resources needed to take part in the auction without the guarantee of winning a contract may deter their participation, reducing competition and posing disadvantages for small and medium-sized businesses, which impacts the market liquidity and goal of developing an upstream hydrogen sector when such a goal is set. These negative repercussions can be avoided through tailored auction design.

There are different types of auctions to support green hydrogen, with varying geographic reach.

Auctions can be held domestically, *i.e.* off-takers and producers are within the same country borders such as in India; regionally, *i.e.* off-takers and producers are within the same bloc such as the European Hydrogen Bank auction; and internationally, *i.e.* off-takers and producers can be anywhere within the designated countries such as the H2Global auction. There are four types of auctions.

In supply-side auctions (subject of this report), the competition takes place between hydrogen producers. Supply-side auctions aim at scaling up electrolyser capacity and the production of green hydrogen (or its derivates). They are particularly suitable in cases where there is good potential for renewable energy sources and logistical capabilities. They can reflect the set targets in a straightforward way.

In demand-side auctions, hydrogen consumers compete for support. Demand-side auctions may create incentives for hydrogen imports, as the supported end users may opt for importing hydrogen (or derivatives) from other countries rather than from domestic producers. While such a process could result in decarbonising industries, it would not directly lead to the development of a domestic green hydrogen sector. Demand-side auctions are relatively easy to embed in a country’s industrial policy, as policy makers can target specific end-use sectors.

Double-sided auctions and joint supply- and demand-side auctions aim to support both the supply and demand sides mostly through matchmaking the hydrogen producers with the consumers. By competitively selecting suppliers offering green hydrogen at the lowest price as well as those off-takers with the highest willingness to pay for the product, the price difference between supply and demand that needs to be covered through funds of the intermediary is minimised. Joint supply- and demand-side auctions are a subset and simplification of the double-sided auction whereby bids have to include hydrogen supply and off-take. This type of auction typically requires on-site hydrogen production and demand consortia which are often physically co-located or include the transport infrastructure.

Green hydrogen auctions should be designed in a way that helps deliver the policy objectives pursued in the national green hydrogen strategy.

Drawing upon lessons learnt from renewable power auctions,[2] this report has been developed to guide policy makers in the design of auctions to deploy green hydrogen to achieve defined policy objectives, recognising the opportunities this instrument has for encouraging project developers to submit high-quality bids, and promote transparency and fair competition in the allocation of support or contracts, while minimising the resources used to support deployment.

Policy objectives that may be pursued include achieving climate and environmental goals; developing a local green hydrogen economy with localised value chains to enhance energy security or participate in the international trade of green hydrogen and diversify energy exports; and attracting foreign investments in energy-intensive industries and supporting their international competitiveness.

If the primary aim is to decarbonise economies at the lowest price, countries or jurisdictions could consider design elements that aim for lowest price and reduced cost of support such as: technology-neutral auctions that favour only the lowest-price technologies, winner selection criteria based on price only, and the introduction of a ceiling price above which bids would not be considered. Such approaches would be unlikely to support the development of local value chains but could suit countries such as Japan and the Republic of Korea, which are likely to focus on imports rather than in-country production.

Countries or jurisdictions that want to decarbonise while simultaneously increasing energy security through local green hydrogen production (*e.g.* China, India) might consider a schedule of auctions to attract investments in upstream activities, auctions that aim at developing specific technologies, and winner selection criteria and qualification requirements aimed at local content. Provisions to avoid market concentration may also be considered to encourage new players and accelerate hydrogen market liquidity.

Countries or jurisdictions with ample renewable energy, land and water resources that would like to engage in international hydrogen trade (*e.g.* Morocco) might consider design elements that aim for competitive prices while supporting innovation and industrial development. Design elements to consider include denominating the contracts in hard currency or including indexation clauses to inflation.

It should be noted that domestic value creation, industrial linkages, technological learning and permanent employment are more likely to be achieved when green hydrogen is produced for local uses, *i.e.* for decarbonising the domestic economy and for promoting green industrialisation, as planned in Namibia, Türkiye, Uruguay and the United Arab Emirates (UAE). Countries in this category can benefit from building up a green heavy industry and exploiting their early-mover potential in the international trade of green commodities. In this case, auctions can be organised for procuring green products (*e.g.* green steel, green ammonia) to create more value in downstream activities.

2 IRENA has produced an extensive body of knowledge on the topic that can be found at www.irena.org/Energy-Transition/Policy/Renewable-Energy-Auctions.

Auctions should also be designed in a way to address challenges and barriers such as those related to system integration of variable renewable energy and hydrogen transport.

In countries with high shares of variable renewable energy (VRE), auction design can aim at supporting system integration. One example is site-specific auctions whereby locations are selected such as to avoid electricity grid constraints or those that provide guidance in the form of incentives/requirements to guide siting to or away from pre-determined zones with lower integration costs. In liberalised power markets, selecting projects based on price only while avoiding electricity price-based support level indexation can lead to the lowest-price projects being designed to produce when renewable electricity is cheapest, leading to a higher system integration. Setting a maximum amount of annual full-load hours for electrolysers or a maximum amount of support hydrogen can also be an option.

To address barriers related to green hydrogen transport, auctions can be designed to procure derivatives or green products, or they can allocate the costs and risks associated with transport to the public entity facilitating the auction.

Regardless of other policy priorities, auctions should be designed in a way to ensure environmental and social sustainability and should adhere to the concept of additionality.

Under qualification and documentation requirements, proof of project sustainability and social contracts can ensure that the projects selected satisfy social and environmental sustainability criteria. These include proof of balanced use of land and water resources including credible arrangements to access water resources sustainably, proof of a land lease agreement, and passing an environmental and social impact assessment (ESIA). Social contracts in the context of green hydrogen production projects primarily revolve around the welfare of local communities and can vary depending on the specific context, as those implemented in Chile and South Africa. They include revenue-sharing agreements, job opportunities for community members and investments in community development, such as improved housing and healthcare facilities for communities. These criteria can also be embedded as winner selection criteria, assigning weights to each of the objectives considered and scoring projects accordingly. In developing countries with limited access to electricity, developers may be required to allocate a share of renewable energy production to local electricity consumption; in water-stressed areas, they may include agreements to support local agriculture through sustainable water management practices or desalination projects sized to provide water to the local population (UNIDO, IRENA and IDOS, 2023).

In case the green hydrogen produced is for export, additionality requirements might be imposed by importing markets to ensure that hydrogen production does not displace the use of renewable electricity (*e.g.* the European Union). Many low- and middle-income countries with abundant solar and wind energy in Africa, the Middle East, Southern Asia and the western regions of South America have some of the most promising sites for green hydrogen production. Most of these countries currently have very limited renewable energy production capacity, and substantial efforts will be necessary to increase it (to decarbonise their carbon-intensive power system or provide access to electricity) before or at the early stages of green hydrogen production. Imposing strict additionality requirements can cause complexities and increase project costs which may hinder the rapid deployment of hydrogen. It should be noted that the concept of additionality addresses the negative indirect impacts of using grid power but it should vary from one jurisdiction to another to address unique challenges such as power outages, grid constraints, limited access of local communities to electricity, and varying levels of compliance and monitoring capabilities. A nuanced approach that considers these factors should be adopted.

Auctions alone are not enough. Their success relies on them being part of a broader mix of policies with effective policy coordination among the different sectors and strong international collaboration.

In addition to the auction, other deployment policies and financing instruments can be used to attract or support private investment (*e.g.* concessional funds, capital subsidies, grants and tax incentives). In addition, integrating policies stipulate how public investments can fund infrastructure and assets that integrate green hydrogen into the energy system (*e.g.* pipelines or storage facilities). Enabling policies include targets and long-term energy plans, active policies to create a demand for green hydrogen (quotas, carbon contracts for difference, retirement of fossil fuel-based applications), industrial policies, fossil fuel subsidy removal, public money to support, capacity building and training, and research and development (R&D). Macroeconomic policies (fiscal, monetary and currency exchange policies) affect the delivery of public funds towards green hydrogen. Under structural change and just transition policies, public funds can go into policies to ensure that the energy transition promotes social inclusion, among many other priorities.

The global policy framework defines international collaboration, which is key for knowledge exchange, technology transfer, collaboration in hydrogen technology and R&D. In addition, international collaboration for the development of international standards and certifications for, sustainability, safety and, operations of hydrogen production are crucial for fostering market growth. International collaboration is also essential for establishing early green hydrogen trade corridors. Such collaborative efforts are crucial for pooling resources, sharing knowledge, setting common standards and accelerating the development of hydrogen infrastructure. Finally, international collaboration is also linked to hydrogen trade objectives including imports, exports and achieving self-sufficiency through trade partnerships and policies implemented in different countries. For example, policies that promote green hydrogen domestic production in advanced economies (*e.g.* the Inflation Reduction Act in the United States – see Box 2) may discourage investment in developing countries that lack comparable subsidy schemes.

Finally, the development of green hydrogen calls for coordination across various policy areas to lay the foundation for robust localised value chains, including education and training, infrastructure, and industrial and structural policies aimed at facilitating a fair and sustainable expansion of the domestic market. Strategic interventions and instruments aimed at green industrial diversification, encouraging both existing and emerging industries to engage in the production of green goods and maximise the benefits of green hydrogen, must be prioritised. Such diversification has the potential to create more value and jobs and enhance the export potential of high-value green goods compared with only producing and exporting hydrogen. Countries that are unable to generate significant linkage effects should integrate green hydrogen trade with benefit-sharing mechanisms in order to prevent the creation of export-driven energy enclaves and ensure a green hydrogen roll-out that is deeply embedded in and advocates for a just transition.

1 Introduction

IRENA's pathway to achieving the Paris Agreement's goal of limiting the global temperature rise to 1.5°C by 2050 is outlined in the 1.5°C Scenario in the *World Energy Transitions Outlook* (IRENA, 2023a). Along with renewable use in power generation and direct uses of renewable energy (*e.g.* modern use of biomass), energy efficiency and conservation measures, and electrification of end-use sectors, clean hydrogen[3] and its derivatives such as ammonia and methanol are an essential component of the Scenario to decarbonise hard-to-abate sectors.[4] It can furthermore be used as feedstock for industrial applications. Clean hydrogen accounts for about 12% of GHG emissions abatement in 2050 under the 1.5°C Scenario (IRENA, 2023a).

Policy makers are increasingly paying attention to the role of clean hydrogen in climate abatement. In the "UAE Consensus", the outcome of the climate negotiations at the 28th Conference of the Parties (COP28), clean hydrogen is recognised as one of the solutions needed for deep, rapid and sustained reductions in GHG (UNFCCC, 2023).

The benefits of clean hydrogen in general and green hydrogen – derived from renewable sources through water electrolysis (see Figure 1) – in particular go beyond reducing GHG emissions to reinforcing energy security and creating opportunities for green industrialisation. Green hydrogen can spark a transformation with beneficial impacts on the economic and social dimensions of sustainability: economic through green industrialisation, energy independence, increased participation in global trade and markets; and social through job creation and reliable energy access. For countries with vast renewable energy potential, land and water resources, the production of green hydrogen can open avenues for green industrial development and local value creation including job creation, skills upgrading, investment mobilisation and wealth generation. This is particularly attractive for developing countries, for reinforcing their overall economic resilience and facilitating the development of diversified and knowledge-based economies (UNIDO, IRENA and IDOS, 2023).

3 For the purpose of this report, "clean hydrogen" refers to both "blue" and "green" hydrogen. For the color-coding meaning, please refer to Figure 1.

4 Hard-to-abate sectors are energy-intensive sectors for which electrification may not be practicable, if not impossible, such as steel, cement, chemicals, long-haul maritime shipping and aviation. For these sectors, a clean hydrogen solution can be the "missing link".

Driven by these potential benefits, policy makers are increasingly embarking on ambitious plans to support the development of clean hydrogen in their jurisdictions. As of May 2024, about 52 countries and had a hydrogen strategy or roadmap in place, with more than 50% share from emerging and developing economies[5] (IRENA, 2024). Such strategies offer clear policy direction for the industry about future market conditions by explicitly outlining targets across the value chain. Although these plans differ in terms of targets and measures, they address similar issues that arise when creating a sustainable green hydrogen market.

Clean hydrogen still faces many challenges and barriers requiring government intervention and support. These include providing regulatory clarity and stability (*e.g.* by setting and committing to concrete targets, establishing standards, easing permitting), providing support for early movers (*e.g.* providing access to public funds and blended finance), and policies that create demand (*e.g.* quotas and targets, financial incentives, and off-take or price guarantee schemes).

In particular, competitive public procurement – or auctions – is emerging as a tool to promote green hydrogen production and use while reducing public expenditure, with multiple countries interested in this instrument. The interest in auctions can be attributed to their successful use for the deployment of renewables-based power: in 2022 alone, a record-breaking 100 gigawatts (GW) of renewable power capacity was rewarded through auctions (IEA, 2023a).

Auctions can be used to create demand for green hydrogen and create the enabling conditions for its deployment. It is a competition-based mechanism whereby the government (or appointed auctioneer) issues a call for tenders to procure or support the procurement of a certain quantity of green hydrogen (or its derivatives) or capacity of electrolyser installed (Section 4.1 lays out the different options for the *Auctioned product*). Typically, developers or producers/sellers who participate in the auction – referred to as bidders – submit a bid with a price per unit of green hydrogen (or derivatives) produced/sold or electrolyser installed. The auctioneer evaluates the offers based on the price, and other criteria depending on the auction design (see Section 4.4 for options for *Winner selection criteria*), and awards support or a purchase agreement (see *Type of remuneration* in Section 4.5.2) to the successful bidder(s). In some cases, the auctioneer is not the off-taker, but plays the role of a matchmaker between the sellers and the buyers and guarantees off-take.

Drawing upon lessons learnt from renewable power auctions,[6] this report has been developed to guide policy makers in the design of auctions to deploy green hydrogen to achieve defined policy objectives, recognising the opportunities this instrument has for encouraging project developers to submit high-quality bids, and promote transparency and fair competition in the allocation of support or contracts, while minimising the resources used to support deployment.

The report begins with a brief overview of the current status of hydrogen production and use, followed by the main barriers to green hydrogen deployment, and discusses some of the instruments (production-based support) that can help address some of these barriers (Chapter 2). Chapter 3 makes the case for the use of auctions as one of the possible instruments and presents the types of auctions that can be considered. The rest of the brief focuses on supply-side auctions. Chapter 4 lays out the design elements based on IRENA's framework for the design of renewable energy auctions and provides insights on the trade-offs to consider between producing green hydrogen at the lowest price, which is considered the primary objective of competitive procurement processes and achieving other policy objectives.

5 According to country classification laid out in World Economic Outlook 2023 by the International Monetary Fund (IMF).

6 IRENA has produced an extensive body of knowledge on the topic that can be found at www.irena.org/Energy-Transition/Policy/Renewable-Energy-Auctions.

2 Green hydrogen: Status, barriers and support instruments

2.1 Hydrogen production and use

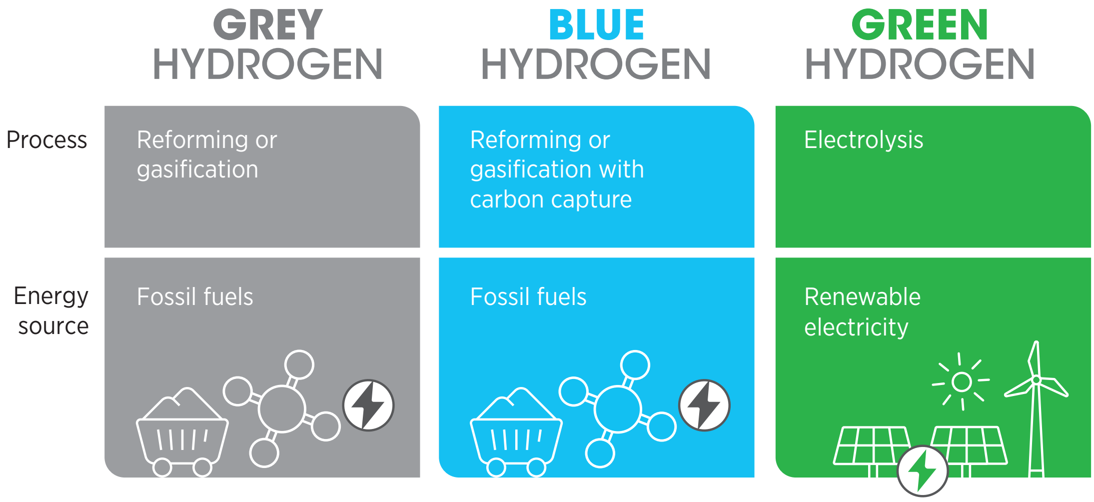
Hydrogen is an energy carrier and can be produced from a variety of energy sources. It is already widely produced, in particular for uses in petrochemical and chemical industries (IRENA, 2022a).

2.1.1 Hydrogen production

Since hydrogen can be produced from different sources, a colour-coding system has emerged to differentiate between the processes (Figure 1). Green hydrogen refers to hydrogen that is produced from water electrolysis fuelled by renewable electricity. As the most established technology option to produce clean hydrogen, it is the subject of this report.[7]

7 It should be noted that other technologies are under investigation to produce hydrogen from renewable energy, but have, at the time of writing, low technological readiness levels and cannot be supported with competition-based instruments, and are therefore excluded from the analysis.

Figure 1 Selected colour-coded typology of hydrogen production



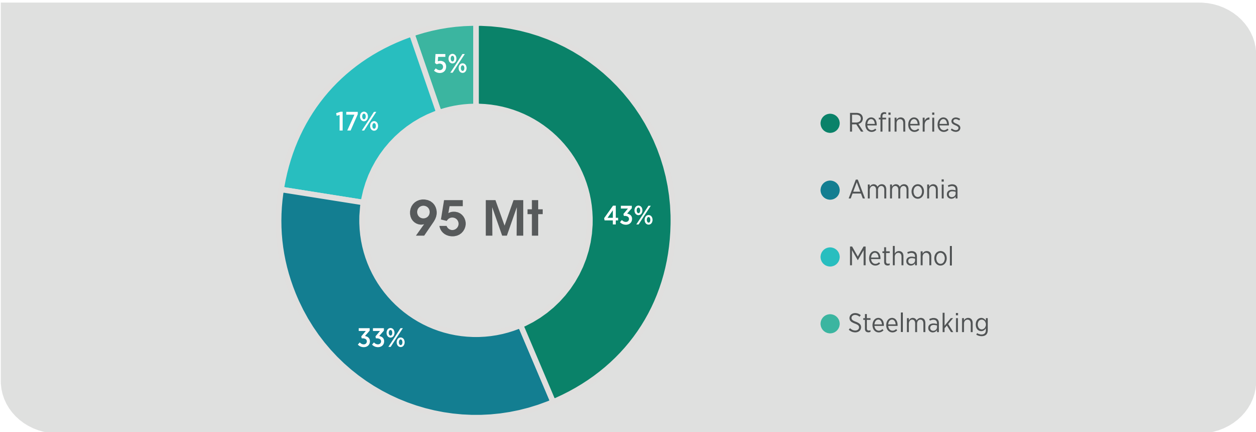
Source: (IRENA, 2020a).

About 95 million tonnes (Mt) of hydrogen were produced globally in 2022 and China, India, the Middle East, the Russian Federation and the United States accounted for about 70% of the global hydrogen produced that year (IEA, 2023b) which was almost completely grey, from natural gas (62% of total production) and coal (21% of total production). By-product hydrogen, which is produced at refineries and in the petrochemical industry during naphtha reforming, accounted for 16% of global production. Only 0.7% of the total production in 2022 was either green or blue (IEA, 2023b).

2.1.2 Hydrogen use

Of the 95 Mt of produced hydrogen in 2022, 43% was used in the oil refining industry, for hydrotreating and hydrocracking, followed by the production of ammonia and methanol – accounting for 33% and almost 17% of hydrogen consumption, respectively (Figure 2). Almost all the ammonia (85%) is used to produce fertilisers, exposing food prices to shocks in natural gas prices. A small share of current hydrogen production is used in the direct reduction of iron for steel production (5%).

Figure 2 Main uses of hydrogen in 2022



Source: (IEA, 2023b).

2.1.3 Greenhouse gas emissions from hydrogen production

Although the combustion of hydrogen does not produce any direct carbon emissions, its fossil-based production contributes to significant GHG emissions. The current emissions intensity of global hydrogen production is 12-13 kilogram carbon dioxide equivalent per kilogram of hydrogen (kg CO_2eq/kg H_2) (IEA *et al.*, 2023). The hydrogen sector, therefore, is responsible for 1.3 gigatonnes (Gt) of GHG emissions every year. To put it into perspective, this is around four times the emissions of a country such as the United Kingdom.

Among the different shades of hydrogen, green hydrogen from water electrolysis is the most suitable for fully sustainable energy and has been gaining increased interest in the past few years (IRENA, 2020a). First, green hydrogen production is consistent with the net-zero route, with no GHG emitted in the production phase. Second, the cost of production of green hydrogen is decreasing with the falling costs of renewable energy technologies together with technological improvement. Finally, electrolysers can bring flexibility to the grid.

2.2 Barriers to green hydrogen uptake

Green hydrogen faces barriers that prevent its full contribution to the energy transformation. Barriers include those that apply to all shades of hydrogen, such as the lack of dedicated infrastructure for increased use (*e.g.* transport and storage infrastructure), and those mainly related to the production stage of electrolysis, faced only by green hydrogen.

It is possible to categorise the main barriers faced in the early stages of green hydrogen development into four main categories: technological barriers, economic barriers, institutional barriers and social barriers. Table 1 presents these barriers, which are described in detail in IRENA (2024) and previously in IRENA reports (IRENA, 2020a, 2021, 2022a). The rest of this section describes many of these barriers, and introduces the role that auctions may play in addressing them. How auctions can be designed to address these barriers is found in Chapter 4.

Table 1 Main barriers to green hydrogen uptake

Technological	Economic	Institutional	Social
Immaturity of specific hydrogen technologies	High and uncertain production cost	Regulatory framework not ready for green hydrogen sector	Public awareness and acceptance
Energy consumption and losses and hydrogen losses	High delivery cost	Lack of coordination among national public bodies	Fear of missing out on hydrogen
Poor compatibility of existing energy infrastructure with hydrogen	Lack of suitable end uses	Conflicting drivers and lack of policy ambition	Lack of investor confidence
	First movers' disadvantage		
	Lack of know-how, personnel and skill sets		

High production costs. Considerable reduction in the cost of producing green hydrogen will be necessary to unlock its full potential. The production costs are estimated to be three to six times higher than for grey hydrogen (USD 3/kg to USD 6/kg versus USD 1/kg to USD 2/kg), even in the most favourable production sites. Major cost factors include the renewable electricity required to power electrolysers and the cost of electrolysers. The competition brought on by auctions can lead to the selection of locations with abundant renewable resources to enhance the cost-competitiveness of green hydrogen. In addition, reducing electrolyser costs – including through innovation and competition[8] – could potentially lead to an 80% reduction in investment costs in the long term (UNIDO, IRENA and IDOS, 2023).

Uncertainty regarding levelised costs. The levelised cost of hydrogen (LCOH) serves as a critical metric for assessing the production cost of hydrogen, analogous to the levelised cost of electricity (LCOE) for renewable energy sources. This metric encompasses many components and expenses involved in hydrogen production (Box 1). The real LCOH for large green hydrogen production is still to be discovered; being a nascent technology, identifying all the costs incurred is challenging, and it is therefore key to understand of the full spectrum of costs involved and the impact of various factors. Competitive procurement mechanisms can help with actual price discovery (see Section 3.1).

Box 1 The levelised cost of hydrogen

The calculation of LCOH starts with the cost of the power supply, specifically the LCOE of the electricity used in the process. It then incorporates the capital expenditure (CAPEX) for electrolysers, which includes not just the electrolyser stack but also the entire balance of plant. This encompasses power electronics, gas/liquid separator units, purification units, water tanks, pumps, and utilities such as water supply, cooling services and nitrogen supply. Furthermore, hydrogen processing infrastructure such as storage tanks and compressors are considered, alongside indirect costs such as expenses for engineering, procurement and construction (EPC) contractor selection and management, budget contingencies, feasibility studies, pilot projects, permitting, financial arrangements, land and grid fees, insurance, and ramp-up tests.

Another crucial element in determining the LCOH is the capacity factor, which reflects the annual operational hours of the electrolyser; a higher capacity factor results in a lower LCOH, enhancing the economic viability of hydrogen production.

