Box 1.3 Hydrogen emissions from grid-powered electrolysis

For hydrogen from electrolysis to have lower overall emissions than grey hydrogen, CO_2 emissions per unit of electricity need to be lower than 190 grams of CO_2 per kilowatt hour (gCO_2/kWh) (Reiter and Lindorfer, 2015). Only a few countries (mostly benefiting from hydropower) have average CO_2 emissions per kWh below that threshold and thus can ensure the sustainability of electrolytic hydrogen. Most other countries are currently above that threshold.

However, electrolysers can be designed to be flexible demand-side resources and can be ramped down or turned off when the national power mix is above a certain threshold of CO_2 emissions, if tracked, and then turned back on when renewable production is higher, and in particular when VRE production would otherwise be curtailed. In general, low electricity prices are a proxy for high renewable energy production (IRENA, 2020c), so electricity prices may be naturally the signal for electrolyser activities. Moreover, when electricity prices are too high to produce competitive hydrogen, the electrolyser would shut down anyway. The significant (for some countries) and increasing renewable energy share of electricity production will also decrease the carbon footprint of electrolytic hydrogen production.

A hybrid model can also be used, where off-grid VRE generation is the main source of electricity, but grid electricity can top up production to decrease the impact of initial investment costs while causing only a small increase in the carbon footprint of the electrolysis plant.

Power purchase agreements with grid-connected VRE plants may also ensure the sustainability of electricity consumption and at the same time make green hydrogen an additional driver for the decarbonisation of the power grid.

1.4. POLICIES TO SUPPORT GREEN HYDROGEN

Historically, every part of the energy system has enjoyed some form of policy support. This has been and is still true for fossil fuels (which are supported with both direct and indirect subsidies) and for renewable energy sources, across all sectors – power, heating and cooling, and transport (IRENA, IEA and REN21, 2018). The hydrogen sector has also received some attention from policy makers with dedicated policies. But more dedicated policy support is needed at each stage of technology readiness, market penetration and market growth.

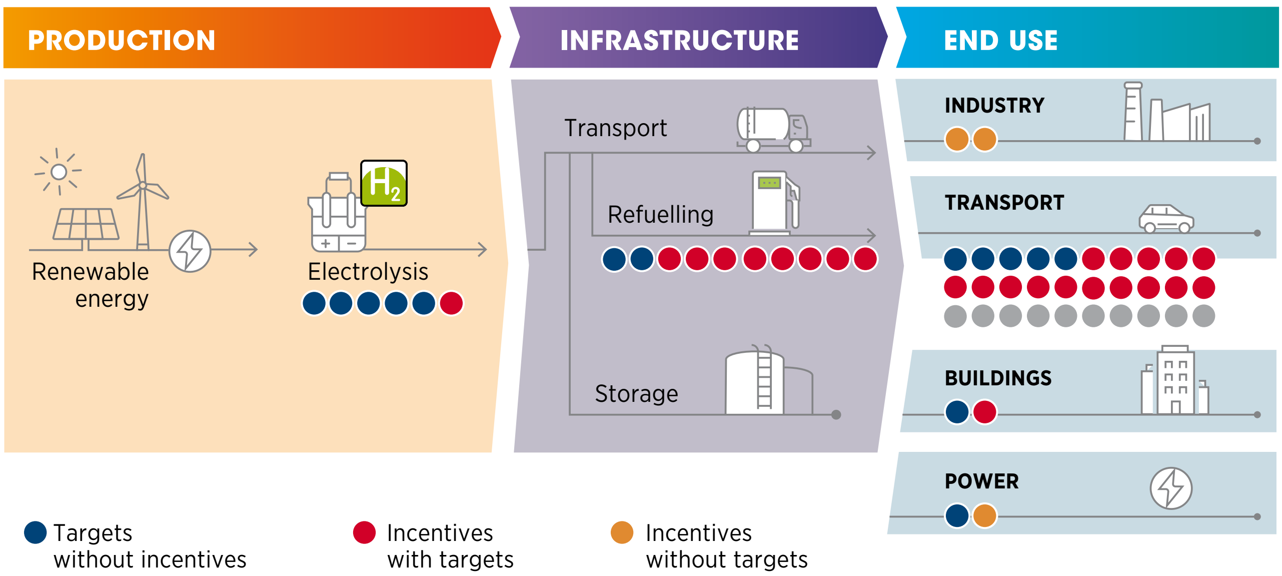
Status of policy support for green hydrogen

By 2019, hydrogen was being promoted in at least 15 countries and the European Union with supporting policies (other than standardisation processes or national strategies).[9] These policies directly or indirectly promoted hydrogen use across various end uses. However, due to previous focus on land transport uses for hydrogen, about two-thirds of the policies targeted the transport sector (Figure 1.4).

