Hydrogen Council

Policy review

Policy Toolbox for Low Carbon and Renewable Hydrogen

Enabling low carbon and renewable hydrogen globally

November 2021

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Executive summary

The recent surge in interest by policymakers for low carbon and renewable hydrogen[1] reflects a growing recognition of its important role in decarbonizing the energy system. Hydrogen will play a key role in enabling greater and faster integration of renewable energy in the system and fostering greater resilience, cost-efficiency, and optimization at the system level. Going hand-in-hand with electrification, the development of the hydrogen economy is set to enable deep decarbonization worldwide in an effective manner, allowing countries to meet their climate goals, boost green growth, and create sustainable jobs. Over 30 countries have already introduced hydrogen strategies, while industry has announced more than 520 large-scale low carbon and renewable hydrogen projects.

While rapid technological learning brings cost competitiveness within reach for some applications, unlocking the full potential of low carbon and renewable hydrogen (defined in the Appendix) requires further policy development. Notwithstanding a very large volume of projects and funding announcements, there remains a significant gap to realize global climate change mitigation ambitions. The full potential of hydrogen requires direct investment of around USD 700bn by 2030. Projects and government support worth USD 160bn have been announced already, leaving a gap of nearly USD 540bn[2]. For these investments to take place, the industry needs a clear policy and regulatory framework, and support for scaling up hydrogen solutions, especially during the early market building phase. Coordinating policy and regulatory activity on the one hand with projects and investment activity on the other is key for industry and governments to jointly deliver on the shared climate objectives as soon as possible.

Countries in Europe and in Asia have been at the forefront of hydrogen economy development. In the EU, dedicated hydrogen support instruments such as Contracts for Differences (CfDs) and Carbon Contracts for Difference (CCfDs), designed to provide a ‘push’ for supply and a ‘pull’ for demand respectively, are already under development. Retrofitting and repurposing the existing gas infrastructure and building new dedicated transmission and storage systems for hydrogen constitutes another priority for the industry and policymakers. In Europe, for example, a plan for the development of a Hydrogen Backbone connecting large-scale production of hydrogen with demand clusters has been put forward. At the same time, many other regions have set their low carbon and renewable hydrogen ambitions and are looking at developing the legislative frameworks that would enable their achievement.

Against this backdrop, this report, provides a practical guide to the full policy toolbox. It is directed at policymakers and legislators who can use it as a menu of policy tools to deploy when designing or implementing hydrogen policy and regulatory frameworks. The study is based on an assessment of the performance of hydrogen policies in different stages of market maturity (e.g., before and after the technology is commercially viable) and segments of the value chain (e.g., hydrogen production, mid-stream hydrogen infrastructure and hydrogen use). 48 policies were shortlisted based on their economic efficiency and effectiveness and mapped to barriers across the value chain and over time. These policies were subsequently clustered into policy packages for three country archetypes: a self-sufficient hydrogen producer, an importer, and an exporter of hydrogen. Last but not least, we explored the societal value that can be unlocked by countries thanks to the development of the hydrogen economy, looking at it through the lens of Sustainable Development Goals (SDGs).

Six key principles for effective hydrogen policy and regulatory frameworks emerged from this analysis. It should be noted that all six pillars are equally important and the sequence at which they appear does not reflect any particular hierarchy.

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[1] See Appendix section Defining low carbon and renewable hydrogen
[2] Appendix 2.1

6 pillars of efficient policy design for low carbon and renewable hydrogen

1 Make use of local strengths & benefit from cross-border cooperation

Leveraging local strengths is an important starting point in policy design, which should be complemented by cross-border cooperation and trade to unlock efficiency gains.

2 Create certainty through targets and commitment

To drive down cost and attract investment, governments can create certainty through legislation, reducing policy risks and market uncertainty.

3 Provide hydrogen-specific support across the value chain

To catalyze and grow new markets, hydrogen-specific support is required across production, midstream infrastructure, and end-use sectors like industry and transport.

4 Support robust carbon pricing

Robust regional carbon pricing mechanisms should be built up from existing schemes, and work together with hydrogen-specific support to drive efficient and effective uptake in the longer term, whilst mitigating carbon leakage.

5 Adopt harmonized certification schemes

International standards and robust certification systems play a crucial role in the development of the hydrogen economy, enabling cross-border trade in hydrogen.

6 Factor in societal value and values

Societal value and values can be factored into policy decisions. Well-designed hydrogen policies can make a positive contribution to several UN Sustainability Development Goals.

1 Leveraging local strengths is an important starting point in policy design, which should be complemented by cross-border cooperation and trade to unlock efficiency gains.

Hydrogen is a key energy vector to reach net zero emissions globally. As a starting point, countries seeking to participate in the hydrogen economy are likely to take into consideration

- Countries' resources and technological endowments (e.g., renewable electricity and natural gas production capacity; existing gas infrastructure and prospects for repurposing or retrofitting it to transport or store hydrogen, as well as synergies with CO_2 infrastructure) (see Box 1)
- Local institutional and regulatory frameworks where the energy industry currently operates (while in some jurisdictions the energy sector is fully liberalized, in others it may be vertically integrated)

Most commonly, these starting conditions are factored into policy design at the outset.

Based on these premises, we identify three archetypal country groups:

- Self-sufficient countries aiming at producing and consuming hydrogen within their respective jurisdictions. These countries would need to create the entire value chain: upstream supply, midstream transmission and storage, distribution, and downstream demand.
- Exporters would focus on developing export infrastructure and optimizing project locations to create export hubs in a manner that contributes to the development of the local hydrogen economy.
- Importers would focus on developing import infrastructure, work with exporters to ensure they get access to affordable low carbon and/ or renewable hydrogen and develop downstream applications, ensuring they have control over where hydrogen is used.

At the same time, countries and regions can reap the benefits brought by international cooperation and optimization of cross-border infrastructure. In many cases, cross-border integration can maximize infrastructure use and improve the overall system efficiency by linking greater production capacity with larger demand centers. International trade in hydrogen will play a key role in efficiently matching lower cost supply locations and major demand pools across geographies.

Box 1

Low carbon hydrogen production: synergies with CO_2 infrastructure

Jurisdictions seeking to unlock their low carbon hydrogen potential can use dedicated policy tools to incentivize carbon capture and retrofit existing carbon-intensive hydrogen production. For example, in the UK, private law contracts, similar to CfDs, will be introduced to provide the emitter with a payment per ton of captured CO_2.

In addition, many jurisdictions are already considering policy instruments to support CO_2 pipeline network and port infrastructure development (e.g., the EU proposal for TEN-E revision of Dec 2020). Provision of CAPEX support for multimodal transportation of CO_2 can also help avoid stranded assets in the long term (by way of enabling a switch to transporting hydrogen or ammonia) and unlock access for CO_2 storage in locations where there is no business case for hydrogen pipeline network development.

The UK's Carbon Capture Readiness Directive, introduced in 2009, states all planned combustion plants above 300 MW need to be constructed with space allocated for CCS facilities and infrastructure. In July 2021, there were calls for this to be expanded to include combustion plants below the current 300 MW generation threshold.[3]

[3] UK Government, Decarbonisation readiness: call for evidence on the expansion of the 2009 Carbon Capture Readiness requirements, 2021. https://www.gov.uk/government/consultations/decarbonisation-readiness-call-for-evidence-on-the-expansion-of-the-2009-carbon-capture-readiness-requirements

2 To drive down cost and attract investment, governments can create certainty through legislation, reducing policy risks and market uncertainty.

Reducing risk is a vital component of delivering hydrogen at scale, given the high capital cost of many applications and uncertain investment environment. High policy risk can make investment difficult or raise the cost of capital. De-risking effectively lowers the cost of capital for hydrogen projects, which both reduces hydrogen costs and hence drives uptake. This not only means decarbonization targets are more likely to be achieved, but also that the overall transition will be delivered at lower total costs.

Policy risk can be reduced through a package of targets, roadmaps, and reshaped domestic policy to underpin national delivery:

- **Targets for decarbonization of the economy and national hydrogen strategies or roadmaps.** Policymakers can reduce policy-related risk through a combination of long-term goals and short-term targets. Long-term decarbonization goals, clear roadmaps, and enabling legislation coupled with binding short-term targets for hydrogen deployment, quantified CO_2 reduction targets, quotas and standards incentivizing low carbon and renewable hydrogen in end-use sectors can pave the way for the hydrogen economy. These policy tools help provide direction and market foresight to the industry. For example, as part of the implementation of the EU Hydrogen Strategy, the European Commission recently announced its proposal for an EU-wide 2030 target for a 50% share of renewable hydrogen consumption in industry.[4]
- **Commitment to a schedule of budgets for hydrogen.** Where project delivery depends on subsidies, it is important to provide visibility, ideally for 5-10 years in advance, over the likely subsidization regime. This could be through a schedule of budgets, commitment of a minimum volume of projects and clear decision rules about how subsidization may change over time in response to technological developments. Given the multi-year lead times for the development of many hydrogen projects, this visibility is crucial to reducing risk and making projects financeable.
- **Correcting market distortions that disincentivize low carbon and renewable technology adoption.** For example, removing subsidies for fossil fuels can make clean technologies, including low carbon and renewable hydrogen, more competitive.
- **Streamlining policy and removing excessive regulatory barriers**, including simplifying licensing and permitting processes and removing undue legislative barriers for renewable and low carbon hydrogen production (see Box 2).

[4] This target is proposed in the framework of the European Commission proposal for the revision of RED II (recast Renewable Energy Directive) published on 14 July 2021

Market risks, such as uncertainty over prices for hydrogen in the market can be reduced by providing revenue stabilization through government-backed contracts such as CfDs and CCfDs (see CCfD deep-dive). These revenue stabilization schemes– which provide a 'push' for supply and a 'pull' for demand respectively – are increasingly recognized and adopted as part of a holistic policy framework for decarbonization encompassing a hydrogen strategy. Examples of these schemes are already being enacted. For instance, the German government is setting up the H2Global[5] initiative featuring a CfD scheme that enables temporary compensation for the difference between the purchase price (production plus transport costs) and the sales price (currently the market price for fossil hydrogen) of renewable hydrogen and derived products. It is due to be applied to imported renewable hydrogen specifically in the initial phase, and it may be expanded to incentivize renewable hydrogen production at the national level. Downstream, several countries are considering introducing carbon contracts for the difference (CCfDs) for hydrogen covering industrial sectors initially, aiming to expand it to other end-use sectors in the future.

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5 H2 Global, https://h2-global.de/

3 To catalyze and grow new markets, hydrogen-specific support is required across production, midstream infrastructure, and end-use sectors like industry and transport. Design of support could evolve as the market matures.

During the market creation and growth phases, a package of hydrogen-specific support is essential to attract investment in infrastructure, hydrogen production, and create demand for low carbon and renewable hydrogen and their products.

A holistic approach to policy design is crucial to unlocking the full potential of hydrogen as an energy vector. Such an approach should underpin roadmaps and reflect the key role of hydrogen in enabling faster and greater integration of renewable capacity, greater cost-efficiency and optimized energy systems. Supply-push and demand-pull measures should be accompanied by efforts to repurpose and retrofit existing gas infrastructure, and build new dedicated transmission and storage capacity for hydrogen as appropriate..

This report identified effective hydrogen policy packages from a new, comprehensive evaluation of 12 key policies designed to increase hydrogen adoption. The analysis measured these policies against six performance criteria, including their ability to deliver first of a kind (FOAK) projects, minimize societal costs, span value chains and their flexibility of ambition, ease of implementation and ease of bankability. The resulting policy packages are broadly applicable across the value chain. Policy packages can be tailored depending on policymaker preferences for maximizing efficiency, retaining control over where and how much hydrogen is produced or maximizing the speed of deployment.

Design of support can evolve as the market matures. During the market creation and growth phases, a package of hydrogen-specific support for the whole hydrogen value chain is essential to attract investment in infrastructure, hydrogen production, and to create demand for low carbon and renewable hydrogen and derived products. CAPEX and OPEX support, alongside dedicated targets and quotas for renewable and low carbon hydrogen deployment in end use sectors - industry and transport in particular - will be crucial in early market and market ramp up phase. Over time, this package can and must evolve, exposing developers and investors to more risk and competition, and driving costs down further.

One key finding is that the evolution of policy and regulatory measures should be factored into policy design upfront, providing the necessary policy and regulatory predictability for market participants and investments. This evolution can be seen in the policies applied to three different phases of market maturity.

1. Market creation. A full policy package consisting of incentives, de-risking infrastructure, and downstream demand-pull measures can help commercialize technologies and create demand. The core elements of a policy package include:

- **De-risking infrastructure** can reduce costs and unlock private investment. Policy instruments to achieve this objective include debt guarantees, as well as loans and grants for hydrogen projects upstream (e.g., hydrogen production) and midstream (e.g., retrofitting and repurposing the existing gas infrastructure and new dedicated gas infrastructure).
- **Demand creation** policies targeting the downstream segment of the value chain include price support mechanisms (e.g., revenue top-up and stabilization mechanisms) coupled with quotas, targets, and standards for a minimum quantity of hydrogen used in specific market segments. Tools enabling market-based valuation of the sustainability attributes of hydrogen, in particular robust certification systems, will play a key role in creating consumer trust, pulling forward demand.

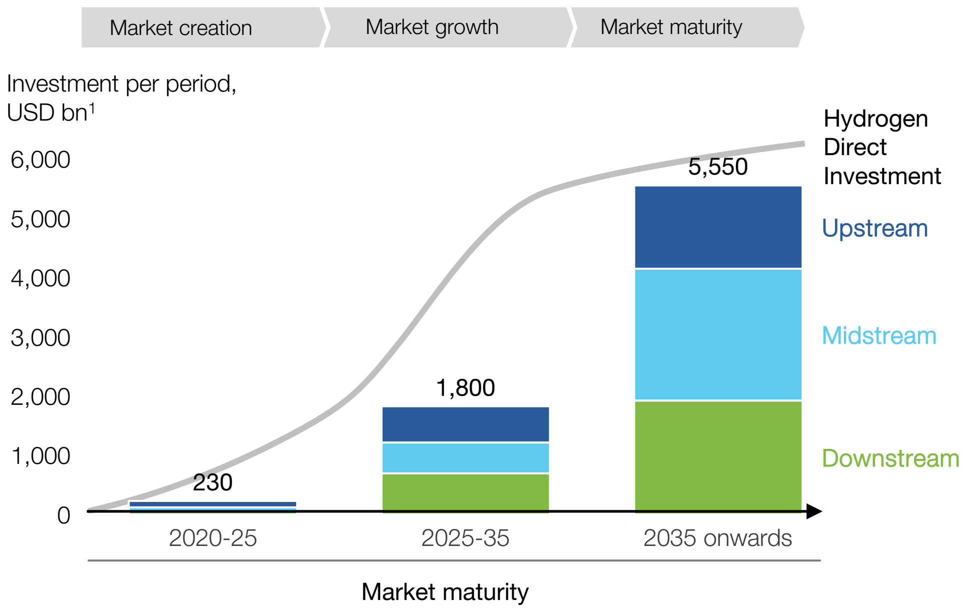
2. Market growth. Moving towards increased exposure to market prices and increasing competitive tension to drive costs further down:

- **Cost reduction** can be achieved through designing a delivery mechanism that encourages competition, such as allocating subsidies through auctions. Countries may choose to hold distinct auctions for low carbon and renewable hydrogen projects based on their policy choices.
- **As the number of market participants increases** and hydrogen uptake gains momentum, hydrogen producers and users should reach economies of scale, thereby reducing costs further.
- In jurisdictions where carbon cap-and-trade systems and CCfD schemes are in place, the gap between the strike price required for hydrogen projects and the reference price covered through CCfDs will gradually decrease, provided that the carbon price becomes more robust.