A recent increase in CAPEX has been identified, driven by financing, labour, materials costs, inflation and a slower-than-expected scaling of the market. As a result, the costs associated with electrolyser systems, particularly for alkaline electrolysis, have risen more than initially anticipated, marking an increase of 46-65% since 2022 (Wang, 2024). For instance, the Hydrogen Council's estimates for the United States (US) Gulf Coast region's LCOH escalated from USD 2.9/kg to USD 5/kg.

The prevalent uncertainty surrounding the actual costs indicates that achieving cost-competitive green hydrogen production remains a moving target subject to fluctuations in underlying cost drivers and market dynamics.

Source: (Hydrogen Council and McKinsey & Company, 2023).

8 Key actions include increasing the size of electrolysis plants to achieve economies of scale; leveraging learning rates to drive down costs; and optimising material sourcing to reduce reliance on scarce materials (UNIDO, IRENA and IDOS, 2023), which can be targeted by the design of the auction.

High costs and barriers associated with hydrogen transport. According to IRENA's 1.5°C Scenario, around 25% of hydrogen production could be internationally traded by 2050, with about half transported through pipelines. The international transport of green hydrogen remains hindered by regulatory and technological uncertainties, impeding its cost-effective transport in line with environmental and technical standards. Transporting hydrogen generates additional costs, between USD 0.05/kg H_2 and USD 2/kg H_2, depending on the means of transportation, volumes and distance (IRENA, 2021). Maritime transport of hydrogen (including conversion and reconversion) can increase costs significantly, placing countries located outside the pipeline distance from major import hubs at a comparative disadvantage (UNIDO, IRENA and IDOS, 2023). The compression process, considering the capital costs of the compression plant and electricity consumption, adds around USD 1/kg H_2 to USD 1.5/kg H_2. Similarly, the liquefaction process could add around USD 2/kg H_2 to USD 3/kg H_2. Estimates of the cost of conversion from hydrogen to ammonia in 2030 are in the range of USD 0.4/kg to USD 0.9/kg. Reconversion can double or triple these costs; however, as ammonia can be used as a feedstock and fuel source, this process may not be required. As such, auctions can be designed to procure derivatives or green products (see *Auctioned product* in Section 4.1), or they can be designed in a way that transport is handled by the auctioneer (see R*esponsibility for transport* in Section 4.5.2).

Lack of certainty regarding off-take. A significant barrier to the widespread adoption of green hydrogen lies in the stark lack of demand, as evidenced by the scarcity of signed off-take agreements. Demand-side stakeholders often adopt a cautious "wait and see" approach, resulting in a lack of off-take agreements, which are pivotal for securing the sale of green hydrogen, reducing risk perception and facilitating the financing of production facilities. As of May 2024, only 5% of the announced clean hydrogen production volume has reached final investment decision (FID), equivalent to 11 Mt/year. Only 11% of the volume of the contractual agreements (equivalent to 1.2 Mt per annum) are binding, with an additional 23% of the project in FID stage aiming at self-consumption (2.5 Mt/year). The vast majority, or 67% (7.4 Mt/year), were non binding, consisting mainly of memoranda of understanding or unspecified arrangements (BNEF, 2024). This shortage of off-take agreements stems from two intertwined issues: the prohibitive production costs of green hydrogen (see above) and the competitive pressure from substitute technologies that are more economically viable. Such alternatives offer a more attractive option for end users, further eroding the potential demand for green hydrogen.

Facilitating guaranteed off-take, such as through green hydrogen purchase agreements (GHPAs), potentially resulting from auctions, can help address this issue. Other forms of strategic intervention include the introduction of mandatory green hydrogen quotas, the implementation of carbon pricing mechanisms or other incentives for adopting green hydrogen.

First movers' disadvantage. Early investors must navigate a landscape where future cost reductions, technological advancements, and market dynamics remain unpredictable. First movers in the green hydrogen market face a distinctive disadvantage, as more cost-effective solutions are expected to come to the forefront, with green hydrogen LCOH declining as the market matures and technologies advance. Those who initially invested could find themselves at a competitive disadvantage, with their once-pioneering assets potentially becoming stranded. At the same time, anticipation for future price reduction might lead off-takers to hesitate about committing to long-term agreements. The reluctance to lock in prices today stems from the potential for cheaper hydrogen in the near future, which further exacerbates the first movers' disadvantage. Support for early movers in terms of stable revenues at tariffs that both producers and off-takers agree to for a period that covers the lifetime of the project can reduce significantly their market disadvantage.

Lack of coordination among national public bodies. In cases where public bodies work in silos and miss out on opportunities to effectively coordinate their efforts, this may result in duplicated efforts and an overall lack of cohesion in the regulation of the hydrogen sector. This can lead to inefficiencies, higher costs and a slower pace of growth in the industry. The process of designing and implementing an auction may include consultation with different stakeholders that can help address this issue.

Information asymmetry. Information asymmetry occurs when one party to a transaction needs more or better information from another that may possess it. Suppliers are hesitant to invest without secured off-take agreements; off-takers are reluctant to commit without more data on hydrogen prices, properties and available quantities to assess feasibility; policy makers are cautious about enacting regulations without a deeper market understanding, making it challenging to develop effective policies and determine fair tariffs administratively; and financial institutions are wary of investing in what is perceived as high-risk ventures. This cycle of waiting and watching creates a scenario where the necessary investments in the green hydrogen sector are slow to materialise, hindered by the dual challenges of navigating an uncertain future and overcoming the barriers posed by information asymmetry. Auctions can bridge this information asymmetry.

The discussed barriers can be addressed by implementing auctions, one of the many instruments available. The following section discusses the range of instruments that can be considered, focusing on tariff-based instruments such as auctions.

3 Auctions to support green hydrogen development and deployment

Several policy instruments exist to overcome the barriers faced by the green hydrogen sector. These are presented in various IRENA reports (IRENA, 2020a, 2021, 2022a; IRENA and WEF, 2021; UNIDO, IRENA and IDOS, 2023). In the mix of policies to kick-start the hydrogen sector, targeted support payments are an important instrument. Past renewable power support schemes offer lessons for hydrogen policy making. Indeed, a large part of the cost reduction of renewable power generation can be attributed to support schemes that continue to address challenges that are similar to those faced by the green hydrogen sector today.

Such support schemes can target potential consumers of green hydrogen, such as in the case of carbon contracts for difference used in Germany (see case study 6.4); and producers, through tax incentives such as in the Inflation Reduction Act (IRA) in the United States (US) (Box 2); and they can be introduced in the form of production-based or tariff-based instruments, which provide long-term revenue certainty to producers and help achieve dynamic efficiency by enabling the move of the technology along the learning curve.

Box 2 The Inflation Reduction Act in the United States

The government of the United States provides support to producers of "clean hydrogen"* – defined by the law as emitting less than 4 kg CO_2eq/kg H_2 based on a life-cycle assessment, regardless of the production technology – through investment tax credits (ITCs) or production tax credits (PTCs) as part of the IRA. Low-carbon hydrogen producers can opt for only one of the two instruments.

Such tax credits can typically be offset against tax liabilities, but they can also be paid directly to the beneficiaries (for instance, in case no tax liabilities exist), through the so-called "elective or direct payment". While for other low-carbon products, such as clean electricity, tax credits can be converted into direct payments from the government only by, among others, tax-exempt organisations or state governments, tax credits for clean hydrogen are eligible for elective payment by any business.

Project developers receive an **investment tax credit** from 1.2% to 30% of the investment expenditure of the electrolyser. The exact percentage of ITCs depends on the GHG emissions per kilogram of hydrogen and wage and apprenticeship requirements of the project.

The **production tax credits** provide from USD 0.12/kg to USD 3/kg for each unit of clean hydrogen produced. Similar to the ITCs, the exact amount of support provided by the government depends on the overall GHG emissions per kilogram of hydrogen as well as wage and apprenticeship requirements of the project. The producers are entitled to the PTC for ten years. Historically, PTCs for renewable energy projects in the United States were accessible only as tax deductions, necessitating complex ownership arrangements for projects to leverage the full value of these credits. However, hydrogen developers will have the option to receive these tax credits as direct pay. This direct pay option will be available for the initial five years. Subsequently, for the following five years, the project will benefit from transferable tax credits.

Green hydrogen producers are expected to receive a minimum of USD 0.6/kg H_2 as PTCs or 6% as ITCs, as green hydrogen typically emits less than 0.45 kg CO_2eq/kg H_2 over the lifetime. If producers meet specific labour and wage standards, the support is multiplied by a factor of five, which culminates at an overall support payment of USD 3/kg H_2 as PTCs or 30% as ITCs.

Moreover, the IRA allows for cumulation of support, *i.e.* hydrogen producers are allowed to use subsidised renewable electricity or even receive support for their dedicated renewable energy plant.

* It should be noted that local legislation defines thresholds, system boundaries and definitions of what kind of hydrogen production is going to be supported; this comes with different definitions of the supported hydrogen (*e.g.* "clean" hydrogen in the United States, "low-carbon" in the United Kingdom) (IRENA, 2024).

Sources: (U.S. Department of Energy, n.d.; U.S. Department of Treasury, 2024).

Tariff-based schemes, if properly designed, can be an effective instrument to scale up green hydrogen. Policy makers strive for these support schemes to be cost-efficient, minimising the cost of public support while maximising the benefits. This leads to the question on how to best set the remuneration level. There are two main approaches to determine remuneration levels: the administratively set approach and the competitively set approach (auctions).

Administratively set support: Under this approach, support payments are set by the government, with the assistance of experts, who estimate the production costs of green hydrogen and determine adequate support payment levels that could be calibrated for electrolyser capacity and for the different configuration options for producing green hydrogen (*e.g.* based on the power supply model). The government may foresee an overall budget cap on the support. This approach is more standardised than the funding-gap approach and thus requires lower administrative effort from the government, although policy makers still need to decide on the most adequate level of support. The feed-in tariffs for renewable power projects were also based on this approach. Experience from the feed-in tariff for power shows that although developers are still incentivised to reduce their costs to increase their profit, the administratively set approach offers the lowest incentive for producers to reveal their true costs, contributing to the asymmetry in information.

Competitively set support (auctions): Under this approach, support payments are determined through volume control in a more efficient manner compared with the administratively set approach. It involves either a negotiation, whereby the government negotiates with various project developers and chooses the preferred ones, or an auction, whereby bidders submit their bid prices and typically no negotiation is foreseen. The auction-based approach is more standardised, offers a higher level of transparency, and involves less administrative effort related to price determination. Moreover, auction-based schemes are less susceptible to regulatory capture[9] compared with the administratively set approach. Producers have a high incentive to reduce costs (and reveal their true price) as they are in direct competition for a limited off-take volume or budget.

3.1 Strengths and weaknesses of auctions as a support scheme for green hydrogen

Strengths of auctions to support green hydrogen development and deployment

Auctions, if well-designed, can help policy makers address some of the challenges identified in Section 2.2, mainly those related to the missing market, lack of certainty regarding off-take, asymmetry of information regarding costs, and nascent technology and lack of competitiveness of green hydrogen.

Auctions have several strengths and provide many benefits. These include those inherent to all tariff-based support schemes – they offer long-term revenue certainty, allow for long-term budgetary planning and enable moving down the technology learning curve – which are presented in Table 2. These mainly address some of the market and regulatory barriers identified in Section 2.2.

Table 2 Strengths of tariff-based support schemes (including auctions) for green hydrogen

Long-term revenue certainty for producers	By providing (long-term) revenue certainty to producers through, for example, GHPAs, tariff-based instruments can increase investor confidence and project bankability and incentivise investments in the green hydrogen value chain. Greater revenue stability reduces financing costs and therefore the cost of green hydrogen.
Long-term budgetary planning for governments	Depending on their design (*i.e.* in the presence of volume caps and price ceilings), tariff-based instruments can allow for long-term planning regarding the budgetary spending on support over the years.
Dynamic efficiency – moving through the technology learning curve	By ensuring revenue certainty that drives investments in electrolysers, tariff-based instruments can achieve dynamic efficiency, *i.e.* green hydrogen production costs can decrease in the future due to technological advancement, innovation and learning by doing. For example, the global weighted average generation cost of utility-scale solar photovoltaic (PV) and onshore wind went down by 89% and 69%, respectively, between 2010 and 2022 (IRENA, 2023b). This can be largely attributed to policies driving their deployment.

9 A situation where a regulatory agency, created to act in the public interest, instead advances the commercial or special concerns of interest groups that dominate the industry or sector it is charged with regulating.

In addition to the strengths of all tariff-based instruments, competitively set support schemes – or auctions – enable true price discovery and the revelation of asymmetric information between the remuneration of the producers and the willingness to pay of the consumers, incentivising production and off-take. They can also ensure the effectiveness of the policy instrument (timely delivery of what is promised in the bids) while minimising the overall cost of public support. Auctions also provide a clear pipeline of future projects and enable budgetary planning, and provide transparency in the selection of projects and the level of support they receive, and they can be designed to achieve broader policy objectives for green hydrogen deployment or to address specific barriers. These strengths inherent to auctions are presented in Table 3.

Table 3 Strengths of auctions for green hydrogen

Enable competition that can lead to true price discovery, minimising the overall cost of support	If well designed, the competitive nature of auctions incentivises bidders to minimise the prices they offer and reveal their "true" production costs. This can help minimise the risk of overpayment by a public body implementing the support scheme and the total cost of deployment support. The competitive pressure exerted on project developers can also lead to lower production costs, as developers and their suppliers make efforts to lower costs to allow for maximising profits and increasing the chances of being awarded after they cut the prices they offer, which in turn lowers support costs. Auctions assume that market actors will have better and faster insights into technology and market developments than regulators and therefore better insights into costs. But it should be noted that in the long run, excessive competition may cause players to aggressively cut into their profit margins, threatening the sustainability of the industry, or cut costs related to R&D and innovation and training, or cut jobs. As such, considerations must be made to avoid such situations since the ultimate objective is to kick-start a sector for the long term and not only cut costs.
Ensure effectiveness	Effectiveness describes the ability of the auction to achieve the pursued policy objectives. Effectiveness is typically defined as a high realisation rate of awarded projects and a high production/availability of green hydrogen with the achievement of other policy goals mentioned below. Auctions work particularly well with achieving effectiveness if coupled with penalties for project non realisation and delays.
Clear pipeline of future projects	If scheduled rounds of auctions are announced beforehand, they can provide the sector, such as project developers and equipment and component manufacturers, as well as the consumers, such as the industry, with a clear pipeline of projects well into the future, which is crucial for the development of the sector.
Transparency	If appropriately designed, auctions allow for transparency in the way projects are selected and remunerated and provide access to open information on the level of government support provided to the sector.
Flexibility for additional objectives	Auctions are a versatile policy instrument and can be designed to achieve policy objectives besides cost reduction and real price discovery, such as socio-economic benefits, or addressing infrastructure challenges. For instance, bids can be evaluated based on criteria besides the price in the selection process.

Policy objectives that can be targeted in the auction design include contributing to achieving climate and environmental goals; developing a local green hydrogen economy with localised value chains to enhance energy security or participate in the international trade of green hydrogen and diversify energy exports; attracting foreign investments in energy-intensive industries and supporting their international competitiveness (see IRENA, 2024); and supporting system integration of VRE. At the same time, auctions can be designed in a way to help address specific barriers such as infrastructure challenges. These objectives are described in Table 4.

Of course, auctions on their own cannot achieve these goals, and they must be part of a more comprehensive policy mix that includes other deployment, enabling and integrating policies, along with policies for structural change and socio-economic benefits, and a global framework for international collaboration (IRENA, 2023a).

Table 4 Policy objectives for green hydrogen that can be targeted through auction design

Contribute to achieving climate and environmental goals	Climate goals and the reduction of GHG emissions may be addressed through carbon-neutral processes using green hydrogen.
Support the development of a domestic green hydrogen economy (upstream activities) to diversify energy exports or enhance energy security	The development of local upstream value chains for green hydrogen along the different segments (including manufacturing of electrolysers, developing renewable energy power plants, operating and maintaining the system, and securing the infrastructure to store and transport the green hydrogen) can increase energy security and create socio-economic benefits. Policy makers can aim to develop a local export-oriented green hydrogen sector for socio-economic gains without necessarily targeting a large local use of green hydrogen (*e.g.* Namibia to export hydrogen derivatives, Uruguay to develop a port solution for synfuels export). Auctions for green hydrogen can be designed to maximise these benefits, *e.g.* generate export revenues from green hydrogen trade, create jobs, accelerate innovation and industrial growth, develop business opportunities, and bring benefits to local communities.
Decarbonise local industries (downstream activities) and increase their global competitiveness	Policy makers can support the development of a local green hydrogen sector to supply sufficient green hydrogen for the local demand to create opportunities and increase competitiveness of downstream activities, such as the production of fertiliser, ammonia, green steel and further end-use cases (*e.g.* United Arab Emirates, Kenya to produce fertilisers, India to enhance low-carbon steel production).
Increase hydrogen market liquidity	A liquid market of hydrogen with many actors increases competition and reduces hydrogen prices. This typically involves scaling up the green hydrogen market and ramping up both the supply and demand sides to enable liquid market activities.
Support system integration of VRE and electrolysers	Auctions can be designed to reduce the negative effects of hydrogen production on the electricity system, such as pressure on the electricity grids in case of geographical distance between the renewable energy power plants and the electrolysers. They can also be designed in a way to increase the positive effects on the electricity system, for instance by promoting electrolysers able to react to system signals to provide ramping capabilities.

Address infrastructure challenges including for green hydrogen transport and electricity network transmission and distribution capacities.	Auctions can be designed to address the challenge of hydrogen transport infrastructure. For instance, site- or regional-specific auctions can ensure that electrolyser location is strategically aligned with the existing or future hydrogen transport infrastructure. Another option would be to conduct auctions for industrial clusters that colocate green hydrogen production and consumption, which can ensure that transport infrastructure solutions exist. Moreover, auction mechanisms can rapidly inform stakeholders on where and when new production capacity will be developed, potentially encouraging investments of off-takers in the same region. Nonetheless, the government can still provide transport infrastructure support measures outside the auction.

Weaknesses of auctions

Along with the strengths, there are weaknesses associated with the auction as a means of allocating support for green hydrogen:

Price pressure can lead to projects not being realised, the sector being compressed and inability to invest in capacity building and technological improvement: Price pressure in auctions can result in bidders being forced to bid too aggressively, making too-optimistic assumptions on cost reductions, availability of components and revenues. As a consequence, winners might either decide to cancel an already awarded project or use inferior, cheaper components, reducing the plant's lifetime or output. In some situations, the cost reduction that is needed to bid for low prices can lead to innovation in systems and technologies but in others, it can compromise budgets for R&D, training and retaining employees.

Lack of competition results in high prices: Auctions are successful in bringing down prices only if there is sufficient competition, otherwise bidders will bid close to the ceiling price (if one is determined and revealed) or it may even lead to collusion, especially as the sector is still in its nascent stages with a small number of market actors. While in general, auctions can be designed to increase the level of competition, with emerging technologies such as green hydrogen, high levels of competition in early stages may be a challenge.

Higher barriers to smaller producers: Auctions imply that bidders are subject to risks and they incur pre-development costs but are not guaranteed receiving awards. For smaller producers that might lack such a risk appetite, these barriers might be too high to participate, reducing competition in auctions and posing disadvantages for small and medium-sized businesses, which impacts the goal of developing an upstream hydrogen sector when such a goal is set.

3.2 Types of auctions for the support of hydrogen

There are four main types of auctions to support green hydrogen projects. They differ according to the focus of the auction, and more specifically, who is eligible to receive the support provided by the government. In all four types of auctions, there is only one auctioneer, typically the government or a governmental agency, that sets the rules and conducts the auction (in an open and transparent way).

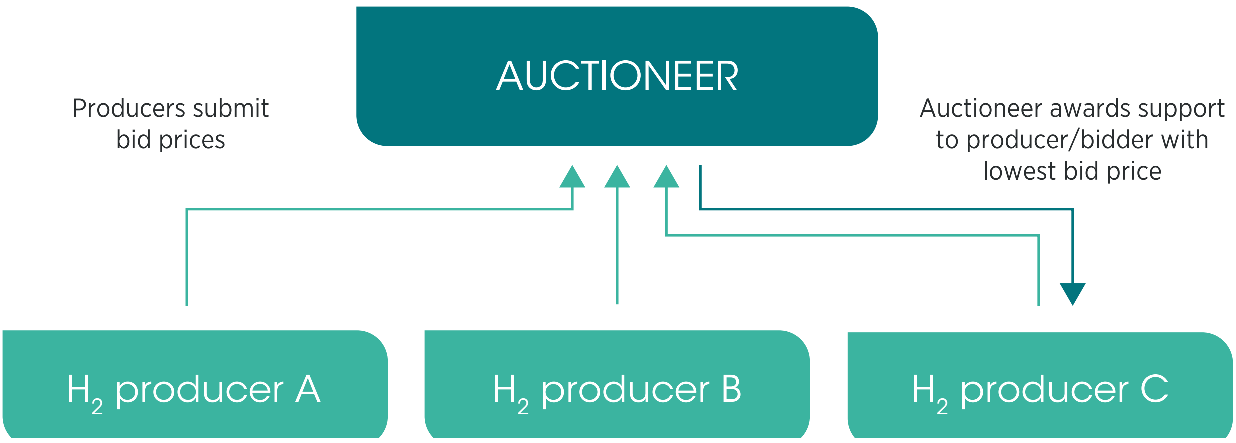
In **supply-side auctions**, the competition takes place between hydrogen producers/sellers or project developers, depending on the product being auctioned. In **demand-side** auctions, hydrogen consumers compete for support, such as heavy industry or the transportation sector. **Double-sided auctions** and **joint supply- and demand-side auctions** aim to support both the supply and demand sides mostly through matchmaking the hydrogen producers with the consumers.

All types of auctions can be held domestically, *i.e.* off-takers and producers are within the same country borders such as in India (see case study 6.5); regionally, *i.e.* off-takers and producers are within the same bloc such as the European Union (see case study 6.3); and internationally, *i.e.* off-takers and producers can be anywhere within the designated countries such as H2Global (Box 3).

Supply-side auctions

Supply-side auctions competitively allocate support to the production of hydrogen (Figure 3). Typically, producers who require the least amount of support are awarded in the auction along with other possible selection criteria. Supply-side auctions aim at scaling up electrolyser capacity and green hydrogen production, for domestic use and/or export. Countries and regions that are considering implementing or that have implemented supply-side auctions include Chile (case study 6.1), Denmark (case study 6.2), India (case study 6.5) and the European Union (case study 6.3).

Figure 3 Illustrative set-up of a supply-side auction for green hydrogen



Supply-side auctions have several advantages, including the relative ease of implementation (compared with the other types – see below) and the ability to drive the increase of domestic production capacities. Moreover, the supply side typically has a larger pool of bidders (compared with the demand side), which can lead to a higher level of competition. Additionally, supply-side auctions can better reflect the green hydrogen targets, which are usually defined in terms of electrolyser capacity and/or produced hydrogen (IRENA, 2022b).

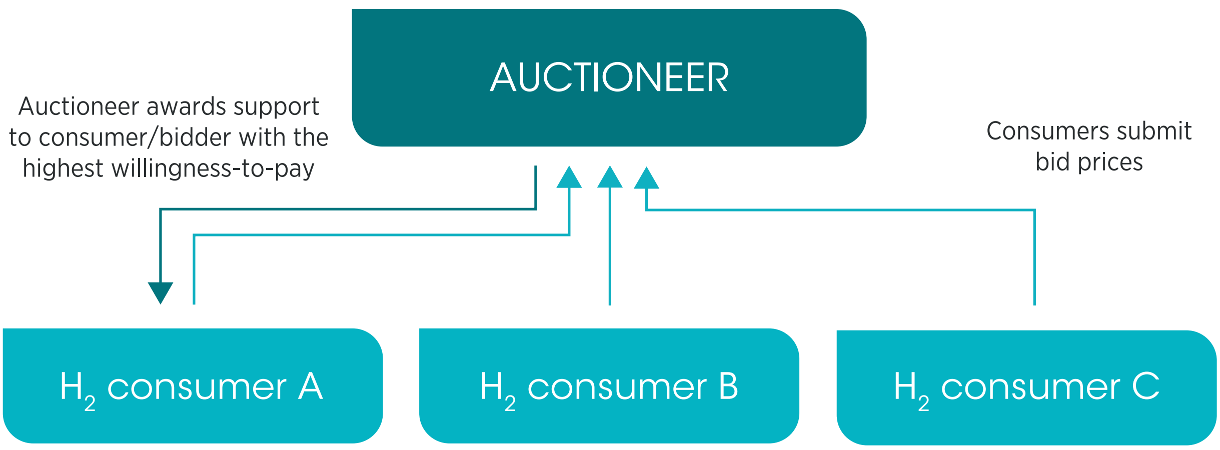
However, there are challenges associated with the use of supply-side auctions. Emissions reductions depend on the end-use sector which consumes the supported hydrogen. By implementing supply-side auctions, policy makers might have difficulties steering the support and consumption towards specific demand-side sectors. The additional costs for the demand-side transformation (beyond the higher costs of green hydrogen) are not directly covered through supply-side auctions, possibly resulting in a missing demand problem. Moreover, when demand-side time profile is heterogeneous, the contract to be awarded may be more difficult to design. Finally, depending on the design of the auction, off-take might not be guaranteed (see Section 4.5), which would not address one of the main barriers for green hydrogen uptake, as described in Section 2.2.