Most countries include FCEVs with battery electric vehicles in their zero-emission vehicle policies. This gives FCEVs the opportunity to benefit from incentives given to zero-emission vehicles in general, without the need for policies that specifically promote hydrogen use.

The past two years, however, represented a game-changing moment for green hydrogen policies, with interest rising around the world. Many countries (including Austria, Australia, Canada, Chile, France, Germany, Italy, Morocco, the Netherlands, Norway, Portugal and Spain, along with the European Union) announced, drafted or published national hydrogen strategies and post-COVID-19 recovery packages that included support measures for clean hydrogen.

FIGURE 1.4 Number of hydrogen policies at a global level by segment of the value chain



Source: IRENA analysis based on IEA (2019)

9 Belgium, Canada, China, France, Germany, Iceland, Italy, Japan, the Netherlands, Norway, New Zealand, Republic of Korea, Spain, United Kingdom and United States.

The change is not just quantitative (with pledges in the order of the billions of USD), but also qualitative: the emphasis of these new strategies has shifted to industry and product differentiation and future competitiveness, away from the previous focus on hydrogen use in transport.

Indeed, hydrogen can cater for a wide range of uses, as shown in Figure 1.1. It is important to prioritise the sectors where its use can add the most value to avoid diluting efforts or putting hydrogen in competition with more immediate decarbonisation solutions, such as battery electric vehicles. When green hydrogen has achieved higher shares of final energy consumption, policy priorities should expand and evolve (see Section 2.2).

The stages of green hydrogen policy support

As the penetration of green hydrogen technologies increases and costs come down, policies will have to evolve accordingly. The briefs following this report use the concept of **policy stages** to reflect the evolution of policy needs with the increased deployment of green hydrogen. Here are the three basic stages and the overall milestones for each:

STAGE 1

First stage: Technology readiness. At this stage, green hydrogen is a niche technology with little use except in demonstration projects; it is mostly produced on-site with limited infrastructure development. The largest barrier to greater use is cost. The main role of policy makers is to encourage and accelerate further deployment of electrolysers. This can be done in part through long-term signals, such as a commitment to net-zero emissions, which offer certainty to the private sector and improve the business case for green hydrogen.

As important, however, are shorter-term policies that help to close the investment and operational cost gaps. These include research and development (R&D) funding, risk mitigation policies and co-funding of large prototypes and demonstration projects to decrease the cost of capital. In addition, end uses still at the demonstration stage may need dedicated mission-driven innovation programmes with clear timelines and collaboration with the private sector to accelerate their commercialisation. Supportive governance systems and guidelines should also be put in place at this stage, ensuring that the growth of green hydrogen is sustainable.

STAGE 2

Second stage: Market penetration. At this stage, some applications are operational and able to prove what green hydrogen can do and at what cost. Scaling up these technologies and developing experience through learning-by-doing reduces costs and helps close the profitability gap. This stage also begins to see benefits from synergies between applications, increasing hydrogen demand and realising economies of scale for production and infrastructure. These synergies can take place in industrial clusters, hydrogen valleys (*e.g.* cities) or hubs (*e.g.* ports).

Industrial users can drive the development of dedicated "green hydrogen corridors" that connect regions generating low-cost renewable energy with demand centres. Most of this infrastructure is not developed from scratch, but is repurposed from existing natural gas networks and power grids. The first international trading routes for hydrogen (or its derived products) are established at this stage, and the existence of multiple producers and users leads to the creation of a real global market for hydrogen. As the use of green hydrogen grows, it becomes necessary to ensure that sufficient renewable electricity generating capacity is available, so that green hydrogen production does not displace more efficient direct electrification.

STAGE 3

Third stage: Market growth. At this stage, green hydrogen becomes a well-known and widely used energy carrier and is close to reaching its full potential. It has become competitive both on the supply side and in its end uses. Direct incentives are no longer needed for most applications and private capital has replaced public support in driving hydrogen growth. There is full flexibility in converting hydrogen to other energy carriers, making it possible to use the most convenient alternative depending on the specific conditions in each region. The power system has been decarbonised and only green hydrogen is being deployed. Most natural gas infrastructure has been repurposed to transport pure hydrogen.

Currently, green hydrogen is at the first stage for most sectors. Some regions may be more advanced in specific sectors or uses, while still being immature in others. For instance, California is ahead in FCEV deployment, but has no large-scale electrolysis industry, while Germany has focused on converting natural gas infrastructure to hydrogen. These cases illustrate how progress will be mixed in individual countries and that each country should not necessarily focus at the onset on all end uses of green hydrogen.

