INTERNATIONAL HYDROGEN STRATEGIES

A study commissioned by and in cooperation with

the World Energy Council Germany

September 2020

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Final Report

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The report was enhanced with contributions and expert interviews from the World Energy Council network in France, the Netherlands, Australia, Morocco, Germany, Japan, Italy, California, Switzerland, and China.

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ACRONYMS AND ABBREVIATIONS

AFID	Alternative Fuels Infrastructure Directive 2014/94/EU
B€	Billion Euro
BOG	Boil-off gas
CAPEX	Capital expenditure
CCfD	Carbon contracts for difference
CCS	Carbon capture and storage
CCU	Carbon capture and usage
CGH_2	Compressed gaseous hydrogen
CHP	Combined heat and power
CVD	Clean Vehicles Directive (EU) 2019/1161
DBT	Dibenzyltoluene
DWV	Deutscher Wasserstoff- und Brennstoffzellen-Verband (German Hydrogen and Fuel-Cell Association)
ETS	Emissions Trading System
FCEV	Fuel cell electric vehicle
FCH JU	Fuel Cell and Hydrogen Joint Undertaking
GDP	Gross domestic product
GHG	Greenhouse gas
H_2	Hydrogen
HDV	Heavy-duty vehicle
HRS	Hydrogen refuelling station
IPCEI	Important Projects of Common European Interest
LDV	Light-duty vehicle
LH_2	Liquid hydrogen
LOHC	Liquid organic hydrogen carrier
M€	Million Euro
MCH	Methylcyclohexane
MENA	Middle East and North Africa
METI	Ministry of Economy, Trade and Industry (in Japan)
MOOI	Mission-oriented research, development and innovation
NECP	National Energy and Climate Plan
NEV	New energy vehicle
NG	natural gas
NH_3	Ammonia
OPEX	Operational expenditure
PtL	Power-to-Liquids
R&D	Research and development
RED II	Renewable Energy Directive recast (EU) 2018/2001

RES	renewable energy sources
TYNDP	Ten-Year Network Development Plan
ZEV	Zero emission vehicle

Countries

AU	Australia
CA	California
CH	Switzerland
CN	China
DE	Germany
ES	Spain
EU	European Union
FR	France
IT	Italy
JP	Japan
KR	South Korea
MO	Morocco
NL	The Netherlands
NO	Norway
PT	Portugal
RU	Russia, Russian Federation
UA	Ukraine
UK	United Kingdom

EXECUTIVE SUMMARY

Analysis of government action for hydrogen in 16 countries and the EU

Hydrogen can play an significant role in a future energy system based on renewables as an important link between intermittent wind and solar electricity production and energy consuming sectors traditionally relying on a chemical energy carrier that can be stored in bulk quantities and converted to electricity or heat at the point of use. However, implementing hydrogen at relevant scale including its production, transport, distribution, and use requires a certain governmental support as well as a beneficial policy and regulatory environment allowing for a positive economic outlook for industrial deployment.

As a result, major economies around the globe are currently assessing their position and are discussing, preparing, and agreeing on dedicated hydrogen strategies. This study analyses government action for hydrogen in 16 countries (UK, Japan, South Korea, Australia, the Netherlands, France, Italy, Spain, China, Ukraine, Germany, Switzerland, Morocco, California [1], Russia, and Norway) and in the European Union, focusing on the respective national goals, targeted sectors and infrastructures, current support measures, requirements on the hydrogen used, and achievements so far, aiming to provide an informed factual input to policy discussions and corporate decision-making.

Quickly emerging hydrogen strategies indicate dynamically growing market

In a high-level review of countries representing over 90% of global GDP we found that 20 countries representing 44% of global GDP already have passed a national hydrogen strategy or are on the verge of doing so. Additionally, another 31 countries (another 44% of global GDP) are supporting national projects and discussing policy action. Main drivers are GHG emission reduction goals, the integration of renewables, as well as the opportunity for economic growth. While national strategies obviously differ in detail, reflecting particular country interests and industrial strengths, this demonstrates that there is a clear, strong, and lasting global momentum behind the universal recognition that hydrogen is an essential and indispensable element of a decarbonised energy system.

The analysis clearly shows that we should expect a dynamically growing market for hydrogen. Scaling upper hydrogen demand expected for 2050 in national strategies to global level indicates a potential of up to 9000 TWh or around 270 million tons of hydrogen per annum, this is an amount as large as the annual primary energy currently provided globally by renewables.

Target sectors notably include transport and industry, the latter particularly in countries with a strong industrial sector and a high priority on greenhouse gas reduction. In the long run with a view towards

[1] US federal states follow their own strategies with regard to clean transport and energy supply; the study team has chosen to include California in the analysis as it is the most advanced US state in that respect.

a largely decarbonised world by 2050, the majority of national strategies and discussions focus on using green hydrogen sourced from renewable energy only. However, in the interim other types of low carbon hydrogen are seen as an effective and pragmatic way to ramp up volumes and to get the associated hydrogen economies started.

Emerging opportunities and areas to watch for industry

The expected market development signals emerging opportunities and areas to watch for industry including the following:

- A large cumulative market of over 40 B€ for green hydrogen production equipment will develop within the EU until 2030.
- Large industrial partnerships will be formed for production and export/import and industry players should start to engage now.
- Refineries and the chemical industry are expected to become the first important large-scale hydrogen markets in the mid-term.
- The road transport market (vehicles and trucks) is currently stronger in Asia than in Europe, signalling a difference in strategy between OEMs in the two continents, which is worth watching closely in the coming years.
- Green synthetic liquid e-fuels (PtL) can grow into an interesting opportunity with large potential quantities particularly in the aviation and/or maritime sector.

New policies needed to achieve strategic aims

Most strategies focus on targets for green hydrogen production and technology deployment rather than on measures supporting these. Current measures are insufficient to catalyse the envisaged strong growth and new policies are required.

These policy elements have been found particularly helpful in fostering commercialisation:

- Sectoral quota can stimulate large scale demand and create markets.
- Targeted support for establishing comprehensive value chains provides nuclei for sustainable business activity.
- Moving from CAPEX to OPEX support will be important to establish sustainable business cases for operators.
- Globally high CO_2 prices would help to further reduce the cost gap.
- Instruments need to provide a long-term perspective and security of investment.
- A broadly agreed green or low carbon hydrogen certification mechanism is crucial for market development.
- Any activities should be complemented by measures supporting public acceptance.

The time for policy discussions is now and policymakers will likely be open to sensible approaches and good arguments.

1 INTRODUCTION: NATIONAL GOVERNMENTAL SUPPORT FOR HYDROGEN

By 2025, hydrogen strategies can be expected to cover countries representing over 80% of global GDP.

A total of 16 countries plus the European Union have been selected for a more detailed analysis:

- Europe : European Union (EU), Germany (DE), the Netherlands (NL), France (FR), United Kingdom (UK), Italy (IT), Spain (ES), Switzerland (CH), Norway (NO, Ukraine (UA), and Russia (RU)
- Rest of the world: Japan (JP), South Korea (KR), China (CN), Australia (AU), California (CA), and Morocco (MO)

1.1 Background of the study

Internationally, the discussions around hydrogen as a future energy carrier and renewable feedstock for industry processes are increasingly gaining momentum. One of the main drivers for this development is the increasing awareness of the fact that large amounts of green hydrogen are required for fully decarbonising large-scale applications in industry, transport, heat, and power. Additionally, since several of the larger industrial nations in Europe and Asia anticipate a limited capability of producing sufficient amounts of green or low carbon hydrogen domestically, countries with beneficial conditions for producing renewable power at low cost are seeing substantial opportunities for economic growth by hydrogen export. As a result, hydrogen has become an item on government agendas across the globe and an increasing number of national administrations have established or are working on a hydrogen strategy, already support hydrogen demonstrations activities, or at least are in the status of initial policy discussion regarding the future role of hydrogen.

Focusing on national strategies and associated documents, this study analyses government action for hydrogen in 16 selected countries (UK, Japan, South Korea, Australia, the Netherlands, France, Italy, Spain, China, Ukraine, Germany, Switzerland, Morocco, California[2], Russia, and Norway) and in the European Union. It focuses on the respective national goals, targeted sectors and infrastructures, current support measures,

[2] US federal states follow their own strategies with regard to clean transport and energy supply; while not a 'country', the study team has chosen to include California in the analysis as it is the most advanced US state in that respect.

requirements on the hydrogen used, and achievements so far, aiming to provide an informed factual input to policy discussions and corporate decision-making.

By the analysis of the respective country approaches, we aim to serve the following objectives:

- Provide an understanding of international trends and developments towards supporting hydrogen as a low emission energy carrier
- Show a taxonomy of international hydrogen strategies
- Compare national activities and put them into context
- Generate a solid background for upcoming policy and strategy discussions
- Identify major topics for the political discussion

1.2 Country selection for a detailed analysis

A preliminary screening of hydrogen strategies in 56 countries around the world, representing over 90% of global GDP, reveals that nine countries already have an existing comprehensive national hydrogen strategy and further eleven are in the process of developing one (see Figure 1). Together, these 20 countries stand for 44% of global GDP. Another 14 countries (38% of global GDP) are already supporting hydrogen pilot and demonstrations projects (without dedicated hydrogen strategy) and in 17 countries first government and/or stakeholder discussions regarding hydrogen are ongoing. Hydrogen activities are well spread around the globe with major interest being located in Europe, in the Asia and Pacific region, as well as in the Americas (Figure 2).

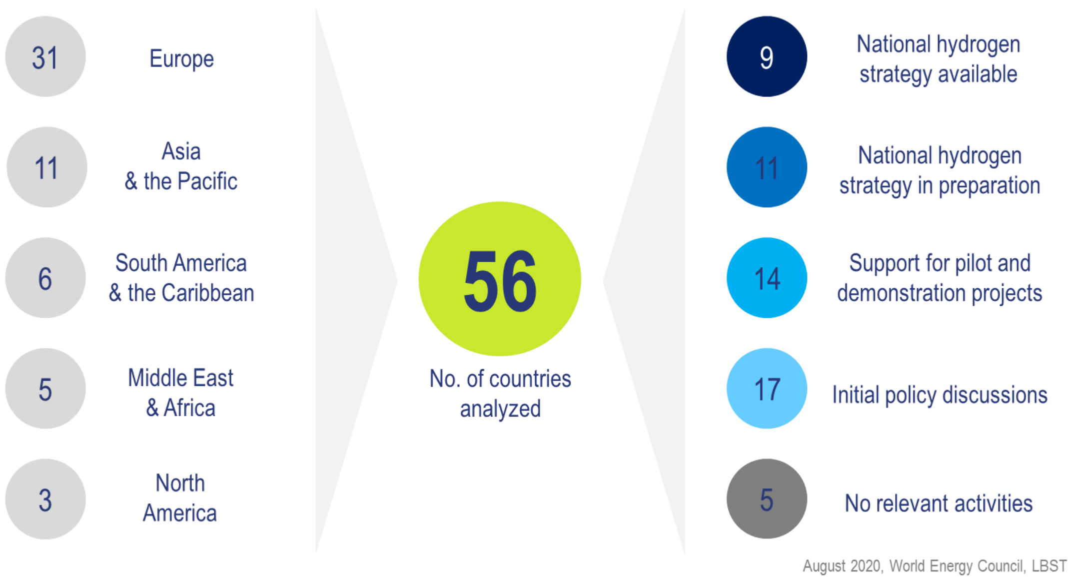

Figure 1: Analysis of 56 countries for their hydrogen activities (August 2020)

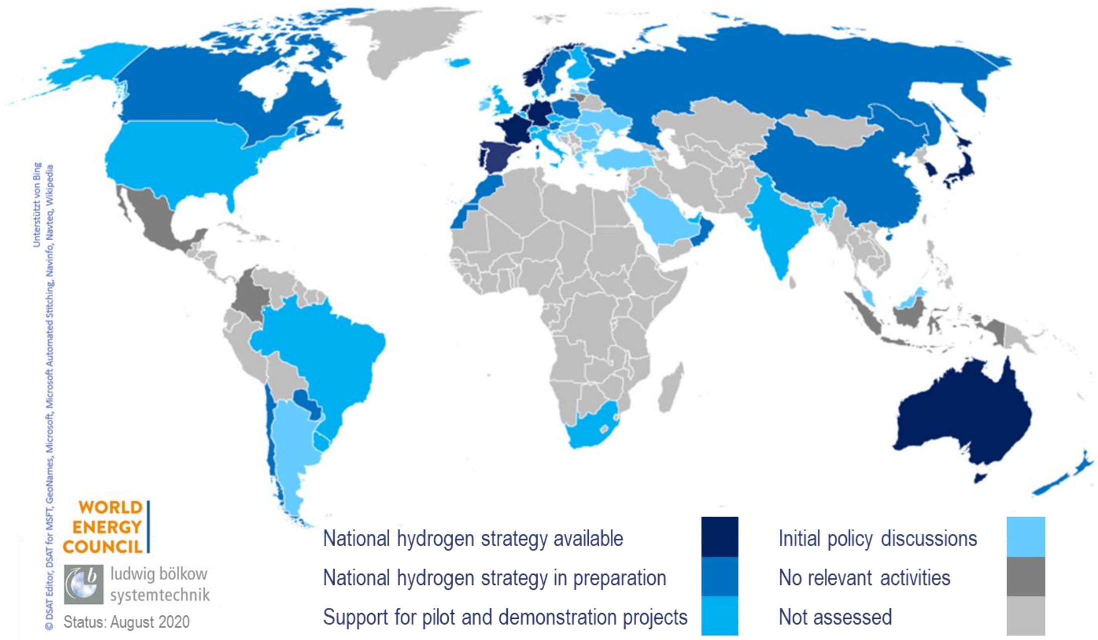

Figure 2: Status of international hydrogen activities of national governments (August 2020)

Based on this pre-screening of international hydrogen strategies a total of 16 countries (ten in Europe and six in rest of the world) plus the European Union have been selected for a more detailed analysis:

- **Europe[3]:** European Union (EU), Germany (DE), the Netherlands (NL), France (FR), United Kingdom (UK), Italy (IT), Spain (ES), Switzerland (CH), Norway (NO, Ukraine (UA), and Russia (RU)
- **Rest of the world:** Japan (JP), South Korea (KR), China (CN), Australia (AU), California (CA), and Morocco (MO)

The rationale behind the country selection was to have a balanced picture including the most active countries, a global representation, and a broader spectrum of opportunities and aims, also including countries with a potential for significant hydrogen exports. The report was enhanced with interviews carried out by the World Energy Council with selected experts from France, the Netherlands, Australia, Morocco, Germany, Japan, Italy, California, Switzerland, and China.

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[3] Portugal was chosen to be covered only in a brief summary in Annex B, as the strategy was finalized late in the course of this study.

1.3 Structure of the report

The report is structured into the following:

Chapter 2 summarises the goals of national governments in supporting hydrogen technologies and applications along with the associated time horizons for reaching them.

Sectors, applications and related infrastructure developments targeted in national strategies are addressed in chapter 3. Here, we also comment on plans for large-scale hydrogen import or export as well as on the role of synthetic fuels derived from hydrogen.

Policies and regulatory measures supporting hydrogen adoption are discussed in chapter 4. Here, we also review plans for ramping up hydrogen production as well as requirements on the source of hydrogen (e.g. "blue" vs. "green" H_2).

Chapter 5 looks at what has been achieved by current policies and associated market development and discusses lessons learned, and conclusions are presented in chapter 6.

Annex A provides an overview on relevant hydrogen transport vectors, which are currently discussed. More detail on the individual country strategies of the selected geographies is presented in Annex B.

2 WHAT ARE THE GOALS OF NATIONAL GOVERNMENTS?

Greenhouse gas emission reduction is a main driver for hydrogen adoption in all countries analysed, along with the role of hydrogen in the integration of renewable wind and solar energy.

Hydrogen is clearly recognised as an essential element of a decarbonised energy system.

Other goals notably include secure energy supply and economic growth.

Market ramp-up will happen in in three phases: market activation in the current decade, sustainable growth after 2030, and a large and well-established market by 2050.

2.1 Classification of strategies in selected countries

Most of the selected countries already have a dedicated national hydrogen strategy (AU, ES, NO, NL, EU, FR, JP, DE, and KR) or are currently preparing such strategy (RU, CH, MO). Five countries only provide support for pilot and demonstration projects without a specific strategy (CA, UK, IT) or have just initiated discussions in this respect (UA and CH). As depicted in Figure 3, most strategies have been developed and announced recently, i.e. in 2020 or in late 2019, (AU, NL, NO, DE, EU, ES). Only three of the selected countries have a strategy older than one year (JP, FR, KR).

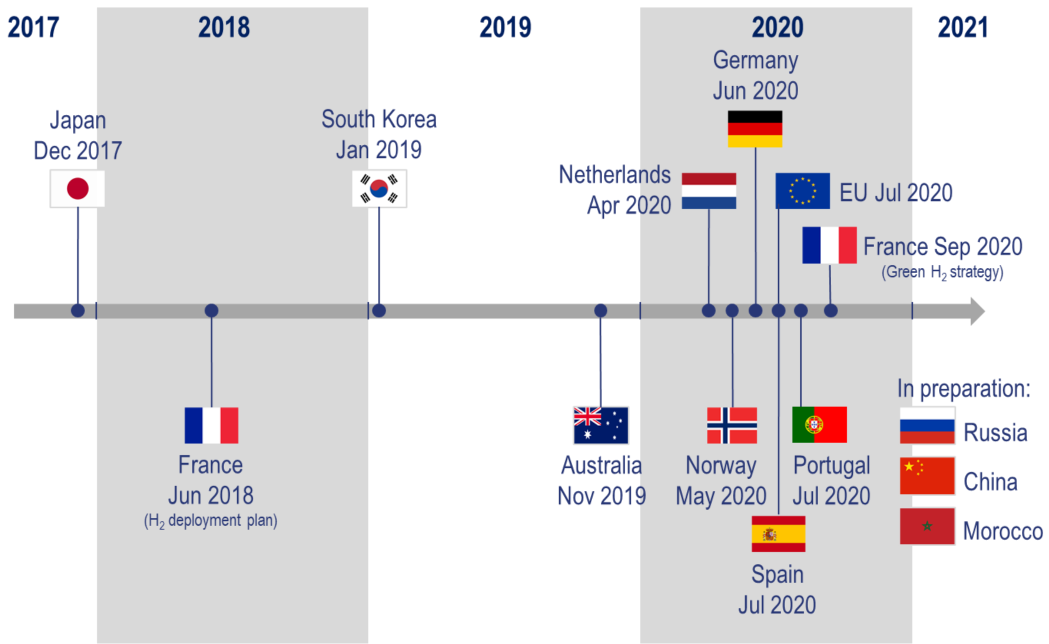


Figure 3: Timeline of national hydrogen strategies publication

For a better view on certain hydrogen-related goals of the selected countries the national strategies are differentiated by the respective role of hydrogen imports or exports (Figure 4) as well as by the level of detail of the strategy (Figure 5).

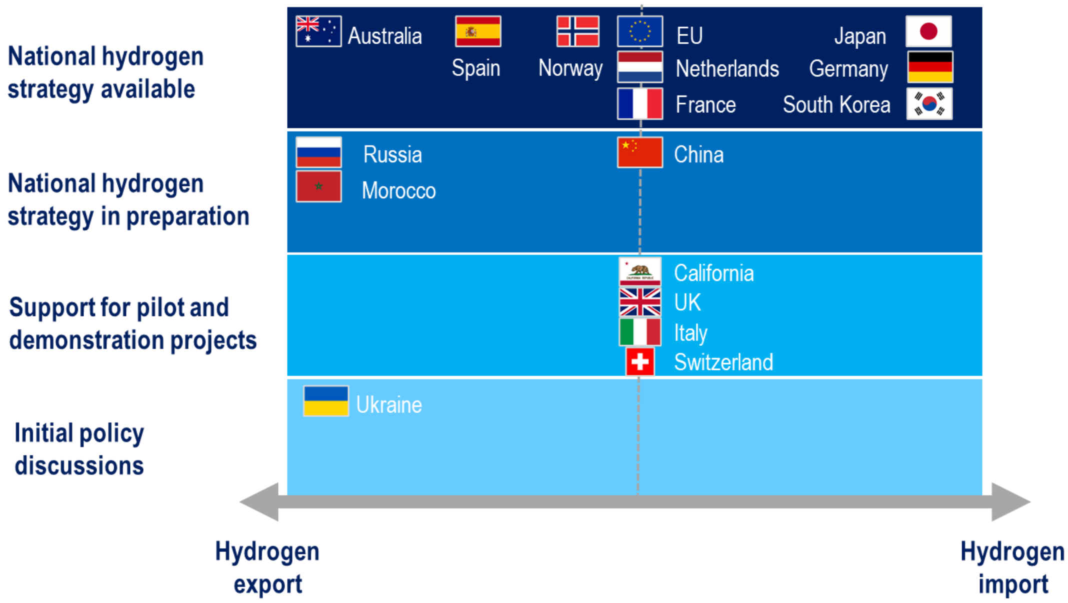


Figure 4: Selected countries classification in respect to availability of a dedicated strategy and hydrogen imports/exports

Regarding hydrogen imports or exports, most countries (NL, EU, FR, CH, CA, UK, IT, and CH) do not specify a particular preference or role in their strategic documents. Only three more advanced strategies (JP, DE, and KR) explicitly consider hydrogen imports due to the limited domestic production capacities. The remaining six of the selected countries (AU, ES, NO, RU, MO, and the UK) envisage some kind of hydrogen-related energy exports at a very individual extent.

Please note that the country selection is intentionally focused on hydrogen consumers rather than on exporters, which have been covered in a previous study[4]. As a result, the country balance between importing and exporting countries must not be seen as representing any market trend.

4 J. Perner and D. Bothe, International aspects of a power-to-X roadmap, World Energy Council and Frontier Economics, 18 October 2019

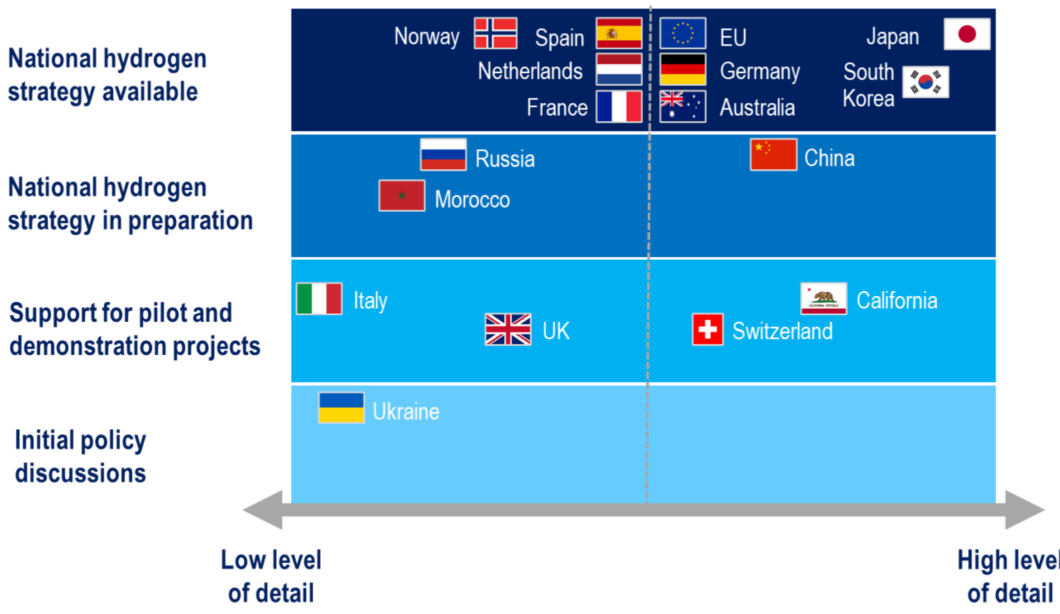


Figure 5: Selected countries classification in respect to availability of national hydrogen strategy and level of detail

In addition, the strategies reviewed also exhibit a very diversified level of detail. Some strategies and policy papers are very specific and provide concrete figures for hydrogen-related targets in various areas (JP, KR, CN, CA, and CH). However, at this point it is important to mention that the individual scope covered by detailed specifications can vary significantly between the countries (e.g. JP provides details for a wide range of topics, whereas CH only addresses very few concrete topics in the transport sector). Most available strategies (DE, AU, NL, EU, ES, FR) are characterised by 'average' detailedness as they are expected to set general boundary conditions, which will be specified in more detail at a later stage in a concrete roadmap or policy framework. Other countries (NO, RU, MO, UK, IT, UA) provide less details on hydrogen related topics within their strategies or policies.

2.2 Main national goals behind supporting hydrogen technologies

The objectives behind the national support of hydrogen technologies and applications are manifold. Generally, however, they serve typical energy policy goals aiming at clean and secure energy supply and at economic growth:

- **Clean energy:** When produced from renewable sources or based on other low-carbon technologies such as Carbon Capture and Storage (CCS), hydrogen can help to reduce GHG emissions especially in sectors which are hard to electrify (e.g. long-distance heavy-duty transport, steel production) or where it substitutes fossil feedstock (e.g. in the chemical industry). Its direct use in some application also allows to avoid local air pollution. Moreover, hydrogen enables large-scale storage of renewable energy and large electrolysers can act as flexible load support helping with the integration of intermittently generating renewable energy generation into the energy system.

- **Secure energy supply:** Hydrogen as a universal energy carrier can help to diversify the energy supply by reducing current fossil fuel dependency through domestic production or through imports.
- **Economic growth:** Domestic hydrogen production and technology development may foster economic growth by creating new jobs and strengthening the national economies. Moreover, exports of hydrogen energy and technologies can generate additional income.