Overall, supply-side auctions are particularly suitable in cases where there are good potential for renewable energy sources, logistical capabilities and water resources, as well as in cases when the export of green hydrogen is the main policy objective. This brief focuses on supply-side auctions for green hydrogen production while other types of auctions may be covered in future IRENA work.

Demand-side auctions

Demand-side auctions allocate support to the consumers of green hydrogen (Figure 4). Typically, consumers with the highest willingness to pay but still requiring support are awarded in the auction (lowest difference between the price of green hydrogen and willingness to pay). Demand-side auctions thus encourage growing demand for green hydrogen and drive the simultaneous ramp-up of new supply and/or imports.

Figure 4 Illustrative set-up of a demand-side auction for green hydrogen



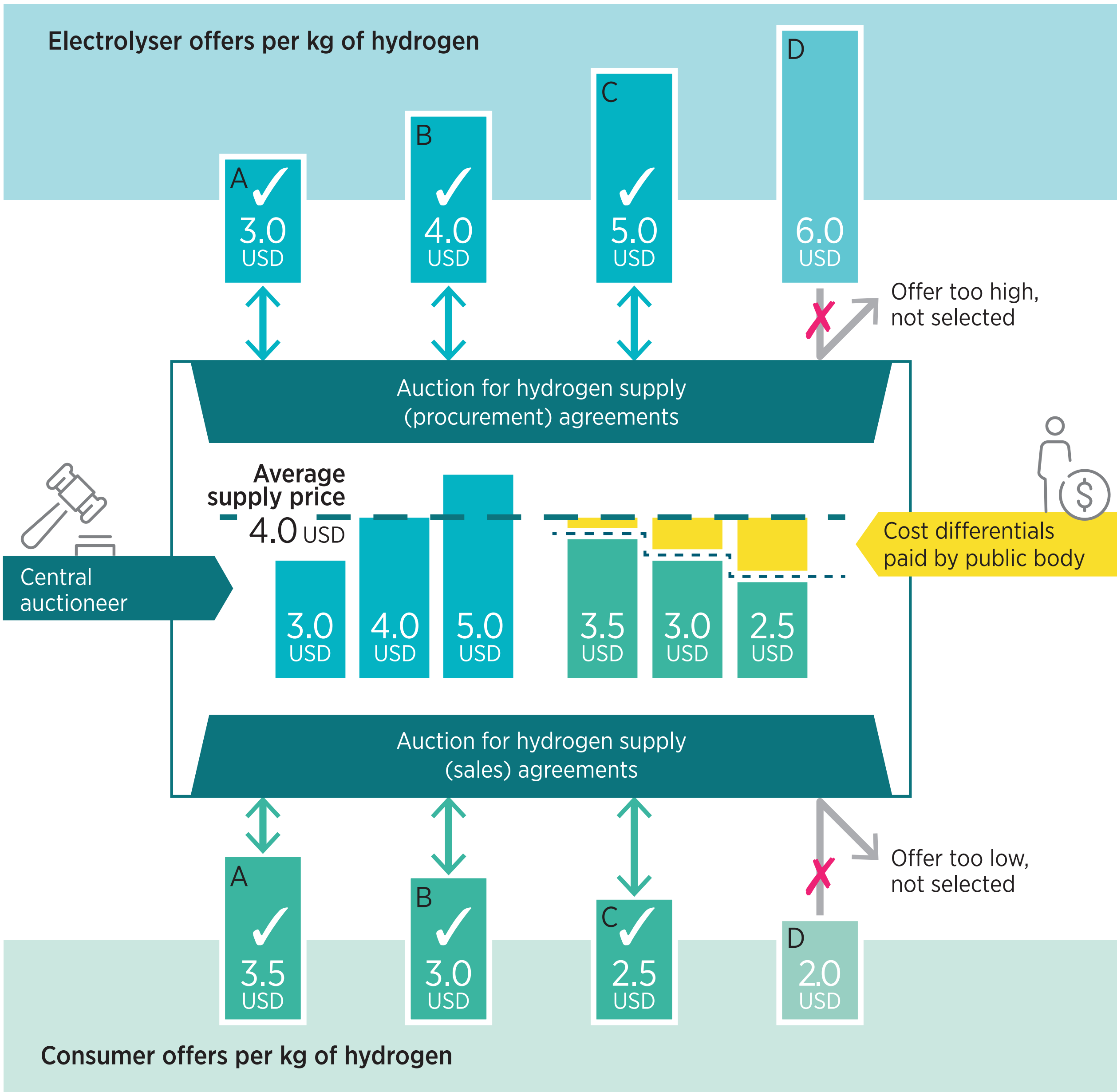
One of the main advantages of demand-side auctions is that they are relatively easy to embed in a country's industrial policy, as policy makers can target specific end-use sectors. This can help maximise emissions reductions, while transforming the existing industry and enabling the creation of new industrial capacities. Furthermore, demand-side auctions tend to be easier to implement for countries with existing industrial capacities, as they already have the necessary infrastructure, such as production facilities and know-how in place to support the development of low-carbon industries. Finally, demand-side auctions can allow to differentiate markets by sector (transport, industry, etc.), creating specific designs that fit sectoral characteristics.

One potential consequence, which may be an issue depending on the policy objectives, is that demand-side auctions may create incentives for hydrogen imports, as the supported end users may opt for importing hydrogen (or its derivatives) from other countries rather than procuring from domestic producers. While such a process can result in emissions reduction and green industrial products, it does not support the development of a domestic green hydrogen sector. Additionally, there may be less competition in demand-side auctions due to the limited number of potential bidders compared with supply-side auctions and the overall lower demand for hydrogen, especially in the absence of complementary policy instruments such as mandates, quotas or carbon credits. This could compromise the auction's potential for minimising the support required. Furthermore, there might be an advantage for bidders with already existing low-carbon processes, as those would require a lower level of support, thus not ensuring a level playing field for some bidders and potential windfall profits for others.

Double-sided auctions

Double-sided auctions target both the supply and the demand sides of green hydrogen (Figure 5) such as in the case of H2Global (Box 3). By competitively selecting suppliers offering green hydrogen at the lowest price as well as those off-takers with the highest willingness to pay for the product, the price difference between supply and demand that needs to be covered through funds of the intermediary is minimised. The aim is to scale up both the supply and demand sides simultaneously, by reducing the off-take and supply risks for both sides.

Figure 5 Illustrative set-up of a double-sided auction for green hydrogen



Source: (IRENA, 2022a).

Double-sided auctions have the advantage of introducing competition for both the demand and the supply sides at the same time, thus revealing the information needed regarding both the costs and the willingness to pay for green hydrogen, thereby discovering the optimal premium needed to support it. They also provide market and price stability and reduce the risk due to the mismatch between supply-side and demand-side contracts, potentially leading to the ramp-up of the hydrogen market, especially if long-term contracts are provided for the supply side, while short-term contracts are offered to the demand side where off-takers are more used to short-term contracts from commodity markets, especially offering access to green hydrogen supply to smaller off-takers with limited market power who are typically able to sign only short-term contracts. These different preferences are addressed in the double-sided auctions conducted by H2Global, by offering contracts with different durations for the supply and demand sides (Box 3).

However, double-sided auctions entail several challenges. One challenge is the administrative effort, as double-sided auctions typically require the implementation and operation of an intermediary. Another administrative limitation could stem from longer timing for the evaluation of the applications. Additionally, there is a high risk of exposure for both the intermediary and the government due to the default risk on both the demand and supply sides. Finally, the transport of hydrogen can be challenging, which could need to be addressed in the auction design.

Despite these challenges, double-sided auctions can be particularly suitable in countries with good potential for renewable energy sources, logistical capabilities and water resources, and where there is an existing demand from domestic off-takers. Additionally, double-sided auctions may be more attractive in challenging investment environments, as the government assumes most risks.

Box 3 Doubled-sided auctions – the H2Global instrument

In 2021, the H2Global Foundation was established with the support of private sector entities in Hamburg, Germany. The foundation and its subsidiary HINT.CO GmbH have developed and implemented a funding instrument called the H2Global mechanism. As an intermediary, Hintco concludes long-term purchase contracts on the supply side and shorter-term sales contracts on the demand side. Based on a mechanism analogous to the contracts for difference (CfD) approach, the difference between supply prices and demand prices is compensated by grants from a public or philanthropic funding body.

On both the purchasing and the selling sides, prices are determined through competitive bidding. In line with sustainability criteria, the lowest supply price and the highest demand price are awarded, in order to minimise the price difference to be compensated. Short-term sales contracts with the demand side allow Hintco to benefit from expected increases in market prices for hydrogen products. This means that the funds required to compensate for the price difference are expected to decrease over the course of the funding period.

Each funding body, *e.g.* a government or an institution, designs its own funding tender by defining the financing, product selection, geographical scope, sustainability criteria and other individual requirements. This allows the provider of funds to tailor the tender to its specific objectives, such as promoting clean energy technologies, diversifying energy partnerships or decarbonising specific sectors.

For the pilot auction, the German Federal Ministry for Economic Affairs and Climate Action (BMWK) provided EUR 900 million to Hintco, which was split into three lots covering renewable ammonia (Lot 1), renewable methanol (Lot 2) and e-SAF (Lot 3).

On the supply side, Hintco concludes long-term hydrogen purchase agreements (for example, a ten-year hydrogen purchase agreement (HPA)) with suppliers. On the demand side, Hintco concludes shorter-term hydrogen sale agreements (one-year HSAs) with off-takers. In the pilot auction, potential off-takers must be based in the European Union (EU), while suppliers need to produce the derivatives in a country outside of the European Union/European Free Trade Association. The responsibility of the transport lies with the bidders, and the bids include the cost of the transport: Sellers are responsible for transporting the derivatives to the European Union, while buyers are responsible for transporting them to their actual point of consumption within the European Union.

Results of the first auction (lot 1 and 3)

The auction, launched at the end of 2022, received interest from over 70 countries across five continents. Fertiglobe was the winner of Lot 1 (renewable ammonia). Lot 3 (e-SAF) ended without a contract being awarded. As a result, the funds from Lot 3 will be allocated to Lot 2. The first HPA for renewable ammonia was allocated through H2Global's auction-based mechanism, with elements of negotiations between the auctioneer (Hintco) and the bidders. First, the bidders submitted their indicative bids, and out of the eligible bidders, five were shortlisted. Hintco then negotiated with the bidders (in this case the suppliers/sellers of the derivatives) and invited them to submit a final bid. The ranking was conducted based on three criteria: 1) bid price in euros per tonne, which is weighted with 30%; 2) the minimum quantity of product to be delivered, weighted with 60%; and 3) the maximum quantity to be delivered, weighted with 10%.

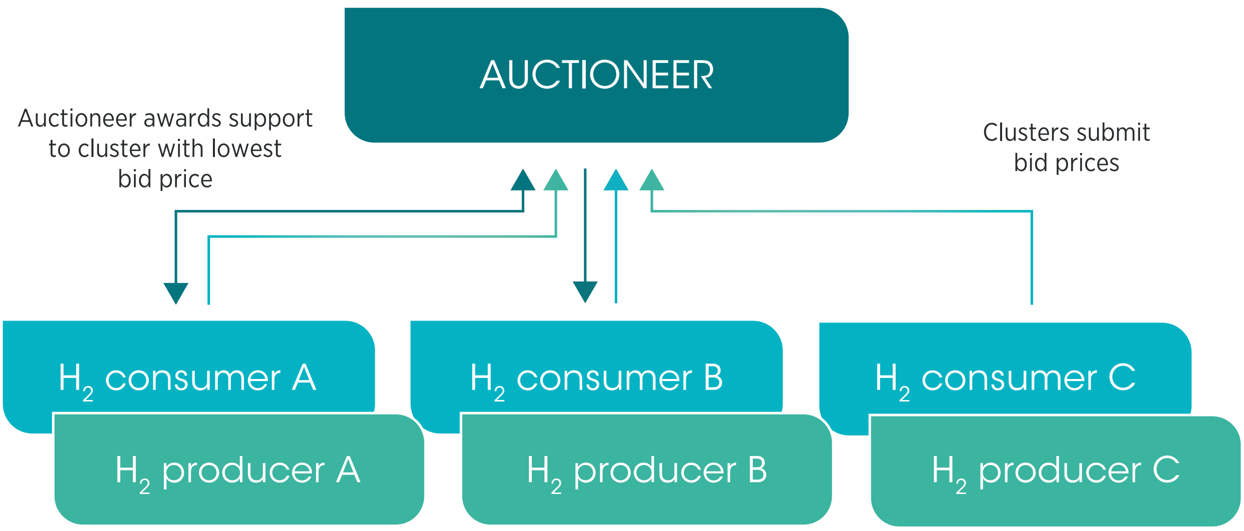
The product price in the awarded bid by Fertiglobe was EUR 811.30 /t of ammonia where the contract price EUR 1000 /t. In addition, 203 MW onshore wind and 70 MWp PV will be built to support the 100 MW alkaline electrolyser that will be produce 13 kt of H_2/year. Production of renewable ammonia is expected to start in 2027.

Sources: (BMWK, 2024a; H2Global-Stiftung, n.d.).

Joint supply- and demand-side auctions

Joint supply- and demand-side auctions are a subset and simplification of the double-sided auction. They require the bid to include hydrogen supply and off-take. Thus, this type of auction typically requires on-site hydrogen production and "hydrogen valleys" consortia which are often physically colocated or include the transport infrastructure (Figure 6). The bid requiring the least amount of total support is awarded, where the support is the cost differential between the hydrogen production cost and the willingness to pay of the end user. Joint supply- and demand-side auctions allow for the scale-up of both supply and demand simultaneously, especially in case of missing transport infrastructure.

Figure 6 Illustrative set-up of joint supply- and demand-side auctions for green hydrogen



Joint supply- and demand-side auctions have the advantage that they require less implementation effort, as infrastructure needs are already addressed by the bid consortium, making them particularly suitable in countries with a lack of transport infrastructure for hydrogen. Additionally, they may be more attractive in challenging investment environments as the off-take is ensured, which reduces the off-take risk and off-take price risk for producers, while end users can profit from the guaranteed supply of hydrogen. Due to the ease of implementation, joint supply- and demand-side auctions can be used as an early starting point for the support of green hydrogen. Furthermore, joint supply- and demand-side auctions are useful in countries with an existing hydrogen demand from domestic off-takers.

However, joint supply- and demand-side auctions are also associated with challenges. They can lead to a low level of competition due to the limited number of available clusters, potentially leading to higher support costs.

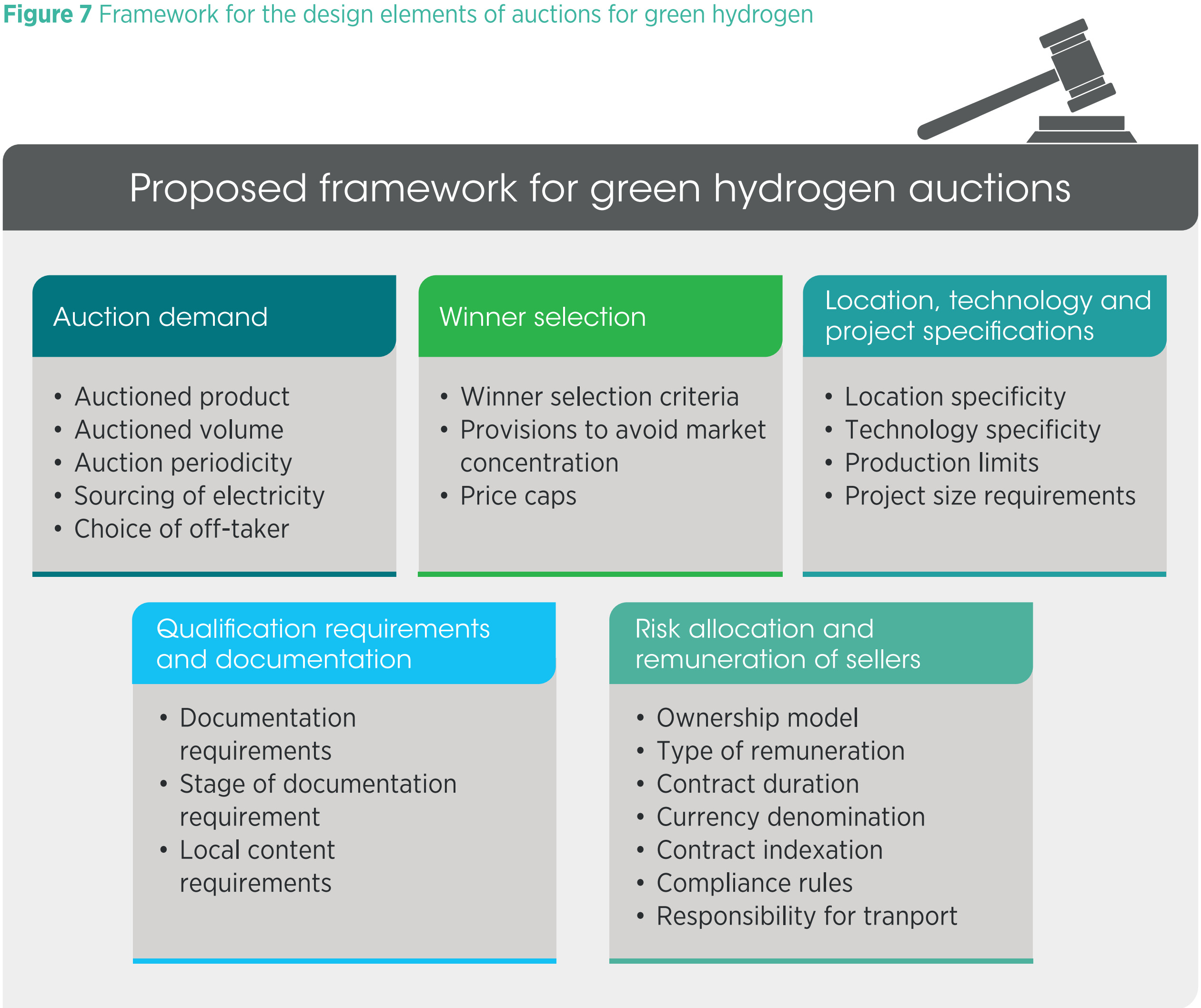
4 Design elements of auctions to support green hydrogen

The overall policy objectives of deploying green hydrogen differ greatly by country/jurisdiction, and green hydrogen auction design options should be selected to serve the specific policy objectives of each country/jurisdiction, based on its market conditions. Determining the policy objectives of deploying green hydrogen is very important for the design of the auction, in order to consider the trade-off between achieving the lowest price and the set objectives, as mentioned in Section 3.1.

Once the objectives are determined, auction design elements can be selected. In this chapter, design elements for (supply-side) green hydrogen auctions are presented and analysed. The framework for the design of green hydrogen auctions (Figure 7) is based on IRENA's framework for renewable power auctions (IRENA and CEM, 2015), adapted to the green hydrogen sector.

Design elements can be classified into five main categories: auction demand; qualification requirements and documentation; location, technology and project specifications; winner selection; and risk allocation and remuneration of sellers.

Figure 7 Framework for the design elements of auctions for green hydrogen



In the tables presented in each of the following sections, the impact of the design element on the policy objectives is presented. The signs in the tables indicate the following:

= very positive impact, = positive impact, = no impact, = negative impact, = very negative impact

4.1 Auction demand

The category of auction demand determines the product that is auctioned, the auctioned volume, periodicity of auction (regular schedule or stand-alone auction), the decisions made regarding the sourcing of renewable electricity for green hydrogen production including physical and contractual considerations, and choice of off-taker.

Auctioned product

The auctioned product defines the good that is to be purchased (in the case where the government/a public body is the off-taker – see *Choice of off-taker*) or supported (in case of a private off-taker) through the auction. It typically defines which part of the green hydrogen supply chain is eligible to receive support.

In the supply-side auctions explored in this brief, options include the support for the installation of electrolysers under the EPC model or the procurement of green hydrogen produced (such as in India – see case study 6.5).

Table 5 summarises the trade-offs to consider when determining the auctioned product.

Table 5 Trade-offs to consider when determining the auctioned product

	Electrolyser capacity	**Green hydrogen production**
Description	**The procurement/support is for electrolysers installed**	**The procurement/support is for green hydrogen produced**
Dynamic efficiency (moving down the technology learning curve)	◒ Supports the learning curve for installing electrolysers only	◒ Supports the learning curve for installing electrolysers and producing green hydrogen
Budgetary planning for government	◒ Straightforward based on electrolyser capacity installed and can be capped using a ceiling price	○ Less straightforward and depends on bids received (volume and bid prices), quantities produced, remuneration type, and caps introduced
Higher number of potential bidders increasing the level of competition	● Minimal risk on developers increases the number of bidders and therefore competition	◒ Producers take on the risk of green hydrogen production impacting number of bidders and competition
Climate and environmental goals	◒ Does not guarantee the production or use of green hydrogen	◒ Guarantees the production and off-take of green hydrogen
Socio-economic goals – greening local industries	◒ Does not guarantee the production or use of green hydrogen locally	○ Does not guarantee that the green hydrogen is used by any specific downstream sector that the government intends to support, such as steel production

Socio-economic goals – development of domestic green hydrogen economy	◒ Supports the development of a domestic green hydrogen economy including jobs and businesses with the potential to export green hydrogen, but could miss out on the added value brought on by expanding the value chain to end uses	◒ Supports the development of a domestic green hydrogen economy including jobs and businesses with the potential to export green hydrogen, but could miss out on the added value brought on by expanding the value chain to end uses
Support system integration of VRE	○ unless specified by the auction, no guarantee that renewable power is used, and green hydrogen is produced	○ Can support system integration if other design elements are introduced (*e.g.* additionality)
Address infrastructure challenges	○ Can address infrastructure challenges if other design elements are introduced (*e.g.* location-specific at proximity of renewable power plant and end uses)	○ Can address infrastructure challenges if other design elements are included (*e.g.* location-specific at proximity of end uses)

Another option is to define the auctioned product as green hydrogen derivatives production, such as ammonia or methanol as done in the H2Global auction (see Box 3), but since this is not the focus of this brief, the analysis is not included in Table 5.

This approach ensures the production of derivatives and products using green hydrogen, thereby addressing climate-related concerns related to the production process of these derivatives. It also helps attract investments in downstream sectors, such as chemicals production, and support the development of a domestic sector with the potential to export green hydrogen derivatives. In addition, this approach can help accelerate the learning curve of conversion processes, thus supporting dynamic efficiency of the sector beyond installing and operating electrolysers. Lastly, green hydrogen derivatives are easier to transport over long distances, which can help address the infrastructure challenges faced by the sector.

However, this approach would allocate more risks to the bidders – those related to producing the derivatives, on top of ensuring sufficient supply of green hydrogen – which might lead to a lower level of competition and limit the auction's ability to discover the real price.

Finally, it is worth mentioning that India has completed two auctions where it awards subsidies for manufacturing of electrolysers (Box 4). This is one example of support for localising value chains in upstream activities.

Box 4 Indian auctions for electrolyser manufacturing

As for July 2024, India has completed two auctions for subsidies to support electrolyser manufacturing.

The first auction offered a maximum incentive of 4 440 Indian rupees (INR; around USD 53.15) per kilowatt (kW) of capacity sold, assuming local content and domestic sales conditions are met, decreasing to INR 3 700 in the second year, INR 2 960 in the third, INR 2 220 in the fourth, and INR 1 480 in the final year. Out of 21 bids — 14 for any technology and seven specifically for Indian-developed electrolysers — only eight winners were announced, meeting the cap of 1.5 GW of manufacturing capacity.

Bidder	Bid manufacturing capacity (MW/year)	Awarded manufacturing capacity (MW/year)	Maximum incentive allocation (INR/year)
Reliance Electrolyser Manufacturing Limited	300	300	4 440
Ohmium Operations Private Limited*	137	137	2 027.6
John Cockerill Greenko Hydrogen Solutions Private Limited**	300	300	4 440
Advait Infratech Limited (consortium with Rajesh Power Service Private Limited)	100	100	148
Jindal India Limited	300	300	4 440
L&T Electrolysers Limited***	300	63	932.4
Homihydrogen Private Limited****	101.5	101.5	1 502.2
Adani New Industries Limited****	300	198.5	2 937.8

*US-based Ohmium already has a 500MW electrolyser factory in operation in India, with plans to expand this to 2 GW.