The stage approach described here provides the background for the policy pillars discussed in the second chapter.

2 PILLARS FOR GREEN HYDROGEN POLICY MAKING

Transitioning green hydrogen from a niche player to a widespread energy carrier will require an integrated policy approach to overcome initial resistance and reach a minimum threshold for market penetration. That policy approach should have four central pillars: national hydrogen strategies, policy priority setting, guarantees of origin, and enabling policies.

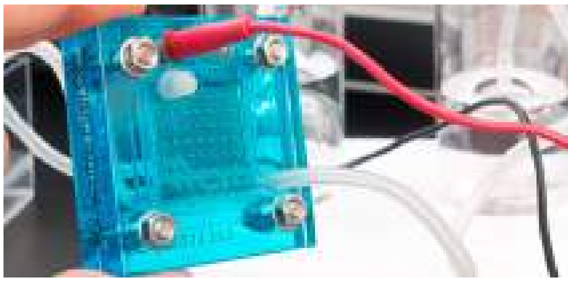
In addition to the four pillars presented in this chapter, successful hydrogen policy making should include the same elements that have been necessary to assist the deployment of renewable energy solutions in the power sector. These inlude, for example, long-term commitments. Long-term signals are essential for private and institutional investors to take the risk of investing in a novel technology, and this is particularly true for green hydrogen. The large levels of investment that are required mean that, in general, public capital alone is not enough to move hydrogen from niche to mainstream.

Long-term commitment from government is necessary to make available the private capital required for the transition to green hydrogen.

International collaboration on energy has been beneficial for countries in many ways, as demonstrated in the R&D and aligning of national agendas to accelerate the energy transition. Collaboration on the deployment of hydrogen-related solutions (e.g. upgrade of the gas grid in a cluster of countries) allows the sharing of risks, lessons learned and best practices, which translates into lower costs. Collaboration on safety and standards enables countries to speak a common language and execute projects that cross borders, as well as enabling replication.

The following sections explore in greater detail the four policy pillars needed to support a green hydrogen transition.

P1 P2 P3 P4



2.1. POLICY PILLAR 1: **NATIONAL STRATEGIES**

Recently announced hydrogen strategies result from a long process and mark the beginning of a new wave of policies. The strategy process usually starts with the establishment of **R&D programmes** to understand the fundamental principles of the technology, to develop the knowledge base that will inform future stages, and to explore multiple technologies and possibilities given that, at this early stage, the end applications are far from clear.

The next step is usually a **vision** document that clarifies the "why": "why hydrogen", "why this jurisdiction", and "why now". The vision document represents a beacon that guides research, industry efforts and early demonstration programmes. Such vision documents are often co-created by governments and private actors attracted by the growth prospects of breakthrough applications.

Next is a **roadmap** that goes one step further. It defines an integrated plan with the activities needed to better assess the potential for hydrogen. It identifies the short-term actions needed to advance deployment, and defines the research areas with the highest priority and the applications where demonstration projects are most needed.

Finally, the **strategy** itself defines the targets, addresses concrete policies and evaluates their coherence with existing energy policy.

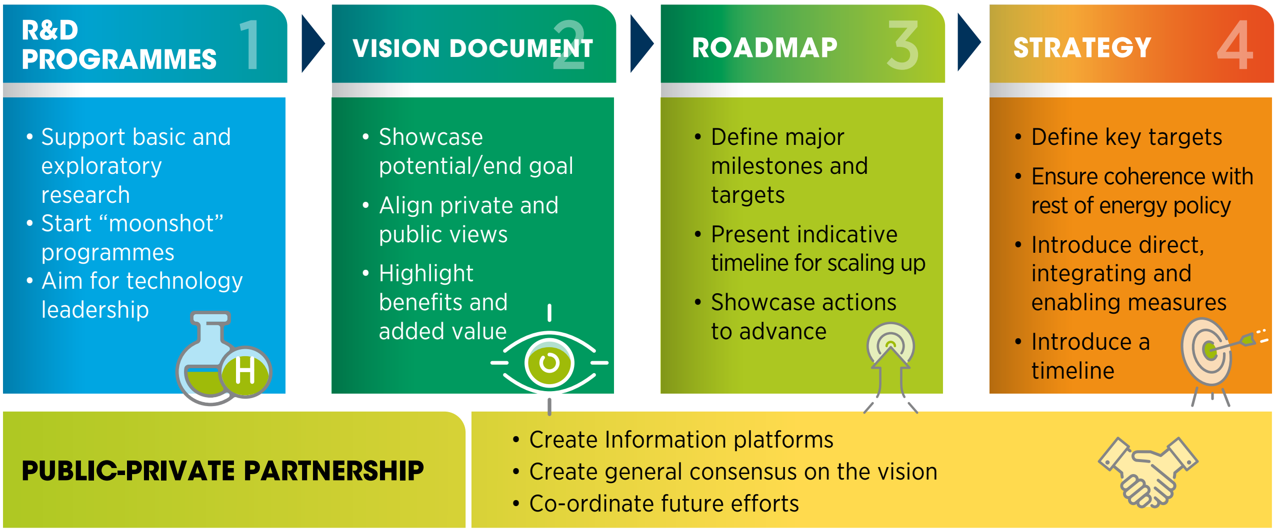
The strategy covers not only specific direct policies (such as feed-in premiums for green hydrogen), but also includes integrating and enabling policies that are needed to ensure deployment across the system, such as those that support the development of a skilled workforce. The strategy is informed by extensive scenario modelling, often with input from academia and industry. It sets the level of ambition that will guide the work in subsequent stages.