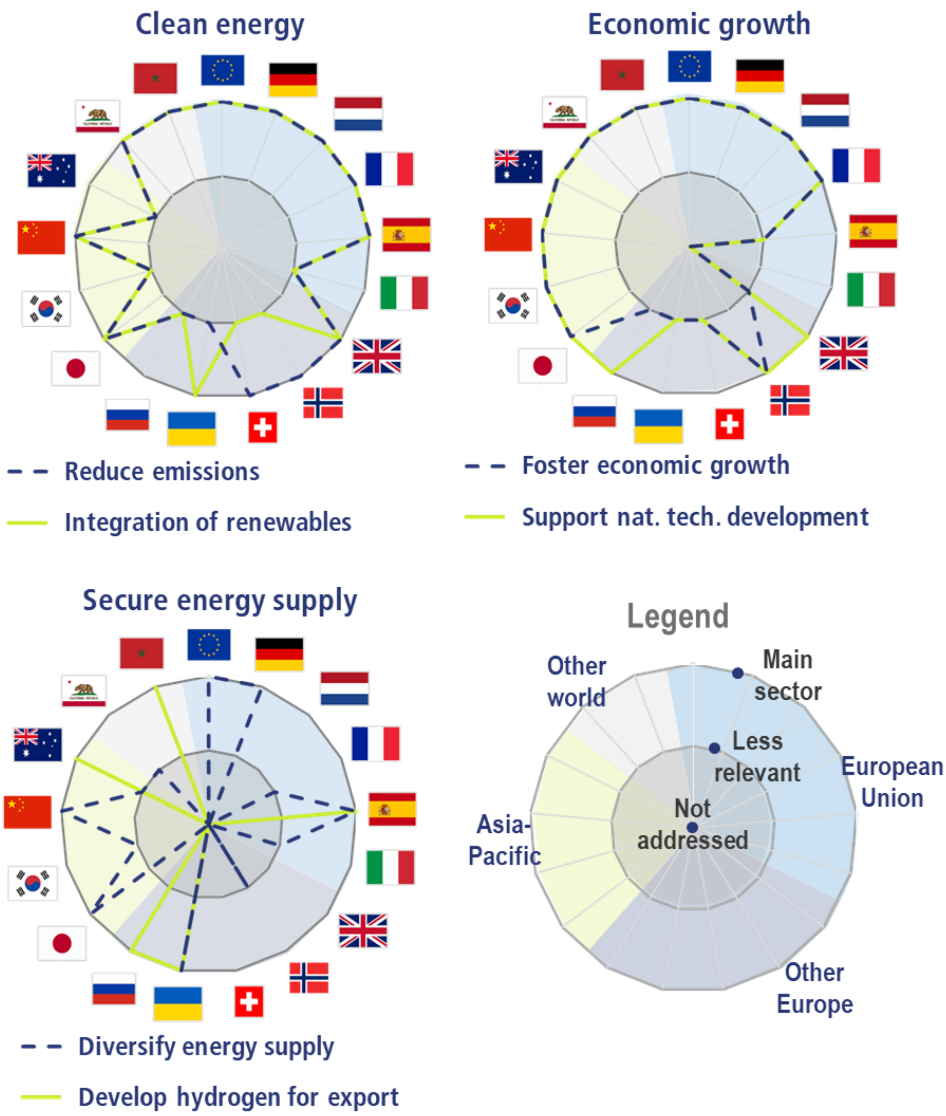


Figure 6: Main goals of current hydrogen strategies per country

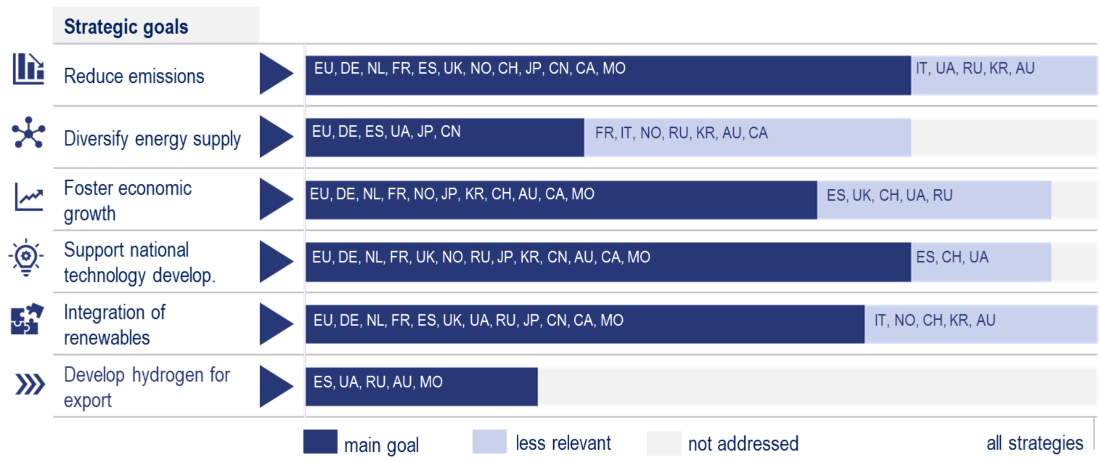


Figure 7: Relevance of strategic goals across the selected countries

As depicted in Figure 6, Figure 7, and Table 1, the broad spectrum of possibilities and opportunities associated with using hydrogen is generally recognised by all countries. However, the ambitions and thus the focus of individual countries typically reflect their national interests as well as strengths and weaknesses that need to be overcome in the future. In addition, different starting points in developing hydrogen supply and demand affect the goals behind the individual national hydrogen strategies. Countries like DE, JP, KR, or CA, having pursued the technologies and their implementation for some time already, will naturally have a different strategic approach compared to newcomers like AU, UA, or MO. Generally, the more sophisticated and/or recent the national H_2 strategy, the more comprehensive the strategic goals.

Table 1: Main goals of current hydrogen strategies per country

Strategic goals	EU	DE	NL	FR	ES	IT	UK	NO	CH	UA	RU	JP	KR	CN	AU	CA	MO
Reduce emissions	✓	✓	✓	✓	✓	(✓)	✓	✓	✓	(✓)	(✓)	✓	(✓)	✓	(✓)	✓	✓
Diversify energy supply	✓	✓	✗	(✓)	✓	(✓)	✗	(✓)	✗	✓	(✓)	✓	(✓)	✓	(✓)	(✓)	✗
Foster economic growth	✓	✓	✓	✓	(✓)	✗	(✓)	✓	(✓)	(✓)	(✓)	✓	✓	✓	✓	✓	✓
Support national technology develop.	✓	✓	✓	✓	(✓)	✗	✓	✓	(✓)	(✓)	✓	✓	✓	✓	✓	✓	✓
Integration of renewables	✓	✓	✓	✓	✓	(✓)	✓	(✓)	(✓)	✓	✓	✓	(✓)	✓	(✓)	✓	✓
Develop hydrogen for export	✗	✗	✗ 1)	✗	✓	✗	✗	✗ 2)	✗	✓	✓	✗	✗	✗	✓	✗	✓

main goal (✓) less relevant not addressed

Greenhouse gas emission reduction is a main driver for hydrogen adoption in all countries analysed, along with the role of hydrogen in the integration of renewable wind and solar energy. Beyond the greenhouse gas related environmental aspects, air pollution reduction as an additional element of the strategy is mentioned only by few (e.g. AU, CA, KR, CN). Integration of renewables is important for both hydrogen importing countries in terms of balancing the domestic energy system and for exporting countries targeting to become a green energy supplier for other economies. Especially for today's fossil energy exporting countries such as e.g. Australia or Norway hydrogen export enables a switch to renewable or low-carbon energy export.

The opportunities for the domestic economy arising from hydrogen are also well recognised by most strategies. For established and large economies (e.g. KR, DE, or JP) hydrogen technology is viewed as an important element to maintain strategic advantage in global competition mainly through technology leadership. For the smaller and/or growth economies (e.g. MO, UA, CN) hydrogen production and technology development allows to enter new markets and to improve the respective economic situation. Hence, in almost all countries the support of national technology development is closely related to economic growth through the opportunity to export technology, knowledge, and expertise to other countries. Hydrogen exports play a role mainly for countries with large renewable energy potential (AU, RU, MO, UA, ES). At this point it is worth mentioning that in the Norwegian strategy hydrogen is not targeted for direct export but indirectly through the export of natural gas in combination with offering local sequestration for captured carbon dioxide. Moreover, the Dutch strategy considers hydrogen transit to neighbouring countries (e.g. Germany).

Finally, the diversification of energy supply through hydrogen is relevant mainly for energy importing countries (e.g. DE, JP, CN). In this context, hydrogen is related to the use of domestic renewables or new sources of energy imports, decreasing the dependency on fossil fuels.

In summary, while national strategies obviously differ in detail, there is a universal recognition that hydrogen is an essential and indispensable element of a decarbonised energy system

2.3 Associated time horizons

The concrete time horizons for achieving the different goals by individual countries strongly depend on their specific starting position, boundary conditions, future ambitions, and available resources. In addition, as mentioned previously, some advanced strategies do not provide detailed timelines for individual strategy implementation steps as these are expected to be outlined in future roadmaps. The ultimate goals of a hydrogen strategy, typically represented by achieving an established hydrogen market by 2050, are expressed in different ways (see Figure 8). For example, the ultimate German goal is to achieve GHG neutrality where hydrogen is one important element of the future energy system. Some Asian countries such as Japan or South Korea focus more on hydrogen and economy-related goals and formulate their long-term objectives as establishing a hydrogen society or economy. Other countries like Australia plan to become a global exporter by 2050.

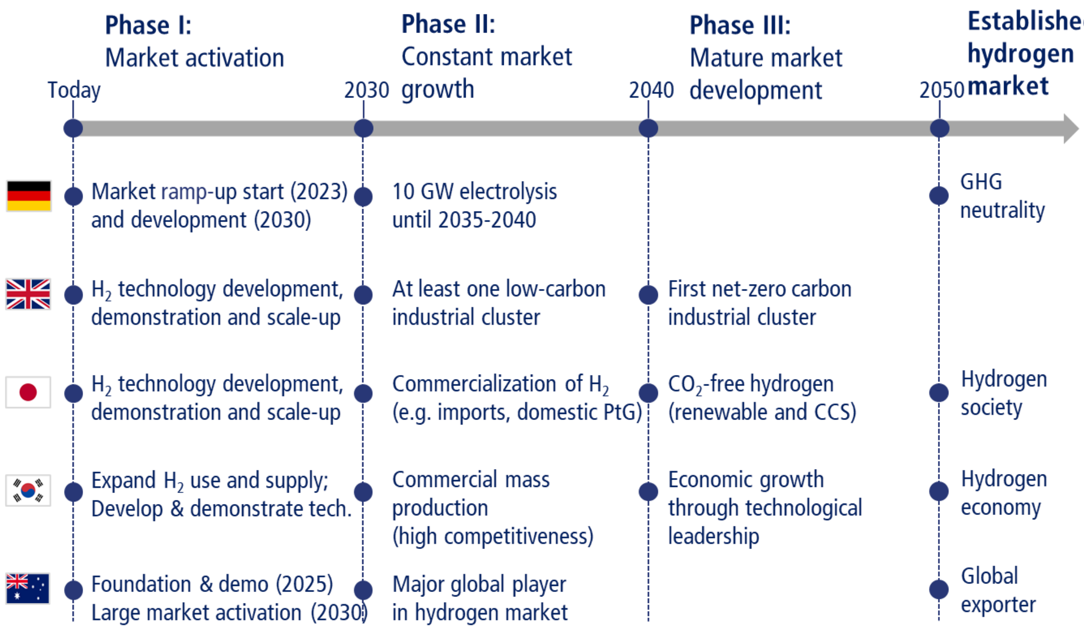


Figure 8: Development of hydrogen market in three major phases (based on examples from selected countries)

Nevertheless, in most strategies one can distinguish between three major phases towards achieving the ultimate goals. The first phase until 2030 can be considered as market activation with technology development and hydrogen demand ramp-up. In the second phase until 2040 most countries expect constant market growth with a build-up of large-scale hydrogen technologies (e.g. in DE up to 10 GW electrolysis capacity between 2035 and 2040) and a commercialisation of hydrogen in a number of applications (e.g. commercial mass production in KR or first low-carbon industrial clusters in UK). Finally, in the thirst phase until 2050 hydrogen markets are expected to mature.

3 WHICH SECTORS, APPLICATIONS, AND INFRASTRUCTURE DEVELOPMENTS ARE TARGETED?

Transport and industry are the most prominent application sectors overall. The industry sector has a particularly prominent role in countries with a strong industrial presence and a high priority on greenhouse gas reduction.

While Asian countries (and California) also focus on using hydrogen in passenger cars, this subsector plays only a limited role in most European strategies.

Japan and Korea also have a different strategic approach in the building sector with their focus on fuel cell CHP, which only play a limited or no role in European strategies.

Scaling demand expectations for 2050 indicates a global hydrogen potential of up to 9000 TWh.

In several countries with high energy needs, a substantial share of this demand will be served by imports, initially on the basis of bilateral agreements.

Synthetic liquid e-fuels (PtL) can grow into an interesting opportunity with large quantities based on quota in aviation and/or maritime sector.

Infrastructure development requires public financing and central coordination for planning and harmonisation.

Existing infrastructure for gas transport and distribution can be converted to transport pure hydrogen.

3.1 Target sectors for governmental H_2 support

Hydrogen as a universal energy carrier can be used in a wide range of applications across various end-user sectors. Typically, the following target sectors can be distinguished:

- **Industry:** Hydrogen is a feedstock for a number of industrial processes in the chemical and petrochemical industry (production of ammonia, methanol, and so-called high value chemicals) and in refining of fossil-based fuels; these are sectors already using fossil-derived hydrogen today in large quantities today, usually producing it on-site. Additionally, the steel industry is expected to be a significant future user of green hydrogen as the direct reduction of iron ore by hydrogen is seen as the only viable way to reduce greenhouse gas emissions and replace the current coal-based blast furnace process. Moreover, hydrogen can be utilised for generating process heat.
- **Transport:** Hydrogen is a fuel for fuel cell electric vehicles (FCEVs) including passenger cars, buses, trucks, trains, and industrial machinery including forklifts. Moreover, synthetic fuels derived from hydrogen are being discussed as a low

carbon fuel in incumbent combustion engines (e.g. in aviation and in the maritime sector).

- **Buildings:** Hydrogen can provide energy for heating and warm water generation in private and commercial buildings, either directly or through producing synthetic methane. In addition, co-generation of heat and power in combined heat and power (CHP) plants is possible.
- **Power:** Hydrogen can be re-electrified by dedicated gas turbines[5] or stationary fuel cell in the power sector. Typically, it is combined with large-scale energy storage for renewable power.
- **Export:** Some countries consider hydrogen as a suitable carrier for (renewable or low carbon) energy exports.

Figure 9, Figure 10, and Table 2 provides an overview over main target sectors of current hydrogen strategies per country.

Table 2: Main target sectors of current hydrogen strategies per country

Hydrogen use sectors	EU	DE	NL	FR	ES	IT	UK	NO	CH	UA	RU	JP	KR	CN	AU	CA	MO
Industry	✓	✓	✓	✓	✓	(✓)	✓	✓	✗	✗	✓	(✓)	✗	✗	✓	(✓)	✓
Power	(✓)	(✓)	(✓)	✓	(✓)	✗	✓	✗	✗	✓	✓	✓	✓	✓	✓	(✓)	(✓)
Transport	✓	✓	✓	✓	✓	(✓)	✓	✓	✓	✓	(✓)	✓	✓	✓	✓	✓	(✓)
Buildings	(✓)	(✓)	(✓)	(✓)	✗	✗	(✓)	✗	✗	(✓)	(✓)	✓	✓	✗	(✓)	(✓)	(✓)
Export	✗	✗	✗ 1)	✗	✓	✗	✗	✗ 2)	✗	✓	✓	✗	✗	✗	✓	✗	✓

✓ main sector (✓) less relevant ✗ not addressed

1) Hydrogen imports transit to other countries (e.g. Germany) considered.
2) For Norway, hydrogen is not targeted for direct export, but indirectly through the export of NG with local CCS.

5 The European gas turbine industry has committed to provide gas turbines that can operate with 100% hydrogen by 2030;
see https://www.euturbines.eu/publications/spotlight-on/spotlight-on-turbines-and-renewable-gases.html

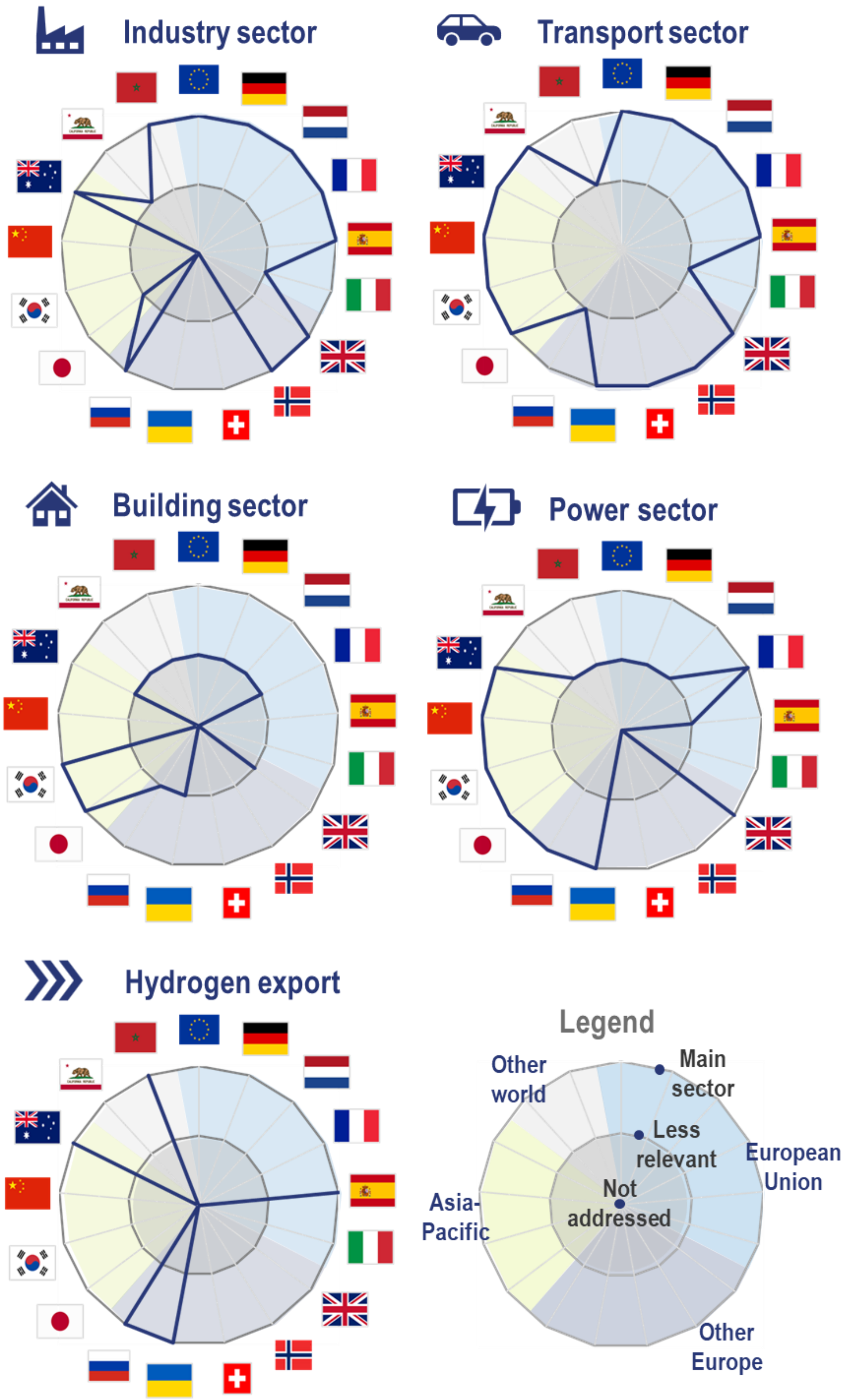


Figure 9: Main target sectors of current hydrogen strategies per country

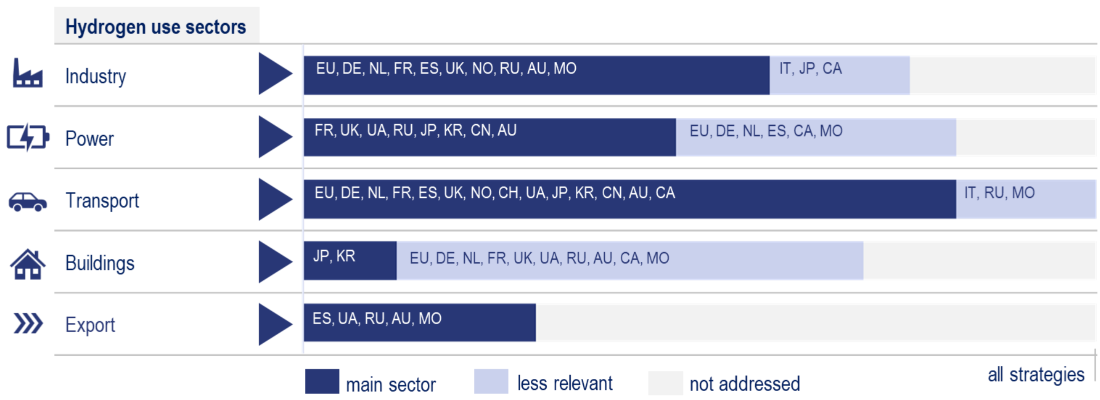


Figure 10: Relevance of target sectors across selected countries

The analysis of the hydrogen strategies in the selected countries shows that the range of applications addressed by a strategy often depends on the time when it was conceived as well as on the ambitions for GHG emission reduction. Typically, newer strategies are characterised by higher and more prominent GHG emission reduction targets. Moreover, increasing GHG emission targets lead to a higher relevance of the industry, building, and power sectors as significant hydrogen consumers; likewise, the absence of these sectors in a strategy is often related to outdated or less ambitious GHG reduction targets. Hence, the newer the strategy, the more ambitious and sophisticated it is on the one hand and the more comprehensive are the discussed applications on the other hand.

However, transport and industry are the most prominent application sectors overall, the latter particularly in countries with a strong industrial sector and a high priority on greenhouse gas reduction.

The possibility of using hydrogen in the industry sector is mentioned by several of the selected countries, although often without concrete steps, actions, or targets. The focus is typically on existing chemical processes such as ammonia or methanol production. In addition, in Europe (EU, DE, UK, FR) hydrogen use in refineries plays an important role due to specific regulations included in the Renewable Energy Directive (RED II)[6]. Steelmaking is recognised by few strategies including EU, DE, UK, FR, and AU, mainly in the long-term as the transition of the sector to an entirely new technology will take time. Detailed results on the envisaged use of hydrogen in industry are summarised in Table 3.

6 Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources.

Table 3: Main target subsectors in industry per country

Industry subsectors	EU	DE	NL	FR	ES	IT	UK	NO	CH	UA	RU	JP	KR	CN	AU	CA	MO
Industry	✓	✓	✓	✓	(✓)	(✓)	✓	✓	✗	✗	✓	(✓)	✗	✗	✓	(✓)	✓
Steel	✓	✓	✗	✓	✗	✗	✓	✗	✗	✗	(✓)	(✓)	✗	✗	✓	✗	✗
Refinery	✓	✓	(✓)	✓	(✓)	✗	✓	✗	✗	✗	✓	(✓)	✗	✗	(✓)	(✓)	✗
Chemicals	✓	✓	✗	✓	(✓)	✗	✓	✓	✗	✗	✓	(✓)	✗	✗	✓	(✓)	✓
Other*	✗	(✓)	(✓)	✓	(✓)	(✓)	(✓)	✗	✗	✗	✗	(✓)	✗	✗	✓	✗	✗

✓ main subsector (✓) less relevant ✗ not addressed

* Glass, electronics, cement industry, mining and process heat generation

The transport sector is targeted by all countries mainly for applications which are hard to electrify such as long-distance trucks, buses, rail, ships, or aviation. While Asian countries such as Japan, South Korea, and China as well as California also focus on using hydrogen in passenger cars, this subsector plays only a limited role in most European strategies. For more details on applications within the transport sector see Table 4.

Table 4: Transport subsectors differentiation

Transport subsectors	EU	DE	NL	FR	ES	IT	UK	NO	CH	UA	RU	JP	KR	CN	AU	CA	MO
Passenger cars	✗	(✓)	✓	✗	(✓)	(✓)	(✓)	(✓)	✗	✓	✗	✓	✓	✓	(✓)	✓	✗
Buses	✓	✓	✓	✓	(✓)	(✓)	✓	(✓)	✗	✓	✗	✓	✓	✓	✓	✓	(✓)
Trucks	✓	✓	✓	✓	(✓)	(✓)	✓	✓	✓	(✓)	✗	✓	✓	✓	✓	✓	(✓)
Rail	✓	✓	✗	✓	(✓)	(✓)	✓	(✓)	✗	(✓)	(✓)	(✓)	(✓)	✓	✗	(✓)	✗
Ships	✓	✓	(✓)	✓	(✓)	(✓)	✓	✓	✗	(✓)	✗	✓	(✓)	(✓)	✓	✓	✗
Aviation	✓	✓	(✓)	(✓)	(✓)	✗	✗	✗	✗	✗	✗	✗	✗	(✓)	✗	✗	✗
Other*	✓	✓	✗	✓	✗	✗	✗	✗	✗	✗	✗	✓	(✓)	(✓)	✗	✓	✗

✓ main subsector (✓) less relevant ✗ not addressed

* Material handling, light utility vehicles, special purpose vehicles (e.g. construction machinery, towing tractors) and drones

Where the building sector is targeted, two major applications are discussed: stationary (natural gas based) fuel cells and hydrogen injection into gas pipelines. Stationary fuel cells are mainly addressed by countries with a relevant technology base like KR, JP, or, to a limited extent, DE. Hydrogen blending is considered usually at distribution grid level, while there is a tendency towards dedicated hydrogen pipelines for transport grid. Gas transport operators have signalled that substantial parts of the current pipeline infrastructure can be adapted to carry hydrogen [Gas for Climate 2020].

It is interesting to note the particular Asian (JP, KE) focus on fuel cell CHP for residential applications, indicating a different strategic approach, whereas the general approach in Europe is to increase the share of low carbon gas, improve building insulation, and keep traditional heating appliances or move to electric heat pumps.

Hydrogen re-electrification is viewed mainly in the long-term to balance out renewable power generation e.g. in AU, UK, or DE. In some countries (e.g. AU) back-up and remote power plays also an important role for hydrogen in the power sector.

As mentioned in the previous chapter hydrogen exports are mainly targeted by countries with large renewable energy potential such as ES, AU, MO, or UA. Often the development of domestic hydrogen demand is considered as a starting point for establishing adequate value chains required for hydrogen exports in the future.

Figure 11 shows expected hydrogen demand as reported by eight individual national hydrogen strategies (UK, KR, DE, FR, NL, MO, CA, NO, AU); other strategies do not mention explicit figures. The overall hydrogen demand accounts for 330-380 TWh_{H2}/a by 2030 and 870-1,600 TWh_{H2}/a by 2050. The comparatively large ranges are based on different scenarios (low and high) for Germany, the UK, Australia, and the Netherlands which are responsible for 55% (low scenario) to 70% (high scenario) of the aforementioned demand by 2050. Scaling upper hydrogen demand expected for 2050 in national strategies to global level indicates a potential of up to 9,000 TWh or around 270 million tons of hydrogen per annum, this is an amount as large as the annual primary energy currently provided globally by renewables.

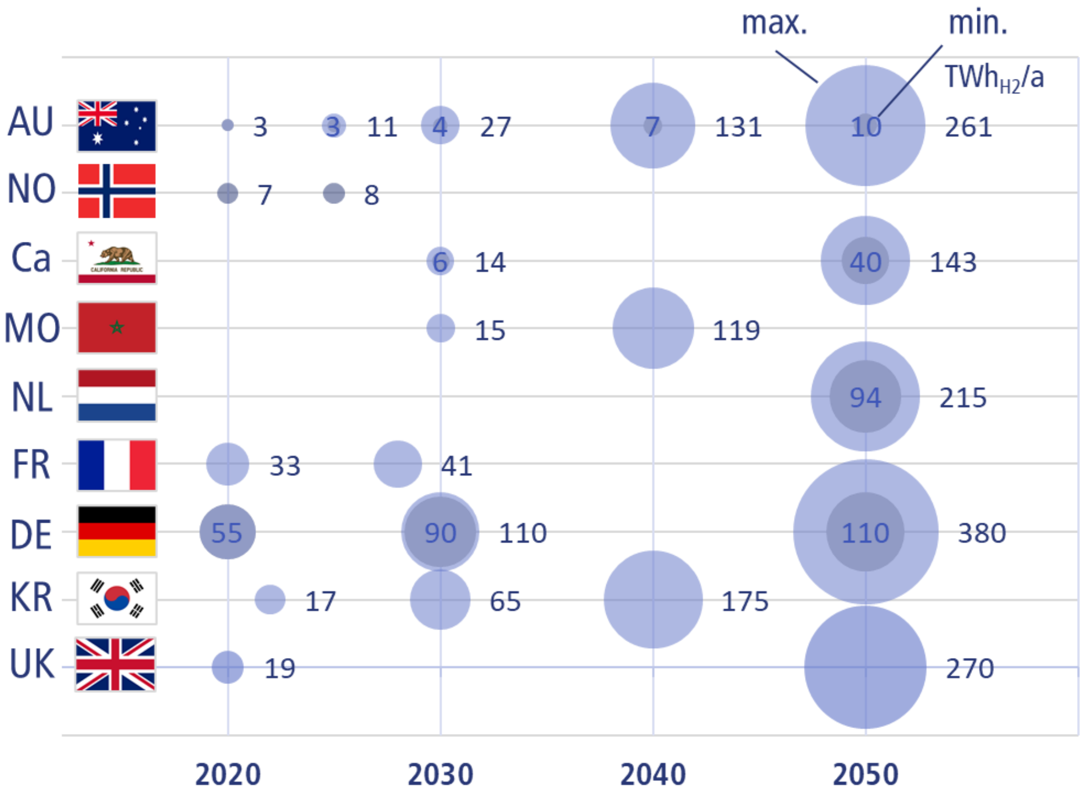


Figure 11: Expected annual hydrogen consumption inTWh$_{H2}$ per year

The expected deployment of the fuel cell road vehicles covered in eight national hydrogen strategies is depicted in Figure 12. Most strategies provide only short- to mid-term figures until 2030 with a total of ca. 6.5 million FCEVs. Most of these vehicles are expected outside of Europe, i.e. in South Korea, Japan, China, and California. Only three strategies include numbers for the time beyond 2030, namely South Korea (for 2040), China, and California (both for 2050) with 6.6, 10, and 17.5 million vehicles, respectively.