3. Market maturity. Once investment expenses are recovered and OPEX support is no longer necessary, revenue stabilization mechanisms can be phased out, and the market can start relying on robust (most likely, regional) benchmark prices for hydrogen. These benchmark prices would be supported by carbon prices robust enough to level the playing field for hydrogen solutions, letting them compete with other low carbon technologies and high emissions counterfactuals, ensuring efficient resource allocation and minimizing societal costs.

Figure 1

Evolution of policy measures along different stages of market development can be factored in upfront to unlock the potential flow of investment



1. Investment in line with the «Hydrogen for Net Zero» scenario; upstream includes hydrogen production (electrolyzers, CCS retrofits for blue H_2, new SMR/ATR plants), excludes renewables/gas upstream; midstream includes distribution, transmission (shipping, pipelines, conversion etc.) and storage; downstream investments for end-applications (ammonia plants, fuel cells etc.)

Source: Hydrogen for Net Zero

Enabling policies play a key role across all phases of market development (see principle 4 below). In particular, robust hydrogen certification schemes (evidencing the origin, carbon footprint and other sustainability characteristics of hydrogen production) are key to enable a market-based approach to hydrogen sourcing.

4 Carbon prices work together with hydrogen-specific support to drive efficient and effective hydrogen uptake in the longer term.

Robust carbon pricing mechanisms can incentivize hydrogen deployment in the longer term and help provide a level playing field for low carbon and renewable hydrogen to compete alongside other low carbon technologies. Regional cap-and-trade can build towards a globally linked carbon pricing regime or regional carbon prices. Interactions between carbon prices and direct incentives can be managed through policy and market design. While carbon leakage can be prevented by well-designed carbon border adjustment mechanisms.

Key design considerations for carbon pricing schemes implementation:

- Efficient delivery: CO_2 prices can play a key role in ensuring competitiveness of hydrogen applications and bringing them 'into the money' with conventional technologies. Cap-and-trade systems across regions have already demonstrated their effectiveness at incentivizing fuel switching from coal to natural gas. Similarly, carbon pricing can encourage switching in segments where low carbon and renewable hydrogen is closest to being cost-competitive with the incumbent technology, such as from grey to low carbon and renewable hydrogen in industrial application, especially if the cost of switching from grey hydrogen to low carbon and renewable hydrogen becomes the key pricing parameter driving cap-and-trade systems[6]. In established markets, reinforcing and expanding cap-and-trade systems to cover all end-use sectors as far as appropriate, can drive cost competitiveness across a wide range of applications[7]. In some geographies and sectors, this cost-competitiveness can be achievable by 2030, with heavy duty trucks, ammonia synthesis process emissions, and urban buses being able to break even with conventional technologies at carbon prices <100 USD/t.
- Preventing carbon leakage and carbon displacement: Policies that target traded sectors need to be secured to ensure carbon is not merely «displaced,» putting producers at a competitive disadvantage. The right policy measures, such as introducing or strengthening carbon pricing, can propagate decarbonization policy elsewhere. Carbon leakage, where carbon-intensive production re-locate their production facilities to other jurisdictions that have no carbon price in place – or where the carbon price is not sufficiently robust – can be addressed through a well-designed carbon border adjustment mechanism (CBAM) to ensure international competition and a level playing field for industries exposed to carbon pricing.[8]
- Evolution at international level: Carbon cap-and-trade systems introduced at national level and complemented by anti-leakage mechanisms if necessary can pave the way for regional or even global carbon pricing in the longer term.
- Potential policy interactions: The combination of direct incentives for hydrogen and carbon price schemes could create both positive policy interactions and potential policy overlaps. Best-practice design can ensure that the interactions between direct incentives such as tax credits, CCfDs, and carbon pricing are accommodated in the schemes' design and managed successfully. For example, the Netherlands' proposed SDE++ scheme is a variable premium model which applies to a variety of low carbon technologies (including renewable hydrogen, low carbon hydrogen and CCUS) that fades as the market value of carbon increases.

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6 BNP Paribas, Deep Decarbonization: green hydrogen, net zero and the future of the EU-ETS, 2020

7 Part of the auctioning revenues from cap-and-trade systems can be used to address its potential distributional effects, such as providing financial support to vulnerable households (e.g., European Commission proposal for the establishment of a Social Climate Fund)

8 BNP Paribas Asset Management, Deep Decarbonization, Green Hydrogen, Net Zero, and the Future of the EU-ETS, (October 2020), https://docfinder.bnpparibas-am.com/api/files/FB39FAB1-A279-41CC-9CDD-4D22827359B0

5 International industry standards and harmonized hydrogen certification schemes play a key role in enabling market-based valuation of hydrogen sustainability attributes, thereby building consumer trust, stimulating demand, and fostering international hydrogen markets.

Ensuring that policy design at the country or regional level is informed by common international standards is a crucial prerequisite for the emergence of global, cross-border hydrogen markets.

International standards create a common language for the industry across the value chain and facilitate the commercialization of hydrogen technologies and hydrogen-based products. A standard methodology for determining the carbon footprint and other sustainability attributes of hydrogen production pathways will play a crucial role in informing the development of harmonized hydrogen definitions and certification systems. Hydrogen certification systems, in turn, are necessary to build consumer trust and stimulate demand while enabling cross-border trade in hydrogen and fostering market liquidity.

Ultimately, **international standards and harmonized rules underpinning certification systems are key to facilitating global trade in hydrogen**, efficiently matching supply and allowing the most cost competitive production regions to be tapped into. In Japan, reduction of the administrative burden on import from Australia through international standards and certification could generate USD 2bn of savings in 2030.[9] While in the case of Germany, by meeting 50% of forecasted low carbon or renewable hydrogen demand in 2030 through pipeline imports from Spain, annual savings of ~USD 340mn can be realized.[10] Countries with production capacity constraints such as Japan and Korea, could import cost-competitive low carbon or renewable hydrogen from a range of exporter regions.

[9] Appendix 2.6
[10] Appendix 2.5

Box 2

Removing regulatory and market design barriers for renewable and low carbon hydrogen uptake

- **Lengthy or complex licensing and permitting processes** for projects in the jurisdictions where they seek to operate may constitute a barrier to renewable and low carbon hydrogen deployment and should be addressed by policymakers.
- There may be unintended consequences of renewable and/or low carbon-specific hydrogen support that need to be managed. In some jurisdictions, policymakers are considering placing stringent obligations on hydrogen producers to **qualify the electricity used for hydrogen production as renewable** (e.g., in Europe, the revised Renewable Energy Directive[11] is likely to include such a provision). Inflexibility may introduce additional costs and act as another barrier to deploying renewable hydrogen and derived fuels at scale.[12]
- It is crucial to **modify the existing energy market design to generate incentives for grid balancing and storage**, which renewable hydrogen can provide. This would allow renewable hydrogen producers to compete on a level playing field with other energy technologies relying on renewable energy and to deliver overall energy system efficiency and optimization by providing grid balancing and flexibility services.

Box 3

Best practices to address methane emissions

Industry players are making efforts to reduce fugitive emissions associated with low carbon hydrogen production. A robust international policy at the international level and regulatory framework aimed at reducing fugitive emissions can help level the playing field at the international level for market participants, considering the performance of the CCS technologies that the industry seeks to deploy (such as SMR + flue gas CCUS or SMR+CCUS and ATR + CCUS with >95% overall capture rates).

[11] The Delegated Acts on Renewable Fuels of Non-Biological Origin (RFNBO) envisaged under Art. 27(3) and Art. 28 (5) of RED II will set out the methodology for qualifying electricity used for RFNBO production as renewable and the methodology for assessing the GHG emissions savings from RFNBO respectively (both DAs are to be adopted by 31 December 2021).

[12] Eurelectric powering people, RFNBOs Renewable Fuels of Non-Biological Origins published in January 2021. https://cdn.eurelectric.org/media/5182/eurelectric_reaction_paper_on_rfnbos-2021-030-0013-01-e-h-B5F7EAF8.pdf

6 Societal value and values can be factored into policy decisions.

Alongside the transition towards carbon neutrality, countries would benefit from considering the full range of societal impacts and the benefits that can be unlocked through the development of the hydrogen economy. The hydrogen economy can benefit society delivering on certain UN Sustainable Development Goals (SDGs), including:

- Good health and well-being
- Green growth and sustainable jobs
- Diversity, equity, and inclusion
- Opportunities for indigenous communities
- Sustainable cities and communities

Section E of the report elaborates on the above in more detail.

Introduction & approach

Strong momentum for low carbon and renewable hydrogen reflects a recognition of its vital and systemic role in decarbonizing the energy system. Over 30 countries have now introduced hydrogen strategies, while more than 520 large-scale low carbon and renewable hydrogen projects have been announced by the industry, amounting to a total anticipated investment at the time of writing of USD 160 bn until 2030. Considering the rapid growth in renewable electricity capacity foreseen for the decades to come, the flexibility that hydrogen provides can reduce total systems costs significantly. In simulations of energy systems without existing hydropower and nuclear power, this flexibility translates into a saving of 10-15% of total power system costs. Looking at well-integrated energy markets, such as those in the EU, with access to flexible capacity provided by hydropower and nuclear, savings are somewhat lower - 2-3 USD/MWh – but still translate into annual savings of roughly USD 12 bn[13]. This points to the key role of hydrogen as the enabler for faster and greater integration of renewable capacity, as well as greater cost-efficiency and optimization at energy system level.

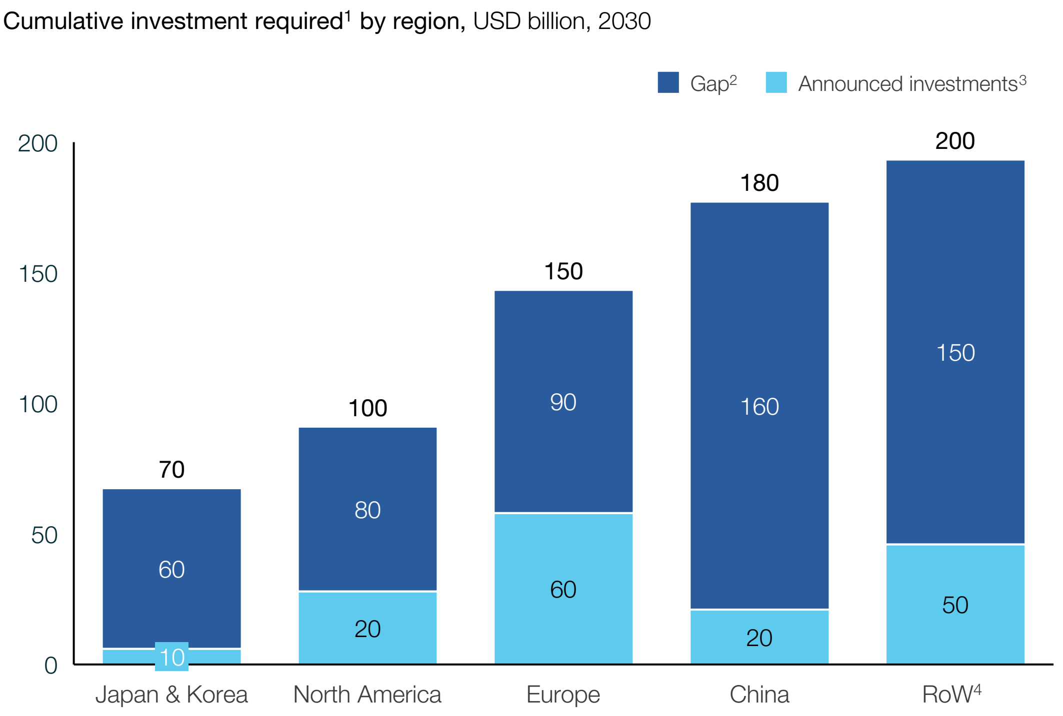
Rapid technological learning is bringing cost competitiveness within reach for many projects and applications. Scaling up projects will further accelerate a downward cost trajectory. Hydrogen Council research has found that scaling up hydrogen solutions can reduce costs along the value chain by 45-70%[14]. In the case of electrolyzers used for renewable hydrogen production, scaling up can lead to cost reduction of as much as 50% by 2030. Midstream, the maximization of the use of hydrogen infrastructure could realize a 70% reduction in the cost of transmission and distribution of hydrogen. Downstream, a 45% reduction in the cost of fuel cell stacks could be realized through manufacturing scale up (e.g., producing 200,000 units of fuel cell stacks rather than 10,000)[15]. Scaling up hydrogen technologies quickly across a wide range of applications can result in earlier tipping points being achieved for breakeven with conventional technologies.

However, unlocking the full potential of low carbon and renewables hydrogen requires well-designed enabling frameworks. Despite the current policy and investment momentum for low carbon and renewable hydrogen, there is USD 540 bn investment gap to meet announced government targets. Europe, Japan, and Korea are examples of leaders in the development of dedicated hydrogen strategies. At the same time, many other countries and regions have set out their low carbon and renewable hydrogen ambitions and are looking at developing the policies and regulations that would enable their achievement. Countries and international organizations, including IRENA and IEA, recognize the importance of policy frameworks to ensure low carbon and renewable hydrogen can deliver its full potential[16]. Investment gaps vary by region, with the highest in China and lowest in Japan and Korea (Figure 2).