Throughout the process of preparing the strategy (Figure 2.1), **public-private partnerships** are often formed. They serve as a platform to exchange information to advance technological progress, create consensus, align views, develop incentives and co-ordinate activities. Public-private partnerships can reduce the risks during early deployment, facilitating the transition from demonstration to commercialisation. They allow companies to build experience while providing the benefits of first-mover advantage in case of success. The objective should be to reach a point where no further public support is needed. This model has already been successful in mobility and in the European Union (through the Fuel Cells and Hydrogen Joint Undertaking) to demonstrate hydrogen technologies for multiple pathways.

P1

National Strategies

FIGURE 2.1. Steps leading to the formulation of a national strategy

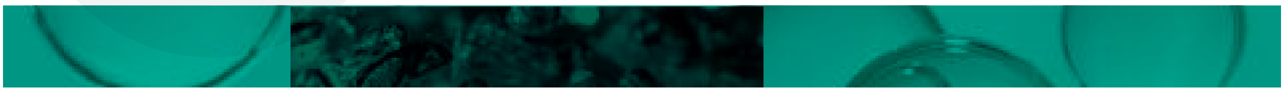


P1

National Strategies

A follow-up to the strategy is a set of analyses to assess the impact of the introduction or change of specific policies. The analyses assess the economic, social and environmental consequences of the implementation of the proposed measures in the strategy. They evaluate alternative timelines and scopes, as well as interactions with other technologies. After these analyses, the actual regulations and laws are introduced, followed by regular revisions to adjust them according to progress and latest trends.

This process from R&D to strategy is far from linear or quick. Moreover, countries can skip the public-facing steps described here and issue a national hydrogen strategy while keeping the investigation activities confidential.



Public support for R&D programmes on hydrogen was triggered by the oil crisis in the 1970s, with leading efforts from the **United States** and **Europe**. At about the same time, platforms for international collaboration were established, such as the International Journal of Hydrogen Energy (1976). Support from federal governments started in **Canada** in the early 1980s and in Japan in 1992 (Behling, Williams and Managi, 2015). The **United States** was one of the leading countries, establishing a public-private partnership in 1999 (California) and issuing a vision document and a roadmap in 2002 (US DOE, 2002).

R&D programmes are still very active and necessary today, with one of the largest recently being adopted in **China**. China is exploring solutions to use hydrogen in cities: the previous subsidies for FCEVs are being replaced by pilot demonstrations in selected cities for an initial phase of four years. A focus will be on research into and application of critical components, and support from central government will be in the form of financial awards to these cities rather than purchase subsidies for consumers.

Other countries have developed their vision or roadmap documents, with final strategies expected in the next years. For example, **New Zealand** published its vision document in 2019, which outlined the potential uses of hydrogen and explored in a non-quantitative manner some of the issues around its use. The anticipated next stage is a roadmap to identify the steps towards making the use of hydrogen possible in the wider economy.

The pace of action is accelerating. In the last two years, given the new wave of interest in hydrogen, many countries have progressed through the steps in Figure 2.1 and have issued their own national strategies (Figure 2.2). **France** first published a hydrogen strategy in 2018, which was updated in June 2020. The **European Union** established a High-Level Working Group on hydrogen in 2002 (with 19 stakeholders from the research community, industry, public authorities and end users), issuing its vision document one year later (European Commission, 2003). It established the Fuel Cell Technology Platform in 2004, which paved the way for the inception of the Fuel Cells and Hydrogen Joint Undertaking (FCH JU, 2017).