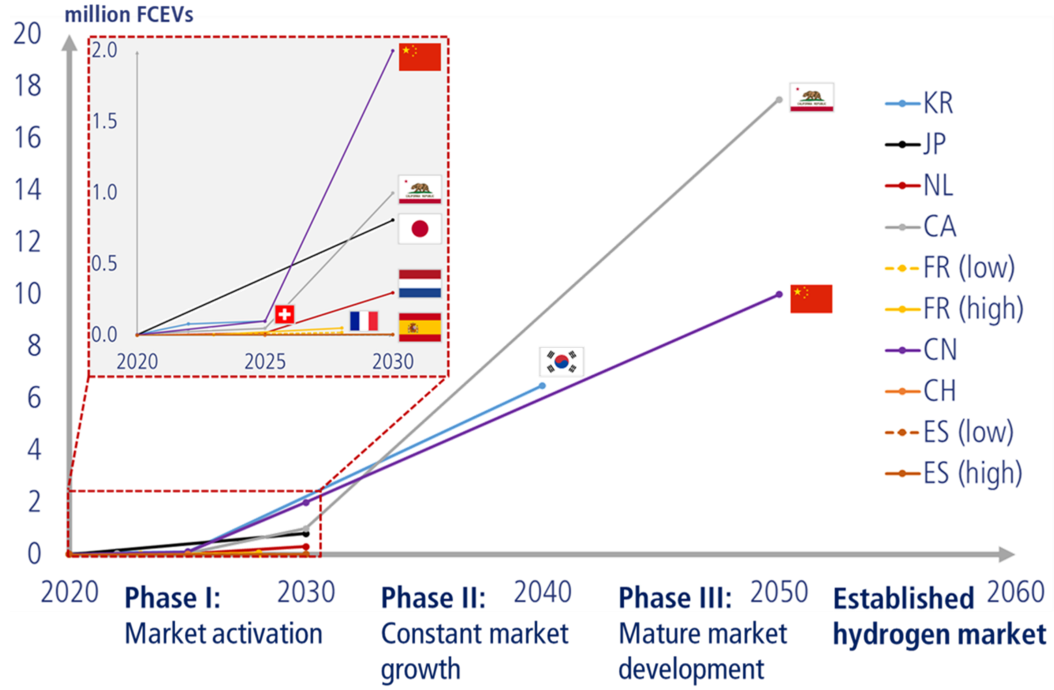


Figure 12: **Expected deployment of fuel cell electric vehicles (FCEVs)**

3.2 Hydrogen imports and plans for national H_2 infrastructures

Hydrogen import will be relevant especially for highly populated industrialised countries, to complement insufficient domestic hydrogen supply due to limited available renewable resources or expected issues with public acceptance of new energy infrastructures. Large-scale long-distance transport of hydrogen enables to tap into foreign (renewable) energy resources in countries offering attractive conditions for low-cost hydrogen production like high solar irradiation, attractive wind potentials and load factors, and available land area. Countries offering fossil resources combined with geological reservoirs for CCS also eye export opportunities into countries where local policies are open to blue hydrogen. Connecting world regions with large and attractive hydrogen production potentials to those with hydrogen production deficits will be a key challenge in the next decades.

There are various hydrogen carriers and transport technologies available to address the import/export and infrastructure challenges[7]. Obviously, compressed gaseous hydrogen (CGH_2) is required as energy input for a number of applications such as FCEVs or industrial processes and therefore plays important role in all selected countries. In this context, some strategies with a significant domestic demand foresee dedicated pipelines for hydrogen

[7] see Annex A for an overview of the technologies and hydrogen carriers involved in large-scale long-distance transport of hydrogen

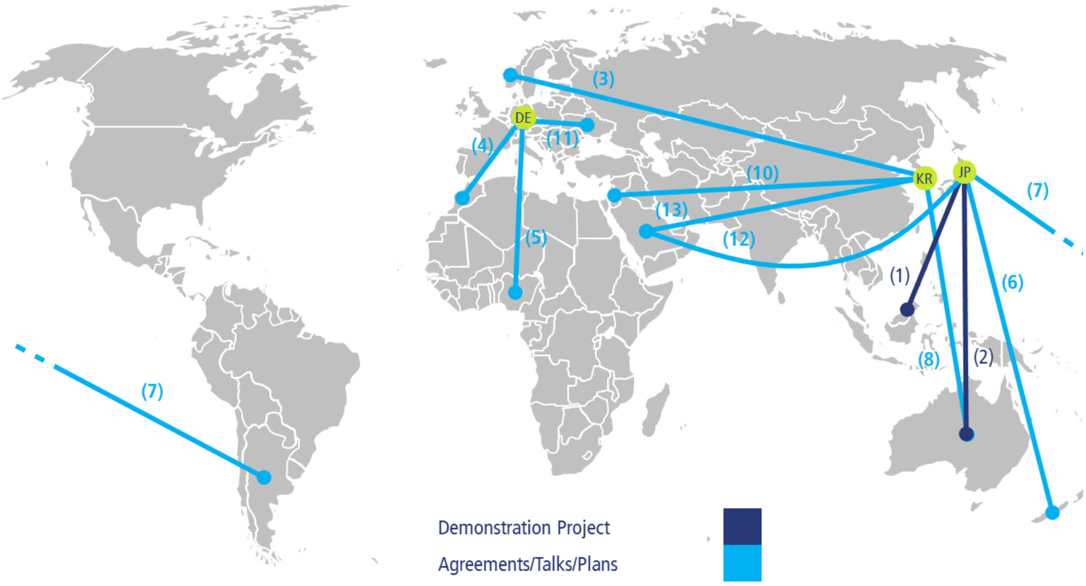
transport within the country (e.g. DE, NL, JP, UK) or for direct hydrogen exports/imports (e.g. MENA-EU). Some countries such as the Netherlands consider creating a backbone of hydrogen pipelines including for transit to neighbouring countries within the next decade, taking advantage of existing hydrogen infrastructure. In addition, blending hydrogen into the natural gas network mainly at distribution level is considered by few strategies (DE, UK, AU, NL) as an additional option to integrate hydrogen into the existing gas infrastructure. In contrast, hydrogen blending into the gas network at high pressure transport level is explicitly excluded or postponed by the British and Australian strategy due to expected safety/technical issues.

Other options for hydrogen exports/imports being currently discussed include transporting liquid hydrogen (LH_2), using liquid organic hydrogen carriers (LOHC), and converting hydrogen to ammonia. Generally, all these can be transported by ship as well as by truck. Although the future of the hydrogen transport technology mix is still open, CGH_2 for shorter distances, LH_2 for longer distances, and pipelines for large volumes seem to be favoured so far. The role of Power-to-Liquids (PtL) both for hydrogen exports/imports and as a fuel for domestic application will be discussed in more detail in the following section.

Establishing supply chains for long-distance transport of hydrogen allowing for import and export requires large investments in production capacity in the exporting countries as well as in the associated logistics infrastructure along the supply chain on both sides. This is currently addressed in bilateral agreements between potential exporting and importing countries, and such bilateral relationships can be expected to prevail in the coming years. Figure 13 provides a non-exhaustive snapshot of established and envisaged relationships of Germany, Japan, and Korea, the main countries preparing for hydrogen, with potential exporting nations. The map shows that Germany is envisioning to tap sources nearby, whereas Japan and Korea need to explore longer distance relationships.

Currently, the most prominent activity is certainly the "Hydrogen Energy Supply Chain Pilot" project between Australia and Japan. In this project, hydrogen from brown coal gasification will be liquefied to cryogenic LH_2 in Hastings, Australia, and sent to Kobe, Japan, by ship [Hystra 2020]. For this project, the world's first ocean-going liquid hydrogen carrier, the "Hydrogen Frontier", rolled down the slipway in December 2019 [Financial Times 2020]. Small-scale pilot operation is planned to start in 2020/2021, large-scale commercialisation of the supply chain is planned for around 2030.

In another project, small amounts of hydrogen were already shipped in a container from Australia to Japan by using the liquid organic hydrogen carrier (LOHC) methylcyclohexane (MCH), in 2019 [AuManufacturing 2020]. In July 2020, a large project that will use ammonia to export renewable hydrogen from Saudi-Arabia was announced [Air Products 2020]. This project is expected to come onstream already in 2025. Further international export/import relations are discussed e.g. between MENA countries and Japan, Korea, and Europe and from South America to future international hydrogen markets.



1	BN - JP	AHEAD demonstration project	▪ hydrogen supply chain utilizing the LOHC methylcyclohexane ▪ operational phase: January 2020 - December 2020; up to 210 tons to be transported
2	AU - JP	Hydrogen Energy Supply Chain Pilot Project	▪ first LH_2 pilot supply chain currently under development ▪ full-scale commercial supply chain operational in 2030 (300,000 t p.a.)
3	KR - NO	MoU	▪ combine Korea's strength in hydrogen vehicles and Norway's in production and supply capabilities ▪ cooperate on technologies and demonstration hydrogen economy (including liquid cargo vessels)
4	DE - MO	MoU	▪ establishment of a hydrogen alliance ▪ Joint project on a hydrogen production plant in Morocco
5	DE - NG	package of measures	▪ joint research hydrogen supply chains in West Africa ▪ expand the strategic partnership
6	JP - NZ	MoC	▪ use New Zealand's abundant renewable energy sources ▪ planned construction of a pilot hydrogen production plant using geothermal energy
7	JP - AR	MoC	▪ promote investments ▪ framework to integrate Argentina to sustainable energy global value chains
8	KR - AU	LOI	▪ develop a hydrogen implementation plan by 2030 ▪ develop joint cooperation projects in the hydrogen field
9	EU - US - JP	Joint Statement	▪ envisaged cooperation → expansion of int. collaboration / scale-up hydrogen in the global economy ▪ initiate and implement an effective framework for cooperation on hydrogen
10	KR - IL	MoU	▪ bilateral cooperation in the hydrogen economy
11	DE - UA	Initial talks and MoU	▪ Hydrogen Bridge Initiative between DE and UA; first talks held in 2019 ▪ MoU between German H2 Association DWV and Eastern European Association for the Development of the Hydrogen Economy
12	JP - SA	Initial talks	▪ Hydrogen from Saudi-Arabia's oil sources ▪ Shipping of ammonia
13	KR – SA	Initial talks	▪ hydrogen from Saudi-Arabia's oil sources
MoU: Memorandum of Understanding; LoI: Letter of Intent; MoC: Memorandum of Cooperation			

Figure 13: Selected international hydrogen import cooperations of JP, KR, and DE (Status June 2020, not exhaustive)

Expected growth of the hydrogen refuelling station (HRS) infrastructure in different strategies is depicted in Figure 14. Typically, HRS deployment is addressed in countries with a strong vehicle industry (e.g. KR, JP, DE) and depends mainly on further development of hydrogen demand in the transport sector. Hence, the level of detail in this respect can vary significantly between the strategies (e.g. no concrete figures for Australia vs. detailed plans for Japan and South Korea). Based on the numbers included in the national strategies or announced in other relevant documents, most countries (CN, FR, CA, JP, KR) expect to reach around 1,000 HRS until 2030 ahead of the actual FCEVs deployment (see also Figure 12). This can be seen as an attempt to solve the chicken-and-egg problem between the infrastructure and FCEV fleet development. Surprisingly, in Germany as a country with the most HRS in Europe (ca. 100 HRS in 2020) and a dedicated infrastructure company, H2 MOBILITY, future plans are vague, predicting additional 300 HRS after 2020 depending on the evolution of new FCEVs figures [H2 MOBILITY 2020]. Other countries (NL, ES) expect even lower number of HRS until 2025-2030.

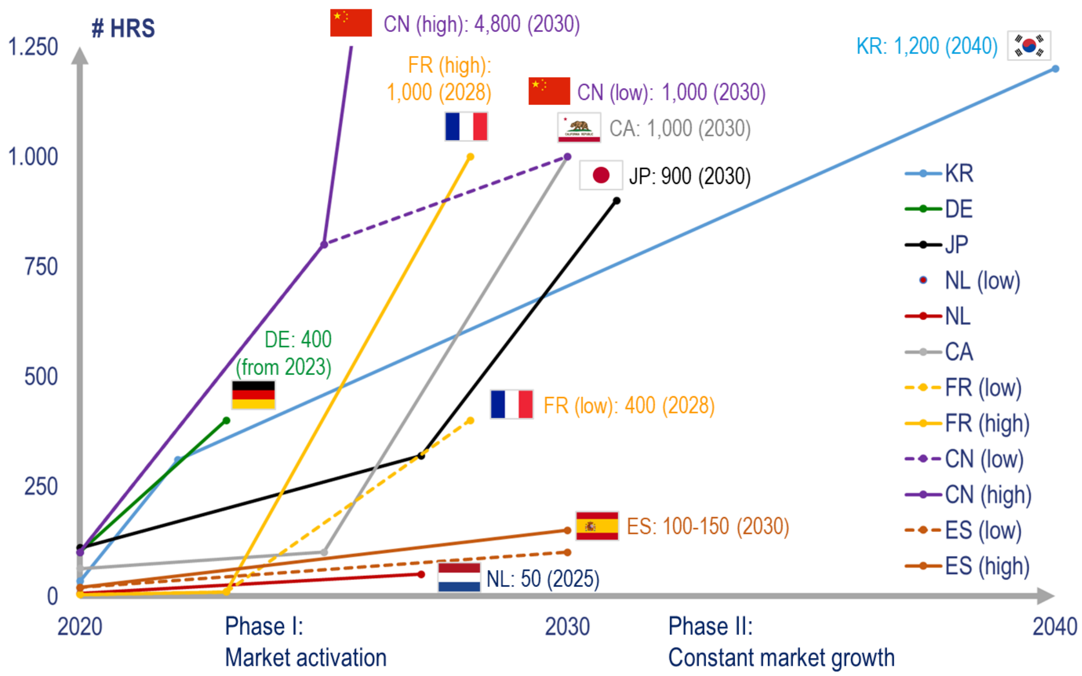


Figure 14: Expected hydrogen refuelling station (HRS) growth

3.3 Role of e-fuels

In the context of this study e-fuels are defined as synthetic fuels produced from (renewable) hydrogen. In a broader sense such production process can cover liquid fuels such as synthetic diesel, gasoline, or kerosene (the conversion processes are also known as Power-to-Liquids - PtL), synthetic methane (also known as Power-to-Methane - $PtCH_4$), as well as ammonia and methanol. Apart from ammonia, all other e-fuels require the addition of carbon, usually in the form of carbon dioxide, which is generally taken from the atmosphere[8].

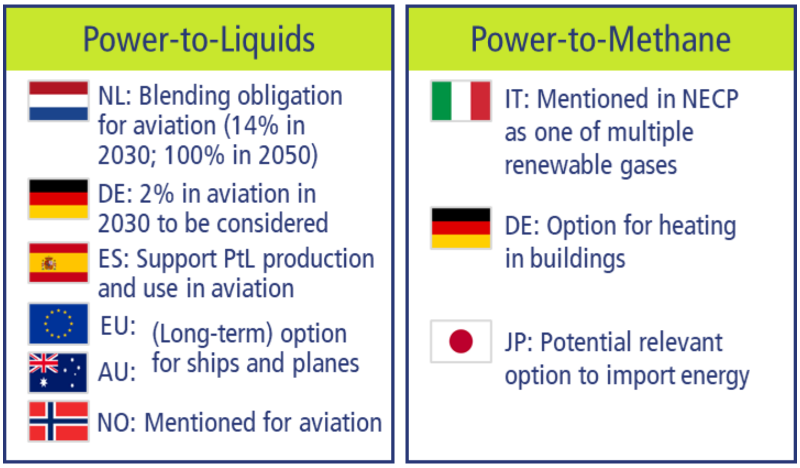


Figure 15: Role of Power-to-Liquids (left) and Power-to-Methane (right) in national hydrogen strategies

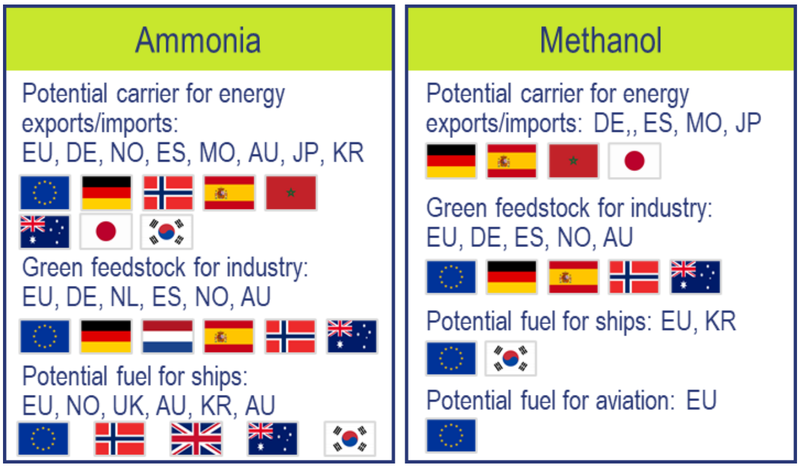


Figure 16: Role of ammonia (left) and methanol (right) as energy carrier in national hydrogen strategies

In general, e-fuels provide an additional option for hard to decarbonise applications e.g. in the transport sectors and can be used as a high-density energy carrier for long-distance energy transport without significant changes in the engines or supply infrastructure. Hence, PtL is mainly viewed by some national strategies (NL, DE, ES, EU, AU, NO) as an important

8 While local sources of concentrated non-fossil carbon exist, available volumes are not sufficient to meet large scale production needs.

fuel in the aviation and maritime sectors (Figure 15 left). For example, the Dutch strategy plans a PtL-blending obligation of 14% for aviation in 2030 and expects full substitution of fossil fuels in this sector until 2050. Also, the German strategy calls for a discussion of a PtL share of 2% in the aviation fuel mix until 2030[9]. In contrast, $PtCH_4$ is less prominent within the national strategies of the selected countries, being mentioned only as an alternative within the gas infrastructure (IT, DE) or considered as a potentially relevant option to import energy (JP). As shown in Figure 16 ammonia and methanol are mainly viewed as potential ship fuels (e.g. EU, AU, NO, UK) or as a carrier for energy exports and imports (DE, MO, JP, KR, AU).

At present, national strategies mainly focus on hydrogen and less on other fuels derived from it. As a result, e-fuels only play a limited role in the national strategies and are mentioned mainly in the more recent and more advanced ones. As a result, the potential role of e-fuels merits a more detailed discussion within the further development of the national strategies.

3.4 Hydrogen carriers

While hydrogen has the highest gravimetric energy density (kWh/kg) of all chemicals, the volumetric energy density (kWh/litre) of hydrogen at ambient temperature and pressure (15°C, 0.1 MPa) is very low. As a result, it needs to be conditioned or converted into a higher volumetric density form in order to facilitate long range transport of larger volumes. The most relevant options are pressurising the gas (compressed gaseous hydrogen CGH_2), liquefaction (liquefied hydrogen LH_2), liquid organic hydrogen carriers (LOHCs), and conversion into a higher density chemical:

- **CGH_2**: Like for any gas, compression reduces volume and increases the volumetric energy density. This is used for pipeline transport and storage e.g. in vehicle tanks.
- **LH_2**: Hydrogen becomes (cryogenic) liquid at a temperature of -253°C. During liquefaction, the energy density increases by almost 3 orders of magnitude.
- **LOHC**: LOHCs are liquid organic substances that can absorb hydrogen by chemical bonding and release it again by supplying high temperature thermal energy. Prominent examples for LOHCs are dibenzyltoluene and methylcyclohexane.
- **Chemicals**: Candidates for potentially suitable chemicals in principle include ammonia as well as methanol and other more complex hydrocarbons. Generally,

9 Based on the 2018 kerosene consumption in Germany, the 2% green kerosene quota would require an electrolyser with a power rating of around 0.5 GW to produce the necessary green hydrogen.

more complex hydrocarbons have a higher volumetric energy density, but will also require more effort for extracting the hydrogen.

Figure 17 (taken from Annex A) shows an overview of selected hydrogen carriers along with their volumetric and gravimetric energy densities. The choice of hydrogen transport vector, meaning the hydrogen carrier including the conversion and storage technologies, for long-distance transport of hydrogen will eventually be made based on the resulting economy of the entire supply chain for a given transport relation, CAPEX and OPEX of each step along the supply chain being the relevant parameters. Processes to consider include conditioning or conversion, storage, transport, and conditioning or extraction.

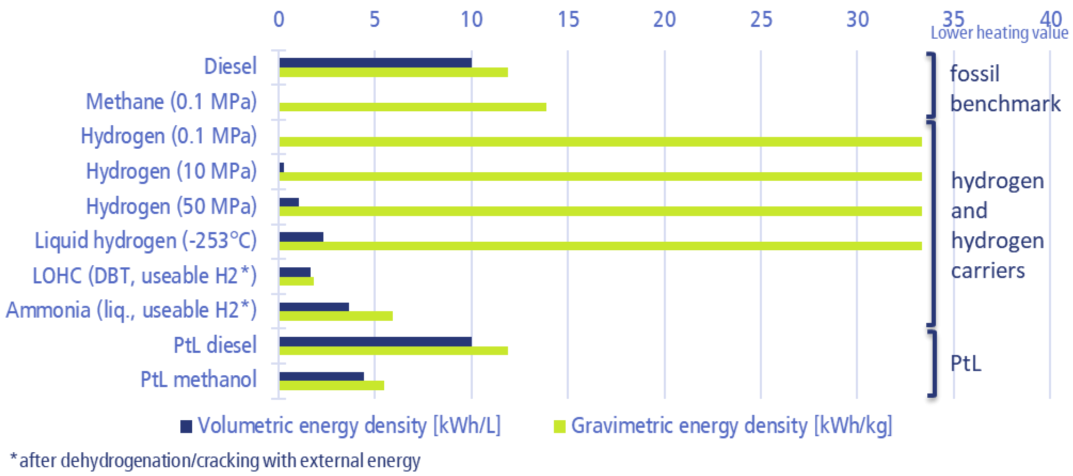


Figure 17: Comparison of energy densities of different energy carriers

For economic reasons, converting hydrogen into a more complex higher density chemical is mainly discussed for projects, where the respective chemical is used as such and no reconversion to hydrogen is necessary.

Annex A provides a more comprehensive overview on hydrogen carriers, supply chain considerations, available technologies, cost structure, and advantages and disadvantages of selected hydrogen transport vectors.

4 WHICH SUPPORT STRATEGIES OR MEASURES ARE DISCUSSED?

R&D activities, regulatory measures, as well as financial aid are in place or planned in almost all analysed countries to support the development, demonstration, and deployment of hydrogen and hydrogen technologies.

Sectoral quota for green feedstock and fuels in industry and transport can stimulate large scale demand.

Moving from CAPEX to OPEX support will help to establish sustainable business cases for operators.

Public acceptance is understood as crucial to successful technology deployment.

European envisaged public funding is large, ranging from 22-42 B€; however, some of that applies to a broader range of technologies where hydrogen is one of several options.

Looking at 2050, over half of the countries analysed focus on using green hydrogen sourced from renewable energy only. Other types low carbon hydrogen are seen as an effective and pragmatic way to ramp up volumes in the interim.

4.1 Government activities supporting H_2 technologies and applications

A broad range of existing and planned regulatory measures to support hydrogen are implemented and discussed within the analysed countries. They can be grouped into five major categories:

- **Research and development (R&D)** with the main objective to improve hydrogen technology
- **Regulatory measures** to set specific boundary conditions for the development of hydrogen related value chains and markets
- **Financial support** providing different kinds of funding budgets for the build-up and operation of hydrogen technologies at all value chain steps
- **Acceptance and training** aiming at spreading hydrogen-related knowledge and gaining acceptance for all stakeholders
- **Governance and other measures** monitoring and steering the implementation of national hydrogen strategies based on a set of different governance and control instruments

The development, demonstration, and deployment of hydrogen and hydrogen technology is backed in almost all analysed countries by supporting R&D activities, regulatory measures, as well as financial support (see Figure 18 and Table 5). The remaining categories for measures shown in Figure 18 are only addressed by advanced strategies with a more comprehensive scope (e.g. DE, AU, JP). In this context, the range of support instruments and mechanism is broad with a different focus based in each country based on national interests and preferences.

However, strategies generally focus more on targets for green hydrogen production and technology deployment than on measures supporting these targets. Many policies in place are still focused on R&D-oriented action, which remains relevant but less important than fostering commercialisation. In most cases, policy development is lagging behind the strategic ambitions and current measures are insufficient to catalyse the envisaged strong growth. New policies required to achieve these targets are still being discussed and are only starting to emerge.

In most countries, R&D support aims at practical R&D activities such as demonstration projects on all elements of the hydrogen value chain as a strategy to activate the market. Hence, the major objectives are technology cost reductions, efficiency improvements, and gaining experience with key hydrogen technologies as an element of market preparation. For example, in the Netherlands, applied research and innovative actions are supported in different MOOI (Mission-oriented Research, Development and Innovation) tenders and programs such as the DEI+ (Energy Innovation Demonstration Scheme). In Japan, R&D budgets of 25 and 20 M€ were made available in 2018 for fuel cells and hydrogen refuelling, respectively. In the same year, 83 M€ were available for hydrogen supply chain, Power-to-Gas and hydrogen to power technologies. There is also a tendency towards moving from showcasing individual technology pilots towards demonstrating entire hydrogen value chains, successful programmes having e.g. been launched by the European Fuel Cells and Hydrogen Joint Undertaking FCH JU ("hydrogen valleys") as well as in the Netherlands and in Germany.