** Belgian manufacturer John Cockerill aims to build a 2 GW plant in the country, in partnership with one of India's biggest clean-energy developers, Greenko.

***Indian conglomerate L&T (Larsen and Toubro) has agreements in place to use the technology of two European electrolyser makers — France's McPhy and Norway's HydrogenPro.

****Bid for subsidies ringfenced for Indian-developed technology

India's second auction for subsidies to support electrolyser manufacturers in the country has seen bids for 2.8 GW of annual manufacturing capacity — nearly double the 1.5 GW capacity. The auction was split into three tranches based on the origin and scale of the stack technology: 1.1 GW of any technology; 300 MW of Indian-developed stacks; and 100 MW of small-scale indigenously-designed technologies. While the first two buckets required a minimum bid of 100 MW and a maxmimum of 300 MW, the final tranche allowed for much smaller manufacturing capacities of between 10 MW and 30 MW. Possibly due to this lower bar to clear, the third bucket was the most popular among bidders, with 13 bids into this tranche. As with the first auction, the second tender offers its winners a base rate of INR 4 440 (USD 53.15) per kilowatt of electrolyser capacity sold, decreasing to 3 700 in the second year, INR 2 960 in the third, INR 2 220 in the fourth, and INR 1 480 in the final year. The bidders (listed below) range from industrial giants such as Adani to smaller, pure-play green hydrogen companies, such as Greenzo Energy.

Sources: (Martin, 2024a, 2024b).

Auctioned volume

Defining the volume auctioned is an essential aspect of designing a successful auction as it directly affects the competition and thereby prices offered by bidders. It can be determined in terms of maximum budget available for support, or the total volume of electrolyser capacity or quantity of produced green hydrogen that would be supported. Under any definition, the auctioned volume should be carefully set by taking into account the market environment and project pipeline to allow for competition.

Defining the auction volume in terms of the total available support budget is a rather straightforward approach. The government sets a fixed budget for support, and bidders submit bids based on their costs and required support levels. Bidders are awarded until the total support they are requesting reaches the total volume on offer. Sometimes the total support cannot be accurately determined and can only be estimated ex ante, as in the case of CfDs (see case study 6.7 for the case of the UK HAR1 [first Hydrogen Allocation Round] with a total budget of EUR 2.3 billion estimated at the start of the auction). This approach is followed by Chile, with a total support budget of USD 50 million in the 2021 auction (case study 6.1); in Denmark, which auctioned around EUR 167.5 million in 2023 (case study 6.2); and most recently in the European Hydrogen Bank pilot auction, which earmarked EUR 720 million for EU-wide projects and EUR 350 million for German projects (case study 6.3). This approach can be followed regardless of the choice made regarding the product being auctioned, as presented in the previous section.

Defining the auction volume in terms of the **total electrolyser capacity to be supported** can ensure that the auction results in the deployment of a specific amount of electrolyser capacity. This approach can be followed regardless of the choice made regarding the product being auctioned.

Defining the auction volume in terms of the **total amount of produced green hydrogen (or derivatives)** to be supported is another option. Bidders would submit bids for the amount of hydrogen they aim to produce, and the government would allocate contracts based on the total amount of green hydrogen to be supported. This approach is typically more suitable if green hydrogen production is the auctioned product, as presented in the previous section.

Table 6 summarises the trade-offs to consider for each option.

Table 6 Options to define the auctioned volume

	Budget available	Electrolyser capacity	Green hydrogen produced
Description	**Available budget to support green hydrogen production is fixed and auctioned**	**Electrolyser capacity to be supported is fixed and auctioned (*e.g.* GW electrolyser)**	**Green hydrogen production to be supported is fixed and auctioned**
Budgetary planning	● Total available support budget fixed	◒ Straightforward based on electrolyser capacity installed and can be capped using a ceiling price	○ Less straightforward and depends on bids received (volume and bid prices), quantities produced, remuneration type, and caps introduced

Effectiveness in supporting green hydrogen production	Green hydrogen production supported only until budget is exhausted	Can support and ensure the development of electrolyser capacity but does not inherently ensure the production of green hydrogen	Greater certainty that a certain quantity of green hydrogen is produced

A further consideration regarding the auctioned volume relates to whether it should be auctioned in a single round or through several rounds (with a schedule of upcoming rounds announced). Table 7 presents the trade-offs to consider for each option.

Table 7 Options on how to auction the total volume

	Total volume available auctioned in a single round	**Total volume available auctioned in many rounds**
Description	**The total volume available is auctioned in one round**	**Total volume available auctioned in many rounds (announced) of smaller volume each**
Competition leading to true price discovery	Especially in nascent markets, volume on offer might be too high to create competition	Partitioning the total volume into tranches helps create competition
Clear pipeline of future projects	No clear pipeline of future projects	Clear pipeline of future auctions and prospects
Effectiveness in meeting set targets	Green hydrogen targets are met faster	Can take more time to meet targets and future rounds might get cancelled with policy changes
Climate and environmental goals	Climate goals can be met faster	Can take more time to meet climate goals and future rounds might get cancelled with policy changes
Socio-economic goals – development of domestic green hydrogen economy	Reduced prospects for players getting awarded projects	Incentivises future players into the market across the whole value chain

Auction periodicity

Auctions can be conducted as **standalone auctions** on an ad hoc basis with no long-term planning required (usually when the total volume is auctioned in a single round – see previous section), or alternatively, a more **long-term auction schedule**, with approximate dates of various rounds announced, along with the auctioned volume for each round. Experience with renewable power auctions has shown that the auction periodicity plays an important role in developing a local value chain. Table 8 presents the trade-offs to consider for each option. It is worth mentioning that both approaches can be combined and a long-term schedule with at least one auction per year for example can be announced, with the possibility to increase the frequency and volumes on an ad hoc basis.

Table 8 Trade-offs concerning the auction periodicity

	Stand-alone auctions	**Long-term auction schedule**
Description	**The auctioneer announces and conducts auctions on an ad hoc basis**	**The auctioneer defines and announces a long-term auction schedule**
Competition leading to lower bid prices and minimising total cost of support	Lower interest from market players can lead to fewer participants in the auctions, thus a lower level of competition	A transparent, long-term auction schedule can increase interest of market players and investor confidence and thus reduce cost of capital, in addition to potentially more market entrants, leading to a higher level of competition
Budgetary planning	Standalone auctions provide more flexibility to the government to react to budgetary constraints	Long-term commitments due to an auction schedule might reduce the government's flexibility
Socio-economic benefits – local green hydrogen economy and industrial decarbonisation and competitiveness	The unpredictability of auctions can lead to "stop and go" dynamics, which harms the sector	A long-term auction schedule can increase investor confidence and lead to a higher project pipeline, thus supporting the development of the sector and industry

Sourcing of electricity

Green hydrogen producers can own the renewable power plant themselves, which can be directly connected to the electrolyser as an insular or captive solution or can be located elsewhere and the electricity would be transported through the electricity grid, or they can source the renewable power from third-party renewable electricity suppliers (IRENA, 2023c).

If the electrolyser is fed with the electricity from the grid, it needs to have a power purchase agreement (PPA) in place or a proof of sourcing of renewable power through Guarantees of Origin scheme (see *Documentation requirements* in Section 4.2). Renewable electricity procured through a long-term PPA can be transported through the grid, but it is also possible to conclude a PPA with a renewable power plant that is directly connected to the electrolyser. Lastly, producers can buy the required electricity from electricity markets with high shares of renewables, if those are available. This option will most likely entail a connection to the electricity grid.In any case, to achieve an overall decarbonisation effect in the energy system, hydrogen production should not happen at the expense of the decarbonisation of the power sector, and electricity sourcing should follow the principle of "additionality", *i.e.* renewable-based power plants for green hydrogen production should be additional to the existing power plants (IRENA, 2020). Nevertheless, grid-connected electrolysers without PPAs concluded with newly built renewable plants could still produce green hydrogen in power systems with high renewable shares.

The auction design (or in most instances the overall regulatory framework and definitions of green hydrogen) therefore sets requirements on the sourcing of the electricity, which directly impacts the renewable power sourcing risks discussed in Section 4.5. They can be distinguished between physical and contractual, for the types of power sourcing.

Physical consideration

The physical requirements define whether the electrolyser is directly connected to the renewable power plant or whether it is connected to the grid. If the auctioneer requires an insular solution, also called captive, the electrolyser needs to be directly connected to a renewable power plant and not to the grid.

As mentioned above, if the electrolyser can be connected to the grid, the producers might be required to prove that the electricity is indeed renewable. This can be accomplished by providing Guarantees of Origin, while in countries with a high share of renewables, this provision can be forfeited. Table 9 presents the options to consider.

Table 9 Options regarding physical requirements of electricity sourcing

	On-site (captive)	**Through electricity grid**
Description	**The renewable power plant is located on-site close to the electrolyser and they are directly connected**	**The electrolyser is connected to the power grid, allowing the renewable power plant to be located elsewhere**
Lower bid prices and total cost of support	○ Depends on the resource potential of the site (which might be selected according to the location of end uses)	◒ Allows the power plants to be located in areas with high renewable energy potential, not necessarily at the same site as the electrolyser ○ Risks of grid-related issues (technical issues or grid congestion) can be allocated to the bidders or the auctioneer
Effectiveness (realisation rates, green hydrogen production)	◒ Higher risk due to strong reliance on local resources availability	◒ Grid bottlenecks can challenge green hydrogen production ◒ Potentially higher load factors of electrolysers through diversified renewable energy sources
Support system integration of VRE	○ No system-friendly dispatch necessary	○ Electrolyser electricity consumption could affect grid stability ◒ Can support system integration if other design elements are introduced (*e.g.* production within the same bidding area)
Address infrastructure challenges	○ Can address infrastructure challenges of transporting renewable power to the electrolyser but incentive to locate electrolyser in zone with renewable potential may lead to location away from end uses	◒ No requirement related to renewable energy-rich zones can permit electrolyser to be located close to end uses

Contractual considerations

The contractual requirements between the producer of green hydrogen and the renewable electricity generator(s) differ according to the sourcing of renewable power. Options to consider are presented in Table 10.

Table 10 Options regarding contractual arrangements of electricity sourcing

	Own renewable plants	Long-term PPA	(Short-term) Renewable power market
Description	**The renewable plant is owned by the green hydrogen producer**	**The green hydrogen producer concludes a long-term PPA with a third-party renewable electricity supplier**	**The hydrogen producer procures electricity from the electricity market (with high shares of renewable energy sources)**
Lower bid prices and total cost of support	Risks of technical issues (*e.g.* construction risks) affecting renewable energy sourcing is allocated to the bidders Green hydrogen production not subject to electricity price risks	Lower CAPEX may lead to lower costs, yet electricity transmission/ distribution costs might increase costs Risks of grid-related issues (technical issues or grid congestion) can be allocated to the bidders or the auctioneer Electricity price risks low for the green hydrogen producer	Risks of grid-related issues (technical issues or grid congestion) can be allocated to the bidders or the auctioneer Risk of unexpected increases in the electricity prices allocated to the green hydrogen producers If renewable energy shares are high, lower LCOH due to longer full-load hours of electrolyser use
Effectiveness (realisation rates, green hydrogen production)	Renewable energy sourcing risk due to exposure to one electricity source should be considered	Renewable energy sourcing risk outsourced to the renewables generator (except for PPA counterparty default risks)	Renewable energy sourcing risk subject to availability of renewables in the market
Climate and environmental goals	No additional efforts needed to ensure hydrogen plant supports climate goals	PPA-sourced electricity and hydrogen production should have a temporal match in place (relaxed in early stage of development)	Risk of increasing consumption from non renewable power plants

Choice of off-taker

The auction determines the off-taker of the produced hydrogen, *i.e.* the entity that buys the hydrogen and either consumes it or further sells it to (industrial) consumers. The choice of the off-taker (and therefore its creditworthiness) has an impact on the risk perception of producers and directly impacts the off-take risks discussed in section 4.5.

This entity can be a public body or government-owned institution tasked with off-taking the green hydrogen produced, either to consume it or to resell it. In this case, an HPA would be signed between the producers and the designated public body (or with a private intermediary endowed with public funds, such as HINT.CO GmbH in the German H2Global mechanism described in Box 3).

Another option assigns the producers the responsibility of finding (generally private) off-takers to purchase the produced hydrogen under an HPA. Under this approach, producers typically receive the support through a CfD or fixed premium (see "Type of remuneration"). This is the case in Chile (case study 6.1), India (case study 6.5) and the European Hydrogen Bank auction (case study 6.3).

Table 11 presents the considerations when deciding on whether the off-taker is a public body or private companies.

Table 11 Options for the choice of green hydrogen off-taker

	Public off-taker	**Private off-taker**
Description	**A public body acts as the off-taker of the produced hydrogen/derivatives**	**Private companies are the off-takers of the produced hydrogen/derivatives**
Competition and reduced risks on developers leading to lower bid prices	Reduces risk for investors and thus the price bid	Higher prices due to higher off-take risks
Reduce the total cost of support	Public body off-taker might be tied to high prices for a long period, taking on all first-mover risks	Depends on the market competition and the off-take price in the HPA as the public support typically tops it up
Effectiveness (green hydrogen production)	More guaranteed off-take and therefore green hydrogen contribution to the energy mix	Low to no hydrogen production if there are no private off-takers or they default until new off-takers are found
Hydrogen market liquidity	Government/public body takes over functions of market actors	Producers are responsible to find off-takers, and private off-takers fulfil the role of the demand side in the market
Socio-economic goals – development of a local industry	Off-take guaranteed with direct use of hydrogen	Off-take of hydrogen may be led by the most transformative industry

4.2 Qualification requirements and documentation

Pre-qualification and documentation requirements aim to ensure high project realisation rates, reduce delays and help achieve broader policy goals. Pre-qualification requirements can address the bidder's capabilities and technical and commercial preparation stage of the project. The criteria restrict the access of bidders to the auction to the ones whose experience, capabilities and stage of project pre-development meet the set criteria. However, these requirements can increase the risk of sunk costs especially if the project is not awarded, thereby deterring potential bidders, especially small and new players.

Decisions to be made relate to the documentation required (*e.g.* proof of financial and technical capability to carry on the project, permits and agreements required), the stage at which the permits and other documents are required, and whether there would be any local content requirements.

Documentation requirements

Among the documentation requirements, the auctioneer can require bidders to submit **proof of their capability** to realise the project. This ensures the bidder's capability for projects already at the bidding stage. The auctioneer can select between a range of legal (type of legally registered entity), financial (such as having a strong balance sheet) and/or technical (such as having experience in the realisation and operation of large infrastructure projects) requirements. This section does not discuss the requirements in detail as they are often context-specific and instead focuses on the effects of strict bidder capability requirements.

Auctioneers may also require **proof of (preliminary) commercial agreements** underpinning the sourcing of renewable electricity for the electrolyser and/or the off-take and transport of the produced hydrogen. These requirements seek to ensure the commercial viability of the projects already at the bidding stage so that the risk of project defaults and stranded investments can be reduced. For instance, the European Hydrogen Bank auctions ask for these commercial agreements (in form of a letter of intent or memorandum of understanding) as a pre-qualification requirement (see case study 6.3), while the Chilean hydrogen auction assigns a higher score to bidders who can present the commercial agreements as part of the winner selection process (case study 6.1).

Requirements for renewable electricity supply and grid access agreements. If the hydrogen producers do not source the power from their own on-site or dedicated off-site renewable plant, bidders might need to submit a Letter of Intent or any other type of preliminary agreement for a PPA with a renewable power producer. In addition, since power will not be sourced on-site, an indication of prospective grid access arrangements might also be required (*e.g.* in the form of a letter from the grid owner/operator).

Requirements for additionality. If the green hydrogen produced is for export, additionality requirements might be imposed by importing markets to ensure that hydrogen production does not displace the use of renewable electricity (*e.g.* the European Union[10]). Many low- and middle-income countries with abundant solar and wind energy in Africa, the Middle East, Southern Asia and the western regions of South America have some of the most promising sites for green hydrogen production. Most of these countries currently have very limited renewable energy production capacity, and substantial efforts will be necessary to increase it (to decarbonise their carbon-intensive power system or provide access to electricity) before or at the early stages of green hydrogen production. Imposing strict additionality requirements can cause complexities and increase project costs, which may hinder the rapid deployment of hydrogen. It should be noted that the concept of additionality varies from one jurisdiction to another to address unique challenges such as power outages, grid constraints, limited access of local communities to electricity, and varying levels of compliance and monitoring capabilities.

Requirements for green hydrogen off-take and transport agreements. In the cases where the public body or intermediary does not off-take the hydrogen directly and only pays a support premium, bidders could be required to submit a (preliminary) HPA to reduce the risk of awarded projects not finding an off-taker after the auction. Bidders could also be required to present a concept of proof of transportation arrangements ensuring that the produced hydrogen can be transported to the off-takers.

10 Additionality – which was initially introduced in the European Union – mandates that the electricity used in the production of hydrogen come from renewable sources that would have otherwise not been generated.

Lastly, through project requirements, the auctioneer can require bidders to submit **proof of the project's development progress including permits obtained**. Such requirements ensure that awarded bidders are more likely to realise their projects as several pre-development barriers would already have been overcome. Potential technical project requirements can include building or other permits and secured power connection permits for the renewables powering the electrolyser.

In addition, **proof of project sustainability and social contracts** can ensure the projects selected satisfy social and environmental sustainability criteria. These include proof of balanced use of land and water resources including credible arrangements to access water resources sustainably, proof of a land-lease agreement, and passing an ESIA. Projects may prove to be technically and economically feasible, but without social contracts, their potential can be significantly reduced. Social contracts in the context of green hydrogen production projects primarily revolve around the welfare of local communities and can vary depending on the specific context. They include revenue-sharing agreements, job opportunities for community members and investments in community development, such as improved housing and healthcare facilities for communities; in developing countries with limited access to electricity, they can require developers to allocate a share of renewable energy production to local electricity consumption; in water-stressed areas, they may include agreements to support local agriculture through sustainable water management practices or desalination projects sized to provide water to the local population (UNIDO, IRENA and IDOS, 2023).

Table 12 presents the trade-offs to consider when deciding on whether to introduce strict documentation requirements.

Table 12 Implications of strict documentation requirements

	Strict documentations requirements
Description	**Bidders need to present proof of their capability to realise the project, proof of (preliminary) commercial agreements, proof of the project's development progress including permits obtained, and proof of sustainability and social contracts to be allowed to participate in the auction**
Competition and reduced costs on developers leading to lower bid prices	◒ Too-strict requirements and higher pre-development expenses risk decreasing the level of competition and increasing the costs on the bidders, which is reflected in higher bid prices
Reduced total cost of support	○ Bid prices can be higher, but these requirements help filter bidders to only those that have high chances of delivering the project, reducing risks of future complications with implications on overall system costs
Effectiveness (project realisation rates)	● Increases the chances of project realisation as bidders' capabilities are proven, and challenges related to project development, commercial agreements or permits are addressed
Socio-economic benefits – development of a local green hydrogen economy	◒ Might limit new and particularly small entrants
Hydrogen market liquidity	◒ Potentially reduces the market liquidity of hydrogen as not enough project developers emerge due to too-strict requirements

Stage of documentation requirement

Defining at which stage during the project development process bidders can participate in the auction and when they need to submit the documentation required can influence the level of competition and the types of bidders that participate. There are two options available for the stage of project development and the documentation required for bidders to participate in the auction: advanced project development with elaborate documentation, or early project development with light to no documentation required.

In the option of early project development with light documentation required, bidders can participate even before selecting a site, obtaining building permits, etc. On the one hand, this option allows more bidders to participate, increasing competition, as the documentation requirements are less stringent. It furthermore reduces the sunk cost that bidders incur when preparing for the auction without the certainty of being rewarded a project. On the other hand, this option may lead to higher risk of projects not being realised as they face greater uncertainties in the development process.

As for advanced project development with elaborate documentation requirements, for instance in cases where only projects that have obtained permits or grid connection, with sites identified and secured, green hydrogen off-taker confirmed, etc. can participate, this option reduces the risks and uncertainty for the government and bidders, as the projects are more developed and have a higher chance of being realised. As an example, bidders in the Danish Power-to-X auction need to provide a screening agreement from the Danish transmission system operator (TSO) if electrolysers will be connected to the grid (see case study 6.2). However, it may limit the number of bidders that can participate in the auction, as the requirements are more stringent, thereby reducing competition and increasing prices offered (although in turn, prices might be better informed and thus potentially more realistic).

Table 13 Stage of the project development process when the auction takes place

	Early project development with light documentation required	**Advanced project development with elaborate documentation required**
Description	**Projects can be at the early development stage when participating in the auction with light to no documentation required**	**Projects required to be at an advanced development stage when participating in the auction with elaborate documentation required**
Competition and reduced costs on developers leading to lower bid prices	◒ Lower costs on developers and increased competition leading to lower bid prices	◒ Increased costs on the bidders and lower competition which is reflected in higher bid prices
Reduced total cost of support	○ Prices bid can be lower but higher risks that future complications might arise, with implications on overall system costs	◒ Prices bid can be higher but lower risks that future complications might arise, with implications on overall system costs

Effectiveness (realisation rates)	Higher risk of projects not being realised or delivering as per the bid due to potential permitting or price issues after the award	Lower risk of projects not being realised or delivering as per the bid
System integration	In the case of grid-connected electrolysers, grid-related issues are identified only after the auction takes place	In case of grid-connected electrolysers, TSOs and distribution system operators are informed ahead of time regarding new capacity to be added to the grid
Address infrastructure challenges	Not requiring such documentation at early stages increases risks that infrastructure will not be developed on time	Documentation required increases chances that infrastructure will be developed on time

Local content requirements

The auction can impose mandatory requirements for the share of project equipment, labour and services (*e.g.* operation and maintenance, implementing R&D and educational programmes) to be sourced locally in order to participate in the auction. **Local content requirements** (LCRs) have been introduced as part of the eligibility requirements for developers to participate in renewable power auctions with mixed outcomes depending on policy design, implementation and context (IRENA, 2019). Although they may increase prices in the short term, such requirements can help develop local supply chains for green hydrogen production to maximise local value creation.

Monitoring mechanisms are needed for LCRs to ensure compliance with the requirements after the project is awarded and developed. Additionally, LCRs should be implemented as part of a holistic industrial policy, including for example fiscal incentives such as tax breaks to support the establishment of factories by attracting foreign suppliers to partner with local manufacturers, and guaranteed long-term sales and a global market for the produced goods. Table 14 presents the implications of LCRs.

Table 14 Implications of local content requirements

	Implementing local content requirements
Description	**Bidders are required to source a percentage of their assets and services locally**
Dynamic efficiency (moving down the technology learning curve)	Local sourcing of products and services can build local capacity, know-how and expertise
Competition and reduced costs on developers leading to lower bid prices	Higher costs on developers (at least in the short term) and lower competition leading to higher bid prices
Reduced total cost of support	Prices bid can increase and this additional support goes towards building local capacity and creating domestic value

Effectiveness in supporting green hydrogen production	◒ Potentially low number of hydrogen projects awarded if local content requirements are strict or unachievable
Climate and environmental goals	◒ Might slow down decarbonisation if requirements are too strict and projects not feasible
Socio-economic goals – greening local industries	○ Depends on the impact of localisation on the price of green hydrogen
Socio-economic goals – development of domestic green hydrogen economy	● Designed to support the development of upstream services

4.3 Location, technology and project specifications

In this category of design elements, decisions need to be made regarding the location and technology specificity of the auction, production limits that can be imposed along with any project size requirements.

Location specificity

The location specificity determines the flexibility/responsibility for project developers to select a suitable site for their electrolyser, considering factors such as resource availability (*e.g.* availability of water for the electrolysis or renewable energy potential in case of captive hydrogen production – see design element Section 4.1 *Sourcing of electricity*), land availability, infrastructure, and proximity to customers or markets.

One option is for the auctioneer to identify and typically pre-develop a suitable site, the so-called **site-specific** auction, which could include a guaranteed electricity grid connection in the case of grid-connected renewable power sourcing, water connection, environmental impact assessment, existing transport infrastructure, potential use of by-products of electrolysis (waste heat and oxygen), etc. When selecting sites, policy makers could also consider locations close to existing industrial clusters to replace existing conventional hydrogen consumption. Bidders would then submit bids to realise the project on the auctioned site.