[13] Appendix 2.7
[14] Hydrogen Council, Path to Hydrogen Cost-Competitiveness: a cost perspective, 2020
[15] Hydrogen Council, Path to Hydrogen Cost-Competitiveness: a cost perspective, 2020
[16] IEA, Global Hydrogen Review 2021, 2021

Figure 2

Investments announced vs. the required investments to meet stated government targets for 2030.[17]



1. Excluding downstream investments (e.g., factories, mines) and renewables and CCUS infrastructure)
2. Direct investments only
3. Taking into consideration of the direct investments and the ~USD 150bn of government direct investments
4. Rest of the world

Source: Hydrogen Insights Project and Investment tracker

[17] Appendix 2.1

Role and value of this report

The report is directed in particular at policymakers and legislators who can use it as a menu of policy packages and tools to deploy when designing or implementing hydrogen policy and regulatory frameworks in their jurisdictions. The report delivers this by:

- Capturing the evolution of policy design along different stages of hydrogen technology and market maturity. It demonstrates the role of direct support measures for hydrogen in the early market building phase. It also shows that the scope for the evolution of these measures as the market matures over time can be factored in policy design upfront to ensure policy and regulatory predictability for market participants.
- Setting out policy pathways through country archetype examples that can be used to inform hydrogen policy and regulation in different national and regional contexts. There is no 'one type fits all' policy to unlock low carbon and renewable hydrogen across geographies. Through the development of multiple policy pathways, the assessment lets policymakers choose policy packages that best serve their ambitions, preferences, and local and regional context.
- Offering insights into the cross-cutting policies and measures that are vital to enable cross border trade in hydrogen, while building consumer trust. These include development of international industry standards and harmonized rules to underpin certification systems for hydrogen.
- Identifying learnings from the deployment of other low carbon and renewable technologies, considering the success stories in policy design (such as direct support schemes and quotas for renewable electricity), as well as the remaining policy barriers and challenges (including those associated with licensing and permitting requirements).
- Shedding light on the broader societal value of hydrogen policy, including positive impacts that hydrogen can have along the UN Sustainable Development goals that go beyond carbon reduction. These include impacts on good health and well-being by reducing air pollution, developing affordable and clean energy, providing green growth and jobs allowing countries to continue to benefit from their natural endowments, and others.

Researchers, NGOs, and the wider community thinking about the energy transition and the role of hydrogen in it may also find this report a useful point of reference on hydrogen policy design.

CCfD deep-dive

What are Carbon Contracts for Difference (CCfDs)?

CCfDs are government or institution-backed contracts between two parties whereby the beneficiary is compensated for the difference between the effective CO_2 price and the mitigation costs of a breakthrough technology, also known as the 'strike price'. CCfDs have been considered by the European Commission and member states, such as Germany.

How do CCfDs work?

A CCfD constitutes a hedging instrument for future carbon prices and can help bridge the gap towards a viable business cases for low carbon and renewable hydrogen projects. CCfDs use a market specific carbon price as reference, for instance the EU carbon price, and calculate the effective CO_2 mitigation price or 'strike price' of introducing low carbon or renewable powered technologies relative to conventional technologies. CCfDs quantify avoided CO_2 between emissions of breakthrough technology and those of a conventional benchmark and compensates producers for the difference between the market CO_2 price and the 'strike price'. Subsequently, as decarbonization efforts progress and CO_2 prices increase the subsidy is reduced over time. CCfDs are a flexible tool which support low carbon and renewable hydrogen production and use, while avoiding over-subsidization.

CCfDs support and subsequently enable the implementation of hydrogen strategies and roadmaps, including sectoral targets for hydrogen and help accelerating hydrogen uptake as part of broader decarbonization efforts.

What barriers to adoption in low carbon and renewable hydrogen do CCfDs address?

- Limited investment due to long payback period and high risk and limited ability to recoup production costs: *In the absence of stable and sufficient CO_2 prices, CCfDs increase stability of revenues and ensure a minimum price to enable producers to recoup production costs.*
- Low availability and high cost of capital: *CCfDs spread and decrease the financial risk of low carbon and renewable hydrogen investments, thereby incentivizing private investment.*
- Inefficient subsidization of unabated fossil fuels that encourages supply: *The introduction of CCfDs can strengthen existing cap and trade systems and provides a strong signal to the markets on the direction of CO_2 price and expected levels in the long term (e.g., by 2040-50).*
- Low availability, and technical and commercial viability of end use appliance for hydrogen: *Building on innovation-funded pilots, CCfDs can provide continuity between demonstration projects and commercial scale projects, thereby supporting the commercial viability of low carbon and renewable hydrogen projects.*

Key design principles and considerations for CCfDs

1. Benchmarking and application

What conventional benchmarks should be used?

- Since the 'strike price' is defined as the currency[18]/tCO_2 for the introduction of emission abating technologies against a conventional energy or technology benchmark, it will vary depending on the application

There will need to be consensus between public and private sector actors on a consistent methodology for application-specific benchmarks (e.g., EU ETS product benchmarks)

Should the carbon price reference be on the producer or consumer side?

- Producer-side carbon price reference may not be reflective of the actual sales price point of abated CO_2 units and could lead to over-subsidization.
- A consumer-side carbon price reference would ensure harmony between subsidy and the actual sales price and would ensure the "strike" price is adapted to specific end-uses

Should the strike price be adjusted with indexation?

- Fixed strike price leaves producers managing their input price risks, resulting in higher strike prices being bid for.
- Strike prices can be indexed to natural gas prices for low carbon hydrogen and to renewable electricity prices for renewable hydrogen as significant drivers of production cost, to mitigate input price risk.

2. Contract duration and evolution of premium

What is the optimal contract length?

- Longer contracts (minimum 10 years) help provide stability.
- Clauses providing for regular reviews of the strike price can help avoid over-compensation.
- Evolution of the strike price should reflect likely higher costs and lower efficiencies incurred by first movers.

How should the variable premium be modelled to reflect market evolution?

- Methodology needs to be established to model the variable premium to ensure it effectively represents the evolution of the hydrogen market and can be applied to different end use cases.

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[18] Currency dependent on the currency agreed upon as part of the cap-and-trade system in question

3. Governance and predictability

Will the process be governed by national governments or institutions?

- National governments tend to have the ability to absorb more risk and thereby provide more funding for CCfDs in the initial phases of market growth
- Standardizing the methodology for CCfDs at the international level (e.g., IMF), however, would support quicker adoption and a greater number of jurisdictions and minimize competition risk

How do regulators ensure consistency and predictability of the regulatory framework?

- Evolution of the instrument should be factored into the upfront policy design to ensure predictability for investors and guard against significant regulatory changes (e.g., 5-yearly reference and 'strike price' reviews)
- Regulation needs to be established to ensure projects receiving contracts are not then liable to receive ETS subsidies or able to sign supply contracts so over-subsidization is prevented.

4. Allocation procedure

Will the allocation procedure occur through auctions or negotiations?

- In the initial phase of CCfDs, with a limited number of projects and to test benchmarking and applications, negotiations are most appropriate
- Negotiations should build in transparency mechanisms to avoid information asymmetry on costs and ensure bidding rounds are set at the appropriate level once allocation moves to competitive auctions
- Once sufficient competition (e.g., number of projects) is established, allocation should shift to auctions to ensure the most cost competitive projects are supported
- In addition to costs, auctions should consider the strategic nature of projects to prioritize projects which unlock further low carbon and/or renewable hydrogen use (e.g., in strategic locations near prospective demand clusters). Additional criteria could include avoided emissions (full life cycle and GHG based) and anticipated volumes of low carbon or decarbonized products.
- A pre-selection phase during auctions would ensure projects that are aligned with specific parameters and national priorities are included which comparisons are too broad (e.g., transport vs power) and overburdening the process where comparisons are too narrow (e.g., project by project review). It could be also used to ensure over-subsidization is prevented through a pre-requisite for projects to be included being that they do not have supply contracts signed.

What level of project clustering should be used?

- Projects should be clustered on an application basis (e.g., steel or ammonia) to ensure comparability and avoid overlooking low carbon or renewable hydrogen applications.

5. Funding options

What financing mechanism should be used?

- High funding requirements means that general tax revenues or ETS revenues would need to be utilized to meet these subsidy levels required in the short term. More medium-term options would be applying a climate surcharge on final products with a high share of basic material, a carbon border adjustment mechanism (CBAM) regime or appropriate quotas and green purchase obligations.

Policy assessment & packages

While dozens of potential policy and regulatory measures could promote hydrogen development, this report's policy analysis first helps determine which ones can be deployed effectively against different market development priorities. This section discusses the major barriers facing hydrogen development at each step of market development: market creation, market growth, and mature market. It then presents 12 key policies to promote market development and the evaluation criteria used to select them. The section then concludes with three policy packages that provide a recipe book for policymakers with different explicit or revealed preferences, be it the need to deploy hydrogen at the most efficient cost, the ability to control the where and how much hydrogen is produced, or the requirement that hydrogen be deployed as fast as possible.

As the starting point, the policy assessment framework in this report analyzes barriers to deployment. Figure 3 presents barriers to hydrogen deployment collated from literature review and a survey with Hydrogen Council member. Barriers differ along the hydrogen value chain segments and market maturity stages. However, some barriers centered around lack of regulatory framework, standardization, and collaboration are overarching across the value chain and market maturity. Consequently, the variability in the barriers requires different policies for different segments of the value chain and different phases of market maturity, but also these policies need to vary in sync to address interdependencies along these two dimensions.

The three market maturity stages each have their own objectives and barriers:

- **Market creation objectives: demonstrate viability of full-scale facilities and develop an industry of multiple project developers, investors, and key value chain stakeholders that could scale the market.** This phase extends from the point of technical readiness (most hydrogen technologies have reached this point already) to the point at which there is an industry that have delivered multiple large-scale projects in a country or relevant regional market.
- **Market growth objectives: market expansion and cost reduction.** This phase extends from the point where the industry has delivered multiple large-scale projects, to a mature industry (see below).
- **Mature market objectives: deploy hydrogen at prices that are competitive with alternatives and to reach the full market potential of hydrogen.** A mature industry is one delivering a large pipeline of projects with costs comparable or lower than alternative technologies.

Figure 3

The deployment and financing barriers are concentrated in the first two market maturity phases

Time/maturity

H_2 value chain	Market cretation	Market growth	Market maturity
Enabling policies	A.1.1 Limited research, development, demonstration and deployment specific funding		
Enabling policies	A.1.2 Lack of standard methodologies and regulatory body to qualify[1] H_2 as renewable or low carbon, and certification systems to support the development of the H_2 market at international level		
Enabling policies	A.1.3 Lack of a regulatory/legal framework defining standards for H_2 technologies, applications, and H_2-derived products		
Enabling policies	A.1.4 Lack of H_2 strategy and societal acceptance as part of broader decarbonisation efforts resulting in uncertainties around future direction/low sectoral collaboration		
A Upstream supply	B.1.1 Locked-in to existing assets and fossil fuels (e.g., using coal/oil)	B.2.1 Inefficient subsidisation of unabated fossil fuels that encourages supply, e.g., carbon pricing	B.3.1. Unstable network and supply, including insufficient access to renewable energy and carbon capture and storage
A Upstream supply	B.1.2 Limited physical access to required inputs, e.g., renewable electricity installations	B.2.2 Limited ability to recoup production costs, e.g., uncertain volumes and price	
A Upstream supply	B.1.3 Low deployment of technology, e.g., electrolysers, carbon capture and storage	B.2.3 Low availability and high cost of capital	
A Upstream supply	B.1.4 Limited investment due to long payback period and high risk		
B Midstream transmission, distribution, and storage infrastructure	C.1.1 Immature and/or inefficient storage options and development (incl. liability issues)	C.2.1 Lack of repurposing, retrofitting or building new infrastructure, e.g., pipeline, refueling stations, port facilities	C.3.1 Lack of reliable infrastructure, incl. last mile distribution infrastructure
B Midstream transmission, distribution, and storage infrastructure	C.1.2 Lack of planning of H_2 infrastructure (e.g., transport, storage, HRS) resulting in delay in investment decision		C.3.2 Lack of monetisation of the flexibility (e.g., buffering, storage) that hydrogen will provide to the energy system
C Downstream demand	D.1.1 Locked-in to existing assets that do not use H_2, e.g., fleet	D.2.1 Limited demand-pull and uptake of H_2 in end-use sectors, e.g., industry, transport, buildings	
C Downstream demand	D.1.2 Low availability, and technical and commercial viability of end use appliance for H_2, e.g., boilers	D.2.2 Lack of H_2 familiarity for offtakers, causes reluctance to adopt or need long lead time and cannot reach minimum viable scale	

1. There is also a need for alignment between taxonomies (i.e. how to qualify economic activities as sustainable) to ensure H_2 production is compliant

Source: Literature review, expert interviews

To determine the policy space, the assessment maps a long list of policies on the barriers and groups these into 12 key policies (see Table 1). Each key policy is a grouping of policies aiming to overcome different barriers. For example, policies like CfDs, CCfDs, FiTs, FiPs, and tax incentives and credits are grouped within direct support mechanisms. All these instruments provide additional revenue to projects by providing subsidies and decrease risks around revenue and long payback periods, making the projects bankable.