Table 5: Existing and planned hydrogen support measures by country

Support measure type	EU	DE	NL	FR	ES	IT	UK	NO	CH	UA	RU	JP	KR	CN	AU	CA	MO
R&D support	++	++	++	++	++	+	++	+	o	+	++	++	++	++	++	+	++
Regulatory measures	++	+	++	+	++	+	+	+	+	o	+	++	++	++	++	+	+
Financial support	++	++	++	+	++	+	+	+	+	o	+	++	++	++	++	++	+
Acceptance and training	+	+	o	+	+	o	o	+	o	o	o	+	+	o	++	++	o
Governance and other	+	++	+	+	+	+	o	o	o	o	+	++	++	o	++	++	o

++ Strong focus   + Less pronounced   o Not mentioned

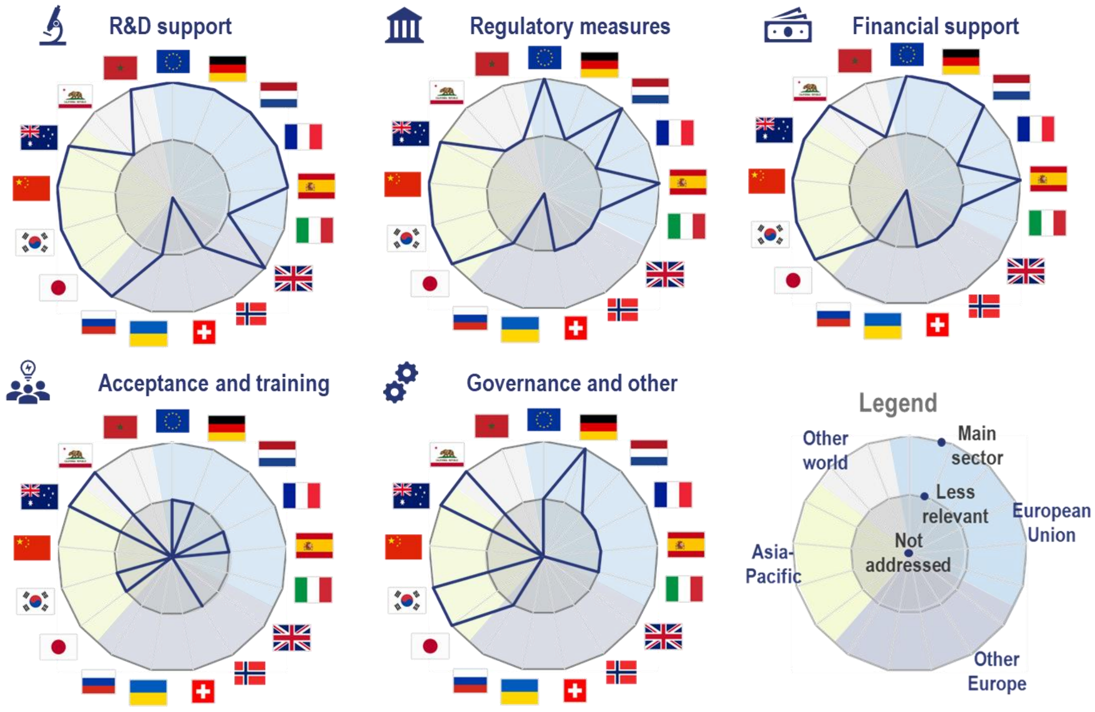


Figure 18: Existing and planned hydrogen support measures by country

Regulatory measures such as legislative actions can be viewed as a very strong and direct instrument to support hydrogen technology. Quota for renewable or hydrogen technologies in certain markets are a prominent example of such measures, have been applied successfully. Examples, not all exclusively aimed at hydrogen, include the mandate for zero emission vehicles in CA, the renewable energy quota of the European Renewable Energy Directive, and the possibility of mandating a PtL share in the aviation sector as mentioned in the NL and DE strategies. In South Korea, the Renewable Portfolio Standard Policy (established in 2012) requires large power producers to meet a minimum portion of their power generation from new and renewable technologies, including fuel cells. Alternatively, they can purchase Renewable Energy Certificates to meet their obligation with a mandatory share rising from 7% in 2019 to 10% by 2022. The certificates are issued per MWh multiplied by a weighting factor for specific generation technologies. Generation from fuel cells is weighted with 2, onshore wind has a weighing factor of 1.

Another strong regulatory instrument, quite complementary to quota, is the banning of specific technologies, notably in the transport sector, the Dutch ban of diesel buses and the plan to put into service only zero emission buses for public transportation from 2025 being an example.

On a general note, it is of course important to allow for hydrogen and hydrogen-derived fuels to count towards the respective policy targets. A prominent example is the change in EU Renewable Energy Directive recast (RED II) compared to the incumbent directive, now allowing green hydrogen in refineries to count towards the RED II renewable energy share in transport, whereas in the current Fuel Quality Directive (2009/30/EC), the renewable quality of hydrogen used within a refinery is not accounted for.

Finally, the harmonisation of legislation on the one hand and standards, codes and approval mechanisms, and review of regulation (e.g. for gas infrastructure) on the other hand are expected to play a relevant role. For instance, on the one hand, the Japanese government supports the revision of a variety of codes and standards for fuel cells and hydrogen infrastructure. This will lead to an adaptation of the currently rather strict regulation on hydrogen refuelling stations, reducing the related refuelling costs. On the other hand, countries such as Australia or several European countries as well as the EU are going to review current legislations to support hydrogen technologies. For example, the EU will revise the Energy Taxation Directive to avoid double taxation of hydrogen. Generally, in Europe the EU Directives play an important role for activities and measures in individual Member States (e.g. AFID[10], RED II[11], CVD[12]). Hence, the regulations in the Member States are often similar and national governments (e.g. NL, DE) plan to use the implementation of European Directives into national law to stimulate hydrogen activities.

The actual financial support for hydrogen technologies in individual countries depends on the corresponding economic strength and advancement of the hydrogen strategy. As a good practice, coordinated, strong, continuous, and focused financial support enables the creation of nuclei for hydrogen technologies (e.g. fuel + station + vehicle). In this context, rather than providing funds for initial investments, most of newer financial support instruments aim at supporting the operating cost differential to incumbent technologies and solutions, e.g. through reduced road toll/fees as in Switzerland or through so-called carbon contracts for difference (CCfD) as suggested in the German and European strategy.

As shown in Table 6 the envisaged public funding budget in Europe is very large ranging from 22-42 B€. However, it is important to note that some of the budget figures included here are not solely dedicated to hydrogen technologies but to a broader range of technologies where hydrogen is one of several options (e.g. for battery electric and fuel cell electric vehicles).

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[10] Alternative Fuel Infrastructure Directive: Directive 2014/94/EU of the European Parliament and of the Council of 22 October 2014 on the deployment of alternative fuels infrastructure

[11] Renewable Energy Directive: Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources.

[12] Clean Vehicles Directive: Directive (EU) 2019/1161 of the European Parliament and of the Council of 20 June 2019 amending Directive 2009/33/EC on the promotion of clean and energy-efficient road transport vehicles

Table 6: Public funding budgets in Europe

Country	Funding budget	Details	Source
EU	1-11 B€	• 10 B€ ETS innovation fund (not only for H_2 but for low-carbon tech.) • 665 B€ for FCH2 JU via the European Horizon 2020 Framework Program	Public announcement
Germany	13-21 B€	• NIP funding (2016-2026): 1.4 B€ • Basic H2 research (2020-2023): 310 M€ • "Reallabore" (2020-2023): 600 M€ • National decarbonisation programme in industry (2020-2023): > 1B€ • "Zukunftspaket Markthochlauf": 7 B€ • International partnerships: 2 B€ • Energy and Climate Fund (Energie und Klimafonds EKF): total 8.1 B€ cars 2.1 B€; LDVs 0.9 B€; buses 0.6 B€; e-fuels 1.1 B€; charging and refuelling infra. 3.4 B€ • FC heating appliances: 700 M€; Hybrid-electric aviation: 25 M€; Zero-emission ship: 25 M€	Hydrogen strategy
UK	307-975 M€	• Low Carbon Hydrogen Production Fund: 110 M€ (100 million GBP); Hydrogen Supply Competition: 36 M€ (33 million GBP) • Industrial Fuel Switching Competition: 22 M€ (20 million GBP); Industrial Energy Transformation Fund: 345 M€ (315 million GBP); Energy Revolution Challenge: 113 M€ (103 million GBP); Clean Steel Fund: 275 M€ (250 million GBP) • Hy4Heat programme: 28 M€ € (25 million GBP); Alterative H2 heating: 33 M€ (3 million GBP) • Innovative large-scale energy storage solution competition: 22 M€ (20 million GBP) • Ultra-low emissions bus scheme competition: 5 M€ (4.4 MGBP); Hydrogen for Transport programme: 15 M€ (14 MGBP)	Public announcement
France	> 7 B€	• 100 M€/a for the implementation of the hydrogen deployment plan • 50 M€/a from multi-annual Energy Programme (PPE): support for decarbonated H_2 • 7 B€ for the development of a green hydrogen economy	H_2 deployment plan (2018) H_2 development plan (2020)
Netherlands	35-45 M€/a	• Ca. 35 M€/a within DEI+ to support operating costs of green hydrogen production • Ca. 10 M€/a between 2019 and 2025 for zero-emissions buses	Hydrogen strategy
Norway	67-78 M€	• PILOT-E programme in 2019: 7 M€ (71 MNOK) • Ca. 50 M€ (550 MNOK) by Norwegian Research Council for H_2 technologies • Unspecified funding as part of COVID-program of 11 M€ (120 MNOK) expected • Fast ferry program: 10 M€ (205 MNOK)	Hydrogen strategy
Ukraine	110,000 €	• Research on wide range of hydrogen technologies for Ukrainian Academy of Sciences	Public announcement

The largest budgets considered in the national strategies come from Germany (13-21 B€), France (7 B€ for hydrogen as part of the 100 B€ recovery plan[13], and 150 M€ p.a. from the 2018 hydrogen deployment plan) and the European Union (1-11 B€), indicating a strong commitment within their respective strategies. In Europe, additional funds can be provided

[13] Announced by French economy minister Bruno Le Maire on 7 Sep 2020; a national strategy for the development of decarbonised hydrogen was subsequently announced on 8 Sep 2020.

by individual Member States within the so-called Important Projects of Common European Interest (IPCEI) which allow for direct state aid for selected hydrogen-related projects.

Table 7 provides an overview of public funding budgets for hydrogen announced in the rest of the world. According to the data, strong commitment can be expected in Japan, South Korea, California, and Australia with a budget of between 200-400 M€ in each country or more than 1 B€ in total. In Russia, only a portion of the research program of 1 B€ dedicated to nuclear power would be used for hydrogen technologies. In China, the presented figures indicated past FCEV subsidies, on the one hand, and the estimated market size for hydrogen technologies, on the other hand, as information on concrete funding budgets is hardly available.

Table 7: Public funding budgets in rest of the world

Country	Funding budget	Details	Source
Japan	231-357 M€	• METI budget for hydrogen and fuel cells (2018): 221 M€ • R&D budget for power-to-gas technology (2017): 10 M€ • Subsidies for clean energy vehicles (2018): 126 M€	Public announcement
Korea	234 M€	• IPP budget for hydrogen (2019): 82 M€ • Hydrogen R&D and development budgets (2019-2013): 88 M€ • Ansan, Ulsan, Wanju/Jeonju as candidate cities for the hydrogen economy: 64 M€	Public announcement
China	11 B€	• FCEV subsidies in 2018: 11 B€ • Estimated market size in H2&FC: 39 B€ (2020); 130 B€ (2030)	Public announcement
California	178 M€	• Assembly Bill No. 8 in total by 2023 for up to 100 public HRS: 55 M€ (65 M$) • Clean Transportation Program renewable H_2 production: 7 M€ (8 M$ 2 projects) • lean Transportation Program renewable for 64 public HRS + fleets: 116 M€ (136 M$)	Public announcement
Australia	403 M€	• Hydrogen funding at Commonwealth level: 305 M€ (500 MAUD) • State governments funding: 98 M€ (160 MAUD)	Public announcement
Russia	1 B€	• Research programme "Atomnaja Nauka, Technika i Technologii" including commercial production of hydrogen in nuclear power plants until 2025	Public announcement

Acceptance and training related issues are addressed only by few countries typically with more advanced strategies. The corresponding measures include a wide range of knowledge management as well as campaigns and activities to introduce the opportunities of hydrogen to a broad public. A good example is found in the Australian strategy advocating explicit participation of local communities in economic benefits from the development of the hydrogen technology and value chains. Some strategies also foresee professional training for technical and rescue forces which are expected to cope with the hydrogen technology in the future.

Governance structures are also typically considered by more sophisticated strategies. Dedicated advisory groups usually consisting of industry, academia, and government are often a core element in the formulation and/or implementation of further hydrogen-related activities in various countries (e.g. JP, KR, DE, AU, IT). For example, the German strategy provides a detailed description of future governance structures including a committee of undersecretaries from selected ministries as well as a “National Hydrogen Council” and a central office to support the decision making. In South Korea, a “Hydrogen Economy Promotion Committee” was established in 2020 to put the hydrogen roadmap into action and to serve as a pan-governmental control tower. In addition to the classical governance structures, international cooperation is recognised as a key strategic element in most countries. Its practical implementation is usually expected to be addressed directly at the governmental level. Moreover, due to the request for renewable hydrogen, many strategies underline the need and importance of global hydrogen certification mechanisms.

4.2 Hydrogen sources

Hydrogen can be produced from various feedstocks and using different technologies. The most relevant differentiator between the source options is the level of the associated GHG emissions. These include emissions from the hydrogen production process itself but also from the feedstock or electricity supply.

Renewable hydrogen is usually defined as hydrogen from water electrolysis using renewable electricity (e.g. from wind and solar energy). It is usually considered to be carbon neutral. Sometimes, hydrogen from biomass is also labelled as ‘renewable hydrogen’, but will generally have a larger carbon footprint. Fossil-based hydrogen with carbon capture and storage (CCS) technology as well as hydrogen from methane pyrolysis, where the carbon is disposed of, are also associated with a low carbon footprint. In these cases, remaining GHG emissions result e.g. from upstream emissions like incomplete CO_2 extraction from the flue gas and/or emissions related to methane leakages during natural gas production and transport. Fossil feedstock e.g. for natural gas reforming or coal gasification (without CCS) is dominating today’s hydrogen production. Today, there is no internationally agreed terminology or carbon-intensity threshold for the categorisation of hydrogen production options. However, the European Union is supporting the creation of a classification as part of a scheme for guarantees of origin for low carbon hydrogen within the CertifHy project.

All analysed countries are quite aware of the relevance and importance of low-carbon and renewable hydrogen to be able to achieve mid- and long-term GHG emission targets; however, they take differing approaches on their respective paths towards a zero emission future (Figure 19).

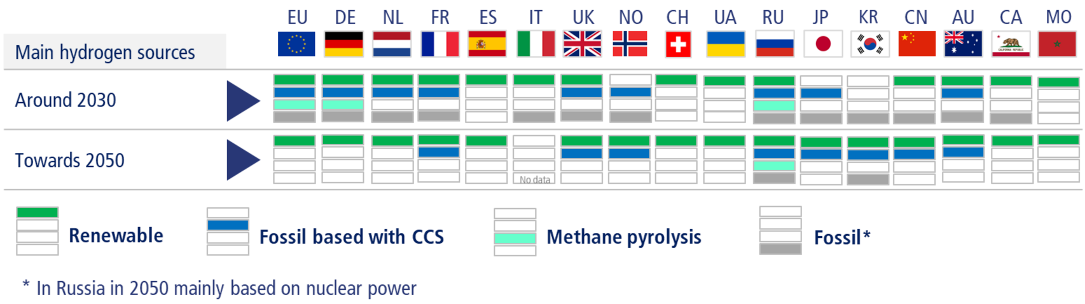

Figure 19: Considered medium- and long-term hydrogen production options by country

In the medium-term (around 2030), renewable and fossil-based hydrogen (with and without CCS) are generally considered viable options by most countries; some mainly make renewable (and existing fossil-based) hydrogen subject of the discussion. However, this is usually related to the limited scope of the discussion (e.g. only addressing additional hydrogen production for the transport sector) or the good availability of renewable energy. In the 2030 timeframe, renewable hydrogen plays a lesser role in the hydrogen strategies of South Korea and Japan. The Japanese strategy is very much focused on cost efficient production and import of hydrogen, addressing the switch to renewable hydrogen in the years after 2030. The Korean strategy is driven by economic growth and technology leadership in the end-use sector. In addition, Korea has rather low GHG reduction targets. As a result, Korea only plans to move to renewable and low-carbon hydrogen sources at a relatively late stage compared to other countries. In fact, fossil-based hydrogen (without CCS) is planned to still play a major role in 2040. Hydrogen production from methane pyrolysis is only addressed as a medium-term bridging technology in the official hydrogen strategies of Germany and the European Union, while Russia also sees a potential role in the longer term. However, broader discussions about methane pyrolysis only popped-up a few years ago along with a few more prominent international research projects in the field, this possibly being the reason for limited appearance in official strategy papers and discussions.

Towards 2050, renewable hydrogen is considered to be significant by all countries. In fact, a range of countries consider renewable hydrogen as the only long-term option (NL, ES, UA, DE, CH, MO, EU). Other countries also accept fossil-based hydrogen with CCS, so-called blue hydrogen, as a long-term option in their plans (UK, JP, KR, AU, FR, CN, NO, RU).

As shown in Figure 20, some countries set ambitious targets for renewable hydrogen production, e.g. up to 950 TWh_{H2}/a in 2050 in Australia, up to 300 TWh_{H2}/a in EU in 2030 or ca. 100 TWh_{H2}/a in 2050 in Ukraine. Figures for the corresponding required large electrolysis capacities, however, are provided by only few strategies (see Figure 21): 40 GW in EU until 2030, 10 GW between 2035 and 2040 in Germany, and 3-4 GW in the

Netherlands, 4 GW in Spain, and 6.5 GW in France until 2030. The EU target alone signals a cumulative market of over 40 B€ for green hydrogen production equipment until 2030.

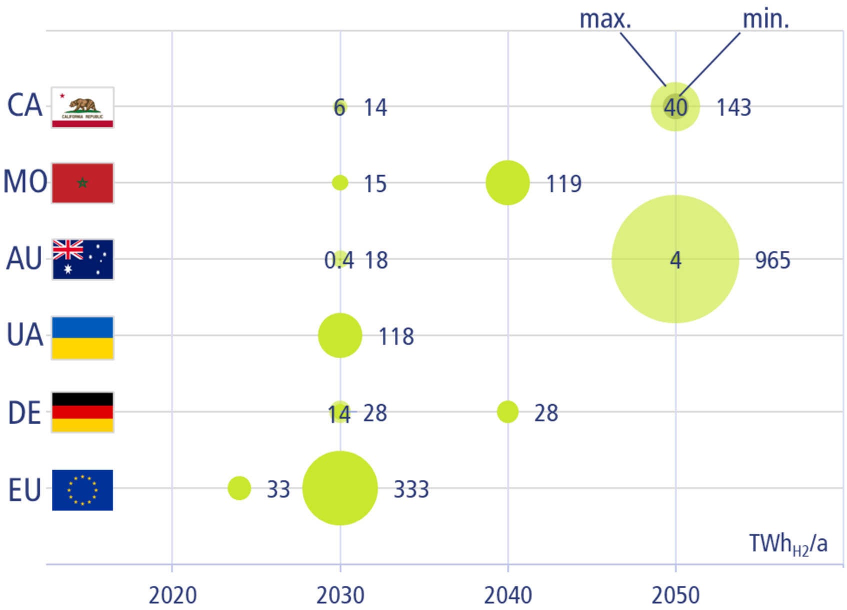

Figure 20: **Targeted renewable hydrogen production**

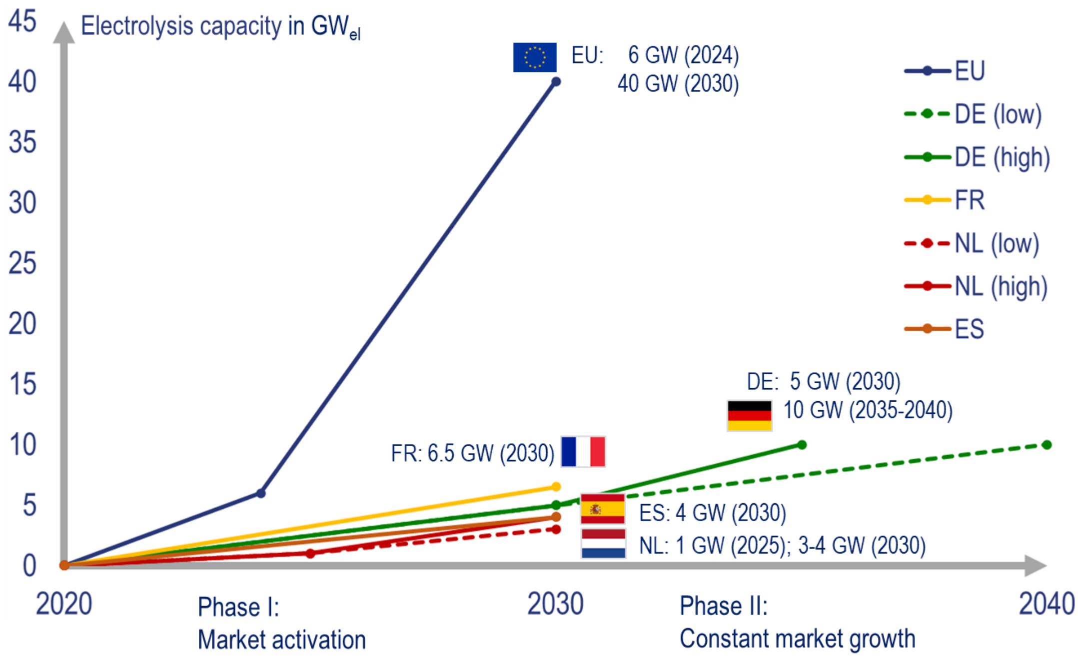

Figure 21: **Targeted electrolysis capacity**

Today's Power-to-X (PtX) demonstration plants are in the single digit Megawatt range at best. The above large-scale production plans signal a transition to plants which are at least two orders of magnitudes larger and a stark move to an industrialisation of the sector. This striking development can be seen in Table 8, showing the number and capacity of current and announced PtX plants in the selected countries.

Table 8: PtX plants ramping up fast in the selected countries (data source: LBST)

	EU	DE	NL	FR	ES	IT	UK	NO	CH	UA	RU	JP	KR	CN	AU	CA	MO
PtX plants in operation	64	34	2	8	1	4	4	1	5	0	0	15	0	1	3	1	0
PtX MW in operation	57	29	1	1	<1	1	3,5	1	1	0	0	11	<1	<1	6	<1	0
PtX plants in preparation*	160	77	14	19	8	4	16	13	2	0	0	2	1	7	10	3	1
PtX MW in preparation*	9500	750	3800	1.600	161	2000	308	288	40	0	0	0	~10	5200	20	3	100

*announced, studied, under construction; incl. plants without detail on size (as of July 2020)

5 WHAT HAS BEEN ACHIEVED AND WHAT CAN BE LEARNED SO FAR?

The countries selected for analysis in this study represent widely varying background regarding their respective history and ambition in the hydrogen sector. The level and nature of the progress regarding the deployment of hydrogen technologies, applications, and infrastructure obviously depend in particular on when activities have started. The European Union has already been supporting R&D projects for two decades and countries like Germany and Japan are already looking at a similarly long history of deployment and experience, while activities in other countries only started gaining momentum in recent years (e.g. AU, K, CH, UA, MO). Nevertheless, successful deployment can be found across the board and they can be traced back to a few triggers, notable examples of which are provided below.

Table 9: Overview of policy achievements, triggers, and associated learnings

Achievement	Trigger	Learnings
German HyLand funding call initiated strong and comprehensive regional planning activities which continue even without funding	3-tiered funding call supporting concepts, project design, and implementation	• Move from isolated pilots to demonstrating comprehensive value chains • Support collaboration • Target commercialisation
Successful establishment of strong regional clusters in e.g. CA, Northern IT, and NL	Dedicated local authorities using available opportunities and funds	• Provide early support to thought leaders and regional initiatives
Successful volume micro-CHP FC deployment	Ene-Farm programme: deployment since 2009, preceded by field-testing and large-scale monitoring	• Endurance pays off • Long-term programmes enable industrial development and cost reduction
Dynamic hydrogen ecosystem development in Australia driven by government and industry	Japanese projects for hydrogen import	• Leverage international cooperation • Identify opportunities for economic growth
Large-scale electrolysis projects developing in and around refineries	RED II allowing for green hydrogen in refineries to count towards GHG reduction targets	• Tailored regulatory incentives work • Identify the right levers enabling early business cases
Alstom, Hyundai, and Toyota see their R&D investment bearing fruit	Dedicated individuals in corporations	• Support early movers in industry
Refuelling infrastructure emerging in several countries	Government support leveraging private investment	• Public-private partnerships help to align interests of industry and government
FCEV vehicle deployment	Regulatory measures (road tax reduction, ZEV quota)	• Targeted regulatory incentives work • Identify the right levers enabling early business cases

5.1 Achievements and triggers

The current move from R&D support, which has been the dominant public support mechanism in the past, to supporting commercialisation and the demonstration of entire value chains has helped to create large and successful partnerships, mobilising sizeable private investment. Examples include the German HyLand funding programme, which initiated strong and comprehensive regional planning and demonstration activities, some of them even continuing without funding, and the European hydrogen valley initiative that has led to HEAVENN projects in the North Netherlands, which is expected to also become the home to even larger and more comprehensive projects[14].

Regional clusters of players have emerged around the world, initially triggered by dedicated individuals or small groups of people in regional governments and administrations. Examples include the above activity in the North Netherlands, the Italian cluster in Northern Italy around Bolzano and the public-private partnerships in the Heide region in Northern Germany, as well as the long-standing hydrogen focus in the US state of California. Other early mover examples include the fuel cell trains developed by Alstom, which have benefitted from the opportunity to quickly enter into regular service in North Germany, and the early development by Hyundai of FCEV in South Korea, which are now an important cornerstone in the national hydrogen strategy. Identifying these early movers and providing adequate support as well as forging and fostering public-private partnerships are important for such activities to bear fruit.

It takes a lot of time to develop industrial and residential markets and to mature the required technologies and solutions. Therefore, it is important to provide a reliable and long-term framework for industrial investment and tailor support programmes such that stakeholders remain on board for the long period until commercialisation. The Japanese "Ene-Farm" programme for installing residential micro-CHP fuel cells has started in 2009, preceded by field-testing and large-scale monitoring, clearly shows that endurance pays off. It is by now the largest and most successful volume deployment of this technology and has enabled Japanese technology companies to globally lead in this sector.

Large-scale electrolysers are being planned in Europe in and around refineries, based on the EU Renewable Energy Directive recast (RED II) that now allows green hydrogen in refineries to count towards the renewable energy share in transport required in RED II. This is a good example showing that tailored regulatory incentives work well if they include the right levers enabling early business cases. It is interesting to note that the underlying policy mechanism is a renewable quota for transport fuels, in this case leveraging significant private investment. Regulatory incentives have also helped initiate fuel cell electric vehicle (FCEV) deployment in California (with the zero emission vehicle ZEV mandate requiring vehicle manufacturers to offer for sale specific numbers of the very cleanest cars available) and in China (providing substantial government support to 'new energy vehicles'). Another

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[14] In February 2020, a consortium of Gasunie, Groningen Seaports and Shell Nederland has announced the intention to launch the NorthH2 project, producing green hydrogen using renewable electricity generated by a dedicated mega offshore wind farm with 3 to 4 gigawatts in 2030 [Gasunie 2020].

regulatory example is the Norwegian requirement for zero emission tourist ships and ferries in the World Heritage fjords, which has kicked off significant clean shipping development programmes, introducing battery and fuel cell electric propulsion systems in maritime vessels.

The cooperation between Japan and Australia is a showcase of successful international cooperation. The Japanese interest for importing hydrogen and the subsequent understanding by Australian public and private stakeholders that this is an opportunity for substantial economic growth has kicked off a flurry of activities in Australia, by now also including a perspective on significant domestic hydrogen use, and has led to the emergence of a dynamic hydrogen ecosystem development driven by government and industry.

5.2 Best practices from the analysis of the hydrogen strategies

When looking at the hydrogen strategies of the selected countries, a few common themes and best practices emerge, also reflecting the above triggers.

It is important to involve the relevant stakeholders in every step of the process and to provide a common and reliable framework:

- Stakeholders are typically involved in devising a strategy, and, once the strategy has been published, remain on board for the subsequent formulation of a roadmap involving both government and stakeholders.
- A suitably selected advisory group including participants from industry, academia, (local) government and possibly also the civil society is often a core element in the implementation process.
- The European Union and its legislation provide a common and reliable framework for all EU member states, serving as a trigger for activities in all EU countries.
- It is realised that the hydrogen market (including competition) will become global. As a result, international exchange and cooperation is increasingly addressed in the strategies.

Comprehensive greenhouse gas reduction is driving adoption and hydrogen applications are not restricted to a single sector:

- Hydrogen strategies need to address all energy consuming sectors including the industries using it as a feedstock. As a result, advanced strategies typically involve various national ministries.
- Green hydrogen use is a central element in all countries, blue hydrogen is envisaged to play a role in many strategies mainly in a transition period and only in a few countries also in a longer term. Defining hydrogen qualities with regard to its GHG footprint and agreeing on corresponding certification procedures will be crucial

going forward. Several future hydrogen-importing and exporting countries have addressed this need in their national hydrogen strategies (EU, AU, DE, NL).

Measures for implementation are usually left to subsequent roadmapping and legislative activities. However, it is clearly recognised that measures need to include a number of relevant dimensions.