Alternatively, **free siting** of electrolysers (and power plant in the case of the captive option) can be selected, where bidders choose the location of their electrolyser freely but are responsible for conducting resource and impact assessments.

Another option is for the government **to guide the siting of the projects** to or away from predetermined zones, typically in the form of incentives (in the merit order or awarded prices) or requirements. This option lies in between site specific and free siting in terms of flexibility for the bidders. Table 15 presents the possible options.

Table 15 Options for the location specificity of green hydrogen auctions

	Site specific	Guidance in the form of incentives/ requirements to guide siting to or away from predetermined zones	Free siting
Description	**Only projects in specific zones/locations/ pre-developed sites can participate**	**Bidders can choose the location with guidance in the form of incentives/ requirements from the auctioneer to or away from pre-determined zones**	**Bidders can choose the location for their projects freely**
Competition and reduced costs on developers leading to lower bid prices	◒ Pre-developed sites can reduce risks and costs on bidders and the prices they offer	○ Lower CAPEX may lead to lower costs, yet electricity transmission/ distribution costs might increase costs ○ Risks of grid-related issues (technical issues or grid congestion) can be allocated to the bidders or the auctioneer ● Electricity price risks low for the green hydrogen producer	○ Risks of grid-related issues (technical issues or grid congestion) can be allocated to the bidders or the auctioneer ◒ Risk of unexpected increases in the electricity prices allocated to the green hydrogen producers ◒ If renewable energy shares are high, lower LCOH due to longer full-load hours of electrolyser use
Reduce the total cost of support	◒ Costs associated with resource and impact assessments, land, grid, water, etc. passed on to the auctioneer	◒ Renewable energy sourcing risk outsourced to the renewables generator (except for PPA counterparty default risks)	○ Renewable energy sourcing risk subject to availability of renewables in the market
Effectiveness (realisation rates)	◒ High realisation probability if site is pre-developed and regulatory issues already addressed	○ There are no guarantees that the sites selected will lead to project realisation	◒ Regulatory issues related to permitting for example can potentially arise that might hinder the realisation of the project
Socio-economic goals – development of domestic green hydrogen economy	◒ Sites could be located in underdeveloped regions to increase impact on domestic economy and reduce impact on environment or in dedicated industrial development zones	◒ Incentives/requirements provided can guide siting to underdeveloped regions	◒ Sites with lowest production cost for producers might not be optimal from a societal point of view
System integration	◒ Locations can be selected such as to avoid electricity grid constraints and ensure the transport of the hydrogen	◒ Incentives/requirements provided can guide siting on locations with lower integration costs	◒ Projects could be located in areas with already stressed electricity grids and suboptimal transport infrastructure

Technology specificity

Technology specificity describes which technologies compete against each other in one auction round. The choice of this design element depends on the policy makers' objectives and relates to the auctioned product and the sourcing of electricity, and has a direct impact on the chances of certain technologies being awarded. Typically, technology-neutral auctions permit the discovery of the most cost-effective technologies or solutions, while technology-specific auctions enable the introduction and deployment of the less mature (and potentially more expensive) technologies.

In its broadest form, the auction can be targeted at procuring **any solution that can reduce emissions** whereby green hydrogen can compete for support, along with other solutions such as renewable electricity, renewable heat or energy efficiency (as applied in the Netherlands SDE++ [Stimulation of Sustainable Energy Production and Climate Transition] support scheme – see case study 6.2). This approach typically ensures that the least costly solution to reduce emissions is supported. The implications to consider are presented in Table 16.

Table 16 Implications of technology-neutral auctions for emissions reduction

	Technology-neutral for emissions reduction solutions
Description	**Several solutions for emissions reduction compete in an auction for support, and green hydrogen can participate**
Dynamic efficiency (moving down the technology learning curve)	More expensive technologies, that are needed for the transition and that have the chance to become cheaper in the future, are not awarded and deployed (*e.g.* green hydrogen)
Effectiveness in supporting green hydrogen production	Potentially low number of hydrogen projects awarded if competing with other solutions
Climate and environmental goals	Selection of solution directly linked to emissions reduction goal
Socio-economic goals – greening local industries	No control over the deployment of technologies that have different impacts on industrial development
Socio-economic goals – development of domestic green hydrogen economy	Support for green hydrogen production not guaranteed

When it comes to auctions focused only on procuring green hydrogen, which is the main scope of this brief, the technology specificity of the auction gets into **the specific technology of the electrolyser** such as polymer electrolyte membrane (PEM), alkaline or solid oxide electrolysers. The implications to consider are presented in Table 17.

Table 17 Options for technology-specific green hydrogen auctions

	Green hydrogen-specific auction but electrolyser technology neutral	**Green hydrogen-specific auction with technology-specific electrolyser**
Description	**Specific green hydrogen auction where different electrolyser technologies compete**	**Specific green hydrogen auction where only one electrolyser technology is allowed to participate**
Dynamic efficiency (moving down the technology learning curve)	Deployment that enables learning effects and cost reductions (when combined with other measures) is supported for the cheapest electrolyser technology	Deployment that enables learning effects and cost reductions (when combined with other measures) is supported for specific electrolyser technologies
Lower bid prices and total cost of support	Cheapest electrolyser technology is selected, which leads to the lowest bid prices	No competition between technologies, potentially awarding a more expensive technology
Effectiveness in supporting green hydrogen production	No control over the electrolyser technology selected	Control over the technology selected can favour the most reliable technology at the time of the auction
Socio-economic goals – development of domestic green hydrogen economy	No support to any specific electrolyser technology which may deter investment in electrolyser supply chain	Can support the development of specific electrolyser technology

Another aspect of the technology specificity of green hydrogen auctions relates to the sourcing of renewable power – in the case of on-site power plants or through PPAs – and whether it can come from **any renewable energy source or a specific technology**. This element together with the trade-offs it presents have been analysed in the guidebook for the design of renewable power auctions (IRENA and CEM, 2015).

Finally, technology specificity of green hydrogen can relate to **the sectors** and/or demand-side technologies in which the supported green hydrogen is allowed to be used (*e.g.* steelmaking versus fertiliser industry). The implications to consider are presented in Table 18.

Table 18 Implications of sector-specific off-take in green hydrogen auctions

	Green hydrogen auction with sector-specific off-take
Description	**Produced green hydrogen is allowed to flow only to specific demand sectors**
Lower bid prices and total cost of support	Could exclude sale to demand-side actors with higher willingness to pay
Climate and environmental goals	Auctions can target the largest emitters
Socio-economic goals – greening local industries	Can ensure the use of green hydrogen in the sector of the demand side with the highest impact on industrial development

Production limits

There are two options for setting minima and/or maxima on the annual production of hydrogen per producer:

- Setting **minimum annual full-load** hours for the electrolyser or a **minimum amount of hydrogen** to be produced is useful for meeting specific hydrogen production targets and providing hydrogen off-takers with a secure supply. Minimum annual full-load hours for the electrolyser could imply a need for a minimum level of stable renewable electricity that for insular systems, could call for combining the power plant with other solutions such as battery storage electrolyser.
- Setting **maximum annual full-load hours** for the electrolyser is useful for ensuring that the renewable power used for the electrolyser is from renewable energy when bought from the market. For instance, the SDE++ scheme caps the number of full-load hours to 5 000 if the electrolyser is grid-connected, and to 6 154 full-load hours in the case of captive production (see case study 6.6). This approach is based on the expected fully carbon-free hours in Netherlands in the future, when merchant price of electricity will be low enough to turn on the electrolyser. In Denmark, the maximum yearly full-load hours is set at 5 500 (see case study 6.2).

India has set both a minimum and maximum annual production of green hydrogen in its technology-agnostic basket (at least 10 000 Mt production per annum but should not surpass 90 000 Mt) and in its biomass-based auction (500 Mt and 4 000 Mt per annum) (see case study 6.5).

Table 19 presents the pros and cons of setting minimum or maximum green hydrogen production amounts.

Table 19 Considerations while setting minimum and maximum green hydrogen production amounts

	Minimum annual full-load hours/produced hydrogen	Maximum annual full-load hours/produced hydrogen
Description	**Ensures a minimum amount of hydrogen produced or full-load hours of the electrolyser**	**Limits the full-load hours of the electrolyser or the amount of hydrogen produced**
Competition leading to lower bid prices and total cost of support	Higher risk for generators to meet minimum amount may be translated into higher prices Supports economies of scale which can lead to lower price	May limit economies of scale of hydrogen production which may limit potential for price reduction
Budgetary planning	Only gives an indication of the minimum support provided	Enables the calculation of (maximum) support payments
Effectiveness in meeting set targets	Can be set in a way to ensure the targets are met	Only gives an indication of the maximum quantity that can be produced
Climate and environmental goals	A minimum amount of green hydrogen production is ensured, but other provisions are required to ensure it is used and displaces fossil fuels	The amount of green hydrogen produced is limited

Socio-economic goals – development of domestic green hydrogen economy	Ensures a minimum amount of green hydrogen is produced	Limiting the production of each producer can limit the risk of market concentration and support the development of the sector Could limit the potential production of green hydrogen (if not enough bidders are selected)
Support system integration of VRE		Potential constraints in the power system can be reflected in design

Project size requirements

Setting project size requirements, typically in terms of electrolyser capacity, in an auction can have both positive and negative impacts.

A **minimum project size requirement** can help reduce the administrative burden of the auctioneer by limiting the number of projects/bids and reducing the costs of managing a large number of smaller projects (*e.g.* the European Union foresees a 5 megawatt [MW] minimum project size requirement in the European Hydrogen Bank auctions – see case study 6.3, while the SDE++ in the Netherlands sets the minimum project size requirement at 0.5 MW – see case study 6.6). On the other hand, it can exclude smaller players from participating and limit innovation in the market.

A **maximum project size requirement** can prevent market concentration of bidders by limiting the dominance of larger projects that get awarded most of the auctioned volume (and which tend to be developed by larger players) and creating opportunities for smaller players (with typically smaller projects) (see also design element on *Provisions to avoid market concentration*). However, it can also limit economies of scale, making larger projects less competitive, and may limit the ability to achieve cost reductions.

Table 20 presents the pros and cons of setting minimum or maximum project size restrictions.

Table 20 Considerations while setting minimum and maximum project size requirements

	Minimum project size	**Maximum project size**
Description	**Electrolysers below a specific minimum capacity cannot participate in the auction**	**Electrolysers above a specific maximum capacity cannot participate in the auction**
Competition leading to lower bid prices and total cost of support	May lead to economies of scale, minimising costs and price bid Can help minimise administrative costs of running the auction	May limit economies of scale Can increase administrative costs of running the auction
Socio-economic goals - development of domestic green hydrogen economy	A large minimum project size might limit participation to players that can handle a project that size, deterring small and new players	Could increase chances of small entrants and pilot projects
Hydrogen market liquidity	May lead to market concentration if minimum size is close to total volume auctioned	Can limit market concentration

4.4 Winner selection

The winner selection category of design elements entails decisions that should be made regarding winner selection criteria (whether the price would be the only criterion or if other objectives would be included), any provisions to avoid market concentration and any price caps to be considered, above which bids would not be considered.

Winner selection criteria

The winner selection criteria dictate how to rank the bids and select the winners. Although it is possible to consider multiple criteria, translating these attributes into a one-dimensional "index" allows for the direct comparison of bids in order to ensure consistency in the selection mechanism.[11]

In **price-only auctions**, bidders with the lowest bid prices are awarded and receive support. For instance, the European Hydrogen Bank auctions (see case study 6.3, Box 4) and the Danish auction (see case study 6.2, Box 4) are price-only auctions. This approach is simple and transparent, but it risks excluding other factors that are important for overall policy objectives.

In **multi-criteria auctions**, several criteria are taken into consideration for selecting the winning bidders, in addition to the submitted bid price. This approach can include criteria such as the quality of project pre-development, share of domestically produced components, or the project's socio-economic and environmental impacts. This approach may result in projects that are more successful at contributing to overall policy objectives, but they can also be more complex to evaluate and can lead to the projects with the lowest prices not being selected.[12]

11 Independent of the winner selection criteria, auctioneers should implement qualification requirements to ensure high realisation rates (see section on *Qualification requirements and documentation*).

12 Adjusted price-only auctions are a variation of the multi-criteria auctions. In adjusted price-only auctions, the submitted bid price is adapted based on different possible criteria, typically using a correction factor or assigning a bonus/malus. This approach can balance the importance of price and non-price criteria and ensure that the most suitable projects are selected.

Multi-criteria auctions are for instance conducted in the H2Global auctions (see Box 3), including criteria such as the proposed minimum quantity of product to be delivered, alongside the bid price. Especially in the case of non-price criteria, auctioneers should be transparent regarding the applied winner selection criteria to build confidence into the auction scheme and not discourage participation.

Table 21 Trade-offs to consider regarding price-only or multi-criteria auctions

	Price-only auction	**Multi-criteria auction**
Short description	**Bidders with the lowest bid prices are awarded**	**Bidders are awarded based on a multitude of different criteria**
Dynamic efficiency	Selection purely based on the bid price might hinder more expensive electrolyser technologies to be awarded and thus limits the potential for technological innovation and learning	Technological innovation could be included in the selection criteria
Lower bid prices and total cost of support	Bidders with the lowest bid prices/ support needs are awarded	Bid price is not the only criterion/main objective when selecting bidders, which may increase the cost of support
Transparency regarding the way projects are selected and support is awarded	Easy-to-understand selection process and to justify payments to the producers	May be complicated to understand selection process and to justify payments to the producers when they are not the lowest bid
Effectiveness (project realisation rates)	Selection purely based on the bid price could sometimes lead to aggressive, unsustainably low bid prices (underbidding)	There is a need for additional compliance mechanisms to ensure projects deliver as per the bid
Socio-economic goals – development of domestic green hydrogen economy	The development of the green hydrogen sector might not be targeted by selecting lowest-price projects	The development of a domestic green hydrogen sector can be included as a criterion in the selection process
Socio-economic goals - development of local green industry	Green hydrogen-consuming industry might profit from cheapest bids	The development of a local industry that consumes green hydrogen might be slowed due to higher prices
Climate and environmental goals	Not addressed, as achieving the lowest price possible is the aim of the bidders	Environmental and socio-economic goals can be explicitly included as criteria in the selection process
System integration	Cheapest projects might have adverse effects on system integration The lowest-price projects can be designed to produce when renewable electricity is cheapest, leading to a higher system integration	System integration can be included as a criterion in the selection process

Provisions to avoid market concentration

Auctioneers can implement seller concentration rules in auctions to avoid market concentration, *i.e.* that only a small number of bidders wins most of the auctioned volume. The auctioneer sets a maximum amount of the auctioned volume that a single bidder can sell (see design element on Production limits) or project size to bid or be awarded (see design element on Project size requirements). For instance, in the European Hydrogen Bank auction, a single bid cannot account for more than 33% of the auctioned budget (see case study 6.3).

Setting a maximum volume for a bid has similar properties to setting a maximum project size (see *Project size requirements*). Table 22 Implications of introducing seller concentration rules.

Table 22 Implications of introducing seller concentration rules

	Seller concentration rule
Short description	**Bidders can bid or be awarded only a certain amount of the auctioned volume**
Competition leading to lower bid prices and cost of support	◒ Might increase competitive pressure as more (smaller) bidders have the incentive to participate in the auction ◒ Might not necessarily lead to the whole volume being awarded at the lowest prices, potentially increasing the total cost of support ◒ Awarded prices might increase due to a loss of economies of scale
Effectiveness (realisation rates)	◒ Higher diversity of bidders increases the chances of projects being realised
Socio-economic goals - development of domestic green hydrogen sector	◒ May attract small and new players
Hydrogen market liquidity	● Reduces market concentration

Price caps

A **ceiling price** is a maximum bid price that is set by the auctioneer and above which bids are excluded from the auction. Auctioneers introduce ceiling prices to reduce the risk of excessively high bid prices, especially in case of low competition.

In contrast, a **floor price** is a minimum bid price that the auctioneers set, under which bids are excluded from the auction. The main goal of a floor price is to avoid unsustainably low bids which are not sufficient for the generator.

Table 23 Implications of introducing floor and ceiling prices

	Floor price	Ceiling price	
Short description	**Minimum bid price, under which no bid is accepted**	**Maximum bid price, above which no bid is accepted**	
		Ceiling price disclosed	**Ceiling price not disclosed**
Lower bid prices and total cost of support	May lead to higher total cost of support, if bidders are able to bid lower than the floor price	Can limit the total cost of support In the absence of enough competition bidders can bid right under the ceiling If set too low, the ceiling price might reduce the competition	Can limit the total cost of support Might disqualify a large number of projects for bidding above the ceiling
Effectiveness (realisation rates)	Ensures a sufficient level of support for realising projects	Bidders could be pressured to lower their bids below the ceiling, even if underbidding	Risks of underbidding not very related to ceiling price

4.5 Risk allocation and remuneration of sellers

The key to a successful auction is the allocation of risks among the different players (project developers, off-takers and auctioneer). This section identifies the main risks faced by bidders in supply-side auctions and investigates the various design elements that allocate the risks among the different players and determine the remuneration to the sellers.

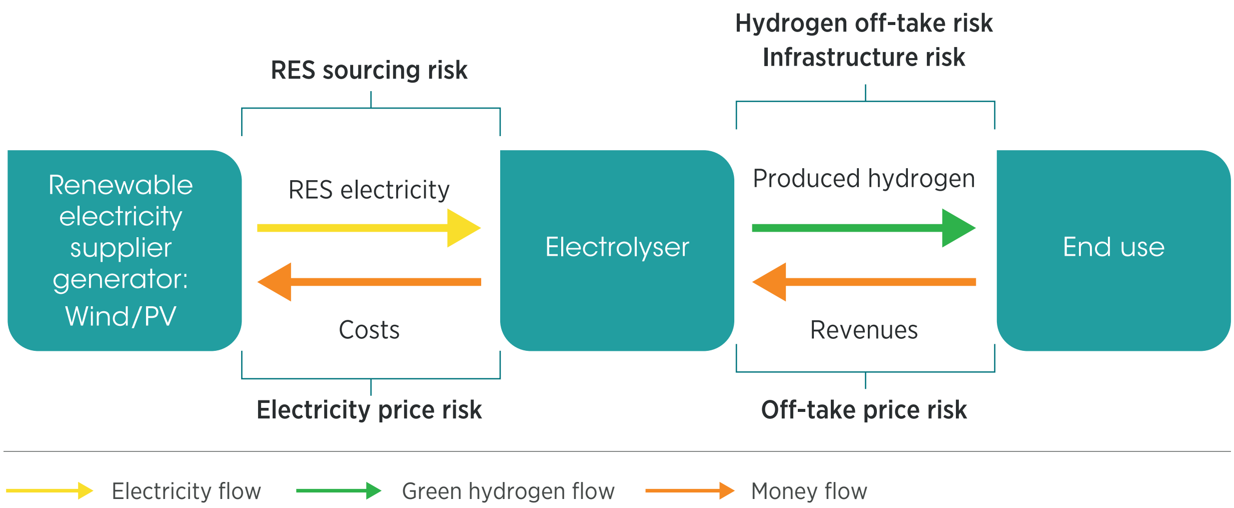
The main risks faced by the bidders in supply-side auctions

Hydrogen producers will face specific risks that impact their level of participation in an auction and/or the bids they submit (Figure 8). When designing auctions, governments face the challenge of allocating the right balance of risks among bidders, off-takers and the public body managing the auction. Where too much of the risk accrues to bidders, this can make projects less bankable, reduce competition, and increase financing costs and therefore bid prices; meanwhile, arrangements that transfer too much risk to the public sector might lead to the government being liable for extra payments or not meeting its intended policy objectives. A good auction design allocates the risks to the party that is most capable of handling it at a given moment to satisfy prioritised policy objectives.

As the green hydrogen sector matures and costs drop, some of these risks can be reallocated to the producers. This is why the auction design should always be context-specific and dynamic, adapting to changing market conditions.

The most relevant risks along the green hydrogen value chain that must be considered while designing an auction are listed below (from the end of the supply chain to the beginning).

Figure 8 Hydrogen value chain and risks that need to be allocated to the different players in the auction design



Notes: RES = renewable energy source; PV = photovoltaic.

Renewable power sourcing risks

The risks of non availability of the sourced renewable electricity needed to produce green hydrogen include:

- Grid-related risks: technical issues with the grid connection or grid bottlenecks can affect the green hydrogen production negatively, limiting the capacity factor of the electrolyser.

- Technical issues with dedicated renewable power plant: similarly, technical issues with a dedicated (captive) renewable power plant can affect the green hydrogen production negatively.
- Default of renewable power generation counterparty with which the green hydrogen producer has signed a PPA: in case of a default of the counterparty, the green hydrogen producer needs to find an alternative source of renewable electricity, which affects the green hydrogen production.

In general, the renewable power sourcing risk is allocated to the green hydrogen producers, especially in the case of dedicated (captive) power plants. In the case where power is sourced from the grid, certain aspects could be borne by the government, such as providing a guaranteed grid connection and the avoidance of grid congestions. Specific risks can be brought by policy design; these include the current EU definition of green hydrogen, based on the Renewable Energy Directive, which requires temporal and geospatial correlation as well as technological additionality, brings with it a specific set of considerations (location of power generator asset, possible inclusion of a battery, *etc.*), that impact the renewable power sourcing risk. One example is grid congestion risks, where the grid congestion can affect the green hydrogen production negatively, as it could not prove to have used electricity from another balancing area.

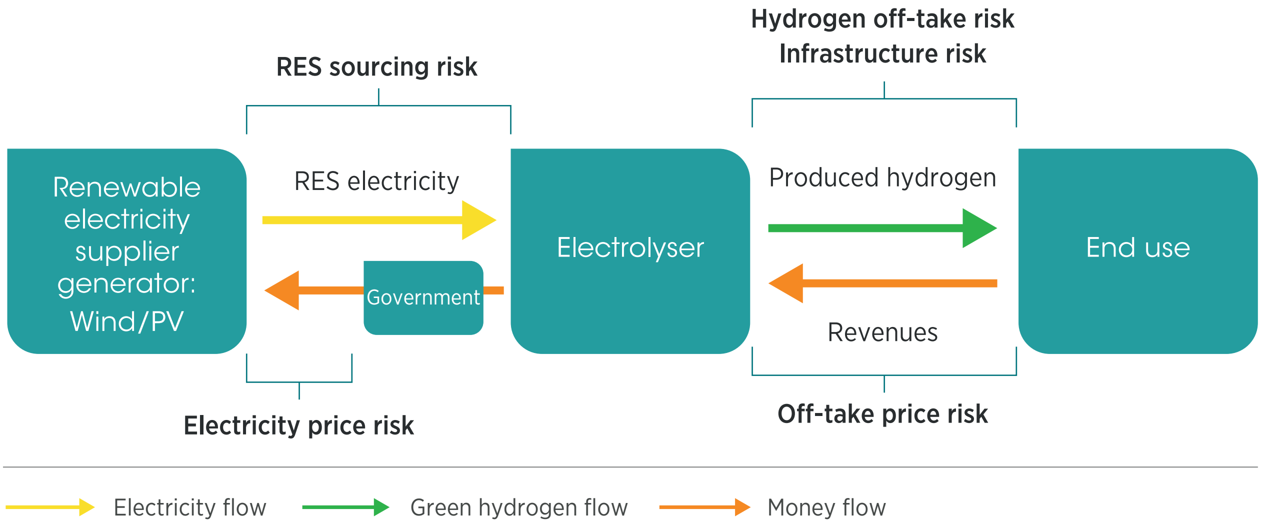
Electricity price risks

Electricity price risks mainly relate to the risk of economic losses due to high costs of electricity.

- Market risk: if electricity is purchased at the electricity market, or in the case of a PPA which is indexed to electricity market prices, unexpected increases in the electricity prices can lead to increases in the production costs, possibly rendering an electrolyser unprofitable. Although very unlikely and associated with potential legal challenges, in case of a fixed-price PPA, the PPA counterparty might have the incentive to cancel or renegotiate the PPA price, adapting the price to the higher level of electricity market prices.
- If electricity is sourced from dedicated (captive) power plant (insular solution), while the price risk is less pronounced/relevant in this case, higher electricity market prices can constitute opportunity costs/missed revenues for the on-site power plant.

The renewable electricity price risk can be allocated to the green hydrogen producer (Figure 10 and Figure 11) or be borne by the government, by indexing the support level provided to green hydrogen (Figure 9).

Figure 9 Hydrogen value chain with government assuming electricity price risk



Notes: RES = renewable energy source; PV = photovoltaic.