Table 1
The policy space considers 12 key policies

Key policy	Description	Instruments contained	Primary barrier for policy to overcome
Emission Trading Schemes	A central authority caps carbon emissions and allocates a limited number of permits to emitters. Emitters can buy permits in the market to cover their excess emissions or sell their excess permits to generate revenue. Internalizes social cost of carbon emissions, making renewable and low carbon technologies competitive	Emission Trading Schemes, including expansions of existing schemes to cover additional sectors	No market for low carbon technologies
Carbon tax	Levies tax on carbon emissions of economic activities to internalize societal cost of carbon emissions, making renewable and low carbon technologies competitive	Carbon tax	No market for low carbon technologies
Alternative revenue streams	Provides secondary revenue stream alongside the main business	Payments for electricity grid flexibility, (e.g., grid firming services, buffering, and storage)	No market recoup costs
Direct support mechanisms (involving competitive auctions)	Forms of subsidies to guarantee investors a higher revenue or lower operation cost. Increases revenue certainty and profitability	Contracts-for-Difference (CfDs), Carbon Contracts-for-Difference (CCfDs), Feed in Tariffs (FiTs), and tax incentives, such as tax credits, lower taxes on electricity and exemptions from renewable electricity levy	Limited investment due to high risk or long paybacks
Financial support mechanisms	Financial support provided by government to projects that meet specific requirements. Lowers upfront investment costs	Monetary support, such as grants and loans	Low availability and high cost of capital

Key policy	Description	Instruments contained	Primary barrier for policy to overcome
Guaranteed offtake	Commercial long-term contracts where volumes of hydrogen and hydrogen-based products are guaranteed to be sold to an entity at a fixed price for the length of a contract. Provides demand and revenue certainty	Long-term contracts	Limited demand pull and uptake in end-use sectors
Investment de-risk mechanisms	Collaboration between a government agency and a private-sector company that can be used to finance, build, and operate projects. Lowers construction and technology risk	Balance sheet support tools, such as debt guarantees and equity	Low availability and high cost of capital
Phasing out of fossil fuel subsidies	Removal of fossil fuel subsidies. Makes high emissions technologies less competitive	-	Inefficient subsidization of unabated fossil fuels
Public procurement	Public procurement requirements added to contracts to kick-start markets, such as preferential treatment of hydrogen and hydrogen-based products. Creates hydrogen demand	-	Limited demand pull and uptake in end-use sectors
Return on investment de-risk	Secures return on investment for developers by passing costs down to consumers. Increases revenue certainty.	Regulated Asset Base Model (RABM), availability payments, minimum revenue guarantee, future purchase commitment	Limited ability to recoup production costs
Quotas, and targets	Dictates mandatory emission reduction/intensity or low carbon and/or renewable hydrogen capacity targets through legislation, can be catch-all or apply to specific sectors, introduce quotas for hydrogen/ low carbon products to be used as electricity sources. Creates hydrogen demand and supply.	Quotas, targets, low carbon and/or renewable hydrogen capacity targets, emission reduction and intensity targets, targets for specific sectors such as transport and industry; in certain cases, midstream targets for hydrogen injection into existing gas grids	Limited demand pull and uptake in end-use sectors
Standards	Dictates minimum standards by which industry must abide. Blending standards can be applied to mid-stream infrastructure and emission performance standards can be mandated in upstream and downstream	Emission performance standards and blending standards	Limited demand pull and uptake in end-use sectors

Note: Although policies often address a multitude of barriers, the table refers to the barrier that is most effectively addressed, considering it as its primary barrier

These 12 key policies were assessed against six performance criteria to lay out their strengths and trade-offs. Table 2 describes the six performance criteria used for the assessment and lists the questions asked to test how a policy performs against each criterion in practice. The questions assess performance of the policies along the two dimensions used to map the barriers. Ranging from delivery of "first of a kind projects" to "ease of bankability", the six criteria are designed to cover the policy characteristics that are most relevant for a new technology that is in its market creation phase and requires to build a system reaching across upstream, midstream, and downstream. Thereby, the framework provides a basis for comprehensive comparison between the key policies and draws out their key strengths. The full assessment of all key policies can be found in the appendix.

Table 2
Six performance criteria are used to assess policies strengths and trade-offs

Criterion	Description	Questions
Delivers first of a kind (FOAK) projects	Success of the policy in incentivizing technology deployment by providing sufficient revenue and certainty to low carbon and renewable hydrogen investments	1. Does the policy provide sufficient revenue or other benefits to incentivize technology deployment? 2. Does the policy provide sufficient certainty to attract private investment? 3. Is there a track record of analogous policies incentivizing significant deployment?
Minimizes societal costs	Extent the policy minimizes societal cost by promoting innovation, competition, and economies of scale, while avoiding rent creation	4. Does the policy minimize costs and maximize output (e.g., through innovation/economies of scale)? 5. Does the policy allow for market players to deploy the most efficient option? 6. Does the policy minimize opportunities for rent creation?
Spans value chain	Scope of policy application to up-, mid- and downstream without additional efforts from a policy maker	7. Does the policy automatically apply up-, mid– and downstream? 8. Can the policy apply up-, mid– and downstream?
Flexibility of ambition	Extent the policy can be amended or abandoned as market circumstances change	9. Can the policy be adjusted over time to reflect increasing maturity?
Ease of implementation	Ease of implementation and administering of the policy and the level of adversity the policy presents and its social acceptability	10. Does the policy avoid adverse effects for the competitiveness of industry, jobs, cost of living, etc.? 11. Can the policy be effective without closely monitored accounting practices?
Ease of bankability	Extent the policy addresses risks to encourage private investment	12. Are the risks of the private sector too large to finance the project?

Strong performing policies are then mapped to the barriers at each of the three stages of market maturity and value chain. These policy packages are shown in the following section for each country archetype – a self-sufficient hydrogen producer, an exporter, and an importer. The full set of policies is shown in the self-sufficient hydrogen archetype, given that this is the example where all stages of the value chain are relevant in one location. (Figure 4) In assembling the policies across the evolution of market and technological maturity, the following observations are relevant:

- Across the market creation and market growth stages, it is important to **maintain long term certainty** over the size of the market, either through decarbonization or hydrogen specific targets.
- Alongside direct hydrogen policy, it is important to **build a robust carbon price signal** at the same time, starting with regional schemes and then linking them, whilst mitigating leakage through border tariff adjustments.
- As the number of players increases in the market growth phase, **competition will increase**, facilitating cost-effective allocation of funding support. Some countries may decide to introduce auctions accounting for the sustainability attributes of hydrogen technologies.
- Alongside hydrogen policy it is vital to expand markets to **generate robust market signals for flexible technologies**, as hydrogen can provide low-cost flexibility to the power system. The full potential of hydrogen can only be reached if these flexibility markets are completed alongside carbon markets.

Figure 4
Policy roadmap for low carbon and renewable hydrogen

Policy objective	Policy roadmap		
Certainty	Emissions targets and hydrogen strategies		
Consumer trust	Develop harmonized standards and certification schemes		
H_2 investment	Market cretation	Market growth	Market maturity
Upstream	**CAPEX & OPEX support** (e.g., CfDs, tax credits), **Financial de-risking** (e.g., grants, loans, and guarantees)	**Evolve to increase competition** (e.g., auctions - potentially separate for low carbon and renewable hydrogen - with a large pipeline of bidders)	**Shift incentives to carbon prices and markets to deliver investment**
Midstream	**CAPEX & OPEX support, financial de-risking** (e.g., regulated returns, price ceilings and floors for transmission and distribution networks, subsidies for storage infrastructure and refueling stations)		
	Blending standards and quotas		
Downstream	**CAPEX & OPEX support, financial de-risking** (e.g., price premiums, CCfDs, free allocation), **Public procurement, targets/quotas**	**Evolve to increase competition** (e.g., auctions - potentially separate for low carbon and renewable hydrogen - with a large pipeline of bidders)	**Shift incentives to carbon prices and markets to deliver investment**
	Product labelling		
Economy-wide uptake	Build robust regional carbon prices		

Moving down the value chain, the following design elements of policy packages are important:

- In upstream and downstream, it is important to **utilize subsidy efficiently**, given the potential for multiple overlapping instruments. Hydrogen support contracts may be provided both upstream (such as hydrogen supply contracts CfDs, and/or grants supporting OPEX and CAPEX) and/ or downstream (such as CCfDs). Depending on the jurisdiction, policy makers may choose to introduce investment and production tax credits. The interaction between these mechanisms should be managed so they do not overlap. It is also important to manage the interaction with the carbon price, by setting any subsidy policy against a full effective carbon price (which may consist of the “market price” for carbon plus additional carbon taxes if they exist in each jurisdiction). If the full carbon price is not used, over-subsidization may occur.
- For the midstream, infrastructure (transmission, distribution, storage) should be incentivized using regulated returns and **learning the lessons from efficient delivery of electricity and gas networks** (e.g., with pricing based on improving performance and efficiency over time). The introduction of price ceilings and floor can also be used to ensure that efficiency is achieved.
- As for HRS, support on both CAPEX and OPEX are necessary for an efficient development
- **Industrial downstream uses of hydrogen may need specific support**, such as the use in steel, chemicals, and refineries. The relative advantages of CCfDs, feed in premia or tariffs should be considered.
- **Downstream quotas or targets** may be required as additional support to generate demand in the market creation phase.

Policy packages may also differ depending on whether they prioritize speed or efficiency of delivery. More directive policies and regulatory mandates can achieve greater speed, whereas market-based policies can support more efficient delivery: **However, we would recommend implementing the combination of both packages at the same time for an optimal deployment of the renewable/low carbon hydrogen sector.**

1. **A policy package focused on efficiency is best suited for policymakers who prioritize cost-competitiveness of support instruments.**[19] In early maturity stages, direct support mechanisms, such as CfDs, FiTs, and production tax credits in upstream, and CCfDs in downstream, provide revenue certainty and allow investors to cover their upfront investment and operation costs, **making FOAK projects economically viable**. In countries where the energy sector is liberalized and where well-functioning markets in electricity and in gas already exist, policymakers may want to offer **dedicated grants and loans** at the initial stage of market development (especially to projects of strategic importance), and grant temporary exemptions to the existing state aid rules.[20] At later maturity phases, exposing market participants to a carbon price while phasing out revenue stabilization mechanisms (such as CCfDs) will promote competition and innovation, **minimizing the societal cost**.

2. **A policy package focused on rapid deployment is designed for policymakers where the priority is rapid scaling of markets and infrastructure.** Standards, quotas, and emissions reduction and intensity targets provide visibility and decrease uncertainties around supply, demand, and prices. This lowers borrowing costs and provides revenue certainty, **making projects bankable**. Financial support mechanisms also lower the initial capital requirements, **making FOAK projects economically viable**. Both types of policies are simple to design, implement and monitor, allowing policymakers to channel resources to the low carbon and renewable hydrogen sector quickly. Due to information asymmetries and uncertainties around new technologies, policymakers may fail to identify the lowest cost technology or the one that may dominate the market in the future, possibly causing inefficiencies and hence higher societal cost compared to the Efficiency packages.

Figure 5 lays out the key policies forming each policy package and how each policy package performs against the six performance criteria, while emphasizing their strengths.[21]

Finally, detailed policy design will need to address the specific implementation challenges in each location. The policy packages address deployment and financial barriers across the low carbon and renewable hydrogen value chain, but depending on the country context, implementation challenges may remain. For example, if there are few or no examples of completed low carbon and/or renewable hydrogen production plants in a country, construction and technology risks associated with a hydrogen production project may be too high, putting off investors. Policy makers can deploy investment de-risk policies, such as debt guarantees and equity by government, to lower construction and technology risks and make FOAK projects viable.

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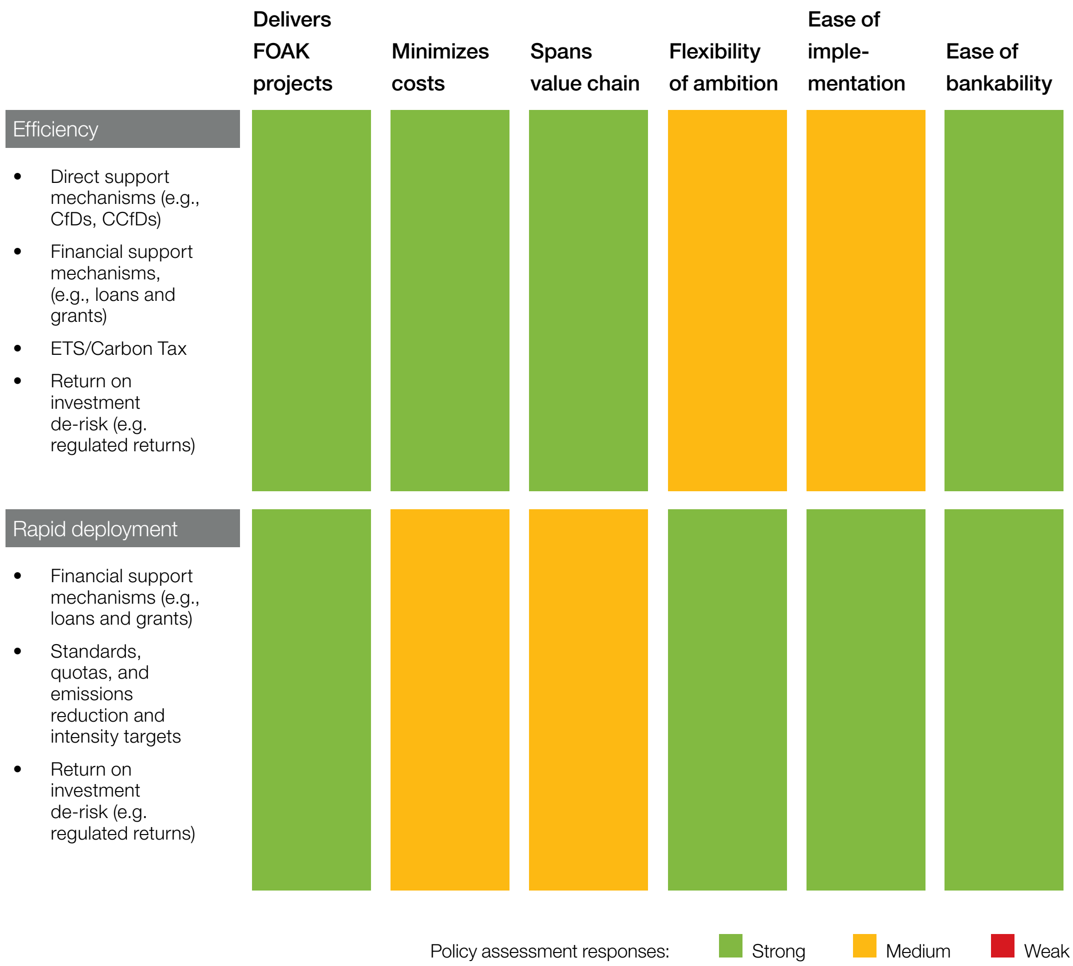
[19] The focus is on minimizing societal cost. After this objective is achieved, the policies can be designed to allocate the societal cost between the stakeholders in an economy, such as consumers, firms, and government, as desired. For example, carbon pricing increases price of products for consumers, decreasing their purchasing power. A government can transfer a part, or all revenues collected from permit sales or carbon tax back to consumers to cover costs accruing to consumers due to carbon pricing.

[20] For example, in Europe, low carbon and renewable hydrogen projects are eligible for grants and loans allocated through the Recovery and Resilience Facility, alongside other public funding instruments, such as the EU Innovation Fund. Important Projects of Common Interest (IPCEI) are granted a waiver of State Aid restrictions with specific conditions.

[21] In all policy packages, RABM is used in midstream transmission, distribution, and storage to prevent natural monopolies from price gauging users, while providing revenue certainty with known decision rules to promote investment.

Figure 5

All policy packages address the barriers to low carbon and renewable hydrogen deployment, but they differ in priorities they meet



Enabling policies

The enabling policies are common component to all policy packages. These instruments have been identified as essential catalyzers to incentivize hydrogen deployment, support the hydrogen sector reach market maturity and enable the development of global, cross-border hydrogen markets. This section describes the enabling policies and how they constitute the foundation for the three policy packages considered in this study, providing specific examples.

1. Targets and carbon prices to drive climate market efficiency

Setting an overarching policy target for decarbonization to usher in transformational change. Overarching decarbonization targets facilitate a country's energy transition as they send a strong political signal and guide the short-term and long-term strategies of investors in energy and climate solutions.