- R&D activities will need to continue, focusing on technology use and demonstration to learn and further improve the technologies involved.
- It is important to harmonise regulations, codes, and standards (RCS) at all steps along the value chain allowing for a reliable operating environment and a level-playing field. While this is largely in place already for FCEV operation, green hydrogen certification is an important issue still being addressed. Establishing a green hydrogen certification mechanism allowing producers to verifiably prove the green quality of their product will be crucial for market development.
- With the move towards commercialisation, financial support mechanisms improving the competitiveness of hydrogen vs. conventional technologies will gain importance, requiring a move from CAPEX to OPEX support.
- Carbon pricing is a well-established instrument in many world regions. While current carbon prices in most countries and regions are too low to enable sustainable green hydrogen business cases, aiming for globally high CO2 prices will help to further reduce the cost gap and create a level playing field.
- As with any introduction of new technology, supporting public acceptance and participation of local stakeholders is crucial.
- Coordinated and concentrated financial support to integrated hydrogen concepts enables the creation of strong nuclei for hydrogen uptake. Several strategies identify strong and continuous financial support to selected regions, cities or industry clusters as an important lever for creating hydrogen eco-systems and for enabling the development of innovative hydrogen value chains (KR, DE, EU, FR).

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Quickly emerging hydrogen strategies point towards a dynamically growing market

By 2025, hydrogen strategies can be expected to cover countries representing over 80% of global GDP.

In a high-level review of countries representing over 90% of global GDP we found that 20 countries representing 44% of global GDP already have a national hydrogen strategy or are on the verge of doing so within the coming months. Additionally, another 31 countries (another 44% of global GDP) are supporting national projects and discussing policy action.

The comprehensive nature of existing and emerging hydrogen strategies, covering relevant application sectors, serving environmental as well as economic goals, and building on a long international experience, is a clear manifestation of the important role the technology is expected to play.

Hydrogen is clearly recognised as an essential element of a decarbonised energy system

Hydrogen plays an important role in a future energy system based on renewables as an essential link between intermittent wind and solar electricity production and energy consuming sectors traditionally relying on a chemical energy carrier that can be stored in bulk quantities and converted to electricity or heat at the point of use.

The analysis of government action for hydrogen in the 16 selected countries and in the European Union shows that the main drivers for these authorities are the GHG emission reduction goals, the integration of renewables, as well as the opportunity for economic growth. While national strategies obviously differ in detail, reflecting particular country interests and industrial strengths, there is a clear, strong, and lasting international momentum behind the universal recognition that hydrogen is an essential and indispensable element of a decarbonised energy system.

Scaling demand expectations for 2050 indicates a global hydrogen potential of up to 9000 TWh

Not all countries quantify the expected national hydrogen demand in their strategies, but the ones that do are all in a similar ballpark with respect to the respective size of the economy. Scaling upper hydrogen demand expected for 2050 in national strategies to global level based on GDP indicates a potential of up to 9000 TWh or around 270 million tons of hydrogen per annum. This is an amount as large as the annual primary energy currently provided globally by renewables.

In several countries with high energy needs, a substantial share of this demand will be served by imports, initially on the basis of bilateral agreements

While hydrogen production from renewable energy offers an opportunity for a higher degree of energy independence, densely populated countries with high energy needs are realising the limits of domestic production capacities. Notably, Japan, Korea, and Germany expect to develop significant import capacities. As these require large investments in production capacity in the exporting countries as well as in the associated logistics infrastructure along the supply chain on both sides, initial developments will likely build on bilateral agreements, de-risking the capital employed.

Initial applications focus on the transport and industry sectors

Target sectors of national strategies notably include transport and industry, the latter particularly in countries with a strong industrial sector and a high priority on greenhouse gas reduction. For transport applications, most strategies do not differentiate strongly between using hydrogen directly and converting it into other synthetic fuels. Where synthetic fuels are mentioned, they are seen as an option for aviation and maritime shipping.

Green hydrogen is central to all strategies

In the long run with a view towards a largely decarbonised world by 2050, over half of the countries analysed focus on using green hydrogen sourced from renewable energy only; the emphasis on green hydrogen is particularly pronounced in the EU. However, in the interim other types of low carbon hydrogen are seen as an effective and pragmatic way to ramp up volumes and to get the associated hydrogen economies started.

Market ramp-up will happen in in three phases

The expected development of the green hydrogen market can be differentiated in three phases. In the current decade, market activation will help to transform current demonstration into an early market (phase 1), which is expected to subsequently experience sustainable growth (phase 2), eventually leading to a large and well-established market by 2050 (phase 3).

6.2 Emerging opportunities and areas to watch for industry

Large cumulative market of over 40 B€ for green hydrogen production equipment will develop within the EU until 2030

Several countries are stating clear and massive targets for ramping up green hydrogen production. The move from the currently installed base of electrolysers in the lower Megawatt range to Gigawatt-size capacities within less than a decade points towards a massive growth path in the coming years and the targeted large hydrogen production capacities translate into a sizeable market. The EU target alone indicates a cumulative market size for electrolysers and balance of plant of more than 40 B€ within the EU until 2030.

Large industrial partnerships will be formed for production and export/import

As pointed out earlier, initial export/import relationships are expected to build on bilateral agreements. Corresponding supply chains will benefit from a tight integration, resulting in partnerships between relevant major stakeholders covering production, infrastructure, and logistics. Such partnerships are already being formed[15] and industry players should start to engage now.

Refineries and chemical industry to become the first important large-scale hydrogen markets in the mid-term

Green hydrogen is seen as one of the main levers to decarbonize the industry sector. Refineries and the chemical industry are large hydrogen users already today, and gradually replacing the fossil-based 'grey' hydrogen by green or low carbon hydrogen is an element in several strategies. In addition, the EU Renewable Energy Directive recast (RED II) allows green hydrogen used in refineries to count towards the mandatory transport sector target of a 14% renewable energy share, creating a strong regulatory incentive. As a result, already now large-scale electrolysers are being planned in and around European refineries.

Road transport (vehicles and trucks) and fuel cell market currently stronger in Asia than in Europe

While the transport sector is a relevant application segment in all countries, when comparing countries with relevant automotive OEMs, the expected use of hydrogen in fuel cell passenger vehicles and trucks is stronger in Asia than in Europe. While Japanese, Korean, and Chinese plans foresee a relevant role of fuel cell electric vehicles in all road transport sectors, European strategies mainly focus on heavy goods vehicles. An interesting observation and a reflection of an obvious difference in strategy between OEMs in the two continents. Similarly, fuel cells in the building and power sector have a pronounced role in Asia while playing only a limited or no role in Europe.

Green synthetic liquid e-fuels (PtL) can grow into an interesting opportunity with large potential quantities particularly in the aviation and/or maritime sector

In a few strategies, green synthetic fuels are mentioned as an option for aviation and maritime shipping. Being able to be used in the existing engines without major modification, they provide a perspective for decarbonisation in the short term, whereas a

15 A prominent example is the recently announced Gigawatt size green hydrogen production plant Air Products, Saudi Arabia's ACWA Power, and Neom [Air Products 2020]

direct hydrogen use is seen as a potential longer term solution, requiring a more profound technology development and longer lead time. A possible introduction of quota in the aviation sector is discussed in the German and Dutch strategies, which would lead to an opportunity for significant volume demand. Likewise, existing emission reduction targets in the maritime sector and international pressure to accelerate the path towards them can help to further enlarge the market.

6.3 New policies needed to achieve strategic aims

Current measures are insufficient to catalyse envisaged strong growth

Most strategies focus on targets for green hydrogen production and technology deployment rather than on measures supporting these targets. Many policies in place are still focused on R&D-oriented action, which remains relevant but less important than fostering commercialisation. In most cases, policy development is lagging behind the strategic ambitions. Current measures are insufficient to catalyse the envisaged strong growth. New policies required to achieve these targets are still in the making and are only starting to emerge.

The time for policy discussions is now and policymakers will likely be open to sensible approaches and good arguments.

Building on earlier successes, policies should focus on commercialisation:

Many countries have already been supporting hydrogen and its applications for quite some time and successful deployment examples can be traced back to a few triggers, which help in discussing policy options. The following measures appear particularly suitable.

- Mandatory quota or emission limits have been employed successfully in the past to help creating a market for low carbon or more efficient technology. **Well-designed sectoral quota for green feedstock and fuels in industry and transport can stimulate large scale demand**.
- Moving from R&D support, which has been the dominant public support mechanism in the past, to supporting commercialisation and the demonstration of entire value chains in e.g. Germany ('Reallabore') and Europe ('hydrogen valleys') has kicked-off large projects and a flurry of activity even in regions not receiving funding. **Targeted support for establishing comprehensive value chains will provide nuclei for sustainable business**.
- While public funding towards project investments lowers the entry hurdle for participants, it usually does not create a green hydrogen business case due to the high cost of green electricity. **Moving from CAPEX to OPEX support will help to establish sustainable business cases for operators**. Measures may range from reducing green electricity costs to the carbon contracts for difference (CCfD)

instrument, which is currently discussed in the European and German strategies as a possible future instrument.

- Greenhouse gas reduction is one of the primary goals behind all hydrogen strategies and carbon pricing is a well-established instrument in many world regions. While current carbon prices in most countries and regions are too low to enable sustainable green hydrogen business cases, aiming for **globally high CO_2 prices will help to further reduce the cost gap and create a level playing field**.
- When it comes to commercial deployment, any policy instrument needs to provide a **long-term perspective and security of investment** in line with typical investment lifetimes.

A green hydrogen certification needs to be put in place

A green hydrogen producer needs to be able to verifiably prove the green quality of its product. A broadly agreed green or low carbon hydrogen certification mechanism is crucial for a successful market development.

Infrastructure development requires central coordination and financial support

A reliable and accessible infrastructure is a necessary prerequisite for retail and SME applications and has to precede market development. This holds similarly for hydrogen pipelines, where existing infrastructure for gas transport and distribution can be converted to transport pure hydrogen, and for refuelling stations. **Comprehensive infrastructure development requires public financing, central coordination for planning and harmonisation, and the appropriate regulatory environment**.

Public acceptance is key

Public acceptance is crucial to any new technology deployment and suitable **measures supporting public acceptance need to complement any policy development**. Examples include education campaigns, training programmes, and community engagement.

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ANNEX A: HYDROGEN TRANSPORT VECTORS

Energy density of hydrogen requires hydrogen carriers for shipping

Conventional liquid energy carriers such as e.g. diesel, crude oil or gasoline are attractive for international energy trade and transport due to their high volumetric (kWh/l) and gravimetric (kWh/kg) energy density. Diesel has a volumetric and gravimetric energy density of about 10 kWh/l and 11.9 kWh/kg, respectively (see Figure 22). At normal conditions (15°C, 0.1 MPa) hydrogen is gaseous and has a significantly lower volumetric energy density of 0.003 kWh/l, making it less favourable to use for energy transport. To reduce this drawback, hydrogen can be conditioned in various ways to increase its volumetric energy density.

For pipeline transport, hydrogen can be compressed to about 10 MPa. This changes the energy density to 0.26 kWh_{LHV}/l. Further pressure increase (e.g. for road distribution) rises the density e.g. to 1.06 kWh_{LHV}/l at 50 MPa. Due to the unfavourable compressibility factor of hydrogen, a pressure increase has a somewhat smaller effect on the volumetric energy density as compared to e.g. methane. A significant change in energy density can be achieved through liquefaction. Hydrogen becomes liquid at a temperature of -253°C. During liquefaction, the energy density increases by a factor of about 786 to 2.36 kWh_{LHV}/l at liquid state. This energy density is one of the most relevant properties why LH_2 is considered a promising option for future large-scale hydrogen transport.

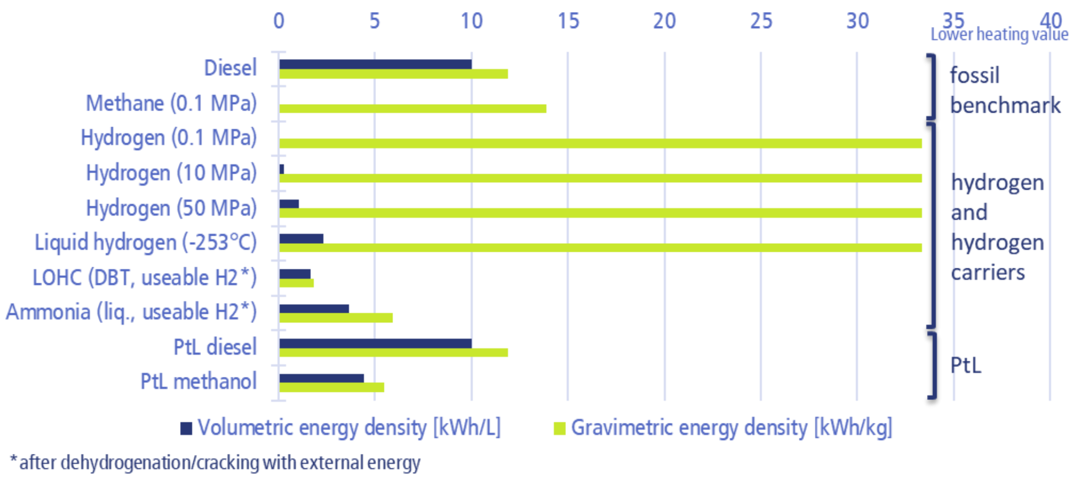


Figure 22: Comparison of energy densities of different energy carriers

To avoid the need for cryogenic temperatures, further technologies are discussed to increase the volumetric energy density for transport purposes. One being the use of LOHCs such as e.g. Dibenzyltoluene[16] (DBT). LOHCs can absorb and release hydrogen and remain liquid at ambient conditions. With DBT, the volumetric density of the transported hydrogen can be increased to about 1.7 kWh/l[17]. At the same time however, the gravimetric density of the hydrogenated carrier is significantly lower than for pure hydrogen. In its liquid form, ammonia has a volumetric and gravimetric hydrogen energy density of about 3.7 kWh/l and 5.9 kWh/kg, respectively. Another option to transport hydrogen-based energy, is the production of synthetic liquids fuels (e.g. synthetic diesel, synthetic kerosene, methanol). Those power-based fuels (Power-to-Liquids, PtL) have the same advantage regarding volumetric and gravimetric energy density and thus transport capability as their fossil-based counterparts. However, PtL fuels are not directly comparable to the above-mentioned hydrogen carriers as the effort for reconverting PtL fuels to pure hydrogen is higher and, for that reason, wherever considered they are usually intended to be used as green hydrocarbons and not as hydrogen carriers for pure hydrogen end-use.

Main elements of hydrogen import supply chains

Energy density is an import parameter for (cost) efficient storage, transport and distribution. It directly determines the amount of hydrogen being transported or stored with a certain vessel size (e.g. ship, trailer). However, the conditioning of gaseous hydrogen into and/or from its transportable form requires a substantial amount of energy and process equipment. Figure 23 depicts the main elements of hydrogen supply chains based on liquid hydrogen, pipeline transport, LOHC (DBT), and ammonia. The supply of PtL is also shown for comparison.

[16] DBT is currently developed as hydrogen carrier e.g. in Germany. Another LOHC that is discussed for hydrogen transport is e.g. Methylcyclohexane (MCH). Different LOHCs have different properties during transport, storage and/or hydrogenation and dehydrogenation. DBT is used as an example in this report.

[17] Referring to the amount of hydrogen after the dehydrogenation of the DBT.

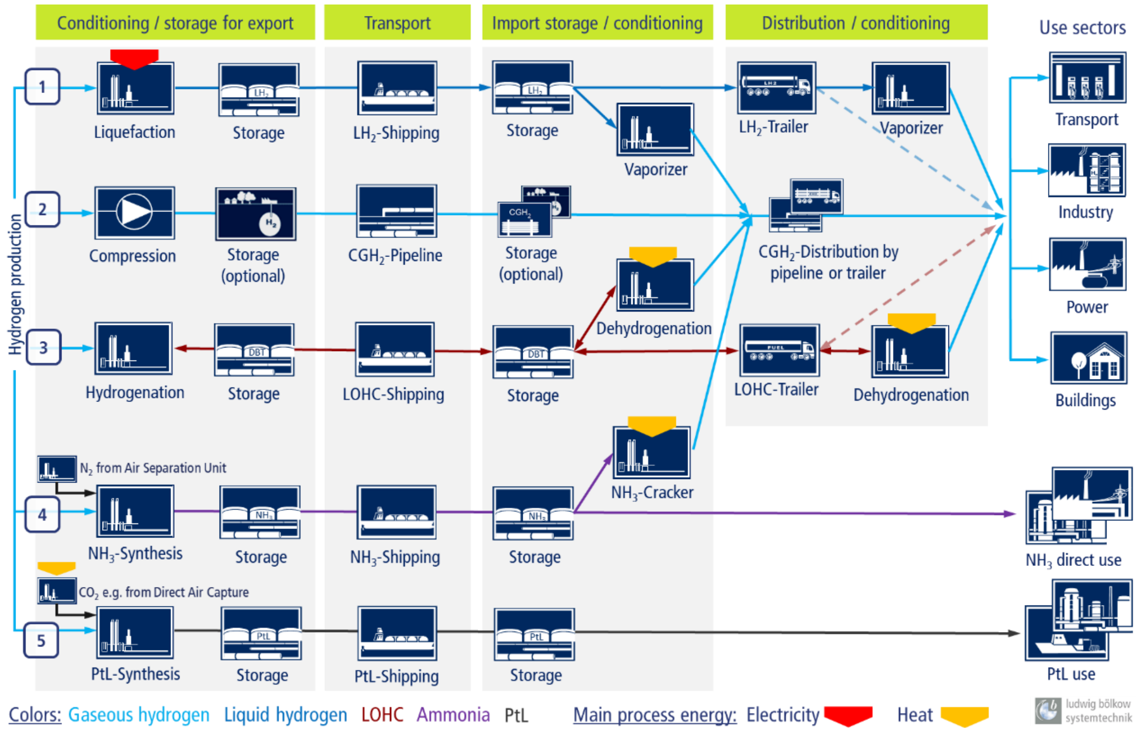


Figure 23: **Main elements of large-scale hydrogen export/import supply chains (1) LH_2 via ship, (2) CGH_2 via pipeline, (3) LOHC via ship, (4) NH_3 via ship, and the supply of PtL for comparison (5)**

Liquid hydrogen (LH_2)

For LH_2 export, the hydrogen needs to be liquefied by reducing the temperature to -253°C. This is an energy intensive process, consuming about 13 to 6 kWh/kg[18] of electricity. After liquefaction, LH_2 is stored in a super insulated tank (requiring vacuum insulation) until and during shipment. The transport capacity of a maritime LH_2 carrier ship is expected to be in the order of about 11,000 t_{H2}. After shipping to the importing country, LH_2 is transferred to a stationary storage until further distribution or use. Depending on the quality of insulation and the storage duration, small quantities of the liquid return to their gas phase due to unavoidable heat influx into stationary and mobile storage tanks. This so-called boil-off gas (BOG) can be used e.g. as fuel during shipment or for stationary applications. BOG can be kept below 0.5% of the vessel capacity per day.

[18] ~ 13 kWh/kg: some existing plants; ~ 6 kWh/kg: anticipated for future plants

Depending on the available infrastructure, the distribution concept, and the final hydrogen use, LH_2 is vaporised before or after further distribution. Distribution in cryogenic liquid state is usually performed by trailers with a capacity of about 3.5 t_{LH2}.

Gaseous hydrogen via pipeline (GH2)

International hydrogen transport via pipeline will be similar to today's methane transport. Gaseous hydrogen is compressed and fed into high capacity pipelines. To achieve long distance and high-capacity transport, the gas needs to be recompressed in multiple compressor stations along the export/import route. Large-scale and long-term (seasonal) storage of hydrogen can be implemented by connecting appropriate storages (e.g. salt caverns, depleted gas fields) to the pipeline. At the import location, appropriate distribution infrastructure and/or consumers need to be in place to handle and/or consume the continuous flows and high hydrogen import quantities usually associated with pipeline gas import.

Liquid Organic Hydrogen Carriers (LOHC)

For the export of hydrogen via LOHC (e.g. Dibenzyltoluene), the first step after hydrogen production is hydrogenation of the carrier liquid. In this process, hydrogen is embedded into the organic liquid carrier substance. This is a strongly exothermal reaction. The theoretic uptake capacity of DBT is 57 kg_{H2} per 1,000 L_{DBT} or 6,2 g/kg_{LOHC} (6.2 wt%[19]). However, the net useable capacity is about 10% less due to incomplete hydrogenation and dehydrogenation processes.

The hydrogenated (and also the dehydrogenated) liquid can be handled (stored, transferred) like any oil product. The LOHC is stored in stationary tanks until shipping. A regular oil tanker takes the liquid to the import destination. A tanker filled with 75,000 t of DBT has a usable hydrogen transport capacity of about 4,000 t_{H2}. On arrival, the liquid is transferred into an onshore storage. The LOHC needs to be dehydrogenated before the hydrogen can be used again in its gaseous state. This may happen before or after further distribution. With LOHC, the hydrogen transport capacity of a road trailer is about 1.5 t. Dehydrogenation is an endothermal process with a required heat input of about 9 kWh/kg at 250 to 320°C and some additional electricity demand for pumps, controls etc. The released gas has a pressure of below 0.3 MPa. The dehydrogenated carrier liquid needs to be transported back to the hydrogen source for reuse.

[19] wt% = abbreviation for weight %

Ammonia (NH_3)

Ammonia (NH_3) is produced from hydrogen and nitrogen in the Haber-Bosch process. In addition to the electrolyser producing hydrogen, an air separation unit is required to provide nitrogen. Before storage and export, NH_3 is transformed to its liquid state to improve density. NH_3 becomes and stays liquid either at a moderate pressure of about 1 MPa or at a temperature of -33°C. For large-scale storage and transport, it is usually economically favourable to refrigerate NH_3, while for smaller quantities liquefaction through compression has economic advantages. The continuously refrigerated medium is transported by a bulk NH_3 ship to the import destination. A very large gas carrier (VLGC) with a storage volume of 82,000 m^3 has a hydrogen transport capacity of about 10,000 t_{H2}. The imported ammonia can either be cracked to produce pure hydrogen for direct use or further hydrogen distribution or it can be used directly as ammonia e.g. for fertiliser production, power generation, or as a fuel e.g. for ships. Ammonia cracking requires substantial amounts of heat and electricity resulting in an energy consumption of about 30% of the contained hydrogen.

Due to the toxicity of ammonia[20], a widespread distribution of NH_3, especially in populated areas, is unlikely to be implemented within future energy import chains.

Power-to-Liquids (PtL)

Power-to-Liquid fuels are produced from hydrogen and CO or CO_2 via the Fischer-Tropsch or methanol route. In the Fischer-Tropsch process, a H_2/CO syngas is converted to a range of different hydrocarbons that are further processed and separated in a refining process to different fuel products such as synthetic diesel, kerosene, or petrol. Alternatively, methanol can be produced by synthesis of hydrogen and CO_2. The methanol can be used for energy storage and transport itself or it can be further converted into synthetic fuels such as diesel or kerosene. After PtL production, the synthetic liquids can be stored, transported, and used in the same way as their fossil counterparts.

To produce CO_2-neutral fuels, hydrogen production and CO/CO_2 supply need to be CO_2 neutral. This can be achieved e.g. by using CO_2 from biogenic resources or by capturing CO_2 directly from the air. The first option is usually limited in scale due to available regional biomass potential; the latter option requires a relevant amount of energy and equipment for air separation or direct air capture.

PtL fuels are mainly considered as drop-in fuels to (partially) substitute their fossil-based counterparts in existing applications, such as e.g. aviation, that cannot easily be switched to battery or hydrogen. The main aim is to reduce the carbon footprint. PtL fuels are not

20 Ammonia is considered a toxic inhalation hazard.

used as hydrogen carriers to supply pure hydrogen to processes or applications and are thus not directly comparable to e.g. hydrogen transport via pipeline, LOHC or in liquid form.

Technology availability

Each above-mentioned transport technology has its advantages and disadvantages as well as different technology readiness levels for the main technologies within the export/import supply chain. The maturity of the main technologies is shown in Figure 24.

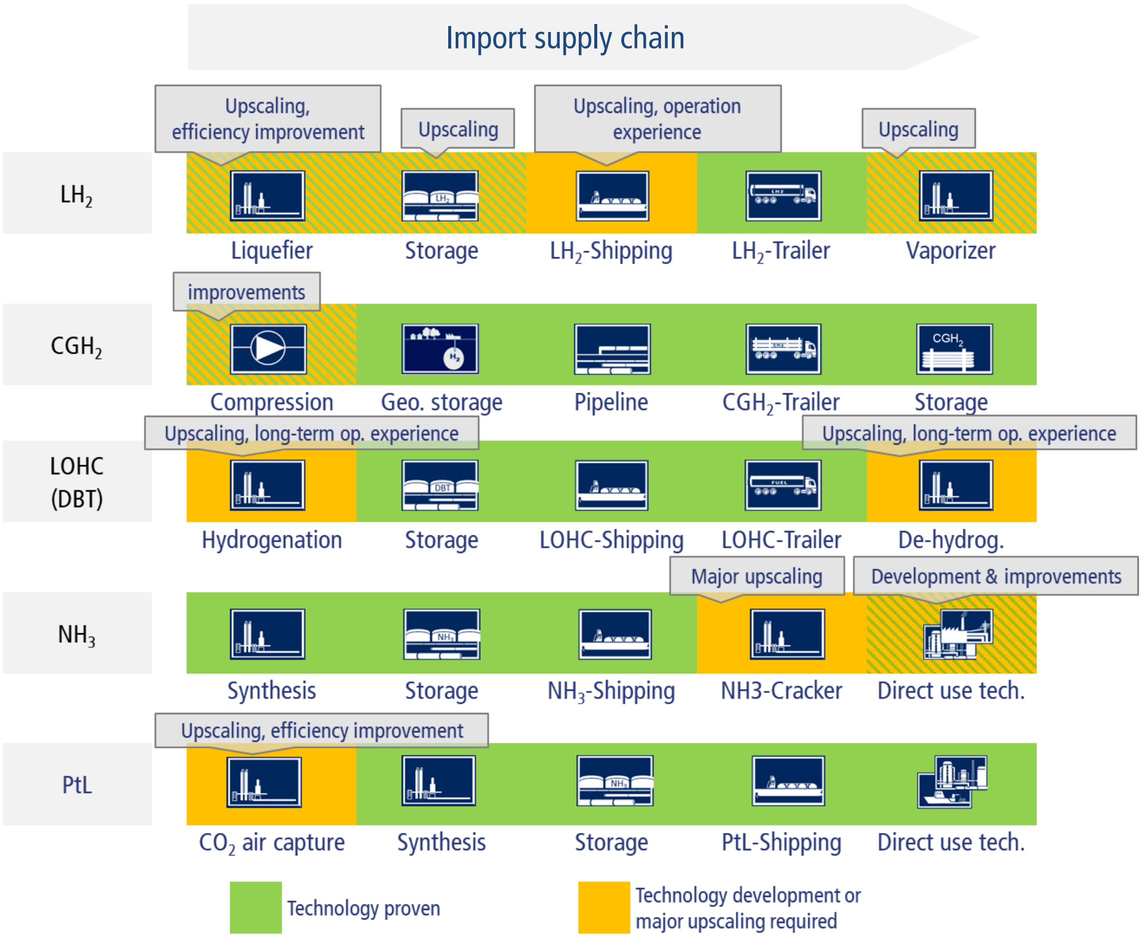


Figure 24: Principle technology availability of main export/import technologies

Further technology development or up-scaling is required in all considered hydrogen export/import vectors and also for PtL production and import. However, pipeline transport can be considered as the most developed technology for hydrogen import. Major key technology development, upscaling or gaining of long-term operating experience are required before international hydrogen transport based on LH_2, LOHC, or NH_3 can be implemented.

Cost structure of hydrogen import vectors[21]

The costs for imported hydrogen are dominated by the hydrogen production costs. In fact, hydrogen production accounts for more than 50% of total costs in the calculation example below. However, details depend on the transport distance, on the scale of the operation, and on the assumptions used. Generally, international transport efforts will amount for a significant share in the resulting cost of the hydrogen at the final destination.