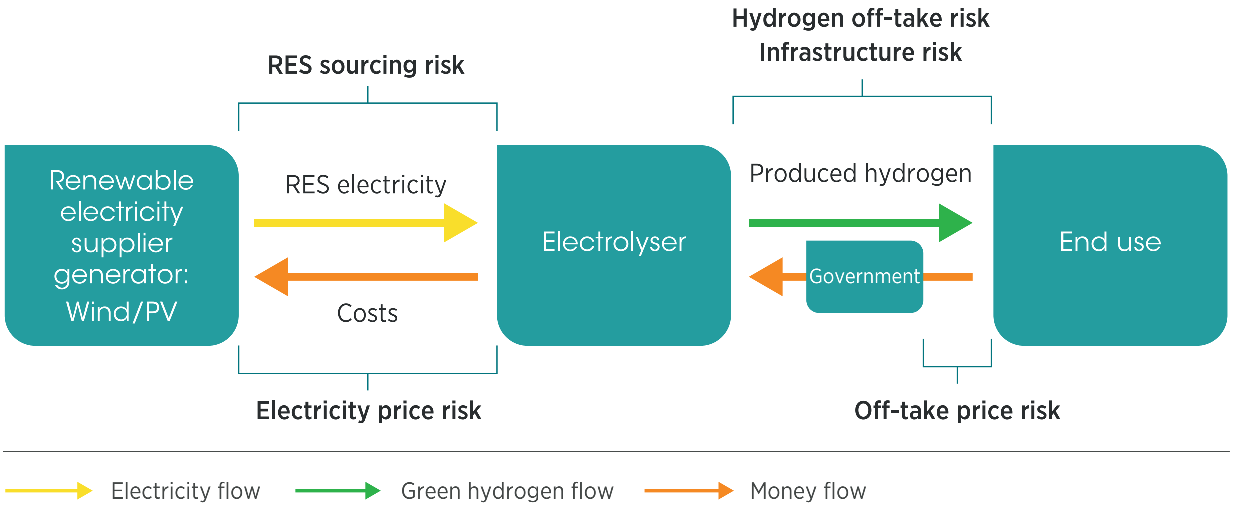
Hydrogen off-take and off-take price risks

Risks associated with the off-take of the produced hydrogen and its off-take price include:

- Absence of off-taker: due to limited existing demand for green hydrogen, the green hydrogen producer might face difficulties finding suitable off-takers for the lifetime of the electrolyser.
- Hydrogen off-take price: low willingness to pay from consumers for the produced green hydrogen can make an electrolyser unprofitable.
- Default of off-taker: an existing off-taker might default, making it necessary to find another suitable off-taker in a short period of time (which might be difficult due to the limited demand).

Risks regarding the green hydrogen off-take could be allocated to the government (Figure 11), but this goes along with the associated administrative costs, as typically an intermediary would need to be set up. Design elements could be introduced to allocate the off-take price risk to the government (Figure 10).

Figure 10 Hydrogen value chain with government assuming hydrogen off-take price risk



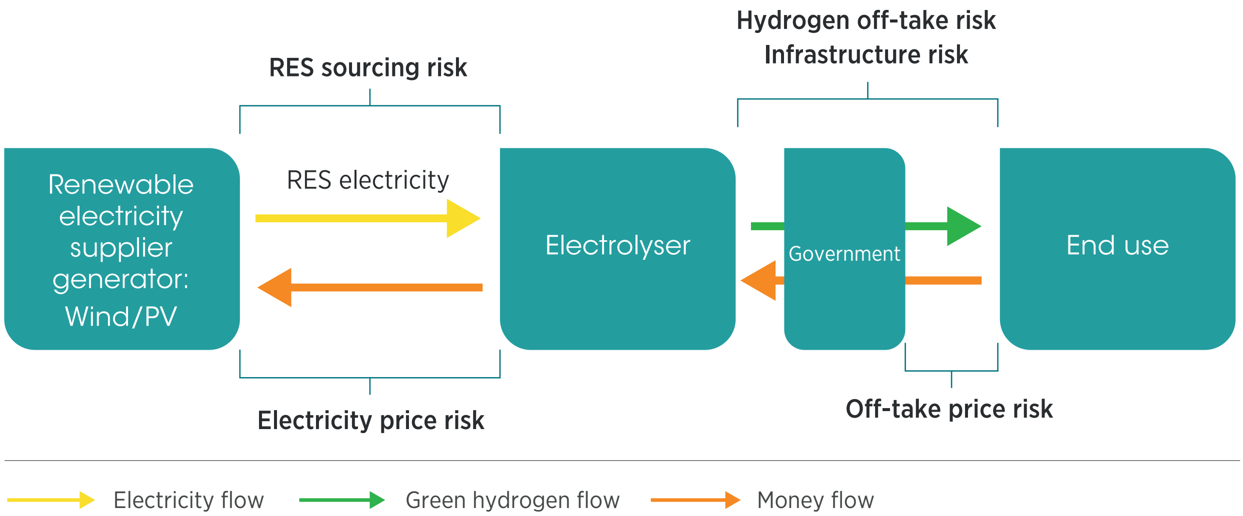
Notes: RES = renewable energy source; PV = photovoltaic.

Hydrogen transport risks

Infrastructure to transport the produced green hydrogen to the off-taker might be non-existent (although already planned) by the start of green hydrogen production or might have technical issues during the operation.

The infrastructure risk could be assumed by the auctioneer, which means that a public body is responsible for setting up and operating (or at least funding) the hydrogen transport infrastructure, or more generally, transporting the hydrogen from the producers to the end users, which also increases the administrative costs (Figure 11).

Figure 11 Hydrogen value chain with government assuming hydrogen off-take price risk, infrastructure risk and hydrogen off-take risk (*e.g.* through a government GHPA)



Notes: RES = renewable energy source; PV = photovoltaic.

Additional risks

Additional risks irrespective of the sourcing and off-take challenges are technology, institutional and regulatory risks, such as the "Immaturity of hydrogen technologies" and the "Regulatory framework not ready for hydrogen sector" (see Table 1). One example of regulatory risks relates to the definition of green hydrogen whereby if an auction is not in line with requirements necessary for the end product to be defined as "green" by the main consumption markets, the bidders risk under- or over-delivering in terms of climate and environmental considerations, therefore making the hydrogen produced ineligible for exports or overpriced, respectively.[13] Other risks relate to safety and environmental risks.

Concerning technology and regulatory risks it is in general best practice that bidders are exposed to the risks they can control, *i.e.* technology costs, and shielded from risks they cannot control, *i.e.* regulatory risks. The allocation of risks also strongly depends on the level of development of the market and the financial means of the government and its willingness to assume additional risks to incentivise the creation of a green hydrogen market.

13 An example is the discussion around the definition of green hydrogen in the European Union, which is regulated in the "Delegated regulation on Union methodology for RFNBOs" (European Parliament, 2023).

The design elements to consider under risk allocation and remuneration of sellers

Design elements to consider include the ownership model of the project, the type of remuneration to the sellers, the contract duration, currency denomination and indexation, along with the seller's compliance rules and the stakeholder that takes on the responsibility for transporting the products.

Ownership model

The ownership model of the project impacts the responsibility and thus the risk exposure of the bidders.

In auctions which follow the **engineering, procurement and construction (EPC) model**, the successful bidders develop/install the electrolysers that would be owned and operated by a state-owned company. This approach reduces the risks associated with the operation of the electrolyser for the bidder including renewable power sourcing risks, electricity risks, and hydrogen off-take and transport risks.

Under the **independent green hydrogen producer (IGHP) model**, the successful bidders develop/install the electrolyser and operate it during the contract duration (see section on contract duration), fulfilling their contractual obligations. Different public-private partnership models exist including the typical IGHP model, which entails the BOO (build-own-operate) or the BOOT (build-own-operate-transfer) model, depending on the provisions for post contract duration.

The **design-build-finance-operate-maintain (DBFOM) model** is a project delivery method that allows a private sector contractor to design, build and finance a project and to handle operations and facilities maintenance under a long-term agreement. Through this model, the government relinquishes responsibility without surrendering ownership. This model has been used in Saudi Arabia, specifically in the South Jeddah Noor solar PV power plant and the South Rabigh solar PV power plant.

Table 24 Options of ownership model

	EPC model	IGHP model
Description	**A governmental institution has ownership of the project and operates it**	**Ownership and operation of project remains with the producer**
Competition leading to lower bid prices and total cost of support	Green hydrogen is produced by a government entity, which could mean lower prices as the potential risks are not handled by market players at a premium The costs and risks are passed to the government, and are accounted for in the cost of green hydrogen support Private companies, especially in a competitive environment, might be more efficient and innovative, and could bring longer-term cost efficiency	The electricity pricing and sourcing risks may be assigned to the producer (see design element Section 4.1, *Sourcing of Electricity*), leading to higher risks and therefore less competition and higher prices Private companies might be more efficient and innovative, especially in a competitive environment, and could bring longer-term cost efficiency

Budgetary planning	Accounting for operational costs and risks of unforeseen changes is the responsibility of the government entity operating the electrolyser and is not predetermined as part of a contract	Operation costs and risks would be estimated and accounted for by the hydrogen producer. These would be passed on in the price which is planned for budget-wise
Effectiveness (realisation rates, green hydrogen production, achievement of other policy goals)	Government retains control over green hydrogen production and ensures policy objectives are met	Depends on other design elements that allocate electricity sourcing and price and off-take risks and that define how strict compliance rules are
Socio-economic goals	Government could more easily implement measures to achieve political objectives such as job creation and local value creation, for instance by employing only local workforce	The fulfilment of socio-economic goals promised in the bid is difficult to track, monitor and penalise in case of non compliance
Hydrogen market liquidity	Not meant to support market development on the supply side, as only one hydrogen producer would exist, *i.e.* the government	Market liquidity on the supply side increases, as several hydrogen producers potentially exist

Type of remuneration

The type of remuneration defines how the support is paid out to the awarded producers and can be differentiated between investment-based and production-based remuneration. The trade-offs to consider are detailed in Table 25. Finding the most suitable type of remuneration can be challenging, especially at early stages of market development. To address this challenge, the United Kingdom (UK) Department for Business, Energy & Industrial Strategy conducted a consultation process that gathered views from stakeholders on the design choices that make up the main elements of the business model of low-carbon hydrogen projects. The outcomes were published in 2021 (UK Department for Business, Energy & Industrial Strategy, 2021).

Investment-based remuneration is a fixed amount of support that is paid at the early stage of project development/right after the realisation of the project. The investment-based remuneration is independent of the actual production of hydrogen and is typically based on the capacity of the electrolyser. The bidder receives the support independently of the quantity produced, transported or sold, thereby shielding the bidders from the associated risks to some extent. This type of remuneration is used by Chile (case study 6.1).

In the case of **production-based remuneration**, support is provided only if green hydrogen is actually produced and delivered to the off-taker, and thus, the bidders are exposed to some of the sourcing, pricing, transport and off-take risks, depending on the design elements selected.

The first production-based option is a **fixed-price HPA** where the off-taker takes and pays for the green hydrogen produced. In this case the off-taker, usually a private or public body, state-owned entity, or the government (see Section 4.1, *Choice of off-taker*), would then either use the green hydrogen itself or sell it as an intermediary to buyers (as for instance the private intermediary in the H2Global concept, see Box 3). Bidders are typically shielded from green hydrogen price and off-take risks.

Production-based support can also be paid out via a **CfD scheme**. In such a scheme a fixed amount of revenue for each unit of hydrogen sold on the market or to private off-takers is guaranteed by the government – irrespective of a potentially fluctuating hydrogen market price. Thus, the overall project revenue consists of the market revenues for the produced hydrogen (reference price) topped up by the support payment covered by the government. If the market revenues are above the strike price, hydrogen producers either pay back the difference to the government (two-sided CfD) or can retain this difference (one-sided CfD), as implemented in the SDE++ in the Netherlands (see section 6.6) and the United Kingdom (section 6.7). This model shields the bidders from hydrogen market price risks, but they generally still take on the off-take risks. Theoretically, the public funding required to bridge the gap between reference and strike price should reduce over time as the market matures and achievable sale prices stabilise. This approach requires defining a suitable reference price for green hydrogen, which could be challenging without a mature market.

Support can also be paid through a **fixed premium**, such as in the European Hydrogen Bank auction (see case study 6.3), in India (see case study 6.5), or in Denmark (see case study 6.2). In such case a fixed amount of support is paid out by the government for each unit of green hydrogen produced on top of the market revenues for green hydrogen, irrespective of the market price. In this situation, the bidders take on some of the green hydrogen price risk as well as the off-take risks.

There are various ways to further adjust the type of production-based support, *e.g.* providing support only for a certain capacity of the electrolyser or amount of green hydrogen produced. Furthermore, there are several methods of calculating the reference price for hydrogen revenues which can be particularly challenging as long as no liquid hydrogen market exists.

Table 25 Types of remuneration

	Investment-based remuneration	**Production-based remuneration**		
		Fixed-price HPA	**CfD**	**Fixed premium**
Description	**Producers receive a fixed amount of support at the investment stage of the project**	**Off-taker takes and pays a fixed price for the green hydrogen produced**	**A fixed amount of revenue for each unit of green hydrogen produced is ensured, which consists of the market revenues (reference price) and the support payment**	**A fixed amount of support is paid out for each unit of green hydrogen produced on top of the market revenues**
Competition leading to lower bid prices and total cost of support	● Bidders subject to high risk since producers' overall revenues highly depend on the market revenues/ off-take prices (high off-take price risk)	◒ Lower risk on producers since the agreed level of support is independent from market prices (low off-take price risk)	◒ Low risk on producers since overall revenues are to some extent independent of the market prices, with potential paybacks to the government if market revenues exceed level of support (low off-take price risk)	◒ Higher risk on, producers since overall revenues highly depend on the market revenues/off-take prices (high off-take price risk)

Budgetary planning	Support is fixed and independent of hydrogen production, thus high degree of predictability (after the auction is concluded)	Level of support is fixed, thus relatively high degree of predictability (after the auction is concluded)	Level of actual support depends on the market revenues/ underlying reference price	Level of support is fixed, thus relatively high degree of predictability (after the auction is concluded)
Effectiveness (realisation rates, green hydrogen production)	Support not directly tied to production	Support depends on project realisation and hydrogen production Revenues are secured and independent of hydrogen market/ off-take price	Support depends on project realisation and hydrogen production Revenues are secured and independent of hydrogen market/ off-take price, and may increase in the case of one-sided CfD, increasing production	Support depends on project realisation and hydrogen production No incentive for production in cases where market price is too low
Hydrogen market liquidity	Producers need to find a suitable off-taker to sell hydrogen and negotiate the off-take price	Producers simply produce green hydrogen and governmental off-taker is responsible for usage/sale	Producers need to find a suitable off-taker to sell hydrogen and negotiate the off-take price	Producers need to find a suitable off-taker to sell hydrogen and negotiate the off-take price

Contract duration

The contract duration defines how long support payments are available and/or the length of the HPA. The chosen contract duration can have an impact on the government's responsibility to provide support and the viability of the project.

The **time-based support approach** defines the support duration in terms of the number of years the support is available. This approach provides certainty for producers and allows them to plan their investment and operations over a defined period. The length of the support period impacts how fast producers are required to make up their return on investment before they go fully merchant with their projects, if they have the chance to. The length of the support period can reflect the potential lifetime of the electrolysers (depending on the technology and the full-load hours producing, up to 20 years), but could take into account the comparably longer lifetime of the renewable power plants (up to 30 years). In Denmark, the European Union and H2Global auctions, the contract duration is set at ten years (see case studies 6.2, 6.3, and Box 3, respectively). India supports green hydrogen production for three years only (see case study 6.5).

The **quantity-based support approach** defines the support duration in terms of the amount of produced green hydrogen that can be supported, typically defined based on a number of full-load hours and the project's capacity or directly in tonnes of green hydrogen produced. This approach provides flexibility and ensures that support is provided when the electrolyser is operating.

Table 26 Options for defining the contract duration

	Time-based		Quantity-based	
	Shorter	**Longer**	**Smaller**	**Larger**
Short description	**The time period during which the support is ensured is set rather short (*e.g.* up to 10 years)**	**The time period during which the support is ensured is set rather long (*e.g.* 10-20 years)**	**The amount of produced green hydrogen that is supported is rather small (*e.g.* up to 10 000 full-load hours for the electrolyser)**	**The amount of produced green hydrogen that is supported is rather large (*e.g.* 10 000-50 000 full-load hours for the electrolyser)**
Competition leading to lower bid prices and total cost of support	Bidders are exposed to higher risks due to uncertainties regarding the off-take prices after the support duration	Less exposure to off-take price risks after the support duration	Bidders are exposed to higher risks due to uncertainties regarding the off-take prices after the supported quantity	Less exposure to off-take price risks beyond the supported quantity
Budgetary planning	Shorter support duration has lower uncertainties (except in case of fixed support – see *Type of remuneration*)	Longer support duration has higher uncertainties (except in case of fixed support – see *Type of remuneration*)	Predetermined quantity can lead to better planning depending on the type of production-based support	Predetermined quantity can lead to better planning depending on the type of production-based support
Climate goals	Risk of no hydrogen production after the end of the support duration, if willingness to pay of off-takers is (still) too low	Hydrogen production can be ensured for a longer period of time	Risk of no hydrogen production after the supported quantity is exhausted, if willingness to pay of off-takers is (still) too low	A higher hydrogen production can be ensured
Hydrogen market liquidity	Short support period could incentivise bidders to identify off-takers/become fully merchant and thus increase market liquidity	Long support period could decrease willingness to switch off-takers after the support period and decrease market liquidity	Lower supported quantity could increase willingness to switch off-takers and increase market liquidity	Higher supported quantity could decrease willingness to switch off-takers and decrease market liquidity

Currency denomination

One important decision to make that impacts the risks bidders are exposed to is the denomination of the currency in the contract. The decision on the currency denomination of the contract generally takes into account the main buyers targeted. For example, if the goal is to produce green hydrogen for export, the contract is typically denominated in hard currency such as USD or EUR. Export revenues in this case can enhance the trade balance and facilitate access to foreign currencies.

When off-takers are local industry players, denominating contracts in local currency can help spur demand and off-take. When the off-taker is a public body, producers can be shielded from currency exchange risks by denominating the support levels in hard currencies. The currency exchange risk is borne by the government and can lead to lower risk premiums and thus lower bid prices. For instance, Chile has provided the support in terms of USD (case study 6.1). However, this can increase support costs for the government if the national currency loses its value compared with the foreign one. This approach can be combined with the options for support level indexation, so that green hydrogen producers are further shielded from further risks. Table 27 presents considerations while deciding on the currency denomination of the contract.

Table 27 Considerations while deciding on the currency denomination of the contract

	Contract denominated in hard currency	**Contract denominated in local currency**
Description	**Producers receive payments denominated in hard currency**	**Producers receive payments denominated in local currency**
Competition leading to lower bid prices	Bidders are shielded from currency exchange risks	Bidders take on the currency exchange risks
Total cost of support	If the off-taker is a public entity, currency exchange costs and risks are passed on to the government and are accounted for in the cost of support. If off-takers are private players, the government takes on only the additional cost for the premium	Cost of support does not entail currency exchange fluctuations
Budgetary planning	Accounting for currency risks cannot be predetermined	Cost of support does not relate to the currency exchange and can be more closely estimated depending on the other design elements
Effectiveness (realisation rates, green hydrogen production, achievement of other policy goals)	When off-taker is public entity, the government handles currency exchange fluctuations and developers carry on with projects When off-takers are private, there is a risk that they would default	Risk of projects not coming online or discontinuing operation if the local currency devalues beyond what is feasible
Socio-economic goals – greening industries	Industry players carry currency exchange risks	Industry players are shielded from currency exchange risks
Hydrogen market liquidity	Market development on the supply side is supported	Market players carry the currency exchange risks

Contract indexation

Indexation can provide a level of long-term stability and confidence for green hydrogen producers by adjusting the support levels based on changing market conditions and shielding them from (unexpected) changes in prices related to electricity market prices – in the case where electricity is sourced from the market – or inflation that could reduce the profitability/viability of the project and could thus lead to lower/no hydrogen production.

For grid-connected electrolysers, electricity price fluctuations could be addressed through electricity price-based indexation to ensure that support levels are adjusted to reflect changes in operating expenses (OPEX), as OPEX, especially electricity prices, make up a large share of the LCOH. Unexpected changes in capital costs during the project development phase can be covered by indexation to inflation.

Inflation-based indexation is especially relevant for electrolysers that have their dedicated renewable power plant (captive, as defined in "sourcing of electricity") or that have long-term PPAs that in principle provide cost predictability, but that can be indexed to inflation themselves. Inflation-based indexation is a common type of indexation in renewable power auctions, applied, for example, in the UK electricity CfD auctions. It is a simple and transparent approach that shields producers from (unforeseen) changes in the overall price level beyond electricity market prices based on the overall inflation or other economic indicators, for instance wage levels.

Table 28 Options and considerations for contract indexation

	No indexation	**Electricity price-based indexation**	**Inflation-based indexation**
Description	**Agreed seller remuneration is fixed over the entire support duration**	**Seller remuneration is adapted according to changes in electricity prices**	**Seller remuneration is adapted according to changes in inflation rate**
Competition leading to lower bid prices	◒ Risk of increase in electricity price (electricity price risk) or inflation factored in the bid price	◓ The risk of increase in electricity price (electricity price risk) not absorbed by producers which may lead to lower price in the bid (with future increases possible according to future increase in electricity price)	◓ The risk of inflation not absorbed by producers which may lead to lower price in the bid (with future increases possible according to future inflation)
Support cost efficiency	◒ Agreed levels account for the risks of future increases in electricity price or inflation	○ Levels of support can increase according to future increase in electricity price	○ Levels of support can increase according to inflation
Budgetary planning	◓ Agreed levels of support do not vary over time	◒ Levels of support can change over time	◒ Levels of support can change over time
Effectiveness (green hydrogen production)	◒ Producers are fully exposed to increases in prices and may opt to reduce green hydrogen production	◓ Producers are shielded against electricity price increases	◓ Producers are shielded against higher general price increases
Support system integration of VRE	◓ Bidders are incentivised to react to electricity price signals and potentially optimise their electricity procurement strategy	◒ Bidders react less to electricity price signals	

Compliance rules

If the producers do not fulfil their contractual obligation, such as the timely completion of the project or producing the required amount of green hydrogen, they may have to pay a penalty to the auctioning authority. Such compliance rules are introduced to limit participation to earnest, financially capable bidders and to give the awarded bidders a high incentive to realise projects on time, produce sufficient amounts of green hydrogen and deliver other policy goals as per the bid.

Compliance rules are usually secured through bid bonds, performance bonds and penalties for delays or under-/overproduction. See (IRENA and CEM, 2015) for definitions.

The **bid bond** is submitted during the bid stage and reduces the risk that bidders bid in the auction without the intention to sign the contract. For instance, India has implemented such a bid bond (see case study 6.5). For the awarded bidders, the bid bonds can later be converted to performance bonds or be complemented by those.

The **performance (or project completion) bond** is submitted by awarded bidders to ensure that projects will be realised, and on time. In many cases, the auctioneer retains the bid and/or performance bond as part of guarantees in case of financial penalties, such as in the case of the European Hydrogen Bank auction (see case study 6.3).

Penalties for underperformance and delay can include financial penalties or gradual termination of the contract in case of delays or underperformance. Penalties for underperformance can increase the impact of the renewable power sourcing risk on the green hydrogen producers. If the sourced renewable electricity is not available (for instance due to grid constraints), the producer will not only miss potential revenues from not being able to produce and sell the green hydrogen but will face potential penalties from the support scheme. Therefore, auctioneers often include the possibility of "banking", *i.e.* generators can shift a certain percentage of their production commitments between the years. For instance, the European Hydrogen Bank auction allows for a downward deviation of up to 30% on average over three years (see case study 6.3).

Table 29 Implications of stringent or lenient compliance rules

	Stringent compliance rules	Lenient compliance rules
Description	**Stringent compliance rules can include high bid/performance bonds and financial penalties or the resolution of the contract in case of delays or non-delivery as per the bid**	**Lenient compliance rules typically include low or no bid/performance bonds or financial penalties and more flexibility regarding delays or non-delivery as per the bid**
Cost reduction and support cost efficiency	Increases the risks and costs for bidders and might lead to lower levels of competition, increasing prices	Fewer risks and costs, encouraging bidders to participate in the auction, increasing competition and decreasing prices
Effectiveness	Producers will aim at fulfilling the contractual obligations	Producers have fewer incentives to fulfil their commitments
Socio-economic and environmental goals	In the case of socio-economic goals, penalties can ensure fulfilment after project realisation (particularly in case of multi-criteria auctions)	No way of ensuring the socio-economic benefits promised are achieved

Responsibility for transport

In case electrolysers are not collocated with the consumer (see design elements under *Location specificity*), an important design element is the party to which the responsibility of transporting the green hydrogen (or its derivatives) would be allocated.