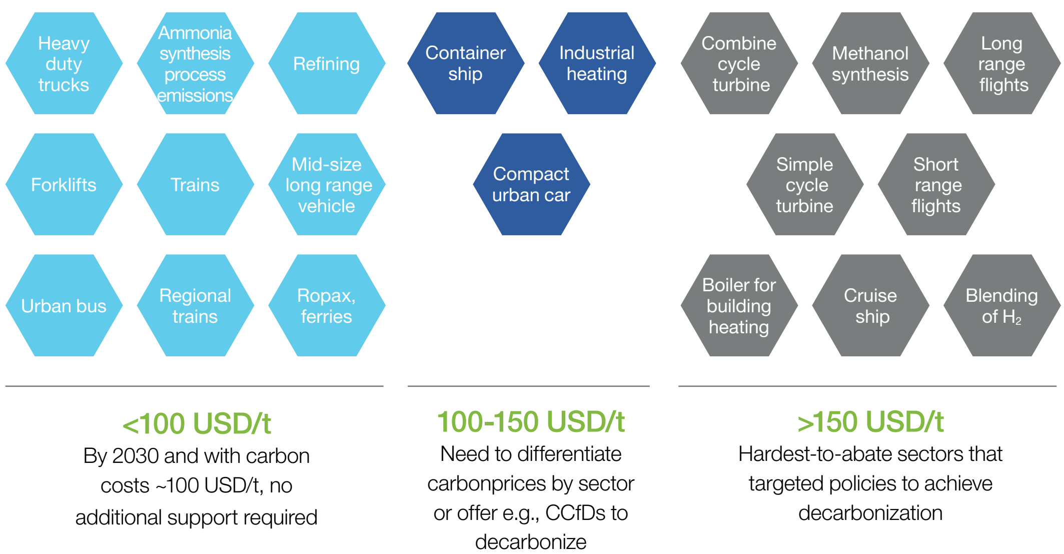
Adopting a carbon price early is the key to creating a market for low carbon technologies, therefore ensuring competitiveness in hydrogen applications, and bringing them "into the money" with conventional technologies. Cap-and-trade systems across regions have already demonstrated their effectiveness at incentivizing fuel switching from coal to natural gas. The earlier carbon pricing is introduced, the easier it will be to calibrate the system in a way that would allow it to deliver a robust carbon price. Carbon pricing can encourage switching in cost-competitive market segments, such as from grey to low carbon and renewable hydrogen in industrial application, especially if the cost of switching from grey hydrogen to renewable hydrogen becomes the key pricing parameter within the cost paradigms of cap-and-trade systems. In established markets, reinforcing and expanding cap-and-trade systems to cover all end-use sectors can drive cost competitiveness across a wide range of applications. In some geographies and sectors, such as heavy-duty trucks, ammonia synthesis process emissions and urban buses this cost-competitiveness is within reach, being able to break-even with conventional technologies at carbon prices of <100 USD/t (Figure 6)[22]. However, some hard-to-abate sectors, such as cruise ships and methanol synthesis, may require special requirements.

[22] Appendix 2.4

Figure 6

Carbon prices required by sector for breakeven

Carbon prices required by sector for breakeven by 2030[1], USD/tCO_2



1. Assumption of average production cost for low carbon and renewable hydrogen of 1.9 USD/kg in 2030

Source: McKinsey & Company analysis

Resolving internal market distortions can help ensure the competitiveness of new technologies such as hydrogen. For example, the phasing out of fossil fuel subsidies for exploration in the upstream and price subsidies for customers downstream could overcome hydrogen's cost disadvantage.

Putting in place safeguards against carbon leakage and carbon displacement. Carbon cap-and-trade systems or carbon taxes can help generate demand for low carbon hydrogen and derived products. The right policy measures, such as introducing or strengthening carbon pricing, can propagate decarbonization policy elsewhere. However, for these benefits to be realized, policies need to be in place to ensure that carbon is not displaced or even increased, putting decarbonizing producers at a competitive disadvantage globally. The carbon border adjustment mechanism (CBAM), for instance, seeks to prevent carbon leakage by ensuring higher-cost decarbonized production can compete with lower-cost, carbon-intensive production from other jurisdictions. The prospect of a CBAMs is likely to incentivize more jurisdictions to adopt carbon regulation, which would help generate a price signal for the uptake of low carbon solutions, including hydrogen.[23]

2. Roadmaps to underpin national delivery

Adopting a national hydrogen strategy or a roadmap to provide direction and market foresight to the industry. Adopting a dedicated hydrogen strategy or a roadmap defines how a country will unlock the potential of a hydrogen economy to reach its overarching decarbonization targets. It provides a policy vector and increased visibility to the industry on future market conditions and projects that are likely to be favored. Importantly, national strategies and roadmaps allow countries to define the milestones for advancing hydrogen deployment, detailing how hydrogen can play a systemic role in an integrated energy ecosystem, by way of enabling coordinated planning and optimization of the energy system, across infrastructures and end use sectors.

Many countries around the world have already announced their national hydrogen strategies and roadmaps. From Japan and Australia to Chile and the EU, countries and regions around the world have been drawing up hydrogen strategies and roadmaps laying out ambitious plans for the development of their respective hydrogen economies. Japan has been a hydrogen front runner with its commitment to develop world's first 'hydrogen society' with the country's Hydrogen Strategy launched in 2017, followed by the Strategic Road Map for Hydrogen and Fuel Cells published two years later. Australia's National Hydrogen Strategy from November 2019 aims to position the country's hydrogen industry as a major player by 2030 and details national coordinated actions with the objective to build a hydrogen export industry valued in the billions.[24] In South America, Chile's Green Hydrogen Strategy from November 2020 sets the goals of producing the cheapest renewable hydrogen in the world by 2030 and becoming one of three largest hydrogen exporters by 2040.

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[23] BNP Paribas Asset Management, Deep Decarbonization, Green Hydrogen, Net Zero, and the Future of the EU-ETS, (October 2020), https://docfinder.bnpparibas-am.com/api/files/FB39FAB1-A279-41CC-9CDD-4D22827359B0

[24] Australia's National Hydrogen Strategy (2019), https://www.industry.gov.au/data-and-publications/australias-national-hydrogen-strategy

3. International standards and hydrogen certification

Harmonized international regulations, codes, performance, and safety standards create a common language for the industry across the entire value chain and facilitate commercialization of hydrogen technologies and hydrogen-based products. Creating harmonized consensus-based international standards also facilitates sharing of good practice amongst countries, which, in turn, enables cost optimization and ensures safety and quality performance for end-users.

2.1 Hydrogen sustainability characteristics, certification systems and definitions

International standards constitute a key prerequisite for the development of the hydrogen value chain and global hydrogen markets, as they create consumer trust and facilitate commercialization of hydrogen technologies and hydrogen-based products.

In particular, standard methodologies for life cycle analysis (LCA) assessment of GHG emissions associated with hydrogen production, alongside other sustainability attributes are crucial to inform

- Thresholds for qualifying hydrogen as low carbon (in tCO_2eq/tH_2 or gCO_2/MJ)
- Aligned taxonomies used for qualifying economic activities, including manufacture of hydrogen, as environmentally sustainable[25]
- Common standards to underpin international certification systems for hydrogen
- Harmonized international hydrogen definitions

Certification systems for hydrogen are key to facilitating the deployment of hydrogen at national level, stimulating demand, and enabling cross-border trade in hydrogen. The development of international rules and standards that would underpin country-level and regional certification systems is necessary to enable the use of and trade in certificates evidencing the renewable/ low carbon origin of hydrogen (based on its production pathway), its carbon footprint (based on the LCA assessment of GHG emissions footprint of the production pathway) and other sustainability attributes (including the use of water, land, and rare earth metals). Subject to country-specific policy and regulatory provisions, certificates evidencing the sustainability attributes of hydrogen could be used for compliance purposes to count hydrogen towards decarbonization targets and/ or targets for renewables production/ consumption in end use sectors.

Together with common standards for calculating the carbon footprint and other sustainability attributes of hydrogen, **certificate systems for hydrogen can enable transparency and consumer trust at international level**, as well as inform consumer choices thereby stimulating demand for renewable and low carbon hydrogen in end use sectors. **Ultimately, such certificate systems would foster the development of a competitive cross-border, global hydrogen commodity market.**

The economic savings that can be realized through implementing these systems and establishing regulatory coherency are significant for countries that will be reliant on imports. For example, in Japan in 2030, assuming <70% of hydrogen is imported from Australia, savings of USD 2 bn can be realized through the minimization of import costs that would be enabled through agreed standards and certification removing regulatory 'red tape'. (Figure 7)[26]

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[25] The EU Taxonomy Regulation and the Taxonomy Climate Delegated Act (DA) provide a classification system for environmentally sustainable economic activities. The provisions under the DA regarding manufacture of hydrogen allow for low carbon hydrogen manufacture to qualify as an economic activity with substantial contribution to climate change mitigation as long the activity complies with the life cycle GHG emissions savings requirement of 73.4% for hydrogen resulting in $3tCO_2eq/tH_2$ and 70% for hydrogen-based synthetic fuels

[26] Appendix 2.6

Figure 7

Domestic production costs in Japan and the price from importing renewable hydrogen from Australia including the additional costs that could be absorbed in a 'worst case' distribution price scenario

Australia to Japan imports

Domestic production costs in Japan[1] and price of importing hydrogen from Australia[2,3] as well as the additional costs that could be absorbed

USD bn cost of production and imports [4]

Japan domestic renewable hydrogen production is unable to meet 2030 demand, with >70% anticipated to be met through imports.

In a 'worst case' price scenario where international standards are not deployed to realize the lowest technological costs and remove legislative 'red tape', an additional 2 bn USD may be absorbed.

1. High uncertainty in cost of dehydrogenation («cracking»)
2. Currently at pilot scale and requires infrastructure investments, uncertain cost and scale of LH2 shipping
3. Assumes large-scale infrastructure and ships for all carriers
4. Assuming 3 MT Japanese demand in 2030 with ~70% imported from Australia
5. Assuming a ‹worst case› price scenario for imports

Source: Hydrogen for Net Zero & Hydrogen Council, Cost Roadmap Report

Relevant intergovernmental and private sector-led initiatives are well underway – those will play an important role in informing the development of dedicated ISO standards for hydrogen. The intergovernmental initiatives, in particular, those led by the International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE) on methodologies for calculating GHG content of hydrogen production pathways as well as on certification play an important role in building international consensus on these matters. Looking at the existing industry-led projects, the CertifHy project in Europe constitutes an emerging good practice in creating a comprehensive certification system for hydrogen covering both guarantees of origin and supply certificates.

Going forward, it will be crucial to ensure that the relevant findings of these initiatives feed into the development of dedicated international standards for measuring and certifying the sustainability attributes of hydrogen (building on the existing ISO 14060 family of standards and ISO 14040). These standards could in turn be used as a reference point in the emerging legislative framework for hydrogen across jurisdictions globally.

3.2 Performance and safety standards: the role of ISO and IEC

Based on national stakeholder input, the International Organization for Standardization (ISO), the International Electrotechnical Commission (IEC) and such regulatory bodies as the United Nations Global Technical Regulations (UN GTR) and the International Organization of Legal metrology (OIML) develop international consensus-based standards and regulations respectively. These global SDOs play a key role in developing international standards and guidelines for hydrogen technologies (ISO/TC 197) and fuel cell technologies (IEC/TC 105).

As discussed above, International (ISO and IEC) component standards are necessary to eliminate global barriers to trade and international projects, paving the way for the emergence of a competitive hydrogen industry and well-functioning cross-border hydrogen markets.

In practice, this requires making sure that a hydrogen component (such as a hose or breakaway device) or an assembly (such as electrolyzer or reformer or dispenser) meets the commonly accepted design and testing criteria and thus can be deployed across the globe without additional bureaucratic burden, which would otherwise lead to increased costs. Installation requirements of those components or assemblies (such as, for example, separation distances) can differ across jurisdictions, but their design and testing requirements should not.

Since ISO and IEC standards are developed by the broadest spectrum of international stakeholders, they become "super" standards and constitute a reference point for the component standards and other relevant legislative initiatives introduced at national level. This consideration leads to at least three following implications:

- National component standards including those that served as seed documents for the development of international standards should be prepared with a view to having their respective design and testing requirements harmonized with the international standards. Essentially, national standards should constitute harmonized adopted international standards, where the only deviations are references to specific relevant national standards and regulations and climatic conditions, where justified.
- National legislation and installation codes should recognize international standards or their national harmonized adoptions as the only / preferred listing or certification components standards
- National installation codes should not contain any design or testing requirements related to components and assemblies and focus solely on the installation requirements. They should also explicitly reference available international component standards or their national harmonized adoptions for design and testing requirements.

It should be noted that there are numerous ISO and IEC Technical Committees besides ISO/TC 197 and IEC/TC 105 that are critically important for the broad market penetration and commercialization of hydrogen and fuel cell technologies. The work of the ISO/TC 207 Environmental Management should also be noted as it develops key foundational guidelines for measuring sustainability elements of hydrogen technologies.

4 Training and Education programs

4.1 Overcoming skills barriers

Training and educational programs on the value and safety of renewable and low carbon hydrogen can help overcome information and skills barriers. General education programs on hydrogen technologies can inform new generations about hydrogen and its role in a net zero economy and play an essential role in building up fundamental skills for hydrogen.

Training programs can upskill existing workforce with applied skills needed by the hydrogen sector as economies transition to net-zero and hydrogen and can play a key role in addressing just transition concerns. For example, the Green Jobs Act of 2007 in the United States provides grants to states to administer renewable energy and energy efficiency workforce development programs. In Australia, the Queensland Government has set up a renewable energy training facility to provide courses and apprenticeships.

4.2 Hydrogen safety training

Hydrogen safety education and training is essential for safe deployment, operation and maintenance of hydrogen and fuel cell equipment. Hydrogen safety training can be classified in two main categories: awareness training and professional training.

Awareness training is suitable for the broadest groups of stakeholders starting from interested public like first adopters of HFC technologies to all types of professionals involved in all different aspects of hydrogen technologies.

Awareness training normally covers general/ basic aspects hydrogen properties and emergency response.