Figure 25 shows the main cost elements of large-scale hydrogen import. Based on the assumptions (electrolysis CAPEX at 400 €/kW_{el}; electrolysis utilisation: 5,000 h/a; electricity price: 37 €/MWh_{el}, transport distance 3,000 km), total import costs are roughly between 3 and 4 €/kg_{H2} with hydrogen production accounting for about 2 €/kg_{H2}. Costs for hydrogen conditioning, storage and international transport are between 1 and 2 €/kg_{H2} depending on the transport vector.

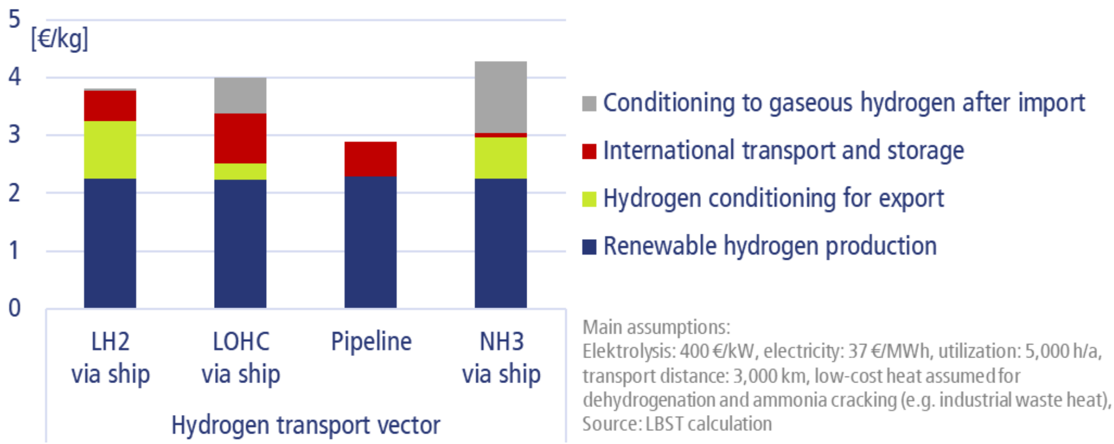


Figure 25: Main cost elements of large-scale hydrogen import in €/kg_{H2}

The transport vectors clearly differ in their cost structure due to the export conditioning, transport, and storage as well as import conditioning. For LH_2, hydrogen liquefaction is the largest cost element after hydrogen production. Shipping of LH_2 plays a somewhat lesser role and hydrogen vaporisation does barely add to the overall costs. This cost structure is completely different for the LOHC and NH_3 import vectors. Costs for LOHC hydrogenation is rather small, while transport and dehydrogenation are more significant. This is the result of

[21] This chapter considers cost for hydrogen import (incl. reconversion to pure gaseous hydrogen). Thus, PtL is not included.

a rather low hydrogen uptake capacity of DBT in combination with high CAPEX for the carrier oil as well as a high energy demand for hydrogen release at the importing site. The costs for NH_3 transport are small, while the costs for ammonia synthesis and cracking have a larger impact on overall costs. The energy demand for ammonia cracking plays a vital role in overall conditioning costs. Hydrogen pipeline transport does not require special conditioning (compression for pipeline transport is included in transport costs) and shows the overall lowest costs in this comparison.

The intended use at the destination may further add to the differentiation. Where pressurised hydrogen is required, LOHC and NH_3 transport will e.g. incur additional cost for compression and possibly for cleaning, depending on the application.

Overall hydrogen import costs are sensitive to a range of parameters such as:

- Future technology costs and efficiency (e.g. electrolysis, conditioning plants)
- Energy costs (e.g. electricity for electrolysis, heat source for conditioning)
- Utilisation rates (e.g. electrolysis, pipeline)
- Project scale and location (e.g. pipeline capacity, renewable resources)
- Interest and depreciation period (large share of infrastructure with long technical lifetime)

Technology advantages and disadvantages

A brief explanation as well as a list of the main advantages and disadvantages is shown in Table 10 (LH_2), Table 11 (Pipeline), Table 12 (LOHC/DBT) Table 13 (ammonia) and Table 14 (PtL).

Table 10: Main advantages, disadvantages, and technology readiness for international LH_2-transport

Advantages LH_2
▪ No major energy input required at importing site (Ambient heat for vaporisation feasible) ▪ Liquefaction and storage technology available, some upscaling required ▪ Distribution and handling technology available and proven (LH_2-trailer, onsite storages, cryopump, …) ▪ High energy density enables efficient road distribution ▪ Efficient high-pressure conditioning via cryopump possible (relevant e.g. for H_2 refuelling, also enables efficient pre-cooling at H_2 station) ▪ LH_2 is potential future fuel for heavy-duty transport applications (e.g. ships, trucks, aircrafts) ▪ High purity hydrogen
Disadvantages LH_2
▪ Boil-off gas during longer storage periods ▪ Electricity intensive liquefaction at -253°C requires about 20 – 35% of the energy content of the hydrogen. ▪ LH_2-shipping not yet demonstrated. However, small-scale demonstrator currently being built.
Technology availability
Liquefaction of hydrogen is a well proved technology. However, further upscaling and efficiency increases are expected for future large-scale export supply chains. Today's electricity consumption of about 13 kWh per kg hydrogen for liquefaction can be significantly reduce to about 6 kWh per kg in the future [METI 2019]. Upscaling is also required for stationary large-scale LH_2 storages. Large-scale liquid hydrogen carrier vessels still need to be developed and demonstrated. A first small-scale prototype is currently being constructed in Japan. In addition, equipment for loading and unloading hydrogen from and to the ship is currently developed for the first small-scale pilot project. LH_2 road distribution is common business around the world. Equipment for the vaporisation of liquid hydrogen is available. However, upscaling of the technology is required.

Table 11: Main advantages, disadvantages, and technology readiness for international hydrogen pipeline transport

Advantages pipeline transport
▪ High capacity hydrogen transport system ▪ Cost efficient hydrogen transport for large volumes ▪ Only marginal cost increase with increasing capacity (pipeline diameter) ▪ Integration of cost effective large-scale long-term hydrogen storage (geologic storages) feasible ▪ Refurbishment of existing pipelines possible
Disadvantages pipeline transport
▪ Inflexible point-to-point connection ▪ Fixed installed transport capacity ▪ High capacity and utilisation required for low transport costs (10 to 20 GW). Sufficient hydrogen offtake might be challenging during early-phase of hydrogen roll-out.
Technology availability
The key elements of hydrogen export/import via pipeline are basically available as a proven technology. Industrial hydrogen pipelines are operated e.g. in Germany, US, France, Belgium, and the Netherlands. Some further investigations and adaptations to (gas powered) compressor station technology are required. Geologic hydrogen storage in salt caverns has been used for decades e.g. in Teesside (UK) or Clemens Dome (US). Salt deposits suitable for new caverns are available in several countries. Gaseous hydrogen road distribution and storage are established technologies. However, further technology improvements (cost reductions, capacity increase) e.g. for road distribution can be expected.

Table 12: Main advantages, disadvantages, and technology readiness for international hydrogen transport using LOHC (e.g. DBT)

Advantages LOHC (e.g. DBT)
▪ Easy and safe to handle, store and transport ▪ Liquid at ambient conditions ▪ Very similar to other oil products ▪ No phase transition in standard temperature range ▪ Storage, transport, and distribution technologies available/proven ▪ No energy losses during longer storage periods
Disadvantages LOHC (e.g. DBT)
▪ Limited energy density ▪ About 10% of the theoretical capacity remain unused ▪ High energy consumption for hydrogen release (dehydrogenation). About 35% of the transported hydrogen energy. ▪ Dehydrogenation produces low-pressure hydrogen. Depending on distribution and end-use additional energy for compression required. ▪ Large-scale hydrogenation/dehydrogenation units need to be developed and tested. Long-term operating experience missing. ▪ Uncertain cycle-life of carrier oil. ▪ Currently high costs of carrier oil (about 3 to 5 € per kg of DBT) ▪ Additional storage volume for dehydrogenated carrier oil required ▪ Hydrogen carrier oil needs to be transported back to H_2 source
Technology availability
Hydrogenation and dehydrogenation of LOHC (DBT) are key processes in this hydrogen supply chain. Small-scale technology prototypes are available. Large-scale hydrogenation and dehydrogenation facilities still need to be developed; long-term operating experience still needs to be gathered. For LOHC (DBT) storage, transport and distribution, proven technology from fossil fuels handling can be applied.

Table 13: Main advantages, disadvantages, and technology readiness for international hydrogen transport using ammonia

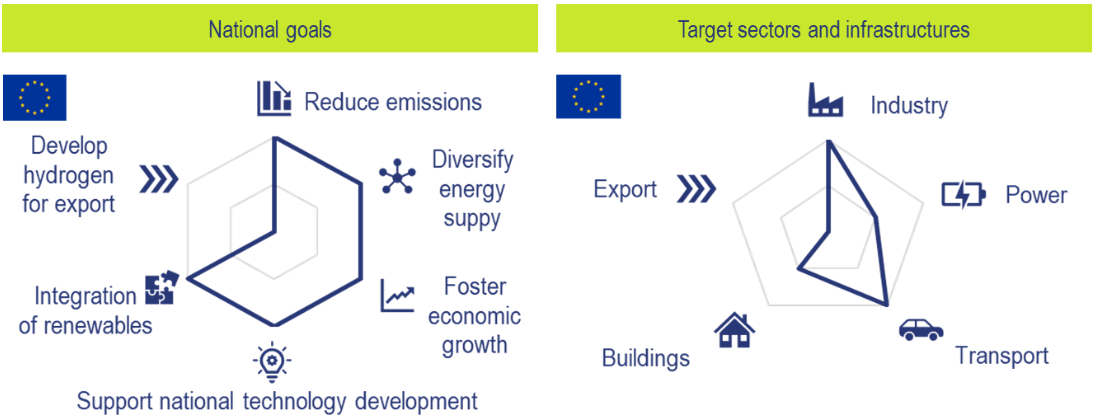
Advantages ammonia
▪ Established export and transport infrastructures and established international markets enables rather easy phase-in of renewable hydrogen-based ammonia ▪ Attractive as a feedstock for chemical and fertilizer industry to substitute fossil based NH_3 ▪ Potential future use as carbon-free fuel either for power generation or in transport (esp. freight shipping) ▪ NH_3 production technology available and proven for years ▪ Liquefaction of ammonia under mild conditions (at 9 bar and room temperature or at -33 °C and atmospheric pressure) ▪ High volumetric and gravimetric energy density (Volumetric density higher than LH_2) ▪ No/small energy losses during storage and transport (some electricity use in case of refrigerated storage)
Disadvantages ammonia
▪ High toxicity of NH_3 vapour if released to air ▪ Due to toxicity, NH_3 not useable for comprehensive energy distribution. For energy distribution other options (e.g. LH_2, CGH_2) need to be applied which reduces overall efficiency. ▪ Due to toxicity, limited to certain end uses (e.g. large-scale, industrial, remote power generation) ▪ Energy intensive production and hydrogen release (gas-to-gas: ~ 30% of energy content) ▪ NH_3-cracker technology for H_2 release not available/proven at large-scale ▪ High H_2 gas purification requirement (low NH_3 tolerance of fuel cells)
Technology availability
Ammonia synthesis (Haber-Bosch process) from syngas (H_2, N_2) is everyday business. Today, the required syngas is produced from fossil feedstock in a reforming process. To produce renewable syngas, nitrogen from an air separation unit needs to be provided (in addition to the hydrogen e.g. from electrolysis). Nitrogen separation from air is an established technology. Technologies for ammonia storage and transport are available and proven. Small-scale ammonia crackers are available; however, large-scale crackers still need to be developed. Technologies that can utilise ammonia directly as a fuel (e.g. for power generation or as fuel) require further development.

Table 14: Main advantages, disadvantages, and technology readiness for PtL (synthetic hydrocarbon) production, storage, and transport

Advantages PtL
▪ High volumetric and gravimetric energy density ▪ Production, storage and transport technology available and proven for years ▪ Easy and efficient to store and transport ▪ Well established global storage and transport infrastructure ▪ Usable as drop-in fuel for a very wide range of applications ▪ Useable as renewable fuel in hard to decarbonise applications such as e.g. aviation ▪ Useable in a wide range of existing applications
Disadvantages PtL
▪ Further reduction of overall efficiency due to synthesis efficiencies of about 80% would force higher renewable power installations ▪ For large production, due to limited biogenic CO_2 sources, carbon neutrality requires CO_2 capture from air, a cost and energy intensive technology ▪ Same environmental concerns as for their fossil counterparts (e.g. shipping of liquid hydrocarbons) ▪ Efficiency of end-use applications (e.g. internal combustion engine) usually lower than for hydrogen (fuel cell) or battery ▪ Lower overall efficiency (e.g. well to wheel) than other renewable energy carriers due to lower synthesis efficiency and lower conversion efficiency of internal combustion engines compared to electro-mobility or fuel cell technology ▪ Similar local emissions (e.g. particulate matter, NOx) as with fossil fuels
Technology availability
Synthetic liquids from syngas have been produced via Fischer-Tropsch process since the 1920s. Thus, it can be considered a well-known process and established technology. Same is true for the storage and transport of the resulting products. However, until now syngas (H_2 and CO) is produced from fossil feedstock. To produce renewable synthetic fuels, renewable hydrogen and CO (or CO_2 converted to CO) need to be used. The challenge is the energy and cost efficient and large-scale CO_2 capture from air. Here, major technology development and upscaling is still required.

ANNEX B: DETAILED COUNTRY ANALYSES

European Union



Current situation

The European Commission's "A hydrogen strategy for a climate-neutral Europe" was published, in July 2020 [EU H2 strategy 2020]. It was published together with the "EU Strategy for Energy System Integration" [EU ESI 2020]. Both strategies address the required transmission of the European energy system to reach GHG neutrality by 2050. Hydrogen and hydrogen-based synthetic fuels are already a relevant element of the energy system integration strategy with more details added in the hydrogen strategy.

European Goals

The goals formulated in the hydrogen strategy cover a range of relevant aspects:

- To foster sustainable growth by hydrogen technologies and applications and the creation of jobs in the EU
(1 million jobs directly and indirectly in the long-term: cumulative investment of up to about 500 B€ for renewable and low-carbon hydrogen until 2050)
- Fast pace deployment of hydrogen is considered key to achieve EU's 2030 GHG emission reduction targets
- Further develop and strengthen European hydrogen technologies, especially electrolysers, hydrogen refuelling stations, and megawatt-scale fuel cells
- Hydrogen to provide flexibility to the electricity system and support the integration of renewables
- Hydrogen as energy vector to store renewable energy and transport it from production locations to distant demand centres

- Advancing energy supply diversification and creation of new, stable and secure energy supply chains with partner countries
- Hydrogen fuel to reduce air pollution [EU ESI 2020]

Target sectors and infrastructures

The European hydrogen strategy clearly focuses on the two end-use sectors transport and industry as well as on electrolysis-based hydrogen production.

In the transport sector, the focus is on heavy-duty applications such as buses, trucks, trains, ships and aviation. Latter two to be addressed with drop-in synthetic fuels and in the long-term with hydrogen for fuel cells. Fuel cell passenger cars are only mentioned for commercial fleets such as e.g. taxis.

In the industry sector, it is of particular interest to replace the use of carbon intensive hydrogen in refineries as well as for ammonia and methanol production. In addition, the reduction of the carbon intensity of steel production and eventually zero carbon steelmaking are targeted.

The use of hydrogen to heat commercial and residential buildings as well as hydrogen as seasonal energy storage and back-up energy source are also addressed in the strategy, however, not as prominent as the industry and transport sector.

For the short- (2024) and medium-term (2030), targets for the production of hydrogen from electrolysis are defined as presented in Table 15.

Table 15: Sector targets European Union [EU H2 strategy 2020]

Sector		Target volume and time horizon
Hydrogen production	Electrolysis	6 GW (2024), 40 GW (2030)
	Renewable hydrogen production	1 million tons (2024), 10 million tons (2030)
Infrastructure	Hydrogen refuelling stations	400 additional (no year specified)

Besides the hydrogen production from electrolysis, some further infrastructure aspects are considered but not quantified. Those include [EU H2 strategy 2020]:

- Further roll-out of hydrogen refuelling stations (additional 400 stations are mentioned, no year specified)
- Until 2024:
    - Limited hydrogen transport infrastructure required as production will be close to or onsite of the demand centres (industry, refuelling station)
    - Blending with natural gas might occur during a transition phase [EU ESI 2020]

  - Start planning of medium range and backbone hydrogen transmission infrastructure
  - Carbon capture and use infrastructure will be required
- From 2025 to 2030:
  - Further retrofitting of existing fossil-based hydrogen production with carbon capture and storage
  - Dedicated regional hydrogen transport and distribution infrastructure for hydrogen clusters ("Hydrogen valleys")
  - Start of EU-wide hydrogen back-bone infrastructure incl. partial repurposing of existing gas grid
  - Establishment of a hydrogen refuelling station network
  - Development of larger-scale hydrogen storage facilities
  - Development of international hydrogen trade
- Transformation of ports to energy centres enabling international trade of e.g. hydrogen and synthetic fuels [EU ESI 2020]

Measures and H_2 requirements

Over the last years, a range of measures to support hydrogen have been established on a European level. Various additional future regulatory and financial support measures are discussed in the hydrogen and energy sector integration strategy. Those include (but are not limited to):

- Possibly installing quota or minimum shares for renewable hydrogen in certain end-use applications through the revision of the Renewable Energy Directive recast [EU ESI 2020]
- Introduction of a comprehensive terminology and European certification system for renewable and all low-carbon fuels [EU ESI 2020] [EU H2 strategy 2020]
- Introduce a low-carbon threshold/standard for the promotion of hydrogen production [EU H2 strategy 2020]
- Develop a pilot scheme (preferably at EU level) for a Carbon Contracts for Difference programme especially for industry applications [EU H2 strategy 2020]
- Revise the Energy Taxation Directive to avoid double taxation of energies including hydrogen [EU ESI 2020]

- Revise the TEN-E[22], TEN-T[23] and AFID[24] regulations and review the scope of the TYNDP[25] and the internal gas market legislation to ensure cross-sectoral and coordinated infrastructure planning, interoperable and liquid markets and possibly support the hydrogen refuelling station roll-out [EU ESI 2020], [EU H2 strategy 2020]
- Develop an investment agenda and build a concrete project pipeline through the European Clean Hydrogen Alliance to stimulate hydrogen use and production [EU H2 strategy 2020]
- Propose support measures for hydrogen (and hydrogen-based products) in the Commission's 2020 Sustainable and Smart Mobility Strategy
- Launch a call (Q3/2020) within the Horizon 2020 framework regarding 100 MW electrolysers, and Green Airports and Ports as well as innovative hydrogen technology demonstration projects through the calls for proposals under the ETS[26] Innovation Fund [EU H2 strategy 2020]
- Stimulate the production of renewable hydrogen-based fertilisers through the Horizon Europe program (from 2021) [EU ESI 2020]

The focus of hydrogen production in Europe is clearly on renewable hydrogen. However, in the short- to medium-term further low-carbon hydrogen production (e.g. fossil based with CCS or pyrolysis) technologies are needed. [EU H2 strategy 2020]

Achievements

Various directives issued by the by European Commission support the direct introduction of hydrogen. However, the implementation of those directives into national law differs for the Member States. Consequently, the directives can have a different level of impact based on national ambitions and preferences. For hydrogen, the most relevant EU directives include e.g. the Alternative Fuel Infrastructure Directive (AFID), the Clean Vehicle Directive (CVD) and the Renewable Energy Directive (RED II). Also important are e.g. the CO_2 emission standards for light-duty vehicles (LDVs) and heavy-duty vehicles (HDVs). The Dutch government, for example, considers the RED II an important aspect for the development of

22 Trans-European Networks for Energy

23 Trans-European Transport Network

24 Alternative Fuel Infrastructure Directive: Directive 2014/94/EU of the European Parliament and of the Council of 22 October 2014 on the deployment of alternative fuels infrastructure

25 Ten-Year Network Development Plan

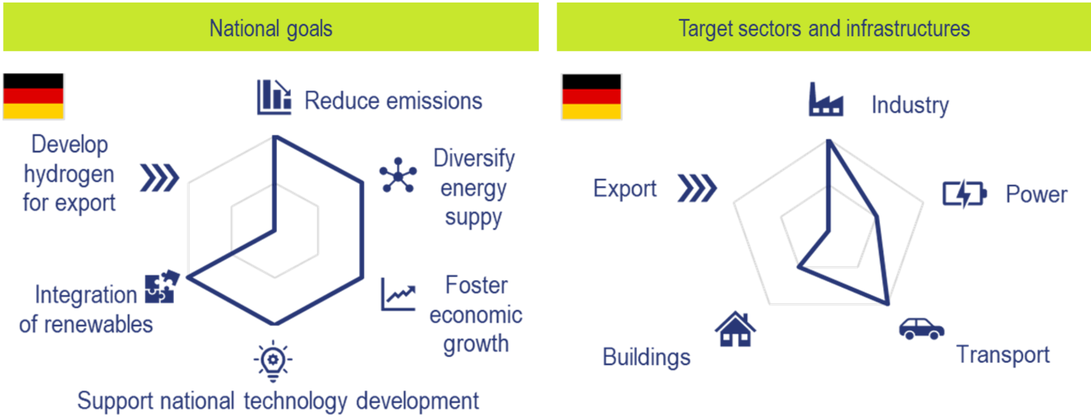
26 Emissions Trading System

hydrogen and is committed to ensure that the national implementation stimulates hydrogen especially in industry and mobility applications [NL H2 2020]. The German government aims at a targeted implementation of the CVD to support zero emission vehicles in public transport [BMWi 2020].

On European level, research, development, and demonstration of fuel cells and hydrogen technologies is supported by the public private partnership "Fuel Cells and Hydrogen Joint Undertaking" (FCH JU). Between 2014 and 2020, the FCH JU had a budget of 665 M€ which is complemented, at least, with an equivalent level of investments by the industry and research partners. All FCH JU projects (2014 to 2020) were funded via the European Horizon 2020 Framework Program. Between 2014 and mid-2019, 91 projects were started. Those projects receive a total of 460 M€ of FCH JU funding, of which about 195 M€ was for projects addressing the transport sector, about 198 M€ for projects addressing the energy sector and another 68 M€ for overarching and cross-cutting topics. The projects significantly contribute to the research, development and demonstration of fuel cells and hydrogen in Europe. The most prominent and most visible projects have usually been associated with vehicle and infrastructure demonstration such as the "Hydrogen Mobility Europe" (H2ME 1&2) project. In this project, a consortium of more than 40 partners puts more than 1,400 fuel cell-based cars and vans on the road and installs at least 45 hydrogen refuelling stations between 2015 and 2022. The project budget amounts to 170 M€ including 67 M€ from public funding. The roll-out activities cover more than 5 European countries. Equally noteworthy is the REFHYNE project, aiming to produce green hydrogen for a refinery using a 10 MW electrolyser, the largest PEM[27] electrolyser worldwide at present.

[27] PEM: proton exchange membrane

Germany



Current situation

In June 2020 German federal government, represented by five federal ministries[28], has published the first "National Hydrogen Strategy" in [BMWi 2020] although Germany already has a long history on hydrogen including a number of research, development, and demonstration projects at national, regional, and local levels and a dedicated federal entity being in charge of hydrogen-related issues[29]. One of the starting points for the development of the national hydrogen strategy was the Gas 2030 dialogue process in December 2018 intended to discuss the future role of the gas infrastructure with the various stakeholders and to derive policy recommendations. The hydrogen strategy has then been developed internally since the first announcement in autumn 2019 in cooperation between different federal ministries and discussed at a stakeholder conference in Berlin in November 2019 with more than 700 participants from industry, academia, politics, various associations, and non-governmental organisations (NGOs). The strategy intends to provide indications for the German EU Council Presidency in the second half of 2020.

Germany already has a comparatively large hydrogen market with an estimated demand of ca. 55 TWh_{H2} per year. Major consumers are the chemical industry (ammonia and methanol production) and refineries and most of hydrogen production is based on fossil fuels. There are already 34 Power-to-Gas facilities in Germany with a total installed capacity of 29 MW.

[28] The work on the German national hydrogen strategy was led by Federal Ministry for Economic Affairs and Energy (BMWi). It was supported and advised by Federal Ministry of Transport and Digital Infrastructure (BMVI), Federal Ministry of the Environment, Nature Conservation and Nuclear Safety (BMU), Federal Ministry of Education and Research (BMBF) and Federal Ministry of Economic Cooperation and Development (BMZ).

[29] NOW: Nationale Organisation Wasserstoff- und Brennstoffzellentechnologie (National Organisation Hydrogen and Fuel Cell Technology).

National goals

The strategy emphasises the role of hydrogen for the successful transition of the German energy system as well as for achieving the climate protection goals from the Paris Agreement and greenhouse gas-neutrality in Europe by 2050. In this context, GHG emission reduction, especially for applications which are hard to electrify, coupling of different end user sectors and integration of renewable energy supply are core objectives. The strategy states that due to limited renewably energy potential hydrogen imports will be necessary to meet the long-term demand in Germany. Nevertheless, fostering of the domestic hydrogen demand and production capabilities is an important first step in developing hydrogen economy.

Besides the environmental issues, the German strategy explicitly recognises economic benefits from exporting hydrogen technologies. Based on a strong focus on current and future R&D activities as well as on development of corresponding hydrogen supply chains, Germany intends to maintain its competitive advantage and to become one of the leading nations in hydrogen technology. In this way hydrogen is seen as a mean for strengthening domestic industry as well as economic growth and job creation in many regions in Germany. It has also the potential to overcome the economic consequences of corona pandemic. Additional benefits from the use of hydrogen are seen in diversification of energy carriers and energy import routes increasing security of energy supply. Moreover, hydrogen imports to Germany could be a good opportunity for hydrogen exporting countries for increasing their renewably energy supply and economic prosperity.

Target sectors and infrastructures

In its advanced and comprehensive approach, the strategy addresses a full range of different end user sectors and applications.

Industry is one of the first and largest sectors for hydrogen use. In particular, the chemical (mainly ammonia and methanol), petrochemical and steel industry are of special interest for hydrogen in Germany. For example, ammonia production and refining is expected to need ca. 22 TWh_{H2} per year by 2050 whereas green steelmaking might require another 80 TWh_{H2} per year. Additional benefits may arise from the use of unavoidable CO_2 emission from some industries such as cement industry which combined with green hydrogen can provide input for new processes in the basic materials industry (as so-called Carbon Capture and Usage-CCU).

The transport sector is another area with a large potential for hydrogen demand. Hydrogen-based technologies represent a decarbonisation alternative for applications which are otherwise hard to electrify. They include planes, ships, buses, trains, heavy-duty trucks as well as utility vehicles (e.g. construction site vehicles), material handling (e.g. forklifts), and military vehicles. In this context, both fuel cell vehicles and hydrogen-based synthetic fuels can be used. Passenger cars can be partially powered by hydrogen, but this sub-sector is not a main target of the German hydrogen strategy.

Additional hydrogen applications such as process heat in industry as well as for heating in the buildings sector might develop. In the long-term hydrogen can also be used to store excess renewable electricity.

Due to the expected need for hydrogen imports the strategy is open to different hydrogen carriers and infrastructure developments. Dedicated hydrogen pipelines, LH_2 and LOHC transport as well as other H_2-based carries such as ammonia and methanol are mentioned as an option. Nevertheless, the strategy emphasises the need for a coordinated infrastructure build-up in line with the demand development in order to avoid malinvestments. Therefore, also further expansion of the hydrogen refuelling network should occur aligned to the vehicle deployment.