The auctioneer can **require bidders to transport the produced hydrogen** or its derivatives to the consumer, or **the public entity itself can be responsible and even pay for the transport**. It can also differentiate between different stages of transportation. For example, in the H2Global auctions (see Box 3), the transport of green hydrogen or derivatives from the producer to the seaport of departure, the shipping at sea, and then transport from the seaport to the site of the hydrogen off-taker, are borne by different parties. Table 30 presents the implications of the different options.

Table 30 Options to allocate the responsibility of transport of green hydrogen

	Transport is auctioneer's responsibility	**Transport is producer's responsibility**
Description	**The government is responsible for organising and paying for the transport from the green hydrogen producer to the consumer**	**The producer is responsible for transporting the produced green hydrogen to the consumer**
Competition and price reduction	Less hydrogen transport risk for producers reduces prices	Higher hydrogen transport risk for producers, factored into the price
Support cost efficiency	Depends on the site selection rules: site- and location-specific auctions would see little to no transport costs while free siting could incur large transport costs on the auctioneer	Might be more efficient when producer handles transport (including site selection in the case of free siting)
Effectiveness (project realisation)	Certainty with transport (and associated regulatory hurdles) can increase realisation rates of projects	Challenges with project realisation due to potential regulatory issues with transport
Climate and environmental goals	Certainty with transport (and associated regulatory hurdles) can increase the use of green hydrogen instead of more polluting fuels	Challenges with transport might lead to favouring of conventional fossil fuels with more reliable logistics
Hydrogen market liquidity	By guaranteeing the transport, the government can increase liquidity by enabling the green hydrogen production in more remote locations	Challenges with transport of products might slow down market liquidity
System integration	Good sites with potentially higher transport costs can be accessed	Projects at good sites might not be developed due to higher transport costs

5 Main takeaways and conclusions

The benefits of clean hydrogen in general and green hydrogen in particular go beyond reducing GHG emissions to reinforcing energy security and creating opportunities for green industrialisation. Green hydrogen can spark a transformation with beneficial impacts on the economic and social dimensions of sustainability: economic through green industrialisation, energy independence, increased participation in global trade and markets; and social through job creation and reliable energy access. For countries with vast renewable energy potential, land and water resources, the production of green hydrogen can open avenues for green industrial development and local value creation including job creation, skills upgrading, investment mobilisation and wealth generation. This is particularly attractive for developing countries, for reinforcing their overall economic resilience and facilitating the development of diversified and knowledge-based economies.

However, green hydrogen faces several challenges that hinder its widespread adoption. Technological barriers include the immaturity of specific hydrogen technologies and safety concerns. Economic barriers revolve around high production costs and uncertainties regarding the LCOH. Institutional barriers include an unprepared regulatory framework and lack of coordination among national public bodies. Social barriers involve public awareness and acceptance issues. Additionally, the lack of dedicated infrastructure for transportation and storage, high transport costs, and limited off-take agreements further complicate the market dynamics. Addressing these barriers requires concerted efforts from policy makers to create a supportive regulatory environment, provide financial incentives and foster market demand.

Various instruments can help overcome these barriers. These include regulatory measures to provide clarity and stability, financial incentives to support early movers, and policies to create market demand, such as quotas and targets. Auctions have emerged as a particularly effective tool in promoting green hydrogen production and use. Auctions offer long-term revenue certainty, facilitate budgetary planning and enable progress along the technology learning curve. The competitive nature of auctions can lead to true price discovery and minimise the overall cost of public support by revealing the feasible remuneration for producers and the consumers' willingness to pay. Auctions also provide a clear project pipeline and transparency in project selection and support levels, and can be tailored to achieve broader policy objectives.

Despite their strengths, auctions must be carefully designed in order to ensure that they can be used to achieve policy objectives. Auctions are successful in reducing prices only if there is sufficient competition. A lack of competition can lead to higher prices and potential collusion among bidders. At the same time, excessive price pressure can lead to unrealistic bidding, project cancellations or the use of inferior components, compressing the sector and hindering innovation. Smaller producers may face high barriers due to the upfront resources required to participate in auctions without a guaranteed contract, reducing competition and potentially impacting market liquidity, innovation and the development of an upstream hydrogen sector. Policy makers need to address these challenges through appropriate design that enables balanced competition and considers the trade-offs between achieving the lowest price and other policy objectives.

There are four main types of auctions for supporting green hydrogen and they can be domestic, regional or international: supply-side auctions, demand-side auctions, double-sided auctions, and joint supply- and demand-side auctions. Supply-side auctions focus on hydrogen producers, and they aim to scale up electrolyser capacity and green hydrogen production, making them suitable for regions with abundant renewable resources. Demand-side auctions target hydrogen consumers, potentially incentivising hydrogen imports but not directly supporting the development of a domestic green hydrogen sector. Double-sided auctions and joint auctions aim to match supply with demand, often involving an intermediary to manage price differences and contract durations. They allow minimising the price gap that needs to be covered by funds. Each type of auction has its advantages and challenges, and the choice of auction type should align with specific policy objectives and market conditions.

This report focuses on supply-side auctions and details the design elements to consider, classified into five main categories.

1. **Auction demand.** The category of auction demand determines the product that is auctioned, the auctioned volume, periodicity of auction (regular schedule or stand-alone auction), the decisions made regarding the sourcing of renewable electricity for green hydrogen production including physical and contractual considerations, and choice of off-taker.
2. **Qualification requirements and documentation.** The key to a successful auction is to strike the right balance between increasing competition to achieve price discovery, while limiting participation to bidders that can deliver. Decisions to be made relate to the documentation required (*e.g.* proof of financial and technical capability to carry on the project, permits and agreements required), the stage at which the permits and other documents are required, and whether there would be any local content requirements.
3. **Location, technology and project specifications.** In this category of design elements, decisions need to be made regarding the location and technology specificity of the auction and production limits that can be imposed, along with any project size requirements.
4. **Winner selection.** The winner selection category of design elements entails decisions that should be made regarding winner selection criteria (whether the price would be the only criterion or if other objectives would be included), any provisions to avoid market concentration and any price caps to be considered, above which bids would not be considered.
5. **Risk allocation and seller remuneration.** Proper risk allocation mechanisms and remuneration structures are critical to balancing the risks between bidders and auctioneers. This includes addressing construction and operational risks, ensuring stable revenue streams, and managing off-take risks. Design elements to consider include the ownership model of the project, the type of remuneration to the sellers, the contract duration, currency denomination and indexation, along with the sellers' compliance rules and the stakeholder that takes on the responsibility for transporting the products.

Green hydrogen auctions should be designed in a way that helps deliver the policy objectives pursued in the national green hydrogen strategy. Policy objectives that may be pursued include achieving climate and environmental goals; developing a local green hydrogen economy with localised value chains to enhance energy security or participate in the international trade of green hydrogen and diversify energy exports; attracting foreign investments in energy-intensive industries; and supporting their international competitiveness.

Auctions should also be designed in a way to address challenges and barriers such as those related to system integration of variable renewable energy and hydrogen transport. In countries with high shares of VRE, auction design can aim at supporting system integration. To address barriers related to green hydrogen transport, auctions can be designed to procure derivatives or green products, or they can allocate the costs and risks associated with transport to the public entity facilitating the auction. Regardless of policy priorities, auctions should be designed in a way to ensure environmental and social sustainability and should adhere to the concept of additionality.

While auctions are a powerful tool, they must be part of a broader mix of policies that includes regulatory measures, financial incentives and strategies to create market demand. International collaboration is also essential for establishing standards, sharing knowledge and developing trade corridors. By leveraging these approaches, policy makers can effectively support the development and deployment of green hydrogen, driving progress toward global climate goals and sustainable economic growth.

6 Case studies

This chapter presents the most recent cases of hydrogen supply-side auctions.

6.1 Chile

The Chilean government aims to accelerate the development of electrolysers in Chile by providing investment support, which is allocated through an auction. In 2021, CORFO, a governmental agency and the auctioneer of the scheme, published a request for proposals with a total budget for support (auction volume) of USD 50 million.

Projects with a minimum capacity of 10 MW could participate in the auction, and their requested investment support was not to exceed USD 30 million. It is a multi-criteria auction whereby CORFO assessed the submitted bids based on the following criteria: the nominal power of the electrolysers (weighted with 30%), the efficiency of the contribution (20%), the project maturity status (20%), the experience of the applicant (20%) and the project financing model (10%).

The auction resulted in 6 awarded projects (out of 12 submitted) with almost 400 MW of awarded electrolyser capacity. The entire USD 50 million were allocated to the awarded projects, which needs to be realised by December 2025.

The auction process in Chile offered more than just funding; it established a direct communication channel between the selected projects and CORFO. This connection is instrumental in two ways. First, it enables project teams to directly convey the specific challenges they encounter during implementation. Second, it provides CORFO with valuable insights into the hydrogen ecosystem, enhancing its understanding and preparedness for future initiatives. Furthermore, the geographic distribution of the selected projects across Chile, a country with diverse landscapes and varying power system challenges, allows for the identification and addressing of region-specific issues. This approach not only aids in overcoming current project barriers but also contributes to the development of tailored strategies for different areas, considering their unique power supply concerns.

Sources: (CORFO, 2021; Djunisic, 2021).

6.2 Denmark

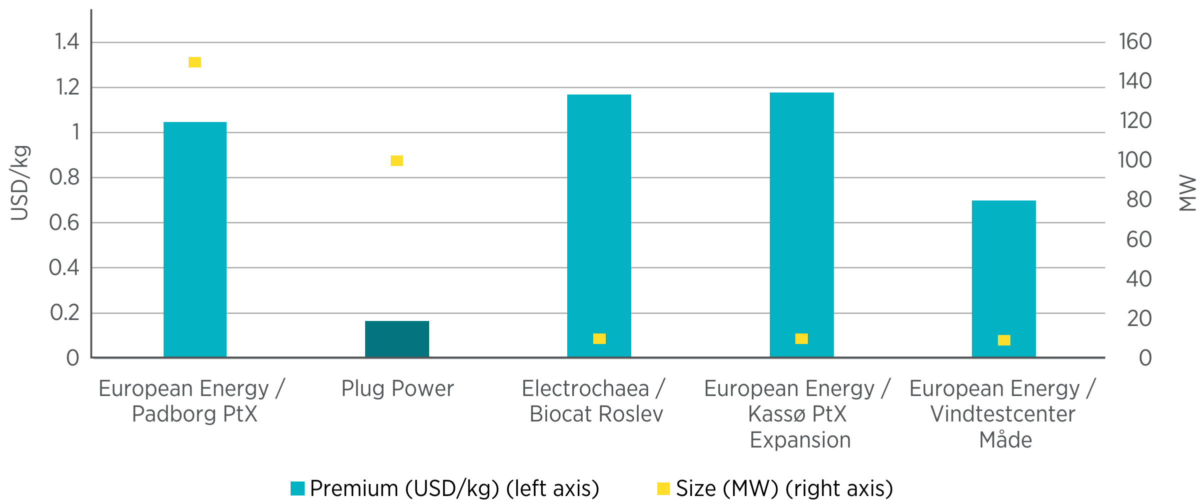
In 2023, Denmark introduced an auction-based support scheme for the production of green hydrogen with a total available budget of DKK 1.25 billion (Danish kroner) (around USD 181 million) for ten years.

The Danish scheme provides support to the producers in the form of a fixed premium, which is determined in an auction, for a maximum of 5 500 full-load hours per year. The fixed premium will be adjusted annually with the consumer price index.

The first ceiling price for the bid was DKK 120 per gigajoule (GJ) (around USD 2.1 per kilogram [kg]). But to avoid the entire budget's being swallowed up on higher subsidies for fewer units and to maximise the amount of hydrogen produced under the scheme, the auctions contained a second, lower bid ceiling of DKK 70/GJ (USD 1.23/kg) to encourage participants to lower their offers further. The auction would close only if all bids came in under the lower ceiling of USD 1.23/kg. If they did not, the auction and its total budget would be split up into two separate rounds of auctions of up to DKK 750 million and DKK 500 million.

The auction in 2023 was significantly oversubscribed, with the Danish Energy Agency – the auctioneer – receiving bids for more than DKK 4 billion (USD 581 million) and corresponding to 675 MW of electrolyser capacity. The six awarded projects (submitted by four different companies) represent more than 280 MW of electrolyser capacity and were awarded at bid prices for the fixed premium between DKK 9.3/GJ (USD 0.16/kg) and DKK 67.5/GJ (USD 1.17/kg).

Figure 12 Results of the Danish auction



After the publication of the results, the Danish Energy Agency withdrew its subsidy offer to US Plug Power, after the firm was unable to provide a bank guarantee for its 100 MW project (Figure 12). As a result, the government bumped up its offer to Everfuel and Hy24 (not depicted in Figure 12) for their project in the municipality of Fredericia to DKK 211 million (USD 30 million). The size of the project had not been disclosed owing to the partial funding and still the increased bid does not cover the full facility. Everfuel and Hy24 bid for a subsidy of just under DKK 67.50/GJ (USD 1.19/kg).

Successful bidders need to start the operation of their electrolyser within four years after the signing of the support contract.

Sources: (Danish Energy Agency, 2023a, 2023b, 2023c).

6.3 European Union

The European Hydrogen Bank (EHB) is an initiative started in 2023 designed to boost EU production and import of green hydrogen. It aims to stimulate private investments within the European Union and other countries by addressing the initial investment challenges.

In the first pilot auction round, the European Commission allocated a support budget of EUR 800 million. Bidders participated with planned electrolysers of a capacity of at least 5 MW and were not allowed to surpass 33% of the auctioned budget.

The auction offered producers a fixed premium per kilogram of hydrogen produced, up to a ceiling of EUR 4.5/kg on top of their revenues from selling to private off-takers, for a maximum period of ten years for certified hydrogen production.[14] Bids were evaluated and awarded based on the lowest price.

Once awarded, successful bidders need to submit a "Completion Guarantee" covering 4% of the maximum grant amount. Bidders must reach operation to develop their electrolyser projects within five years, otherwise the European Commission retains the Completion Guarantee. To be eligible to participate in the auction, bidders needed to show existing letters of intent or memoranda of understanding for the conclusion of an off-take agreement for 60% of the planned hydrogen production. The same documentation was needed for 60% of the required total renewable electricity.

Moreover, the support agreement may be terminated if the green hydrogen production falls on average below 30% of the expected yearly average volume as stated in the bid for three consecutive years (calculated over a rolling three-year period).

The auction attracted 132 bids from 17 European countries for a total electrolyser capacity of 8.5 GW, significantly oversubscribing the available budget by more than 15 times. Out of these, 119 proposals were deemed eligible and admissible. After evaluation, seven projects were selected and announced on 30 April 2024. These projects add up to 1.5 GW of electrolyser capacity, expected to produce 1.58 Mt of hydrogen over ten years.

The selected projects offered bids ranging from EUR 0.37/kg to EUR 0.48/kg (less than ten times the cap), with individual project support ranging from EUR 8 million to EUR 245 million. Projects are based in Finland, Norway, Portugal and Spain. The Hydrogen Bank results are lower than those of other European auctions. Subsidies in Denmark's auction in October averaged EUR 1.10/kg across five projects. At the same time, at least 65% of the projects bid less than EUR 1.5/kg in the EHB auction.

The Commission plans to launch a second EHB auction by the end of 2024. It will draw on the lessons from this pilot auction and also further consult stakeholders before launching the next auction.

14 This certification is for hydrogen as a 'Renewable fuel of non-biological origin', according to the EU Delegated Acts on Renewable Hydrogen.

Box 5 The "Auctions-as-a-Service" mechanism

A notable aspect of the EHB auction is the application the Auctions-as-a-Service (AaaS) mechanism, a novel approach to facilitate the financing of renewable hydrogen projects that participated in the auction but were not selected for support from the Innovation Fund due to budget constraints.

Due to the limited budget available for Innovation Fund support, not all projects that participate in the auction can be selected for funding. The AaaS mechanism allows member states to provide national funding to projects that participated in the auction but were not selected for EU support. By leveraging this mechanism, member states can award funding to additional projects within their territory without needing to conduct a separate national-level auction. Projects supported through the AaaS mechanism benefit from a streamlined state aid approval process, as the auctions are designed at the EU level in line with the guidelines on state aid. In this way, the AaaS mechanism reduces administrative burdens and related costs for all parties involved.

Germany is the first member state to participate in the AaaS mechanism. Germany has made EUR 350 million available from its national budget for hydrogen production in Germany and will support projects that have not been selected for support from the Innovation Fund in the first EHB auction.

The EHB auction had among its objectives also price discovery, and the publication of the data is a valuable contribution to the hydrogen sector visibility. The following observation can be made from the results published by the EHB:

- The average LCOH ranges from EUR 5.8/kg to EUR 13.5/kg in the bids submitted to the EBH auction, with only three countries presenting an average LCOH below EUR 6/kg (Greece, Spain and Sweden). This variation highlights the differing cost dynamics and market conditions across Europe, influencing where future investments may be directed.
- Even with subsidies, buyers need to pay a premium that can be estimated ranging between EUR 3.53/kg and EUR 6.52/kg for winning projects to be economical. As industries using hydrogen have tendentially low margins and an appetite for cheap feedstock, this willingness to pay may underline a desire to be among the first movers in the green industry and/or an expected realisation of enforcing instruments for the realisation of the EU target that 42% of the hydrogen used in industry should be green by 2030.
- This reflects also in the data shared regarding non winning bids. The expected median off-take price stated across all qualifying bids in the first auction ranged from around EUR 5.67/kg for industry to EUR 8.34/kg for the transport sector. Most projects (60%) are targeting industrial decarbonisation, even though industry presents a lower willingness to pay for a green premium. With most bids below EUR 2/kg, it emerges how it is expected that the consumer of green hydrogen may be willing to take the brunt of the green premium.
- The Nordics and Iberia emerged as the cheapest places to make green hydrogen in Europe. The favourable conditions for green hydrogen production in these regions could shift the focus of future investments and project developments towards them. Notably, out of the 2.2 GW submitted by Central European countries, no project was selected.
- Wind and solar PV combined provide a higher capacity factor of the electrolysers thanks to their complementarity, potentially leading to lower LCOH. Indeed, only one of the seven winning projects plans to be powered by solar alone. All other developments that disclosed this information intend to be powered by wind and solar combined.

- Among the winners, there are some of the largest projects in the European Union, up to 500 MW. Smaller projects (down to 5 MW) could not compete with large ones, with a clear correlation between project size and bid competitiveness. This raises the question of whether there should be separate instruments for small projects to ensure a more level playing field and support for diverse project sizes.
- Lower LCOHs were registered for projects expecting to use both alkaline and PEM electrolysis. This technology mix may underline better balance of plant optimisation and a forecast use of alkaline electrolysis for "baseload" production and PEM for flexibility management. These projects have an average LCOH around EUR 7/kg, compared with approximately EUR 11/kg for PEM projects. This suggests that a combination of technologies may offer a more cost-effective solution for renewable hydrogen production.
- Three-quarters of the projects want to use EU electrolysers (totally or partially), and around 15% of the projects aim to use Chinese electrolysers.

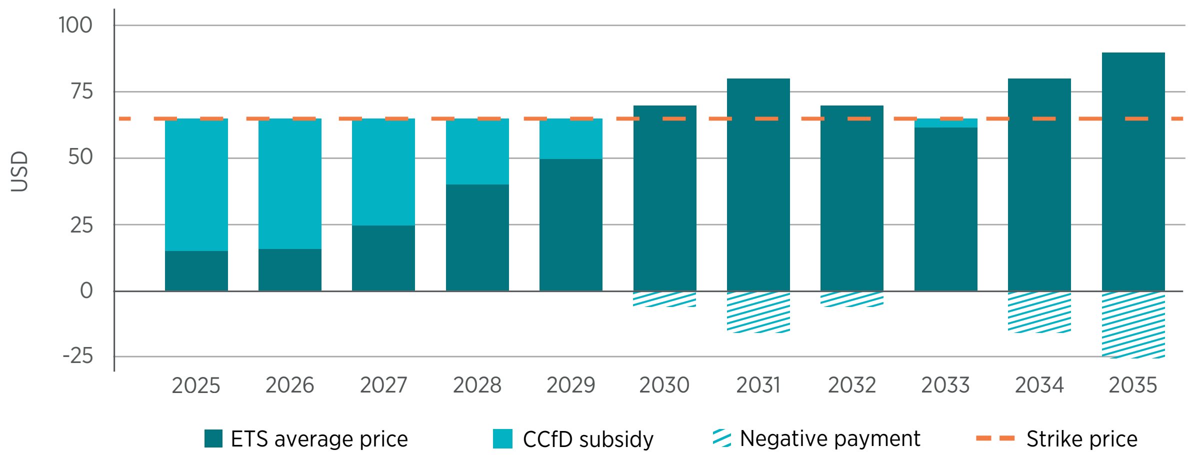
Sources: (Bhashyam, 2024; European Commission, 2023a, 2023b, 2024, n.d.).

6.4 Germany

The Carbon Contracts for Difference (CCfDs) in Germany are and instruments developed for the introduction of modern, climate-friendly manufacturing processes in energy-intensive sectors. Those include paper, glass, steel and cement industries and is therefore also relevant for the nascent hydrogen industry in Germany.

CCfDs are contracts between the government and companies that aim to produce goods with lower carbon intensity by providing industry players with financial support to offset higher abatement costs. These contracts guarantee a strike price in EUR per tonne of carbon dioxide (CO_2) avoided for a predetermined number of years, which represents the additional costs (including both CAPEX and OPEX) of a decarbonisation, such as switching from producing steel with a coal-fired blast furnace to using green hydrogen in the direct reduced iron process. Low-carbon production processes using electrification, such as in the glass sector, are also eligible. If at the end of a certain period (*e.g.* a year) the average annual emissions trading system (ETS) price has been below the strike price, the industrial producer will receive, for each tonne of CO_2 avoided, the difference between the two values. As shown in Figure 13, depending on the development of the ETS-price, the support payments can become negative, meaning the producers need to pay back additional revenues to the government.

Figure 13 Illustration of potential average ETS price and CCfD subsidy at strike price of USD 65/tCO_2



Source: (IRENA, 2022a).
Notes: CCfD = carbon contracts for difference; ETS = emission trading system.

In Germany, the strike price can be adapted to changes in the prices of the various energy carriers, *e.g.* electricity or green hydrogen,[15] to reduce the price risk for companies. The energy carriers of the conventional processes, which are used to calculate the "additional costs" of the low-carbon project, are indexed in any case. In addition, based on specific parameters set by the auctioneer, as well as the submitted strike price, a total maximum support amount over a project's lifetime is calculated for each project to limit the governmental expenditures. The support duration under the CCfDs in Germany is 15 years.

The allocation of the CCfDs and the strike prices are set in auctions, in which projects from companies active in emissions-intensive sectors, for instance steel, glass or lime, are eligible to participate. Only projects with a total support amount of at least EUR 15 million over the entire support period of 15 years are allowed to participate in the auctions. The total maximum support amount for a project has been set at EUR 1 billion in the 2024 auction round. Projects are selected based on the submitted strike prices, as well as the relative emissions reductions of the low-carbon process compared with the conventional reference process in the first five years (weighted with around 20% when ranking the bids). Additional support received prior to the auction is taken into account in the winner selection process, while additional support granted after the award will be deducted from the CCfD support payments.

By using CCfDs, Germany is indirectly supporting the production of green hydrogen, as the scheme can lead to a ramp-up of green hydrogen demand from the industry. The first auction, totalling EUR 4 billion, opened in March 2024 and will last for four months. Further auction rounds are foreseen in the near future, with the overall support expected to reach a two-digit billion euros figure.

Sources: (BMWK, 2024b, n.d.).

6.5 India

India recognises green hydrogen as a central element for achieving its climate goals and energy independence by 2047. Driven by its vast renewable energy resources, India aims to become a leading global producer and exporter of green hydrogen, leveraging its potential to mitigate dependency on imported energy and foster a low-carbon economy. The National Green Hydrogen Mission (India's hydrogen strategy) outlines a comprehensive strategy to build a robust green hydrogen ecosystem, promote technology development, and catalyse both domestic and international demand.

The strategy will include a comprehensive incentive programme to facilitate growth of the green hydrogen industry value chain in the country, called Strategic Interventions for Green Hydrogen Transition (SIGHT). SIGHT will encompass a broad range of financial and non financial measures aimed at encouraging the production of low-cost green hydrogen and the domestic manufacturing of related equipment and technologies.