Specialized targeted professional training can be differentiated for the following categories of professionals:

- Hydrogen technicians and gas / pipe fitters, including lab use
- Design engineers
- Installers
- Operators of hydrogen production and utilization equipment
- AHJs and engineering personnel interacting with AHJs to obtain approvals
- First responders


PORTUGAL
SPAIN
MOROCCO
ALGERIA
SPANISH SAHARA
MAURITANIA
Canaries Current
West Wind Drift
Bay of Biscay
Tenerife I.
Gr. Canaria I.
Islas Canarias
Lisboa
Casablanca
Rabat
Str. of Gibraltar
Islas Baleares
Erg Iguidi
Ouarane (Desert)

Country archetypes

Countries will participate differently in the hydrogen economy and start with different natural resource endowments (e.g., availability of renewables and natural gas resources) and infrastructure endowments (e.g., availability of well-developed gas infrastructure networks that can be repurposed/ retrofitted and salt caverns). This study sets out an archetype-based approach to illustrate how countries with certain characteristics can successfully deploy hydrogen policy.

There are three main archetypes:

1. Self-sufficient hydrogen producers: a country with either sufficient endowment of renewable sources for energy generation, including the physical space required, has potential to serve its own renewable hydrogen demand, and/or natural gas combined with CCUS to produce low carbon hydrogen

2. Hydrogen exporters: a country with sufficiently high endowment of renewable sources and/or of natural gas combined with CCUS, can produce low carbon or renewable hydrogen, and export it to serve international demand.

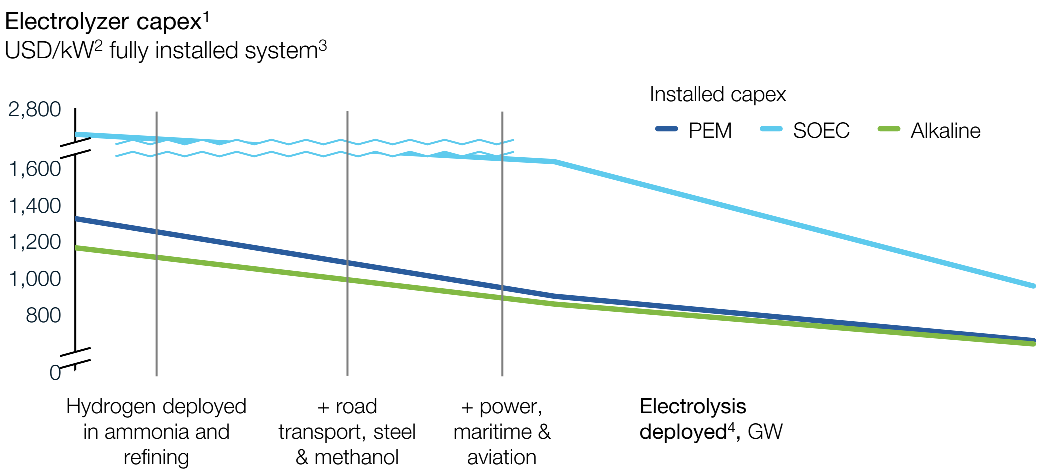
3. Hydrogen importers: a country with limited renewable and low carbon technological endowments or natural gas resources may find it more cost effective to import renewable and/or low carbon hydrogen from third countries. A country that currently imports natural gas has a natural gas infrastructure in place that can be repurposed to import, transport, and store hydrogen, lowering the cost of switching to hydrogen.

As described in the earlier chapter, there is a broad range of other factors that influence policy preferences. For example, the institutional context can impact the policy preferences of policymakers, for example whether there is a preference for market driven solutions (to achieve more efficient outcomes) or a preference for more control and direction (to achieve more directed outcomes). The descriptions of how the policies are implemented draw out the implications of different policy preferences.

The recommended policies have similar objectives across the different phases of market maturity:

- Market creation: Recommended policies provide financing to help with high upfront capital costs (such as grants, loans, and equity) and/or guarantee a revenue premium (such as CfDs, FiTs, FiPs and CCfDs). Complemented with balance sheet support tools (such as debt guarantees and equity), these policies make early investments bankable and support the development of a project pipeline, bringing down costs as a result.
- Market growth: The policies providing support with upfront capital cost and revenue premium evolve, increasing exposure to market signals by reducing optimizing the level of subsidization through auctions. Countries may choose to hold distinct auctions for low carbon and renewable hydrogen projects based on their policy choices. OPEX support may remain necessary in this phase (e.g., exemptions from taxes and levies to decrease the cost of electricity used for renewable hydrogen production). Policies need to expand across multiple sectors to generate the demand necessary for cost reductions to be realized. As can be seen through reductions in electrolyzer capex, these cost reductions are only achieved through the deployment of renewable hydrogen in multiple sectors, acting to unlock more demand (Figure 8). Further to this, appropriate market design plays a key role in ensuring the value of flexibility to the energy system provided by low carbon and renewable hydrogen is signaled correctly. Encouraging the carbon price signal to become more robust and cover more sectors helps to complete the pricing framework.
- Mature market objectives: All policies providing investment and revenue support are phased out. Carbon prices are robust enough to level the playing field for hydrogen and let it compete with fossil fuels, as well as with other decarbonization solutions, ensuring efficient allocation of resources and minimizing societal cost.

Figure 8
Electrolyzer capex and demand by sector, USD/kW[27]



1. 2020-2030 modelled
2. USD/kw of hydrogen produced
3. Medium electrolysers (4000 Nm3/h). Electrolyser capex defined as sum of; indirect costs, building capex, transportation to site, installation and assembly capex, system capex
4. Equivalent global demand

Source: Hydrogen Insights Project and Investment tracker

[27] Appendix 2.3

Archetype 1:
Self-sufficient hydrogen producers

Self-sufficient hydrogen producers need to enable the entire value chain: upstream supply, midstream transmission and distribution and downstream demand (Figure 9).

Figure 9
Self-sufficient hydrogen producer archetype

Policy objective	Policy roadmap for low carbon and renewable hydrogen		
Certainty	Emissions targets and hydrogen strategies		
Consumer trust	Develop harmonized standards and certification schemes		
H_2 investment	Market cretation	Market growth	Market maturity
Upstream	**CAPEX & OPEX support** (e.g., CfDs, tax credits), **Financial de-risking** (e.g., grants, loans, and guarantees)	**Evolve to increase competition** (e.g., auctions - potentially separate for low carbon and renewable hydrogen - with a large pipeline of bidders)	**Shift incentives to carbon prices and markets to deliver investment**
Midstream	**CAPEX & OPEX support, financial de-risking** (e.g., regulated returns, price ceilings and floors for transmission and distribution networks, subsidies for storage infrastructure and refueling stations)		
	Blending standards and quotas		
Downstream	**CAPEX & OPEX support, financial de-risking** (e.g., price premiums, CCfDs, free allocation), **Public procurement, targets/quotas**	**Evolve to increase competition** (e.g., auctions - potentially separate for low carbon and renewable hydrogen - with a large pipeline of bidders)	**Shift incentives to carbon prices and markets to deliver investment**
	Product labelling		
Economy-wide uptake	Build robust regional carbon prices		

Upstream: For upstream hydrogen deployment, the key challenge is to unlock investment in renewable and/or low carbon hydrogen production. The key elements of the policy package are:

- Incentivizing hydrogen supply can be achieved by way of deploying **financial support instruments such as grants, loans, and guarantees** to help de-risk investment, supporting first movers. These instruments also play a critical role in the development of integrated hydrogen projects (hydrogen valleys) and hydrogen projects of strategic importance necessary to pave the way for market take off.
- In addition, a suite of policy measures can be used to provide **OPEX support** for projects in the market creation and market growth stages. Introducing **exemptions from electricity taxes and levies** would help substantially decrease the cost of electricity used for **renewable hydrogen production** as long as market distortion is avoided.
- OPEX and CAPEX support for **low carbon hydrogen** could be introduced in the form of **tax credits for emissions captured** using CCS - 45Q in the US constitutes a good example of such a system of carbon tax credits. In the EU, a scheme for carbon removal certificates that could be tradeable could be adopted in 2023.
- Revenue stabilization mechanisms such as CfDs and FiTs upstream could be used to incentivize both renewable and low carbon hydrogen – subject to policy choices – and can evolve to feature competitive bidding processes.
- In addition to direct support measures, carbon pricing can play a key role. As the market develops and reaches maturity, **robust carbon prices** can play a key role in driving private investment across the economy making hydrogen fully competitive with other energy sources. Appropriate market design will also be key to ensure the value of flexibility to the energy system provided by low carbon and renewable hydrogen is signaled correctly.

Midstream: The key challenge is to secure investment in retrofitting and repurposing of the existing natural gas infrastructure and in new dedicated hydrogen infrastructure. The key elements of the policy package are:

- In the market creation phase and market growth phase, blending can allow avoiding stranded assets and high capital costs. For example, the proposed revision of the TEN-E Regulation in Europe would allow that repurposed networks can be used to transport or store a pre-defined blend of hydrogen with natural gas or biomethane during a transitional period (until 31st December 2029) during market creation and growth. However, blending will be limited to a certain percentage. Retrofitting of existing natural gas assets or even new pipelines will be necessary. Selected projects will have to demonstrate how, by the end of this transitional period, these assets will cease to be natural gas assets and become dedicated hydrogen assets. The assessment of candidate projects will also ensure that the assets are designed in view of creating dedicated hydrogen assets by the end of the transitional period. The purpose is to gradually decarbonize this sector and by increasing the share of renewable gases in the pipelines and/or building dedicated H_2 assets (transmission, storage, distribution).

- At the same time, building new dedicated infrastructure will also be key to connect the clusters of demand with supply and help hydrogen play its role in enabling energy system integration. Guaranteeing returns through a regulated asset base model can, for instance, spur private sector investment into large infrastructure projects.
- When the market reaches maturity, the regulated returns model would remain in place to ensure infrastructure providers are operating competitively and efficiently. Also, at this stage, ancillary services such as a buffering and storage can enable hydrogen as a flexible energy vector and provide alternative sources of revenue that replace financial support policies.

Downstream: They key challenge is to provide funding and allocate it efficiently between off-takers while making hydrogen-based products competitive in the market. Key elements of the policy package are:

- In the market creation phase, direct support can encourage early hydrogen market adopters. For example, offering a price premium to steelmakers that are starting to use hydrogen as an input would compensate for higher operational costs. Financial support can help reduce financial risks of large upfront capital investments required for hydrogen use projects.
- Public procurement, targets, standards, and quotas policies, including incentives, can kick-start markets strategically and provide visibility to downstream users on the direction of low carbon technologies. Canada's Clean Fuel Standard and the California Low Carbon Fuel Standard are examples of supply-side mechanisms.
- As the market enters the growth phase, the importance of carbon pricing grows, and direct support mechanisms may evolve to expose hydrogen users further to market signals. For example, early incentives can be replaced by CCfDs and be awarded through an auction system. In the mature market phase, policymakers can fully withdraw support and a carbon price should remain in place to continue to foster innovation and investment in low carbon technologies.

Archetype 2:
Hydrogen exporters

Exporters have to focus on developing export infrastructure and unlocking efficient production projects that can complete on the international market, as well as striking agreements with offtakers (Figure 10).

Figure 10
Hydrogen exporter archetype

Policy objective	Policy roadmap for low carbon and renewable hydrogen		
Certainty	Emissions targets and hydrogen strategies		
Consumer trust	Develop harmonized standards and certification schemes		
H_2 investment	Market cretation	Market growth	Market maturity
Upstream	**CAPEX & OPEX support** (e.g., CfDs, tax credits), **Financial de-risking** (e.g., grants, loans, and guarantees)	**Evolve to increase competition** (e.g., auctions - potentially separate for low carbon and renewable hydrogen - with a large pipeline of bidders)	**Shift incentives to carbon prices and markets to deliver investment**
Midstream	**CAPEX & OPEX support, financial de-risking** (e.g., regulated returns, price ceilings and floors for transmission and distribution networks, subsidies for storage infrastructure and refueling stations)		
	Blending standards and quotas		
Downstream	**Financial support** (e.g., grants, loans and guarantees)		
	Offtake agreements with importing countries to lock in a long-term hydrogen supply		
Economy-wide uptake	Build robust regional carbon prices		

Upstream: Policymakers may want to coordinate project locations to ensure co-location with transportation hubs and infrastructure. Financial support under bespoke contracts gives governments control over size, timing, and location of investments. For upstream H_2 deployment, direct support on both CAPEX and OPEX (e.g., CFDs, tax credits, grants, ….) should be put in place.

Midstream: Policies are aligned with those recommended for a self-sufficient archetype, except that policies for an exporter country should allow policymakers to exert higher control over the coordination of midstream infrastructure projects. Financial support for new infrastructure and retrofitting and repurposing of the existing assets, as well as provisions for blending, where appropriate, give policymakers the flexibility to channel resources towards sections of the infrastructure network they consider strategic to transport hydrogen and access export markets.

Downstream: A hydrogen exporter will typically start serving domestic off-takers to develop its hydrogen production capabilities, and to achieve this objective, the State could implement legislative measures incentivizing local demand. However, to start engaging in export activities, offtake agreements should be in place with destination countries. These agreements guarantee suppliers a revenue stream and help make projects bankable by lowering borrowing costs.

Exporters may also benefit from CfD schemes introduced by importing countries (such as the CfD scheme for renewable hydrogen envisaged by the German government in the framework of the H2Global initiative).

Archetype 3: Importers

Importers have to focus on developing downstream markets for hydrogen and hydrogen-based products and securing hydrogen supply from overseas (see Figure 11).