The strategy formulates a target for domestic renewable hydrogen production of 5 GW (by 2030) to 10 GW (by 2035-2040) for electrolysis capacity providing 14-28 TWh_{H2} per year and consuming 20-40 TWh per year of renewable power mainly from onshore and offshore wind power plants. The ramp-up of the domestic hydrogen market should occur until 2023 while its consolidation as well as major international developments are expected to take place until 2030. Similar to other strategies the overall goal of GHG neutrality and thus of an established hydrogen market is foreseen for 2050. Table 16 summarises the figures on hydrogen production and demand presented in the German hydrogen strategy.

Table 16: H_2-related targets in Germany

Sector		Target volume and time horizon
Renewable hydrogen production	Electrolysis capacity	5 GW (2030); 10 GW (2035-2040)
	Renewable hydrogen production	14 TWh/a (2030); 28 TWh/a (2035-2040)
	Renewable power consumption	20 TWh/a (2030); 40 TWh/a (2035-2040)
Overall demand	Hydrogen demand	55 TWh/a (2020); 90-110 TWh/a (2030)
	Power-based energy carrier consumption	110-380 TWh/a (2050)
	Hydrogen consumption in industry	55 TWh/a (2020); at least 65 TWh/a (2030)

Measures and H_2 requirements

Research and development activities for key technologies and new approaches along the entire hydrogen value chain are considered as a key element of the strategy. The major objective is to decrease the costs and to improve the efficiency for robust and modular hydrogen solutions which can be applied worldwide. Demonstration projects should provide necessary experience for the use of hydrogen technology in practise and improve its competitiveness against other clean technologies.

The regulatory measures related to hydrogen discussed in the strategy are manifold and include the following:

- Rapid and ambitious implementation of the Renewable Energy Directive (RED II[30]) with an ambitious above-average renewable energy share in the transport sector, support for the use of green hydrogen in refining with a target of a electrolysis capacity of 2 GW, a quota for e-fuels in aviation of 2% by 2030, and the development of a transparent methodology for calculation of fuel CO_2 intensity
- Further development of the Alternative Fuels Infrastructure Directive (AFID)[31] for an ambitious build-up of the refuelling infrastructure and targeted implementation of the Clean Vehicle Directive (CVD)[32]
- Examination of obligatory quota for selected clean products such as clean H_2-based steel
- Testing of combined renewable power and hydrogen generation in one to two pilot projects by repealing unbundling rules and easier designation of areas for offshore wind power plants needed for renewable hydrogen production
- Support for harmonisation of international standards in the transport sector
- Coordinated planning and financing of future electricity, heat, and gas infrastructures
- Development of a regulatory framework for dedicated pipeline network for hydrogen transport and distribution by taking safety issues into account
- Improvement of the regulatory framework for the implementation of research results into real life projects to allow for a large-scale roll-out of the hydrogen technology

[30] Renewable Energy Directive: Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources.

[31] Directive 2014/94/EU of the European Parliament and of the Council of 22 October 2014 on the deployment of alternative fuels infrastructure

[32] Clean Vehicles Directive: Directive (EU) 2019/1161 of the European Parliament and of the Council of 20 June 2019 amending Directive 2009/33/EC on the promotion of clean and energy-efficient road transport vehicles

Financial support for hydrogen technology in Germany is very ambitious. Dedicated funding programmes for hydrogen amount to more than 12 B€ including a wide range of areas and sources such as:

- Ongoing national innovation programme hydrogen and fuel cell[33] (1.4 B€ for 2016-2026),
- Basic research on renewable hydrogen (0.3 B€ for 2020-2023),
- Living labs for energy transition[34] for a broad range of activities ranging from research to real life applications (0.6 B€ for 2020-2023),
- Programme for decarbonisation of production processes in industry ´trough hydrogen technologies (1 B€ for 2020-2023) and
- Economic stimulus package due to corona pandemic[35] for hydrogen market ramp-up (7 B€) and for international cooperation (2 B€).

Additional funding of almost 9 B€ until 2023/2024 may come from other ongoing programmes such as the energy and climate fund[36] or the incentive programme energy efficiency[37] for purchase subsidies for electric vehicles (2.1 B€), utility vehicles, and buses with alternative powertrains (1.5 B€), fuel cell based heating appliances (0.7 B€) as well as for grants for the development of charging and refuelling infrastructure (3.4 B€). It is important to mention that these programmes are not exclusively for hydrogen but for all clean technologies. Hence, actual funding for hydrogen will be lower than 9 B€.

Besides direct funding the strategy also foresees financial instruments to lower the operational costs of hydrogen production and H_2-based applications. On the one hand it includes the reduction of taxes, fees, and levies on renewable power for electrolytic hydrogen production and on the other hand carbon prices for fossil-based technologies such as CO_2-based road tolls for trucks on German roads. Another important instrument is the suggested carbon contracts for difference (CCfD) mechanism, intended to cover the differential costs between the conventional and renewable H_2-based technologies in industries within the ETS sector.

Staff training and education for researches is another measure for hydrogen technology development in Germany. Dedicated stakeholder engagement in form of an ongoing and

33 „Nationales Innovationsprogramm Wasserstoff- und Brennstoffzellentechnologie (NIP)"

34 "Reallabore Energiewende"

35 "Zukunftspaket des Koalitionsausschusses"

36 "Energie- und Klimafonds (EKF)"

37 "Anreizprogramm Energieeffizienz (APEE)"

detailed dialogue on further actions towards the decarbonisation of the economy is also viewed as important element of the strategy in order to increase the acceptance among concerned actors.

International cooperation with countries both from the EU and outside of Europe plays an important role in the national strategy due to the expected need for hydrogen imports. The objective is to develop required supply chains and eventually an international hydrogen market. In the EU context, common technical standards, investment rules, environmental requirements including hydrogen certification and knowledge exchange will be needed for coordinated hydrogen production and transport across Europe. Existing energy-related partnerships and ongoing development between the federal government and other countries should be used to launch new common projects and to test hydrogen import routes and technologies. For this purpose, Germany intends to provide a public funding budget of 2 B€ for international activities and to support the development of an international hydrogen-related "Important Project of Common European Interest (IPCEI)" with German participation.

In order to ensure further development of the strategy and effective monitoring of its implementation, Germany puts in place a sophisticated governance structure. On the one hand it includes a committee of undersecretaries from selected ministries being in charge for strategic management and further development of more detailed action plans. The actual implementation of single actions will be then carried out by the concerned ministries. On the other hand, a national hydrogen council with 25 members from industry, science, trade unions as well as NGOs will provide advice to the committee of undersecretaries on relevant topics. Dedicated central office is intended to support the work and decision making of both committee and council. An annual monitoring report will help to track the progress of the hydrogen-related actions and the strategy will be evaluated in more detail after three years. In addition, the federal government commits to develop an adequate platform to coordinate the governmental activities between the national and regional levels.

The long-term objective in Germany is to use renewable hydrogen in the different sectors in line with the target of GHG neutrality by 2050. However, in the transition phase other clean hydrogen sources including steam methane reforming in combination with CCS and methane pyrolysis (e.g. imported from Russia) are considered to meet the expected growth in hydrogen demand. Nevertheless, the strategy also states that potential lock-in effects have to be avoided. As a consequence, increasing renewable electricity production will be necessary in Germany to meet future demand for renewable hydrogen.

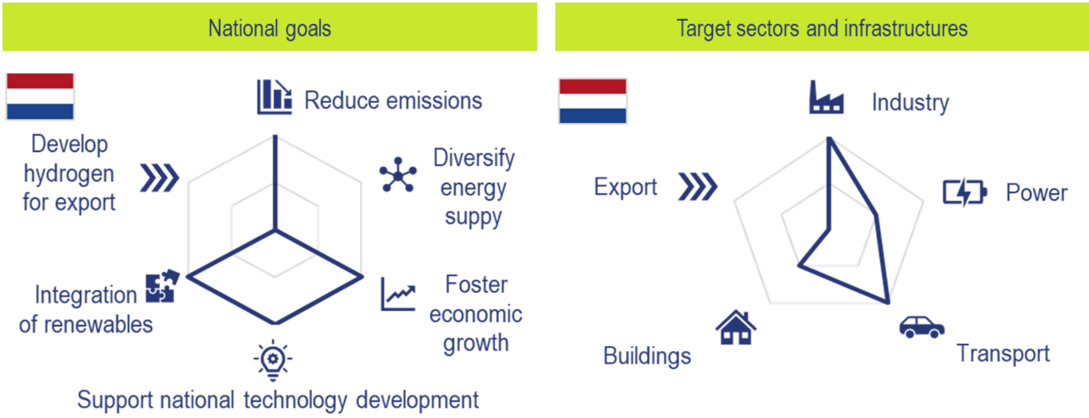
Achievements

As mentioned above, Germany has a long hydrogen-related history. In the past years Germany has launched a number of research and pilot projects related to the entire hydrogen value chain. The large and growing public hydrogen refuelling network currently consisting of almost 100 stations is one of the most important achievements in Germany. The infrastructure is built up and operated by a dedicated company H2 MOBILITY which, on the one hand, is owned and partially financed by five private companies but, on the other hand, also receives public funding from the German government. This achievement shows that public-private partnerships help to align interests of industry and government and to develop critical infrastructures.

Further achievements are strong and comprehensive regional planning activities which were initiated by "HyLand" funding call. Some of the proposed activities which were not selected for funding are now being continued by the stakeholders involved even without funding. This 3-tiered funding call supports concepts, project design, and its implementation in a sustainable way and shows the importance of moving away from isolated pilots to demonstrating comprehensive value chains, of supporting collaborations between different stakeholders and of a target commercialisation of the technology. Other examples for good practises in Germany are:

- first commercial operation of fuel cell train provided by Alstom in Northern Germany,
- comparatively large already existing Power-to-Gas capacity of ca. 30 MW at more than 30 sites or
- Carbon2Chem project designed to use exhaust gases from blast furnaces in steelmaking for hydrogen-based production of selected chemicals.

Netherlands



Current situation

In 2019, the Dutch government presented the National Climate Agreement [NCA NL 2019]. This agreement contains a set of measures and targets, drawn up in consultation with various stakeholders and the Dutch society, on how to achieve a GHG emission reduction of 49% by 2030 compared to 1990 levels. Among other technologies and sectors, this document, explicitly defines some targets for the roll-out of hydrogen and hydrogen technologies including measures on how to achieve them until 2030. Hydrogen related aspects of this agreement have been picked up and merged into the 2020 Government Strategy on Hydrogen also adding some further details [NL H2 2020].

National goals

The Government Strategy on Hydrogen mentions the following reasons for Dutch activities in the field of hydrogen [NL H2 2020]:

- Hydrogen is an indispensable part of sustainability strategies of the industry and ports
- Hydrogen helps to integrate solar and wind energy into the energy system
- Hydrogen enables air quality improvements
- Hydrogen is crucial to enable zero emission transport
- Clean hydrogen will lead to the creation of new jobs
- Rapid hydrogen development is in line with the long-term economic growth strategy of the government

Target sectors and infrastructures

Dutch sector and infrastructure targets as presented in the National Climate Agreement from 2019 which are partially picked up in the Government Strategy on Hydrogen 2020. Main targets per sector are listed in Table 17.

Table 17: Sector targets the Netherlands [NCA NL 2019], [NL H2 2020]

Sector		Target volume and time horizon
Mobility	FCEV	15,000 (2025); 300,000 (2030)
	FC heavy vehicles (incl. agricultural vehicles)	3,000 (2025)

In the aviation sector, the Netherlands firmly supports a European blending obligation for sustainable fuels. Alternatively, the national government pursues a national obligation of 14% in 2030 and 100% by 2050. Blue hydrogen is considered as steppingstone for later green hydrogen use. The use of hydrogen in the shipping industry (ports, maritime and inland waterways) will also be stimulated [NL H2 2020].

For the building sector, no large-scale usage of hydrogen is expected due to uncertain hydrogen costs and available quantities before 2030. However, some pilot-projects will be realised in the 2020 to 2025 period [NL H2 2020].

The long-term relevance of hydrogen for the power generation sector e.g. as carbon-free fuel for dispatchable generation capacity or as long-term large-scale energy storage is mentioned in the National Climate Agreement [NCA NL 2019]. However, Government Strategy on Hydrogen does not provide any further plans or elaborations [NL H2 2020].

The importance of hydrogen in the industry sector is expressed in the strategy although itis rather vague when it comes to concrete applications in the industry sector. One focus is the possible upgrading of existing hydrogen production facilities in industrial areas with CCS technology. Hydrogen use in the industry sectors is mentioned with regards to high temperature heat and refineries. Further industry applications are not explicitly mentioned [NL H2 2020].

In terms of hydrogen infrastructure and supply, the Netherlands intends to increase the number of HRS to 50 by 2025 [NCA NL 2019] [NL H2 2020]. Green hydrogen production via electrolysis is planned to be ramped up to approximately 500 MW of installed capacity by 2025 and to 3-4 GW by 2030 [NL H2 2020].

Measures and H_2 requirements

The Dutch government plans to foster cost reductions for green and blue hydrogen production through existing and new support schemes.

- Applied research and innovative pilot projects are supported in various MOOI (Mission-oriented Research, Development, and Innovation) tenders. In addition, support is available through the DEI+ (Energy Innovation Demonstration Scheme). Maximum funding per project under DEI+ is 15 M€ or 25 to 45% of eligible costs, depending on the type of company [NL H2 2020].

- Roll-out of hydrogen production including hydrogen production by electrolysis will be supported in the SDE++[38] scheme for the first time in 2020. Hydrogen production by electrolysis will be eligible for up to 2,000 full load hours per year to avoid increase of electricity related GHG emission. With this limit there will be CO_2 reductions given that these are hours with significant production of renewable and thus low-cost electricity. Companies will be able to receive support of up to 300 € per ton of avoided GHG emissions. Low carbon hydrogen (via CCS technology) is also supported under the SDE++ scheme [NL H2 2020].
- A new and temporary support scheme aims at green hydrogen production only. Approximately 35 M€ per year will be reallocated within DEI+ to support operating costs of green hydrogen production. This support closes a gap for upscaling of electrolysis between the existing DEI+ and revised SDE++ schemes [NL H2 2020].

The government will evaluate the advantages and disadvantages of linking hydrogen production to offshore wind energy via integrated tenders. In addition, the Netherlands will promote international cooperation exploring offshore hydrogen production. Further, an obligation for hydrogen blending into the gas grid will be evaluated (physical obligation or via certificates) [NL H2 2020].

Pilot-projects on the hydrogen demand side are supported through schemes such as DEI+ [NL H2 2020].

In 2020 a cooperation agreement between hydrogen stakeholders "H2Platform" (i.e. fuel and hydrogen suppliers, leasing businesses, business users and other stakeholders) will be signed to reach the defined 2025 mobility sector targets [NL H2 2020] [NCA NL 2019]. This will be supported by the government (incl. local and regional authorities) by acting as launching customers and by developing subsidy schemes for zero emission urban logistics and heavy-duty transport [NL H2 2020]. The stakeholders and the Ministry of Infrastructure and Water Management will maximise the allocation of EU funds to enable their goals [NCA NL 2019].

[38] SDE++ scheme (Renewable Energy Transition Incentive Scheme) will replace the SDE+ scheme (Renewable Energy Production Incentive Scheme) from 2020 onwards. The new scheme has a focus on energy transition rather than "only" on renewable production. As a consequence, the new scheme does not focus on funding energy produced (€/kWh) but on GHG emissions avoided (€/tCO2). The funding will (partially) close the gap between production costs and market price for a product (e.g. hydrogen produced via electrolysis).

The Administrative agreement on zero emissions buses has the goal to only put zero emission (battery electric and hydrogen) buses for public transport into service, starting in 2025. This ensures that all public transport buses are zero emission in 2030. For this about 10 M€ annually will be made available by the government between 2019 and 2025. In addition, 50% of the taxis must be zero emission by 2025 [NCA NL 2019].

The national implementation of RED II is considered an important aspect for the development of hydrogen in the Netherlands. The Dutch government is committed to ensure that the national implementation is useful and stimulating for hydrogen especially with regards to industry applications and the mobility sector [NL H2 2020].

To further support the development of hydrogen and hydrogen technologies, the Netherlands is active in international initiatives (e.g. IPHE[39], IEA[40]) and collaborations with neighbouring countries and the European Commission [NL H2 2020].

Achievements

There is already a large number of hydrogen projects in the Netherlands. In Spring 2020 an overview listed more than 80 active hydrogen pilot and demonstration projects [TKI 2020]. The most visible hydrogen projects include:

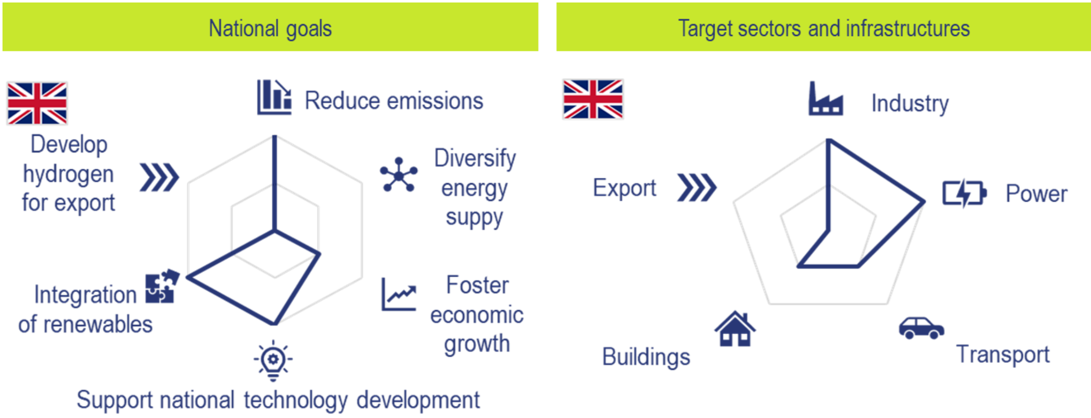
- Porthos: CCUS Infrastructure for Blue Hydrogen in Port of Rotterdam
- HEAVENN: 30 sub-projects in Northern NL

In terms of hydrogen mobility, about 200 fuel cell vehicles and 7 hydrogen refuelling stations were in operation in mid-2020. According to the LBST PtX-database, two PtX plants are in operation with additional 14 plants in preparation (announced, studied, under construction).

[39] International Partnership for Hydrogen and Fuel Cells in the Economy

[40] International Energy Agency

United Kingdom



Current situation

The United Kingdom has no dedicated official hydrogen strategy. The role of hydrogen is discussed in the context of different climate and industry-related policy initiatives and strategy papers such as Clean Growth Grand Challenge under the Industrial Strategy, "Clean Growth: Transforming Heating" or "Maritime 2050: Navigating the Future". Most recently, hydrogen is also being discussed by the Department for Business, Energy & Industrial Strategy (BEIS) within the consultation on "Business Models for Carbon Capture, Usage and Storage" [BEIS 2019a]. A number of national funding programs aim to support the development of hydrogen technologies in the UK.

National goals

The major goal of the British government regarding hydrogen activities is the environmental protection by reducing GHG emission and integrating renewable energy into the energy system. In this way, hydrogen is expected to help in achieving the long-term decarbonisation targets. Moreover, funding programs aim to support the development of hydrogen technologies which can provide economic benefits to the industry and society. Diversification of energy supply and development of hydrogen for export play a minor role in the UK. In fact, low carbon hydrogen can be produced from steam methane reforming in combination with CCS and thus allow for another market for natural gas supply in the UK [BEIS 2019a].

Target sectors and infrastructures

The industry and power sectors are viewed as major targets by 2030 in the UK. In fact, the UK has a larger market potential for hydrogen use in petrochemical and ammonia industries. In addition, there is also some funding for the development of clean steelmaking. Furthermore, the market for low carbon electricity is viewed as mature and re-electrification of hydrogen in adequate gas turbines as an option to contribute to this market [BEIS 2019a].

Blending of hydrogen is seen as an opportunity to decarbonise the gas grid und thus the heating sector in the mid-term [BEIS 2019b]. However, the official documents are concerned about the safety issues with respect to hydrogen in the gas grid and have doubts about its long-term environmental benefit for the heating sector [BEIS 2019a]. Nevertheless, the government commits to form partnerships between industry, academia, and other key stakeholders in order to further investigate and demonstrate hydrogen use for heating purposes. In addition, there are some research and pilot projects on the full conversion of gas grids from natural gas to hydrogen and the use of hydrogen-based appliances such as H21 Leeds City Gate or Hy4Heat which receive public funding.

The role of hydrogen in the transport sector in the UK is considered as limited and supplementary especially in the mid-term until 2030. Major potential applications are buses, trains, ships, and heavy goods vehicles. In the maritime sector direct hydrogen use and ammonia as ship fuel are discussed [DfT 2019].

Measures and H_2 requirements

The focus of the national strategy is to research, test and demonstrate hydrogen technology towards its commercialisation and market activation in an early scaling up phase until 2030. Hydrogen could be then used in at least one low-carbon industrial cluster by 2030 which will emerge as a first net-zero carbon cluster by 2040. Hence, the objective is to better understand the potential and benefits of the hydrogen technology by simultaneously lowering the cost and enhancing the safety. These different activities are supported by public funding including:

- Low Carbon Hydrogen Production Fund: 110 M€ (100 million GBP)
- Clean Steel Fund: 275 M€ (250 million GBP)
- Hydrogen Supply competition: 36 M€ (33 million GBP)
- Industrial Fuel Switching competition: 22 M€ (20 million GBP)
- Hy4Heat programme: 28 M€ (25 million GBP)
- Innovative large-scale energy storage solutions competition: 22 M€ (20 million GBP)
- Development of alterative hydrogen heating appliances: 3.3 M€ (3 million GBP)
- Ultra-low emissions bus scheme competition: 5 M€ (4.4 million GBP)
- Hydrogen for Transport programme: 15 M€ (14 million GBP)
- Industrial Energy Transformation Fund: 345 M€ (315 million GBP)
- Industrial Strategy Challenge Fund: 113 M€ (103 million GBP)

Moreover, the UK aims to adapt market boundary conditions to enable long-term investments. Several approaches are being discussed without a final decision including hydrogen uptake incentives in demand sectors closest to commercialisation, differential pricing for hydrogen and obligatory quota in some sectors.

Based on some analyses, the demand for hydrogen in the UK may increase from currently 10-27 TWh_{H2} per year up to 270 TWh_{H2} per year by 2050 out of which 80% could be based on low-carbon hydrogen production in combination with CCUS technologies [BEIS 2019a]. Nevertheless, renewable hydrogen production via electrolysis will also play a role in the UK to an extent which needs to be determined in more detail in the future.

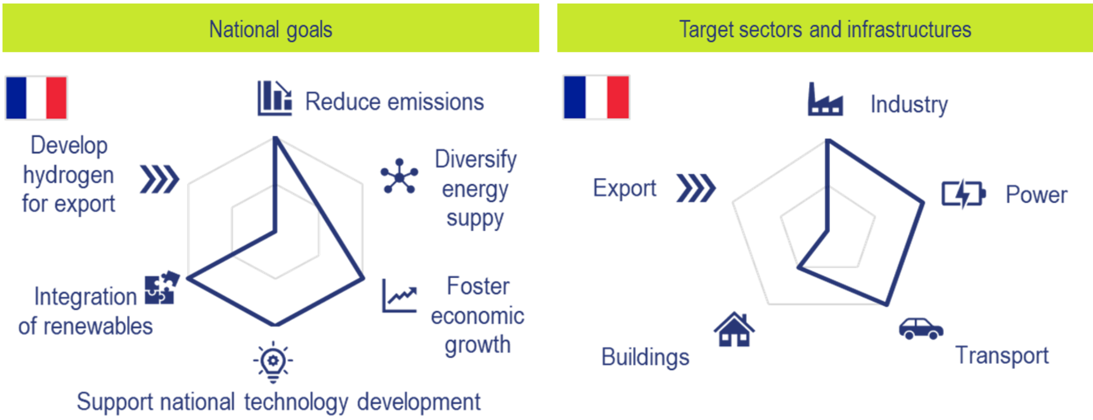
Achievements

Hydrogen technology in the UK is already being developed in a number of demonstration projects receiving public funding as one of the major drivers such as:

- H21 Leeds City Gate (conversion of existing gas grid to 100% hydrogen network),
- HyNet (low carbon hydrogen plant),
- Dolphyn (hydrogen generation at floating offshore wind power plants),
- Gigastack (gigawatt scale PEM electrolysis for hydrogen production),
- Acorn Hydrogen Project (advanced reformation process for hydrogen production),
- HyPer (low carbon bulk hydrogen supply) or
- HyDIME (hydrogen diesel dual fuel injection system for a commercial ferry).

There are also more than 100 fuel cell cars and several dozens of fuel cell buses which can rely on 20 hydrogen refuelling stations (in operation or planned). According to the LBST PtX-database, four PtX plants are in operation with additional 16 plants in preparation (announced, studied, under construction).

France



Current situation

With the Paris Agreements signed at the end of COP21 in 2015, France has placed climate action at the heart of its economic and diplomatic relations and created an unprecedented international dynamic. This action is built around the central objective of limiting global warming to at most 2°C above pre-industrial levels. To accelerate the energy transition and structure a hydrogen sector in France, the French government launched a hydrogen plan at the national level [MTES 2018]. It is intended that the plan will feed into the Government's strategy on hydrogen and electricity storage and is to be reflected in the Multi-annual Energy Programme (PPE, Programmation Pluriannuelle de l'Energie) for the 10-year period 2019-2028. In particular, the plan should launch an emerging hydrogen sector in France.

In addition, France is also developing, in collaboration with ADEME (the French Environment and Energy Management Agency), an original policy of "territorial ecosystems of hydrogen mobility". At city-level, i.e. community of communes or agglomeration, it aims to build decarbonised and economically viable mobility. To this end, local hydrogen production units coupled with green energy sources will be created and made profitable by accelerating the conversion of the most polluting fleets of heavy and / or utility vehicles in the territory. The originality of the approach is to involve regional and local authorities alongside large companies and start-ups.

Very recently, on 7 September 2020, French economy minister Bruno Le Maire announced green hydrogen to be an important element in the French COVID-19 recovery plan, including envisaging a close cooperation with Germany. Subsequently, on 8 Sep 2020, a national strategy for the development of decarbonised hydrogen ("Stratégie nationale pour le développement de l'hydrogène décarboné en France") was announced [Strategie H2 2020].

National goals

In June 2018 the French government announced its ambitions to make France the world leader in hydrogen via its Hydrogen Deployment Plan for the energy transition, which outlined the objectives for developing the use of hydrogen in the energy transition market. Therefore, the major goal of the hydrogen deployment plan is to help in reducing the GHG emission in France and to integrate renewable electricity supply into the energy system mainly through hydrogen storage and additional services provided by the Power-to-Gas technology. Another goal is strengthening of the French industry by developing the technology and providing new business opportunities. These ambitions and goals were reaffirmed in the 2020 hydrogen development strategy, targeting up to 150,000 new jobs directly or indirectly through deploying hydrogen technologies and applications.

Target sectors and infrastructures

The hydrogen plan is based on the strengths of the French industry, particularly present in the production of hydrogen, and aims above all to green existing industrial uses of hydrogen, starting with uses nearest to profitability. By capitalising on these developments, it will then be possible to develop new uses, related to mobility, first with a particular focus on captive fleets, then on storage of renewable energy in the gas network, when the need arises. In this context, the 2018 hydrogen deployment plan is structured around three main axes with dedicated goals:

- **Hydrogen production by electrolysis for industry:** The first target of the French strategy is to create a low-carbon industrial sector. In this context, the cost of electrolysis and electrolysers are crucial factors in the price of hydrogen. Hence, the plan foresees a reduction of the cost of electrolysers by 2028. This cost reduction could reach hydrogen production price as low as 2 to 3 €/kg, with an electrolyser operating during 4,000 to 5,000 hours per year, and could, as a result, generate significant economies of scale. Through a start-up strategy, the plan sets the objective of reaching 10 % of carbon-free hydrogen in industrial hydrogen by 2023 and 20 to 40% by 2028.
- **Enhancing the use in mobility as a complement to battery systems:** The second target is to develop zero emission solutions for road, rail, river transport, etc. From the reduction in electrolyser costs, the Minister for Ecological and Solidarity Transition expects, that by 2030, green hydrogen should be available at a price comparable to the cost of energy for a diesel vehicle (i.e. around 7 €/kg). In order to develop mobility based on hydrogen, the plan provides for the development of a specific range of heavy road vehicles.
- **Stabilisation of energy networks in the medium/long term**: Finally, the third target is to develop storage capacities for renewable energies. In the long term, it is envisaged that hydrogen produced by electrolysis will be a strategic solution for

the integration of renewable energies and it is therefore regarded to be the most promising means of massive storage of intermittent renewable energies.