Under the SIGHT programme, a supply-side auction was launched in September 2023 to support the first production facilities of green hydrogen in India. The government has implemented two auction buckets:

- a technology-agnostic bucket aiming to procure 410 kilotonnes (kt) per year, for plants of any technology able to produce between 10 kt/year and 90 kt/year
- a bucket for biomass-based hydrogen production facilities aiming to procure 40 kt/year, for plants able to produce between 0.5 kt/year and 4 kt/year.

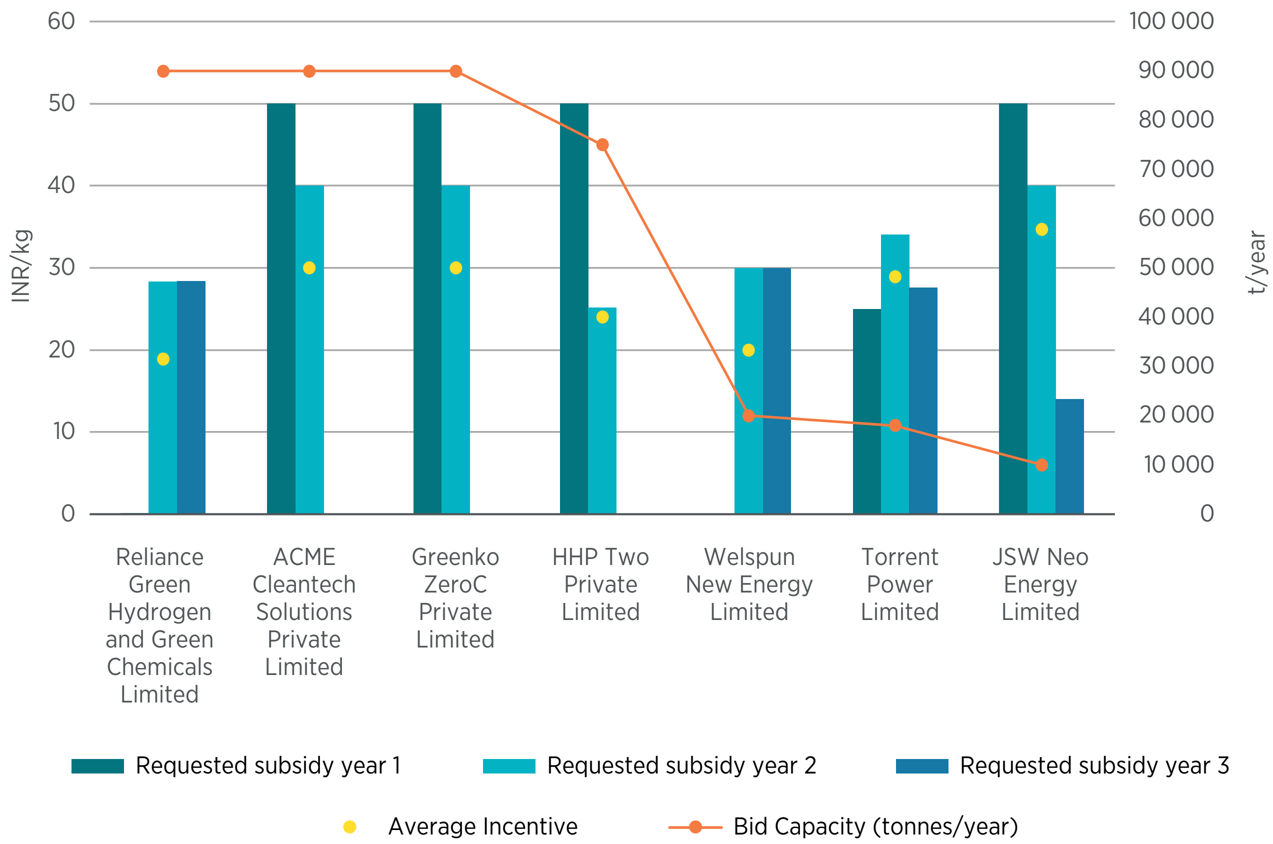
15 For further information on the indexation of the strike price, see (BMWK, 2023).

The auction is for competing for a fixed premium for three years for each kilogram of hydrogen produced. The maximum bid prices for the premiums are INR 50/kg for the first year, INR 40/kg for the second and INR 30/kg for the last year (equivalent to USD 0.6/kg, USD 0.48/kg and USD 0.36/kg). The auction is backed by a budget of INR 197.44 billion (USD 2.4 billion).

To participate in the auction, bidders need to submit a bid bond/bank guarantee of INR 2 500 (USD 30) for each tonne of green hydrogen they plan to produce.

The first bucket achieved 410 kt/year, with seven companies selected with an average bid of INR 26.6/kg (USD 0.32/kg) and two companies included in the list of winners not bidding for any subsidies at all. The results of the auctions are presented in Figure 14. The second bucket was undersubscribed with only one company bidding (and winning) with a project of 2 kt/year for INR 30/kg for three years.

Figure 14 Capacity and requested premium of the winning bids in India



Source: Martin, 2024.

Successful bidders have 30 months from the date of being awarded to commission their projects. Otherwise, a penalty occurs, which is based on the completion bond successful bidders need to submit, which is INR 2 500/t (USD 60/t) of green hydrogen production they submitted.

Sources: (Gupta, 2023s; Solar Energy Corporation of India Limited, 2023).

6.6 Netherlands

SDE++

The Dutch SDE++ (Stimulation of Sustainable Energy Production and Climate Transition) support scheme is a government-funded programme aimed at promoting the development of sustainable energy projects and reducing GHG emissions in the Netherlands. The scheme provides subsidies for a wide range of technologies, including renewable energy production; carbon capture, utilisation and storage; hydrogen production; and energy efficiency measures. All eligible technologies compete against each other for the available support budget.

The support scheme aims to support projects with the lowest cost per tonne of CO_2 emissions reduced, ensuring that public funds are used effectively. The support is paid out in the form of a sliding premium, with the strike price determined in the auction and the reference price defined as the "market revenues" of each technology, which can be for example the market values of renewable electricity or the EU ETS price. Awarded project developers receive support for up to 15 years, depending on the technology.

Green hydrogen production is among the eligible technologies. Electrolysers need to have a capacity of at least 0.5 MW and receive support for up to 4 200 full-load hours per year in the case of a grid connection (3 492 full-load hours in the 2023 auction round) and up to 6 154 full-load hours per year (5 448 full-load hours in the 2023 auction round) if directly connected to a solar or wind farm. Moreover, successful electrolyser projects have 1.5 years for finalising their procurement and up to 4 years to be constructed. So far, three electrolyser projects have been awarded in the SDE++ auctions: one in the 2021 round and two in the 2022 round.

The 2023 SDE++ auction round introduced a quota (so-called "domain fencing") for specific technologies, namely "low-temperature heat", "high-temperature heat" and "molecules". This means eligible projects compete against each other only within each category, until the category's budget is exhausted. After that, they will need to compete against the other technologies for the remaining budget. In 2023, the budget for each of the three categories was set at EUR 750 million, while the overall budget was EUR 8 billion. Green hydrogen production has been included in the "molecules" category, which means electrolysers compete in a first step only against "biomass fermentation techniques (renewable gas)", "biomass gasification", and "advanced renewable fuels". This significantly increases the chances of green hydrogen producers being awarded compared with the previous rounds, where they had to compete with all other, cheaper, low-carbon technologies.

OWE

In 2023, the Dutch government launched an additional auction-based support scheme specifically dedicated to green hydrogen production, called Subsidieregeling Opschaling volledig hernieuwbare waterstofproductie via elektrolyse [Subsidy Scheme for Scaling Up Fully Renewable Hydrogen Production via Electrolyser] (OWE). Electrolysers with a capacity of at least 0.5 MW and up to 50 MW were able to participate. The target capacity is 100 MW.

The 2023 auction round of the OWE scheme provides support for both the investment in the electrolyser, and the production of hydrogen. The investment subsidy is capped depending on the bidder's size: small companies are capped at 60%, medium-sized companies at 50% and large companies at 40%. The eligible investment costs cover typical expenditures of setting up an electrolyser. For projects starting at 30 MW, the eligible investment costs are calculated as the investment for the electrolyser minus the investment costs for a reference system, namely a steam methane reforming plant.

The operational part of the support is similar to the SDE++, as the support is paid out as a sliding premium, for a period of 7-15 years.

In the auction, bidders submit bids consisting of a percentage regarding the investment subsidy and a strike price for the operational support. The combined investment and operational subsidy cannot surpass EUR 9/kg (USD 8.3/kg) of green hydrogen. Both parts of the bid are converted to a value in EUR/MW, which represents the subsidy need per megawatt of electrical capacity of the electrolyser and ranked from the lowest to the highest. While the selection process is mainly based on price, the OWE scheme aims to award projects with different types of electricity sourcing. Therefore, the project ranked second needs to have a different type of electricity sourcing than the highest-ranked one. For instance, if the highest-ranked project is directly connected to the renewable power source, the second project needs to be one that is only connected to the grid (without a direct line to a renewable power source). The remaining projects are again ranked based only on their submitted bid prices.

The auction was concluded and the total available amount was allocated and divided over seven projects. The projects together provide 101 MW of electrolysis capacity; 91 MW comes from projects in the province of Groningen.

The average subsidy of the seven winning projects is EUR 2.5 million/MW (USD 2.17 million/MW) of electrolysis capacity. The companies have until 2028 to complete the construction of their electrolysis plants.

A new auction round with a budget of almost EUR 1 billion (four times the budget of the first auction) has been announced for 2024. Bidders can apply for a maximum of half the total auctioned volume, *i.e.* almost EUR 500 million, and the maximum allowed project size of 50 MW has been abolished.

The main design elements, such as the investment and operational support, remain the same, but some changes have been introduced. For instance, the maximum investment subsidy can now be 80% of the investment cost and the ranking is now completely price-only. Moreover, the support period for the operational support has been reduced to five to ten years.

Sources: (Netherlands Enterprise Agency, 2023, 2024a, 2024b, 2024c).

6.7 United Kingdom

The British government aims to support the production of low-carbon hydrogen in the United Kingdom through the Hydrogen Production Business Model (HPBM) and Net Zero Hydrogen Fund (NZHF).

The HPBM provides production-based support for the production of low-carbon hydrogen following the CfD model for a period of 15 years with the strike price determined as a result of the auction, while the NZHF provides upfront investment-based support to develop low-carbon hydrogen production projects.

In the 2022 Hydrogen Allocation Round (HAR1), low-carbon hydrogen production projects could apply for HPBM revenue support only, or they could apply for joint HPBM revenue support and CAPEX support through the NZHF. Requests for CAPEX support through the NZHF are capped at 20% of the project's CAPEX. The total budget for support allocated was around EUR 2.3 billion.

To be eligible for the support in HAR1, available only for electrolyser, project developers needed to identify at least one potential off-taker, as well as electrolyser supplier(s). The electrolysers needed to have a hydrogen production capacity of at least 5 MW and be located in the country. Besides adhering to the Low Carbon Hydrogen Standard (LCHS), the project developer needs to demonstrate access to finance.

Project proposals were evaluated based on six criteria: deliverability, cost, economic benefits, environmental impact, market development and additionality.

At the end of the HAR1, the government announced 11 successful projects with a total capacity of 125 MW. The 11 projects have been agreed at a weighted average strike price of GBP 241 per megawatt-hour (MWh) (around USD 12/kg). Shortlisted projects then enter the Agreeing an Offer Stage for further negotiation, which includes due diligence and a value assessment. Awarded developers sign a Low Carbon Hydrogen Agreement (LCHA) for the first 15 years of a project's operation.

The second Hydrogen Allocation Round (HAR2) to allocate HPBM support was opened in December 2023 aiming to support 875 MW capacity, with different criteria for the evaluation.

The UK government has established a long-term vision for the HARs, extending planning up to HAR7 in 2029. At the moment, the vision is to allocate 1.5 GW before HAR4 (to be launched in 2026). The government will review the deployment trajectory beyond HAR4. The capacity targets for HARs 5-7 will be informed by a review of the lesson learnt by previous auctions and will be determined by factors such as demand, affordability and strategic decisions on the use of hydrogen across sectors.

Sources: (UK Government, 2023a, 2023b, 2023c, 2024).

References

Bhashyam, A. (2024), *EU Hydrogen Bank Winners Will Need Deep-Pocketed Buyers*, BloombergNEF, www.bnef.com/insights/33949 (accessed 14 May 2024).

BMWK (2023), "Explanatory Note on Climate Protection Agreements", www.bmwk.de/Redaktion/EN/Downloads/E/explanatory-note-on-climate-protection-agreements.pdf?__blob=publicationFile&v=3

BMWK (2024a), "Global hydrogen ramp-up", *BMWK-Federal Ministry for Economic Affairs and Climate Action*, www.bmwk.de/Redaktion/EN/Pressemitteilungen/2024/02/20240220-global-hydrogen-ramp-up.html (accessed 14 May 2024).

BMWK (2024b), "First round of carbon contracts for difference launched", *Federal Ministry for Economic Affairs and Climate Action*, www.bmwk.de/Redaktion/EN/Pressemitteilungen/2024/03/20240312-first-round-of-carbon-contracts-for-difference-launched.html (accessed 14 May 2024).

BMWK (n.d.), "Carbon Contracts for Difference: Klimaschutzverträge", *Federal Ministry for Economic Affairs and Climate Action*, www.klimaschutzvertraege.info/en/home (accessed 14 May 2024).

BNEF (2024), "1H 2024 Hydrogen Market Outlook: Targets Meet Reality - Full Report", *BloombergNEF*, www.bnef.com/insights/34075 (accessed 31 May 2024).

CORFO (2021), "First call for the financing of green hydrogen projects in Chile", https://www.corfo.cl/sites/Satellite?blobcol=urldata&blobkey=id&blobtable=MungoBlobs&blobwhere=1475168300448&ssbinary=true (accessed 6 May 2024).

Danish Energy Agency (2023a), "Conditions for tender of State aid for the Production of Power-to-X in Denmark", www.ethics.dk/ethics/publicTenderDoc/2b3ea81c-1ca9-4d3d-b563-b87f629fb79c/7e7766b3-8c90-4d27-bb5c-abe9b5825f18/download (accessed 7 May 2024).

Danish Energy Agency (2023b), "The first PtX tender in Denmark has been determined: Six projects will establish electrolysis capacity on more than 280 MW", *The Danish Energy Agency*, https://ens.dk/en/press/first-ptx-tender-denmark-has-been-determined-six-projects-will-establish-electrolysis-capacity (accessed 7 May 2024).

Danish Energy Agency (2023c), "The Power-to-X tender is now open", *The Danish Energy Agency*, https://ens.dk/en/press/power-x-tender-now-open (accessed 7 May 2024).

Djunisic, S. (2021), "Six green H2 projects in Chile to split USD 50m in state funds", *Renewablesnow.com*, https://renewablesnow.com/news/six-green-h2-projects-in-chile-to-split-usd-50m-in-state-funds-767487/ (accessed 6 May 2024).

European Commission (2023a), "Innovation Fund Auction", https://climate.ec.europa.eu/eu-action/eu-funding-climate-action/innovation-fund/competitive-bidding_en#auctions-as-a-service-aaas

European Commission (2023b), "Upcoming EU Hydrogen Bank pilot auction: European Commission publishes Terms & Conditions", https://climate.ec.europa.eu/news-your-voice/news/upcoming-eu-hydrogen-bank-pilot-auction-european-commission-publishes-terms-conditions-2023-08-30_en (accessed 14 May 2024).

European Commission (2024), "European Hydrogen Bank pilot auction: 132 bids received from 17 European countries", https://climate.ec.europa.eu/news-your-voice/news/european-hydrogen-bank-pilot-auction-132-bids-received-17-european-countries-2024-02-19_en (accessed 7 May 2024).

European Commission (n.d.), "Competitive bidding: A new tool for funding innovative low-carbon technologies under the Innovation Fund", https://climate.ec.europa.eu/eu-action/eu-funding-climate-action/innovation-fund/competitive-bidding_en (accessed 7 May 2024).

European Parliament (2023), "Commission Delegated Regulation (EU) 2023/1184 of 10 February 2023 supplementing Directive (EU) 2018/2001 of the European Parliament and of the Council by establishing a Union methodology setting out detailed rules for the production of renewable liquid and gaseous transport fuels of non-biological origin", OJ L, http://data.europa.eu/eli/reg_del/2023/1184/oj/eng (accessed 16 May 2024).

Gupta, U. (2023), "India tenders 450,000 MT/year of green hydrogen capacity under incentives scheme", *pv magazine India*, www.pv-magazine-india.com/2023/07/11/india-tenders-450000-mt-year-of-green-hydrogen-capacity-under-incentives-scheme/ (accessed 6 May 2024).

H2Global-Stiftung (n.d.), "The H2Global Instrument", https://h2-global.de/project/h2g-mechanism (accessed 14 May 2024).

Hydrogen Council and McKinsey & Company (2023), *Hydrogen Insights 2023*, https://hydrogencouncil.com/wp-content/uploads/2023/05/Hydrogen-Insights-2023.pdf

IEA (2023a), *Renewable Energy Market Update: Outlook for 2023 and 2024*, International Energy Agency, Paris, www.iea.org/reports/renewable-energy-market-update-june-2023

IEA (2023b), *Global Hydrogen Review 2023*, Paris, www.iea.org/reports/global-hydrogen-review-2023 (accessed 24 November 2023).

IEA, *et al*. (2023), *The Breakthrough Agenda Report 2023*, International Energy Agency, International Renewable Energy Agency, United Nations Climate Change High-Level Champions, Geneva and Abu Dhabi, www.irena.org/Publications/2023/Sep/Breakthrough-Agenda-Report

IRENA (2019), *Renewable energy auctions*: Status and trends beyond price, www.irena.org/publications/2019/Dec/Renewable-energy-auctions-Status-and-trends-beyond-price (accessed 19 August 2022).

IRENA (2020), *Green hydrogen: A guide to policy making*, International Renewable Energy Agency, Abu Dhabi, www.irena.org/publications/2020/Nov/Green-hydrogen

IRENA (2021), *Green hydrogen supply: A guide to policy making*, International Renewable Energy Agency, Abu Dhabi, www.irena.org/Publications/2021/May/Green-Hydrogen-Supply-A-Guide-To-Policy-Making

IRENA (2022a), *Green hydrogen for industry: A guide to policy making*, International Renewable Energy Agency, Abu Dhabi, www.irena.org/Publications/2022/Mar/Green-Hydrogen-for-Industry

IRENA (2022b), *Renewable energy targets in 2022: A guide to design*, International Renewable Energy Agency, Abu Dhabi, www.irena.org/Publications/2022/Nov/Renewable-energy-targets-in-2022

IRENA (2023a), *World energy transitions outlook 2023: 1.5°C pathway*, International Renewable Energy Agency, Abu Dhabi, www.irena.org/Publications/2023/Jun/World-Energy-Transitions-Outlook-2023

IRENA (2023b), "Renewable Power Generation Costs in 2022", www.irena.org/Publications/2023/Aug/Renewable-Power-Generation-Costs-in-2022 (accessed 6 September 2023).

IRENA (2023c), *Innovation landscape for smart electrification: Decarbonising end-uses with renewable power*, International Renewable Energy Agency, Abu Dhabi, www.irena.org/Publications/2023/Jun/Innovation-landscape-for-smart-electrification

IRENA (2024), *Green hydrogen strategy: A guide to design*, International Renewable Energy Agency, Abu Dhabi, https://www.irena.org/Publications/2024/Jul/Green-hydrogen-strategy-A-guide-to-design

IRENA and CEM (2015), *Renewable Energy Auctions: A Guide to Design*, International Renewable Energy Agency and Clean Energy Ministerial, www.irena.org/publications/2015/Jun/Renewable-Energy-Auctions-A-Guide-to-Design

IRENA and WEF (2021), *Enabling measures for green hydrogen roadmap*, International Renewable Energy Agency and World Economic Forum, Abu Dhabi, www.irena.org/-/media/Files/IRENA/Agency/Collaborative-Frameworks/IRENA_Enabling_Measures_Roadmap_for_Green_H2_Jan22.pdf

Martin, P. (2024a), "Here are the winners of India's first green hydrogen and electrolyser subsidy auctions", hydrogeninsight.com, www.hydrogeninsight.com/production/here-are-the-winners-of-india-s-first-green-hydrogen-and-electrolyser-subsidy-auctions/2-1-1583341 (accessed 31 May 2024).

Martin, P. (2024b), "India's second electrolyser manufacturing auction oversubscribed, with bids for nearly double the cap", *hydrogeninsight.com*, https://www.hydrogeninsight.com/electrolysers/indias-second-electrolyser-manufacturing-auction-oversubscribed-with-bids-for-nearly-double-the-cap/2-1-1676342 (accessed 30 July 2024).

Netherlands Enterprise Agency (2023), "SDE++2023 - Stimulation of Sustainable Energy Production and Climate Transition", https://english.rvo.nl/sites/default/files/2023-09/BrochureSDE2023English.pdf

Netherlands Enterprise Agency (2024a), "Nieuwe aanvraagronde OWE in 2024 [New OWE application round in 2024]", *RVO.nl*, www.rvo.nl/onderwerpen/owe/aanvraagronde-2024 (accessed 7 May 2024).

Netherlands Enterprise Agency (2024b), "Stimulation of sustainable energy production and climate transition (SDE++)", *RVO.nl*, https://english.rvo.nl/en/subsidies-financiering/sde (accessed 7 May 2024).

Netherlands Enterprise Agency (2024c), "Subsidieregeling Opschaling volledig hernieuwbare waterstofproductie via elektrolyse (OWE) [Subsidy scheme for scaling up fully renewable hydrogen production via electrolysis (OWE)]", *RVO.nl*, www.rvo.nl/subsidies-financiering/owe (accessed 7 May 2024).

Solar Energy Corporation of India Limited (2023), "Request for Selection (RfS) for Selection of Green Hydrogen Producers for Setting up Production Facilities for Green Hydrogen in India under the Strategic Interventions for Green Hydrogen Transition (SIGHT) Scheme (Mode-1-Tranche-I)"

UK Department for Business, Energy & Industrial Strategy (2021), "Low Carbon Hydrogen Business Model: Consultation on a business model for low carbon hydrogen", https://assets.publishing.service.gov.uk/media/611a801ae90e07054a62c4f8/Consultation_on_a_business_model_for_low_carbon_hydrogen.pdf

UK Government (2023a), "Hydrogen Production Business Model/Net Zero Hydrogen Fund: HAR1 successful projects", *GOV.UK*, www.gov.uk/government/publications/hydrogen-production-business-model-net-zero-hydrogen-fund-shortlisted-projects/hydrogen-production-business-model-net-zero-hydrogen-fund-har1-successful-projects (accessed 14 May 2024).

UK Government (2023b), "Price-based competitive allocation for low carbon hydrogen production", https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1167783/price-based-competitive-allocation-for-hydrogen-production.pdf

UK Government (2023c), *Hydrogen Production Delivery Roadmap*, https://assets.publishing.service.gov.uk/media/659c04aad7737c000df3356d/hydrogen-production-delivery-roadmap.pdf

UK Government (2024), "Hydrogen Allocation Round 2", *GOV.UK*, www.gov.uk/government/publications/hydrogen-allocation-round-2 (accessed 14 May 2024).

UNFCCC. (2023), "Matters relating to the global stocktake under the Paris Agreement," https://unfccc.int/documents/636584 (accessed December 21, 2023).

UNIDO, IRENA and IDOS (2023), *Green hydrogen for sustainable industrial development: A policy toolkit for developing countries*, United Nations Industrial Development Organization, International Renewable Energy Agency and German Institute of Development and Sustainability, Vienna and Abu Dhabi, www.irena.org/Publications/2024/Feb/Green-hydrogen-for-sustainable-industrial-development-A-policy-toolkit-for-developing-countries

US Department of Energy (n.d.), "Financial Incentives for Hydrogen and Fuel Cell Projects", *Energy.gov*, www.energy.gov/eere/fuelcells/financial-incentives-hydrogen-and-fuel-cell-projects (accessed 14 May 2024).

US Department of Treasury (2024), "IRA-Related Tax Guidance", *US Department of the Treasury*, https://home.treasury.gov/policy-issues/inflation-reduction-act/ira-related-tax-guidance (accessed 14 May 2024).

Wang, X. (2024), *Electrolyzer Price Survey 2024: Rising Costs, Glitchy Tech*, BloombergNEF.

IRENA

International Renewable Energy Agency