Figure 11
Hydrogen importer archetype

Policy objective	Policy roadmap for low carbon and renewable hydrogen		
Certainty	Emissions targets and hydrogen strategies		
Consumer trust	Develop harmonized standards and certification schemes		
H_2 investment	Market cretation	Market growth	Market maturity
Upstream	Offtake agreements with exporting countries to lock-in a long-term hydrogen supply		
Midstream	**CAPEX & OPEX support, financial de-risking** (e.g., regulated returns, price ceilings and floors for transmission and distribution networks, subsidies for storage infrastructure and refueling stations)		
	Blending standards and quotas		
Downstream	**CAPEX & OPEX support, financial de-risking** (e.g., price premiums, CCfDs, free allocation), **Public procurement, targets/quotas**	**Evolve to increase competition** (e.g., auctions - potentially separate for low carbon and renewable hydrogen - with a large pipeline of bidders)	Shift incentives to carbon prices and markets to deliver investment
	Product labelling		
Economy-wide uptake	Build robust regional carbon prices		

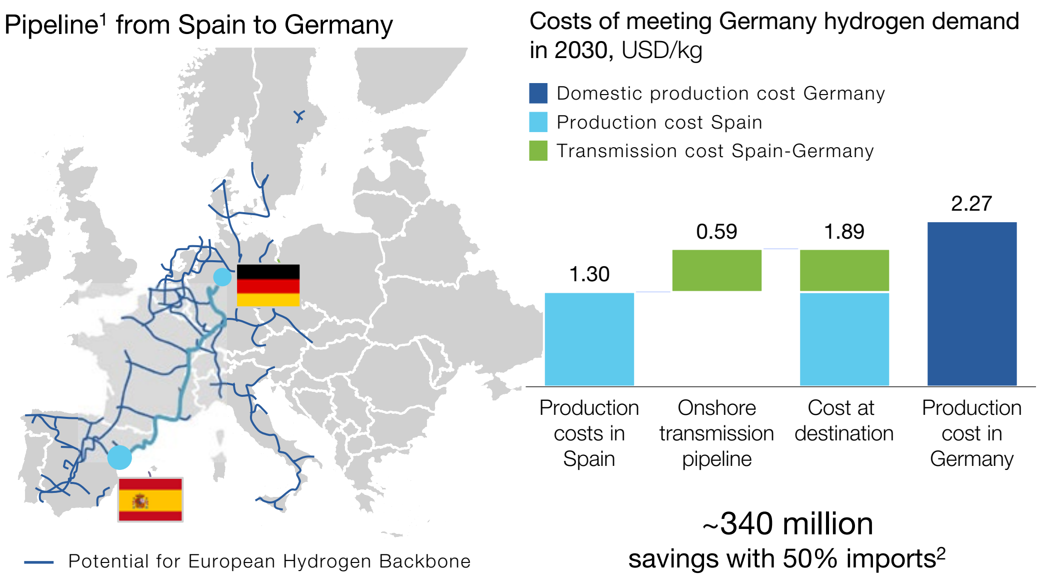
Upstream: the key challenge is to secure hydrogen supply from international markets. Offtake agreements with exporting countries can lock-in a long-term hydrogen supply to reduce supply risks and costs. Bilateral agreements and CfD schemes can help securing hydrogen imports at a competitive price.

Midstream: Hydrogen importers will require financial support from policymakers to coordinate investments and rapidly develop storage and transportation infrastructure that enables hydrogen to reach domestic markets. If countries already import natural gas from abroad, allocating funding for retrofitting and repurposing of the existing infrastructure is essential. In the case of low carbon hydrogen, introducing blending standards and quotas can be applied to repurpose existing infrastructure. Building out this infrastructure, such as pipelines, has the potential to realize savings for importing countries. For example, in Germany, if 50% of forecasted 2030 demand for low carbon and renewable hydrogen is met through pipeline imports through a new, or ideally a retrofitted, pipeline from Spain, annual hydrogen cost savings of ~USD 340 mn can be realized[28]. (Figure 12)

Downstream: Policymakers can follow the proposed policy pathway for self-sufficient archetype countries to foster the use of hydrogen and hydrogen-based products across the economy. In addition, importing countries with a more dispersed demand will require larger financial support as smaller end users have limited financial resource to cover large upfront investment costs when switching to hydrogen. In these instances, policymakers might choose to supplement financial support with public procurement, standards, and quotas to direct specific sectors where its more cost effective to switch to hydrogen and demonstrate early feasibility. As the market growth phase is entered, these policies can cover a wider range of sectors.

[28] Appendix 2.5

Figure 12
Cost of meeting Germany's 2030 hydrogen demand



1. Pipeline 70 bar, 50% utilization, 80cm diameter
2. Assuming 2030 demand of 1.8MT with 50% domestic production and 50% met through pipeline imports from lowest cost renewable production site in Spain

Source: Hydrogen for Net Zero, Hydrogen Council, European Hydrogen Backbone July 2020

Societal value and values

Societal value and values should be factored into policy decisions. Alongside the transition towards carbon neutrality, countries would benefit from considering the full range of societal impacts and the benefits that can be unlocked through the development of the hydrogen economy. Well-designed hydrogen policies could have a positive contribution to several UN Sustainability Development Goals, including:

- Good health and well-being: Eliminating the burning of fossil fuels for transport, coal-plants, and household uses lowers air pollution, which has been linked with improved health outcomes, especially in children, the elderly and those living in poorer and more vulnerable communities.[29] If targets for low carbon and renewable hydrogen deployment are achieved, displacement of fossil fuels by hydrogen is forecasted to realize an annual CO_2 abatement of 0.7 GT CO_2e in 2030, equivalent to USD 23 bn in an annual healthcare savings.[30]
- Green growth and sustainable jobs: The development of the hydrogen economy can provide critical jobs for workers associated with industries that are most likely to be impacted by the energy transition (e.g., fossil fuel extraction). Industry estimates that the US could build 700,000 jobs in the hydrogen sector just by 2030[31]. This can also benefit regional communities, including protecting the rights of indigenous and offering them new opportunities through employment and new business creation.
- Diversity, equity, and inclusion: Public private dialogue on the diversity, equity, and inclusion (DEI) dimension of hydrogen economy development is emerging.[32] Both governments and industry have the opportunity to use the learnings from the development of the established industries to ensure that DEI constitute integral elements of hydrogen economy development from the outset. Continued public-private cooperation on this matter and further research in this area remain essential.
- Opportunities for indigenous communities: Canada's national hydrogen strategy constitutes a best practice example of a hydrogen strategy that recognizes and actively seeks to unlock the opportunities that the development of the hydrogen economy can bring to indigenous communities, offered through employment and new business creation. It also recognizes the need for the local hydrogen economy to grow hand in hand with industry's strategic partnerships that emphasize environmental protection, cultural recognition, community energy planning aligned with traditional values, economic development, and project participation.
- Sustainable cities and communities: Hydrogen infrastructure can not only provide cities with access to renewable transport and heating, it also provides resiliency in cases where renewable electricity production is insufficient due to poor conditions or natural disasters.

[29] World Health Organization. "Health consequences of air pollution on populations" 2019. https://www.who.int/news/item/15-11-2019-what-are-health-consequences-of-air-pollution-on-populations
[30] Appendix 2.9
[31] Hydrogen and Fuel Cell Technologies Office, Hydrogen Shot, https://www.energy.gov/eere/fuelcells/hydrogen-shot
[32] At the time of writing of the present report, this topic has been addressed in the framework of the Hydrogen Shot Summit

Appendix

Defining low carbon and renewable hydrogen

There are currently no common standards for defining renewable and low carbon hydrogen. This is a consequence of the lack of international standard methodology for calculating the carbon footprint of hydrogen production pathways and thresholds for qualifying hydrogen as low carbon that would be applied, for example, across taxonomies for sustainable finance and hydrogen certification systems. This issue is explored further in section D on enabling policies in the report.

In the present study we use the terms renewable, low carbon and grey hydrogen, whereby

- **'Renewable hydrogen' refers to hydrogen produced from energy sources of renewable origin.** For example, i) hydrogen produced through water electrolysis with electricity of renewable origin used as feedstock; and/ or ii) hydrogen produced through the gasification of sustainable biomass which is then reformed or pyrolyzed (if the CO_2 is sequestrated the hydrogen produced can be qualified as carbon-negative). Defined thresholds for qualifying hydrogen as renewable (in tCO_2eq/tH_2 or gCO_2/MJ) need to be put in place.
- **'Low carbon hydrogen' refers to hydrogen produced from energy sources of non-renewable origin with a carbon footprint below a defined threshold.** For example, i) hydrogen produced using natural gas as a feedstock with SMR or ATR coupled with CCS; ii) hydrogen produced through pyrolysis of natural gas into hydrogen and solid carbon; iii) hydrogen produced through gasification of coal with CCS; iv) hydrogen produced through electrolysis using electricity of non-renewable origin as feedstock. Defined thresholds for qualifying hydrogen as low carbon (in tCO_2eq/tH_2 or gCO_2/MJ) need to be put in place.
- 'Grey hydrogen' refers to hydrogen produced using fossil fuels as feedstock, mainly through reforming of natural gas or the gasification of coal.

Detailed policy assessment results

Two dimensions define the low carbon and renewable hydrogen market within the policy framework: the value chain and the stage of market maturity. Figure 13 details the description and desired outcome of each step of the value chain and market.

Figure 13
Barriers to hydrogen market outcomes are assessed along two dimensions

Dimension	Step in value chain/ Stage	Description of each step in value chain/ Desired outcome of each stage
H_2 value chain	A. Core enablers across the value chain	Overall enablers for an H_2 value chain from production through to usage
	B. Upstream supply	Produce H_2 from natural gas reformation or carbon-free electricity electrolysis
	C. Midstream distribution	Compress, store, liquify H_2 and transport via trucking, shipping, or gas/H_2 network to end users
	D. Downstream demand	Use H_2 as an energy source, key sectors include transportation, industry feedstock, industry energy, power generation, and building heating and power
Time/ Maturity	1. Early market building technology readiness	H_2 energy is at TRL[1] 9, and there is a steady stream of full scale projects to prove viability and deliverability with government or private funding and support
	2. Market take-off and increasing penetration	Globally and across key sectors, there is a steady pipeline of at-scale projects by mature developers that are funded and progressing to FEED or beyond
	3. Mature market with diversified growth	H_2 energy is at CRI[2] 5 and is 2-5% of global energy use, projects reaching completion with minimal government intervention and compete for capital as established investments

[1] Technology Readiness Level, ARENA, 2014 and Straub, 2015; [2] Commercial Readiness Index, ARENA, 2014 and Straub, 2015
Source: Vivid Economics

The questions are answered based on real examples of policy implementation, economic theory, and expert insights. Answers dictate the RAG (Red, Amber, Green) color rating assigned to a key policy. Figure 14 presents the color ratings assigned to the key policies for six performance criteria. The assigned color ratings are as below:

- Red: "No" as a response to all questions listed under the criterion. The policy is rated as **Weak**.
- Amber: "No" as a response to at least one of the questions listed under the criterion, and the rest of the responses are "Yes". The policy is rated as **Medium**.
- Green: "Yes" as a response to all questions listed under the criterion. The policy is rated as **Strong**.

Figure 14

The 12 key policies are assessed against six performance criteria and assigned an RAG rating

Policies	Performance criteria: Delivers FOAK projects	Minimizes societal costs	Spans value chain	Flexibility of ambition	Ease of imple-mentation	Ease of bankability
1. Alternative revenue streams, e.g., grid firming services	Weak	Weak	Weak	Weak	Strong	Weak
2. Carbon tax	Medium	Strong	Strong	Strong	Medium	Weak
3. Direct support mechanisms, such as CfD, CCfD, FiTs, and tax incentives	Strong	Strong	Medium	Strong	Strong	Strong
4. ETS	Medium	Strong	Strong	Medium	Medium	Weak
5. Financial support mechanisms, such as loans and grants	Strong	Medium	Medium	Strong	Strong	Strong
6. Guaranteed offtake	Strong	Medium	Medium	Strong	Strong	Strong
7. Investment de-risk, e.g., balance sheet support - debt guarantees, equity	Weak	Weak	Medium	Strong	Medium	Strong
8. Phasing out fossil fuel subsidies	Weak	Weak	Strong	Strong	Strong	Weak
9. Public procurement to kickstart markets	Medium	Strong	Medium	Strong	Medium	Weak
10. Return on investment de-risk, e.g., RABM, availability payments, minimum revenue guarantee, future purchase commitment	Strong	Strong	Medium	Strong	Medium	Strong
11. Quotas & targets	Medium	Medium	Medium	Strong	Medium	Medium
12. Standards	Weak	Medium	Medium	Strong	Medium	Medium

Policy assessment responses: Strong Medium Weak

1.1.1 Alternative revenue streams

Criteria	Alternative revenue streams, e.g., grid firming services
Delivery of FOAK projects	Red – Does not address financial barriers; revenues are not enough to achieve economic viability.
Minimizes costs	Red – Does not provide any incentives for competition and innovation.
Spans value chain	Red – Limited to upstream supply
Flexibility of ambition	Red – No flexibility as the market decides demand for and price of the service.
Ease of implementation	Green – Does not need close monitoring. It decreases the total cost of operating a grid system, benefiting all market participants.
Ease of bankability	Red – Does not address financial barriers faced by the private sector

1.1.2 Carbon tax

Criteria	Carbon tax
Delivery of FOAK projects	Amber – Levels the playing field for low carbon and renewable hydrogen. Similar policies exist, but they have not performed well due to low carbon prices and lack of hydrogen-specific instrument, as ETS is applicable to a range of technologies.
Minimizes costs	Green – Promotes competition and innovation. The market finds the most efficient solution that minimizes the societal cost (assuming all market failures are addressed).
Spans value chain	Green – Creates incentives upstream, midstream, and downstream, so the government does not need to put in extra efforts to apply the policy at all stages of the value chain.
Flexibility of ambition	Green – Can be easily modified as the market matures, and conditions change.
Ease of implementation	Amber – The cost of the policy can be redistributed across market participants. It is easy to implement and monitor like other taxes. However, public acceptance of environmental taxes could become an implementation barrier
Ease of bankability	Red – Levels the playing field for low carbon and renewable hydrogen but does not provide any hydrogen-specific benefits to the private sector. Other policies needed to make projects bankable.

1.1.3 Direct support mechanisms (involving competitive auctions)

Criteria	Direct support mechanisms (involving competitive auctions)
Delivery of FOAK projects	Green – Offers revenue certainty and subsidies, increasing projects' economic viability. Similar policies have been applied in Germany and the UK among many others.
Minimizes societal costs	Green – Promotes competition and innovation and finds the lowest cost through auctions.
Spans value chain	Amber – Needs to be applied at all stages of the value chain to be effective across the value chain.
Flexibility of ambition	Green – Easy to exit, and new contracts can be issued whenever there is a new auction round.
Ease of implement-ation	Green – The cost of the policy can be redistributed across market participants through levies. It does not require a complex system to be in place and does not distort the market in terms of competitiveness.
Ease of bankability	Green – Makes projects bankable creating a consistent revenue stream and providing subsidies to the private sector which encourages the private sector to invest.

1.1.4 Emission Trading Schemes

Criteria	Emission Trading Schemes
Delivery of FOAK projects	Amber – Levels the playing field for low carbon and renewable hydrogen. Similar policies exist, but they have not performed well due to low carbon prices and lack of hydrogen-specific instrument, as ETS is applicable to a range of technologies.
Minimizes societal costs	Green – Promotes competition and innovation. The market finds the most efficient solution that minimizes the societal cost (assuming all other market failures are addressed).
Spans value chain	Green – Creates incentives upstream, midstream, and downstream, so the government does not need to put in extra efforts to apply the policy at all stages of the value chain.
Flexibility of ambition	Amber – Although the requirements for ETS can become stricter over time, adjusting the cap is overall a lengthy process, which can take more than five years.
Ease of implement-ation	Amber – The cost of the policy can be redistributed across market participants, but the system is tedious to install, watch and maintain.
Ease of bankability	Red – Levels the playing field for low carbon and renewable hydrogen but does not provide any hydrogen-specific benefits to the private sector. Other policies needed to make projects bankable.

1.1.5 Financial support mechanisms

Criteria	Financial support mechanisms, such as grants and loans
Delivery of FOAK projects	Green – Lowers the upfront capital investment and borrowing cost. Similar policies are already successfully implemented around the world, also for hydrogen deployment.
Minimizes costs	Amber – Information asymmetries and technology uncertainties may prevent policy makers from achieving most efficient outcome. Interventions may distort competition and stall competition, creating opportunities for rent creation. Well-designed auctions may address some of these concerns.
Spans value chain	Amber – Its impact is limited to the value chain component it is applied to, but they can be applied at all stages.
Flexibility of ambition	Green – Can be adjusted in every financing round. It also is easy to phase out without adverse effects on the market.
Ease of implementation	Green – Can be financed through taxes and levies, while the burden can be redistributed across market participants. It is easy to set up and can be effective without closely monitoring.
Ease of bankability	Green – Lowering upfront capital costs, it reduces risks and encourages the private sector to finance deployment

1.1.6 Guaranteed offtake

Criteria	Guaranteed
Delivery of FOAK projects	Green – Provides revenue guarantee. Analogous policies have been successful in for increasing renewables update in China, and similar policies are under way for hydrogen in the US and India.
Minimizes costs	Amber – Information asymmetries and technology uncertainties may prevent policy makers from achieving most efficient outcome. Interventions may distort competition and stall competition, creating opportunities for rent creation. Well-designed auctions may address some of these concerns.
Spans value chain	Amber – Particularly appropriate for upstream supply and downstream demand.
Flexibility of ambition	Green – Can be adjusted in every financing round.
Ease of implementation	Green – Can be financed through taxes and levies, while the burden can be redistributed across market participants. It is easy to set up and can be effective without closely monitoring
Ease of bankability	Green – Providing revenue guarantee, it reduces risks and encourages the private sector to finance deployment

1.1.7 Investment de-risk mechanisms

Criteria	Investment de-risk mechanisms, e.g., balance sheet support, debt guarantees, equity
Delivery of FOAK projects	Red – Address technology and construction risk but does not lower initial capital investment or provide revenue guarantee.
Minimizes costs	Red – May not incentivize the most efficient technology due to information asymmetries and uncertainties around technology
Spans value chain	Amber – Needs to be applied at every stage of the value chain to be successful.
Flexibility of ambition	Green – Can be adjusted in every financing round.
Ease of implementation	Amber – No need for close monitoring. It may create adverse competitiveness effects as policymakers may fail to endorse right technology and project.
Ease of bankability	Green – Eliminates construction and technology risk for the private sector.

1.1.8 Phasing out of fossil fuel subsidies

Criteria	Phasing out fossil fuel subsidies
Delivery of FOAK projects	Red – Does not provide sufficient revenue and revenue certainty and does not lower upfront capital cost.
Minimizes costs	Red – As a fossil fuel specific policy, it does not provide direct incentives to investors in hydrogen deployment.
Spans value chain	Green – The policy does automatically apply to all stages of the value chain.
Flexibility of ambition	Green – Policymakers can make changes easily to reflect changing market conditions.
Ease of implementation	Green – Solves a market distortion and thereby increase the total surplus. It does not need close monitoring.
Ease of bankability	Red – Risks to the private sector in financing new hydrogen projects remain largely unchanged.

1.1.9 Public procurement

Criteria	Public procurement to kickstart markets
Delivery of FOAK projects	Amber – Provides revenue guarantee to all hydrogen producers but not to specific projects. Analogous policies have been adopted in France, Australia, and Norway.
Minimizes costs	Green – Incentivizes competition and innovation to lower costs, as producers will still compete to offer the lowest price to win a procurement round.
Spans value chain	Amber – The policy is particularly appropriate for downstream demand, but it can apply across the value chain.
Flexibility of ambition	Green – Can be adjusted and exited easily to reflect changes in the market.
Ease of implementation	Amber – Higher costs are likely to be passed through to end users, decreasing households purchasing power. It can be effective without close monitoring.
Ease of bankability	Red – Does not cover risks to the private sector looking to invest in a project.

1.1.10 Return on investment de-risk

Criteria	Return on investment de-risk, such as e.g., RABM
Delivery of FOAK projects	Green – Provides revenue certainty and enough return to cover investment and operation costs. Similar policies have been successful to incentivize investment in midstream projects.
Minimizes costs	Green – Because the return is fixed, firms innovate and increase efficiency to lower their costs and increase their profits, but these policies can distort the market and increases the societal costs if policy makers set revenue levels too high (creates a rent for owners of the midstream infrastructure) or too low (stalls investment).
Spans value chain	Amber – Particularly appropriate for midstream distribution. They do not automatically apply to all the stages of the value chain and
Flexibility of ambition	Green – Policymakers can adjust returns over time.
Ease of implementation	Amber – Easy to implement without close monitoring, but the policies can distort the market and increases the societal costs if policy makers set revenue levels too high (creates a rent for owners of the midstream infrastructure) or too low (stalls investment).
Ease of bankability	Green – Risks around returns are reduced to the point that the private sector is encouraged to finance new projects.

1.1.11 Quotas & targets

Criteria	Quotas & targets
Delivery of FOAK projects	Amber – Analogous policies have been successful in providing additional certainty to private investors, but these do not address financial risks associated with a project.
Minimizes costs	Amber – Creates incentives to innovate, but command-and-control policies may fail to reach the most efficient outcome as the tech and timing endorsed by these may not be the most efficient ones.
Spans value chain	Amber – Policies do not automatically apply to all the value chain stages, but they can extend to all value chain components.
Flexibility of ambition	Green – Over time, policymakers can adjust policies easily to reflect the changes in the market's circumstances, for example by introducing stricter targets.
Ease of implementation	Amber – It is easy to implement and needs no close monitoring. However, command-and-control policies may distort the market, resulting in higher societal costs that are likely to be passed through to consumers.
Ease of bankability	Amber – quotas provide certainty to the private sector which might encourage them to finance projects, but financial risks remain high due to the potential lack of revenue, return guarantees, etc.

1.1.12 Standards

Criteria	Standards
Delivery of FOAK projects	Red – Standards have been successful at incentivizing deployment, but they do not provide revenue and revenue certainty and do not lower upfront capital cost
Minimizes costs	Amber – Create incentives to innovate, but command-and-control policies may fail to reach the most efficient outcome as the technology and timing endorsed by these may not be the most efficient ones.
Spans value chain	Amber – Policies do not automatically apply to all the value chain stages, but they can extend to all value chain components.
Flexibility of ambition	Green – Over time, policymakers can adjust policies easily to reflect the changes in the market's circumstances, for example by introducing stricter minimum standards
Ease of implementation	Amber – Command-and-control policies may distort the market, resulting in higher societal costs that are likely to be passed through to consumers. It is easy to implement and needs no close monitoring.
Ease of bankability	Amber – Standards provide certainty to the private sector which might encourage them to finance projects, but financial risks remain high due to the potential lack of revenue, return guarantees, etc.

We also performed the assessment on the policy packages for efficient delivery verses rapid deployment.

Efficiency

Criteria	Efficiency
Delivery of FOAK projects	Green – Direct support mechanisms and return on investment offer revenue certainty and subsidies., while the auction design can increase competition. Similar policies have been applied widely.
Minimizes costs	Green – Promotes competition and innovation. The market finds the most efficient solution that minimizes the societal cost (assuming all other market failures are addressed).
Spans value chain	Green – ETS spans the value chain, whereas direct support mechanisms can be used in upstream and downstream.
Flexibility of ambition	Amber – Direct support mechanisms can be amended in every financing round but adjusting an ETS the cap is overall a lengthy process, which can take more than five years.
Ease of implementation	Amber – ETS and return on investment de-risk might be harder to implement and maintain, whereas distributional impacts can be alleviated with policy design, such as allocating ETS revenues back to consumers through subsidies or decrease in other taxes.
Ease of bankability	Green – Direct support mechanisms and return on investment de-risk provide revenue certainty, lowering risks faced by the private sector.

Rapid deployment

Criteria	Rapid deployment
Delivery of FOAK projects	Green – Financial support mechanisms lower the upfront capital investment and borrowing cost. Similar policies are already successfully implemented around the world, also for hydrogen deployment.
Minimizes costs	Amber – Standards, quotas and targets and financial support mechanisms create incentives to innovate, but command-and-control policies may fail to reach the most efficient outcome as the tech and timing endorsed by these may not be the most efficient ones.
Spans value chain	Amber – Policies do not automatically apply to all the value chain stages, but they can extend to all value chain components.
Flexibility of ambition	Green – Over time, policymakers can adjust policies easily to reflect the changes in the market's circumstances, for example by adjusting the level of the financial support or introducing stricter targets.
Ease of implementation	Green – Command-and-control policies may distort the market, resulting in higher societal costs that are likely to be passed through to consumers, while the burden can be redistributed across market participants with policy amendments. They are easy to set up and can be effective without closely monitoring.
Ease of bankability	Green – The package provides upfront capital financing and certainty about the size of the market. Risks are reduced to the point that the private sector will finance new projects.

Methodology and assumptions for quantifications

Quantification	Methodology & assumptions	Sources
2.1 Investment gap	Difference between announced investments by governments/ companies and the forecasted demand Investment demand includes Hydrogen production (so electrolyzers, CCS retrofits for blue H_2, new SMR/ATR plants), Distribution and transmission (shipping, pipelines, conversion etc.), storage tanks, and end-applications (so ammonia plants, fuel cells etc.) based on • H_2 demand for Net Zero • Investment costs • Investment multipliers Breakdown by value chain	IEA, 'Net Zero by 2050', 2021 Hydrogen Council, 'Hydrogen insights update', 2021 Hydrogen Council, 'Hydrogen, Scaling Up' report, 2017
2.2 Electrolyzer capex cost down	Sectoral energy demand Calculation of cost reduction based on • External projections • Investment multipliers • Market segmentation	IEA, Energy tech Perspective, 2017 Hydrogen Council member opinion Hydrogen Council, 'Path to hydrogen competitiveness: a cost perspective, 2020 Hydrogen Council, 'Hydrogen, Scaling Up', 2017
2.3 Carbon price required by sector for 2030 breakeven	Application of different carbon price sensitivities to a H_2 industry application matrix Average of low carbon and renewable hydrogen production cost for 2030 assumed at 1.9 USD/kg	McKinsey analysis
2.4 Spain-Germany pipeline imports	Total 2030 hydrogen demand in Germany;1.8 MT Pipeline of 70 bar, 50% utilization, standard 80cm pipeline Efficient renewable production site in Spain with production costs 1.1 EUR/kg FOB; 0.5 EUR/kg Total import price; 1.61 EUR/kg (incl. compression costs) Domestic production cost Germany; 1.91 EUR/kg	Hydrogen Insights Supply & Distribution model

Quantification	Methodology & assumptions	Sources
2.5 Japan import costs from Australia	Japan demand 2030; 3MT Assumption 70% imported from Australia Renewable H_2 production cost in Australia 1.5 USD/kg Import costs including phase change and shipping Range of import prices for 2030 from the model. From this range the assumption was made that the lowest cost import scenario would be where regulation and certification have been implemented. In this scenario importing should realize lower costs as there would be less regulatory 'red tape' and cost reduction benefits are a result of this. The upper end of the import cost range was assumed to represent a scenario without regulation and certification thereby additional costs being absorbed due to logistical irregularities. Calculated as the average upper import price limit for the LH2, NH3 and LOHC. Lowest potential total import cost;1.5 USD/kg Highest import cost; 2.57 USD/kg	Hydrogen Insights Supply & Distribution model Hydrogen Council, Path to hydrogen competitiveness: a cost perspective, 2020
2.6 Energy systems cost	Assuming a fully renewable energy system Difference between scenario where full electrolyser flexibility assumed and another where the load is fixed and there is no response to market signals modelled Project-specific power system modelling (for net-zero city project in the Middle East) Power savings modelling for the EU EU 2030 generation 3920 TWh (some curtailment and transmission losses) and demand (load and electrolysis) of 3860 TWh	McKinsey PowerSolution modelling
2.7 Job creation through a hydrogen economy	Assumption 54,545 jobs per MT hydrogen/12 jobs per million revenue in advanced industries Assuming 2050 hydrogen demand of 675 MT	McKinsey Global Energy Perspective, 2021 Hydrogen Council, 'Scaling Up', 2017
2.8 Emission abatement healthcare savings	Emission reduction benefit of hydrogen Economic benefits through the mitigation of air pollution from fossil fuels: USD 1.9-4.6 per GJ & CO_2 mitigation benefits of USD 3-12 per GJ Calculate the total economic benefit of this globally through the amount of CO_2 predicted to be abated in 2030 as a result of low carbon and renewable hydrogen deployment 2030 abatement; 0.68 GT Total economic benefit calculated through the volume of fossil fuels anticipated to be displaced and replaced by hydrogen	IRENA, 'REmap 2030', 2014 McKinsey Global Energy Perspective

GLOSSARY

ATR	Autothermal reforming
CAPEX	Capital expenditure
CBAM	Carbon border adjustment mechanism
CCfD	Carbon contracts-for-difference
CCS	Carbon capture and storage
CCUS	Carbon capture, use and storage
CfD	Contracts-for-difference
CO_2	Carbon dioxide
CO_2eq	Carbon dioxide equivalent
DRI	Direct reduced iron
DSO	Distribution system operator
EC	European Commission
E-fuels	Electrofuels (synthetic fuels)
ETS	Emissions trading scheme
EU	European Union
FCV	Fuel cell vehicle
FiP	Feed-in-premium
FiT	Feed-in-tariff
FOAK	First-of-a-kind
GGR	Greenhouse gas removal
GHG	Greenhouse gas
GO	Guarantees of origin
IATA	International Air Transport Association
IMO	International Maritime Organization
ISO	International Organization for Standardization
LCA	Life cycle analysis
LNG	Liquified natural gas
OIML	International Organization of Legal Metrology
OPEX	Operating expenditure
PPA	Power purchase agreement
PPP	Public-private partnership
PV	Photovoltaics
RABM	Regulated Asset Base Model
RED	Renewable Energy Directive (EU)
RES-E	Electricity from renewable energy sources
RFNBO	Renewable fuels of non-biological origin
SMR	Steam methane reforming
TEN-E	Trans-European Networks for Energy
TSO	Transmission system operator
TW/GW/MW/kW	Terawatt, gigawatt, megawatt, kilowatt (unit of power, 1 Watt = 1 J per s)
TWh/MWh/kWh	Terawatt hour, megawatt hour, kilowatt hour (unit of energy, 1 Watt-hour = 3600 J)
USD	United States Dollars
VAT	Value-added tax
WTO	World Trade Organization

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