The national hydrogen deployment plan is presented in the Multi-annual Energy Programme ("Programmation Pluriannuelle de l'Energie", PPE) with the quantitative targets as summarised in Table 18.

Table 18: H_2-related targets in France

Sector		By 2023	By 2028
Industry	Incorporation rate for carbon-free H_2 in industrial hydrogen	10%	20-40%
Mobility	Light utility vehicles	5,000	20,000 to 50,000
	Heavy-duty vehicles (bus, trucks, trains (TER), boats)	200	800 to 2,000
	HRS	100	400 to 1,000
Power-to-Gas	Demonstrator	1-10 MW	10-100 MW

Building on the 2018 deployment plan, the 2020 development plan focuses on industry, transport, R&D, and electrolyser development research. The primary focus for hydrogen production in the strategy is to decarbonise France's industrial processes, the main source of demand for hydrogen in France with a current annual hydrogen consumption of around 900,000 tons. The 2020 plan targets an electrolyser capacity of 6.5 GW in France by 2030.

Moreover like some countries which have defined ambitious technological and industrial policies, France undertook at the end of 2019 a process of selecting a limited number of priority markets with the aim of bringing out new leaders in high potential growth markets and in which France can position as a leader. At the end of the work carried out by a college of experts, 22 key markets were identified with 10 priority ones of which the market of hydrogen for energy systems. Based on the report "Making France a technological disruptive economy - Supporting emerging markets with high competitiveness challenges", the government will make the final selection of priority markets to draw up the Productive Pact and define plans actions with all stakeholders to accelerate the development of each of these priority markets. These strategies will notably benefit from the resources stemming from the new future investment program (PIA) requested by the Prime Minister.

Measures and H_2 requirements

The regulatory measures in the French hydrogen deployment plan aim at the collaboration between different relevant actors including state institutions. Inspired by the model of the "Green Deals" implemented in the Netherlands, the so-called ECVs (« Engagements pour la Croissance Verte », Commitments for Green Growth) co-steered by CEA (Commissariat à l'énergie atomique et aux énergies alternatives) and AFHYPAC (the French Association for Hydrogen and Fuel Cells) aim to strengthen the partnership between the French state and the project leaders of innovative projects that contribute to the energy transition. In particular, the objective of the ECVs is

- to emphasise and promote the ongoing actions / initiatives / projects in the French hydrogen sector ("France Hydrogen Team"),
- to facilitate the deployment of the hydrogen sector by acting on the barriers to remove and the drivers to set up by the relevant stakeholders, and
- to have tangible commitments of the French hydrogen players, in addition to the commitments of the government in the plan.

Established for a period of three years, the ECVs are reciprocal commitments between the government and the economic players (industrial, public authorities) to achieve concerted objectives on one or more themes related to ramp-up of an industrial sector for sustainable development. A commitment results in a flexible legal contractual document co-signed by the government and the stakeholders involved, either directly or through a representation (professional union of an industrial branch, association, consortium, etc.). This contract constitutes a moral commitment ("Gentleman agreement") of the signatories and is not legally binding. Based on a bottom-up approach, project leaders are invited to first define their commitments as well as those desired by the state. Based on these proposals, the co-construction of the ECV begins. Depending on the requests expressed concerning the desired commitments from the State, an ad-hoc project team is created on the administration side to further examine these requests and decide whether or not to take them into account in the ECV. This approach helps to remove regulatory, normative or operational barriers.

Another instrument is represented by so-called CSFs ("Contrats Stratégiques de Filière", Strategic Sector Contracts between the French government and the industrial players) for integration of hydrogen in different sectors. The objectives of the CSFs are mainly to facilitate dialogue between industrial sectors and the French government. They should provide a strategic vision at 5-10 years horizon and directly involve the Prime Minister and the Ministry of the Economy.

In addition, the government intends to launch a working group with all the relevant players on the simplification and harmonisation of authorisation and homologation procedures for boats and bunkering solutions.

The financial support for hydrogen technology in French hydrogen deployment plan includes following measures:

- Starting in 2019, 100 M€ will be earmarked for the implementation of the hydrogen deployment plan, with defined targets on each of the three main axes. The calls for projects representing the financial arm of the plan will be operated by ADEME.
- Support investment on clean heavy-duty vehicles (>3.5t) by a fiscal measure of over-depreciation, under the same conditions as for CNG vehicles.
- Mobilise financial institutions (private and public funding) and standardise co-financing models for ecosystem deployment projects which creates synergies with other local uses (mobility, industry, etc.).
- Continue the support for innovation, in particular to support industrialisation and the scaling up of French players.

The ongoing research and development activities are expected to continue the support for innovation, notably to support industrialisation and the scaling up of French players. The plan also indicates the introduction in 2020 of a hydrogen origin traceability system, enabling hydrogen players to use low carbon and/or renewable hydrogen guarantees of origin.

In general, France aims to prepare for the arrival of the Power-to-Gas as a valuable technology for the storage of excess renewable electricity. In this context, both blending of hydrogen into the gas grid and its conversion to synthetic methane are possible. In the short term in the transition phase France allows for both clean and fossil-based hydrogen. In the long term by 2050 only clean hydrogen should be taken into account. Electrolytic hydrogen production can include both renewable and nuclear power.

The new 2020 hydrogen development plan allocates 7 B€ for the hydrogen sector until 2030, 3.4 B€ of which will be made available in the next 3 years until 2023 (thereof 54% to industry, 27% for transport, and 19% for research and development). 2 B€ will be made available for industrial electrolysis projects by 2022, envisaging a close cooperation with Germany. Initial plans point towards a "gigafactory" for hydrogen, for which both countries could provide 1.5 B€, eying to apply for the status of an IPCEI [Euractiv 2020].

Qualification and training in the hydrogen sector is explicitly recognised in the 2020 development plan as a key success factor going forward, identifying several support measures.

Achievements

As part of the national hydrogen deployment plan, two calls for projects and two calls for expressions of interest were launched by ADEME.

- The first call for projects (AAP) entitled "Hydrogen mobility ecosystems" launched in October 2018 made it possible to select 20 projects for a total amount of around 80 M€. The success of this call showed a structured sector in working order, with a real ambition from the regions. All the selected projects will enable the deployment of more than 43 hydrogen refuelling stations (for a target of 100 in 2023), and 158 trucks (for a target of 200 in 2023).

- The second call for projects entitled "Production and supply of decarbonated hydrogen for industrial consumers", launched in February 2019 as part of the Investments for the Future Program (PIA) operated by ADEME, enabled the selection of 5 projects, for a total funding of 11.5 M€. These 5 projects represent different and complementary industrial cases: 2 by-product projects, 3 on-site production projects. All the selected projects will replace more than 40,000 tons of carbon-containing hydrogen with decarbonated hydrogen and avoid the emission of 418,000 tons of CO_2 over the life of the facilities (15 years).
- One call for expressions of interest entitled "Large-scale projects on the design, production and use of hydrogen systems" was launched in early 2020 with the aim to identify industrial and infrastructure projects that could help develop French industrial know-how in the hydrogen sector. This AMI is not directly funded but rather to prepare a hydrogen Important Project of IPCEI proposal by the French government. The selected projects may receive financial support in subsequent tenders and / or at European level.
- Another call for expressions of interest entitled "Aid for the emergence of hydrogen mobility in the rail sector", endowed with 22 M€, was closed in March 2020. This AMI aims to finance the deployment of hydrogen trains in France and in particular by means of dual-mode electric / hydrogen trains.

Moreover, two hydrogen ECVs have been signed by the French government and industrial players:

- The "Production of carbon-free hydrogen for industry" ECV directly linked to the CSF Industries for new energy systems. Today, the national production of hydrogen is mainly obtained by steam reforming. The ambition of the National Plan confirmed in the multi-annual energy programming project is to achieve decarbonisation of 10% of hydrogen production by 2023 and between 20 and 40% by 2028. The industrial players, representing the whole H_2 value chain (product and equipment manufacturers, energy companies, start-ups and mid-caps, hydrogen suppliers, research centres and laboratories), agreed on:
  - decarbonisation of current industrial uses, by implementing production and storage solutions for renewable or low-carbon hydrogen in industrial hubs already producing and / or consuming hydrogen;
  - the new markets for manufacturers with high CO_2 emissions, to produce synthetic methane or e-fuels; and

  - diffuse markets to boost the French electrolysis sector.

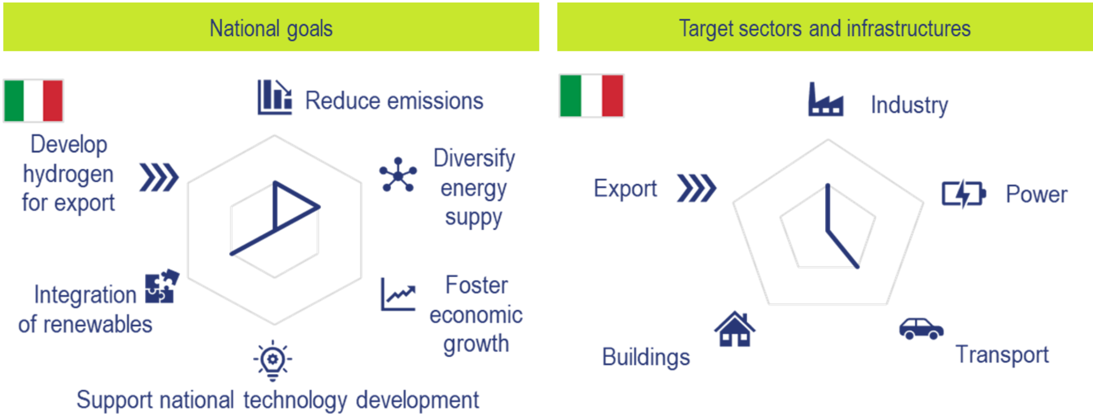
  In return, the French government committed in particular to objectives and actions aimed at developing carbon-free hydrogen and clarifying the regulations for the manufacture and transport of industrial hydrogen.

- The "Hydrogen in road mobility" ECV in which the industrial players and the French government will work jointly toward the goals set in the Hydrogen Plan by developing new hydrogen vehicles and components, deploying new hydrogen distribution stations through territorial ecosystems, and setting new targets for the introduction of vehicles and refuelling stations. The French government will undertake legislative and regulatory actions to facilitate the deployment of infrastructure and hydrogen vehicles. The signatories of this ECV include car manufacturers as well as HRS suppliers.

Industrial players are working, in collaboration with AFHYPAC and CEA, to sign additional hydrogen ECVs with the corresponding CSFs, focusing on maritime and waterway mobility, energy storage and non-interconnected territories.

Although the industry and the French government are structuring their commitment on hydrogen through ECVs and CSFs, the regional administration are also part of this sectorial development by carrying out projects adapted to their local specificities, integrating hydrogen as a storage medium for solar or wind energy and deploying regional hydrogen trains. They focus on developing territorial ecosystems allowing the deployment of hydrogen vehicles and refuelling stations, and in which decarbonated hydrogen is at the heart of strong energy and industrial hubs.

Italy



Current situation

The national hydrogen and fuel cell association "H2IT" has developed a detailed plan for the roll-out of hydrogen mobility, which was integrated by the Italian government into the National Strategic Framework for Alternative Fuels. This framework was published in 2016 and is a requirement following Alternative Fuels Infrastructure Directive (AFID)[41]. However, the framework clearly states that this plan only shows the potential of hydrogen mobility and its requirements and that no financial undertakings have been made to implement this plan [AFID IT 2016].

In December 2019 Italy published its mandatory National Energy and Climate Plan (NECP) following the EU Regulation on the governance of the energy union and climate action[42]. In this plan hydrogen is not considered prominently. However, some potential areas of use are sketched, usually as one of a few renewable gas options among biomethane and synthetic methane).

A strong industry driver in Italy is SNAM, the main Italian operator for the transport and dispatching of natural gas, having kicked off several hydrogen-related strategy activities and projects. The recent "H2 Italy 2050" [SNAM 2020] study, supported and commissioned by SNAM, strongly recommends the government to draft a national hydrogen strategy to leverage Italy's unique competences along the hydrogen value chain and position the country as a European driving force.

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41 Directive 2014/94/EU of the European Parliament and of the Council of 22 October 2014 on the deployment of alternative fuels infrastructure

42 Regulation (EU) 2018/1999 of the European Parliament and of the Council of 11 December 2018 on the Governance of the Energy Union and Climate Action

National goals

The NECP rather briefly mentions hydrogen as option to achieve strategic national goals [NECP IT 2019]:

- Integration of large quantities of renewable electricity into the energy system e.g. by coupling the gas and electricity sector or as long-term energy storage option
- Hydrogen to decarbonise the energy-intensive industry and the transport sector
- Hydrogen to support the diversification of energy supply

Target sectors and infrastructures

There are no comprehensive official targets for the deployment of hydrogen in any sector. However, a few target sectors are mentioned for the use of hydrogen [NECP IT 2019]:

- Road transport sector (explicitly long-haul transport, passenger cars and buses)
- Rail and maritime sectors
- Energy-intensive industrial sectors

Hydrogen and its future admixture or 100% use in the gas grid is considered as one alternative option to the use of biomethane and/or synthetic methane in the gas grid. The need for detailed assessment and alignment within Europe in this context is expressed by the NECP [NECP IT 2019]. For the transport sector the NECP targets the utilisation of 21.6% RES by 2030 out of which about 1% could be covered by hydrogen.

Measures and H_2 requirements

Hydrogen R&D funding in Italy is largely based on European funds via the FCH JU under the Horizon 2020 program. Over the last 13 years, 98 M€ were made available for 140 projects. Further funds are available from the national government. Currently there are 5 hydrogen projects with a total value of 8.5 M€. Further R&D is taking place within Italian universities [IPHE IT 2020].

The establishment of the "Hydrogen Working Table" in June 2019 was one recent measure to support hydrogen and to bring together relevant industry, institutions, stakeholders, developers, and suppliers [IPHE IT 2020].

To support the introduction of renewable gas (incl. hydrogen), a quota is discussed as one possible future option in the NECP [NCEP IT 2019]. Further measures mentioned in the document are:

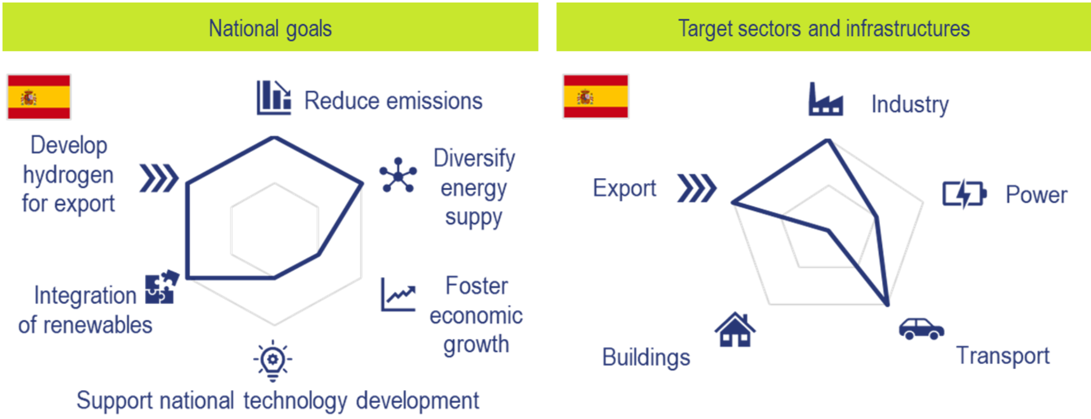
- Starting groundwork for integration of hydrogen into the energy network
- Promoting the production and use of hydrogen based on renewable electricity, starting with research, development, and demonstration activities
- Improving the performance and cost of electrolysis

- Defining legal and regulatory framework
- Investing in research and development and in supply infrastructure (transport sector)
- Regional cooperation to discuss future developments related to hydrogen

Achievements

There are some hydrogen related demonstration projects in Italy. In total, there are 15 fuel cell cars, 10 fuel cell buses and 4 hydrogen refuelling stations in operation [IPHE IT 2020]. One of the most visible Italian hydrogen projects, strongly driven by the Alto Adige regional government, is located in and around Bolzano. Here, fuel cell vehicles are supplied with hydrogen from an electrolyser plant being able to produce up to 345 kg of hydrogen per day.

Spain



Current situation

In 2002 the "Spanish Hydrogen Association" (AeH2) was founded as a non-profit organisation with a focus on research on hydrogen. Out of which the "Spanish Technology Platform on Hydrogen and Fuel Cells" (PTE HPC) was established in 2005, supported by the Ministry of Science and Innovation to promote and to accelerate the development and utilisation of fuel cell and hydrogen systems in Spain and coordinate Spanish activities.

In 2016 hydrogen was included as future alternative fuel for road transport in the government's "National Strategic Framework for Alternative Fuels", following Alternative Fuels Infrastructure Directive (AFID). In this document rather unambitious short-term targets and trends in hydrogen mobility are formulated and expected [AFID ES 2016].

Four years later, the Spanish "National Energy and Climate Plan 2021-2030" (NECP) mentions the potential use of hydrogen in various sectors without making very specific statements on the quantitative measures or targets [NECP ES 2020]. To improve this status, the Ministry of Environment (Ministerio para la Transición Ecológica y el Reto Demográfico – MITECO) started a public consultation process for the preparation of a "Renewable Hydrogen Roadmap" in April 2020 [hidrogenoaragon 2020]. This roadmap was eventually published on 29 July 2020 by the Ministry of Environment [MITECO 2020] outlining the role of green hydrogen and identifying challenges and opportunities of its development in Spain. The roadmap goes well beyond the somewhat limited activities for hydrogen in the past and also provides a comprehensive set of measures aimed at creating incentives for investment in hydrogen technology.

National goals

In the National Energy and Climate Plan, the National Strategic Framework for Alternative Fuels and the Renewable Hydrogen Roadmap the use of hydrogen is associated with the following goals:

- Reduce energy consumption of vehicle fleet by electrification and, additionally, enable a higher penetration of renewables in the transport sector [NECP ES 2020]
- Provide flexibility to the electricity system, enable a coupling of the gas and electricity sectors, and improve management of the power system at increasing shares of intermittent renewable energy production [NECP ES 2020], [AFID ES 2016], [MITECO 2020].
- Reduce GHG emissions and local pollution [NECP ES 2020], [AFID ES 2016] with a particular focus on hard to decarbonise sectors [MITECO 2020].
- Reduce the import dependence in the energy sector, increase the use of local energy [AFID ES 2016], and convert Spain into a powerhouse of renewable energy production including hydrogen export [MITECO 2020].
- Strengthen manufacturers of relevant hydrogen components and equipment (storage tank, fuel cell, electrolyser, renewables) [AFID ES 2016], strengthen industrial competitiveness [RH ES RM 2020], and promote the creation of associated value chains for industrial growth [MITECO 2020].
- Develop a favourable environment for green hydrogen by prioritising its use in industry [MITECO 2020]. For this, ammonia production and refining are the most relevant sectors in Spain although other applications in the petrochemical and chemical industry as well as the metallurgical industry are also mentioned.
- Improve decarbonisation of island systems [MITECO 2020].

The Renewable Hydrogen Roadmap [MITECO 2020] also points out that hydrogen is essential for energy storage in a fully renewable energy system and a key element for sector integration.

Target sectors and infrastructures

Transport: In 2016 a rough target for road transport deployment was formulated: 500 FCEV and 20 hydrogen refuelling stations, by 2020 [AFID ES 2016]. Further, the use of hydrogen is discussed for captive fleets such as busses and trucks, ports, shipping, rail, and aviation [RH ES RM 2020] [NECP ES 2020]. The Clean Hydrogen Roadmap [MITECO 2020] reiterates support for hydrogen use in transport sectors, where other electric solutions are not suitable or efficient like in public transport or in freight forwarding. Suggested measures address road, rail, maritime transport as well as aviation.

Renewable Hydrogen Roadmap [MITECO 2020] identifies hydrogen as a key contribution to achieving the goals of the Spanish NECP [NCEP ES 2020], which are much more ambitious than those in RED II[43] by targeting a renewable share in transport of 28%. As a result, the following minimum targets are defined for 2030:

- 150-200 fuel cell buses
- 5.000-7.500 fuel cell light-duty vehicles (LDVs) and heavy-duty vehicles (HDVs) for freight transport
- A network of 100-150 hydrogen refuelling stations with a maximum distance of 250 km between each other
- Fuel cell trains on at least two non-electrified mid- and long-range connections
- Introduction of fuel cell (material) handling vehicles in the 5 largest (by passenger/freight volume) ports and airports

Industry: The 2030 vision [MITECO 2020] foresees that a minimum of 25% of hydrogen consumed in Spain in all industry sectors (including in the chemical and petrochemical industry) is derived from renewable sources.

Hydrogen production and storage: One focus in Spain is the use of low-cost solar energy for hydrogen production via electrolysis [RH ES RM 2020]. The future use of 100% green hydrogen is clearly anticipated [NECP ES 2020]. The 2030 vision [MITECO 2020] foresees an installed electrolytic hydrogen production capacity of at least 4 GW. It also aims for the establishment of commercial large-scale hydrogen-based energy storage projects.

Progress towards the above targets will be monitored. The roadmap foresees necessary investments of 8.9 B€, expected to be coming largely from the private sector with some public support where required.

After 2030, in line with the EU strategy, the roadmap expects developments to accelerate and technologies to mature for large-scale deployment towards a decarbonised society by 2050.

Measures and H_2 requirements

The Renewable Hydrogen Roadmap [MITECO 2020] outlines 57 measures to support the national goals, addressing the regulatory environment, sector-focused instruments, cross-cutting activities, and RD&I support. The measures focus on the following areas:

- Simplify administrative requirements and eliminate regulatory barriers for hydrogen production plants.

[43] Renewable Energy Directive: Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources.

- Establish a system for renewable hydrogen guarantees of origin.
- Improve the competitiveness of renewable hydrogen e.g. by fiscal measures.
- Monitor hydrogen production and consumption at a national level, differentiating by hydrogen quality.
- Provide incentives for the use of renewable hydrogen in industry, e.g. by considering initial quota, providing targeted financial instruments for large hydrogen users, engaging into a stakeholder dialogue for a decarbonisation strategy and supporting the creation of "hydrogen valleys".
- Boost the adoption of hydrogen applications in the transport sector by providing financial incentives for vehicle purchase and infrastructure erection 44 and facilitating the regulatory requirements for building hydrogen refuelling stations. 25 M€ is made available for targeted vehicle R&D for the automotive industry. Other measures cover the potential use of hydrogen in the rail sector. Hydrogen use in the maritime sector shall be supported by including corresponding refuelling infrastructure in upcoming funding schemes and by incentivising hydrogen use in coastal and domestic shipping. Supporting production and use of renewable synthetic fuels is envisaged to help decarbonise aviation.
- A set of measures addresses the integration of electrolysers into the electricity system as well as the injection of hydrogen into the gas grid.
- The roadmap acknowledges that education and training must be an integral element of any strategy and defines corresponding lines of action. Additionally, market development and socio-economic impact analyses will be launched.
- Measures include setting up an ongoing stakeholder participation process, a regional cooperation with Portugal and active participation in international activities. The roadmap is designed to be updated every 3 years.
- R&D support plays an important role, focusing in particular on large-scale electrolysis and on hydrogen storage and, at least partly, building on already existing national innovation and development initiatives[45].

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[44] MOVES II plan of the ministry of Environment currently totals 100 M€ for all types of alternative road transport; further funds shall me made available

[45] The roadmap mentions the Proyectos CIEN and the Misiones Ciencia e Innovación, both administered by the Centro para el Desarrollo Tecnológico Industrial (CDTI)

Within the national research and development program RIC, hydrogen and fuel cell topics have so far received 3.8 M€ out of a total funding of 116 M€ between 2014 and 2016 [NCEP ES 2020].

Purchase subsidies of 5.500 € are available for alternative fuelled vehicles including hydrogen fuel cell vehicles [SUR 2019]. Hydrogen is not taxed when used in fuel cell vehicles [AFID ES 2016].

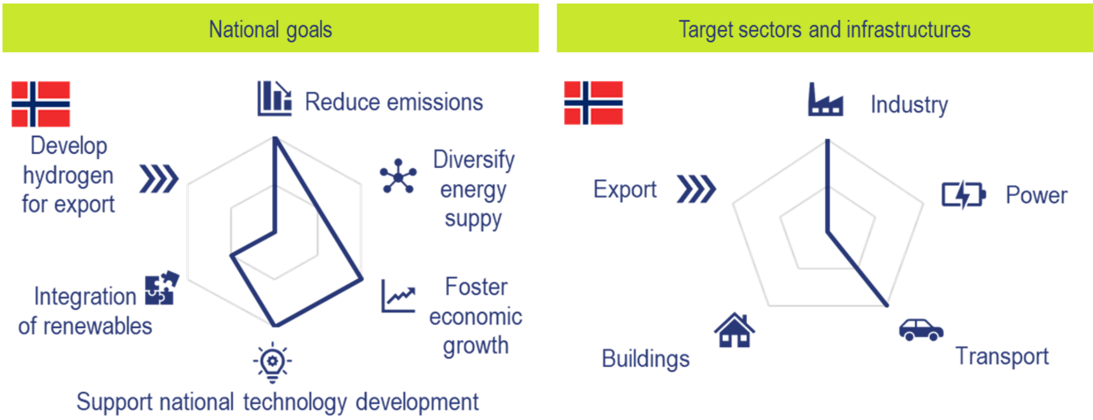
A national climate change and energy transition law (Ley de Cambio Climático y Transición Energética) is currently being developed, which shall include specific measures for supporting the introduction of renewable gases including hydrogen.

The Renewable Hydrogen Roadmap [MITECO 2020] has a clear focus on renewable hydrogen, i.e. produced from renewable energy.

Achievements

A small number of fuel cell vehicles and hydrogen refuelling stations are in operation in Spain. In addition, there are relevant PtG projects such as green hydrogen for chemical industry in Puertollano (2x 10 MW electrolyser) or 10 MW electrolyser on the island of Mallorca. Some regional governments (Andalusia, Aragon) promote hydrogen in existing regional activities [AFID ES 2016].

Norway



Current situation

In May 2020 Norwegian parliament has decided a national hydrogen strategy document, setting a stronger focus on hydrogen energy related research and development as part of the COVID19-related climate package [Strategi 2020]. However, the strategy does not present a plan, in which applications and in which quantities hydrogen shall be applied in short, medium, or long term. It is rather considered as a strategic guidance document, referencing the state of the art and status of discussions on hydrogen energy in Norway. In order to become a full strategy, this document will need to be detailed in the future.

National goals

According to the Norwegian hydrogen strategy report, Norway's general and self-imposed updated energy policy goals are to tighten the CO_2-emission reduction target to 55% instead of 50% (2030) and to 95% instead of 90% (2050) in comparison to the 1990 baseline. An important goal of the Norwegian hydrogen strategy is to combine GHG-reduction with value creation. In addition, the strategy claims that future activities should focus on areas in which Norway has expertise or can influence the developments, given that commercialisation and safety are secured or within reach. In that context, the strategy suggests supporting pilot- and demonstration projects to contribute to commercialisation and taking profit from potential inter-sectoral synergies.

The current national hydrogen strategy expresses little interest in the role of hydrogen as an energy balancing instrument for the power sector as Norway takes already profit from its ample resources of non-fluctuating renewable hydropower and room heating as this is achieved by electric heaters to a large extent, requiring no gas for heating purposes as in many other EU Member States.

Norway accepts the contribution of hydrogen energy to EU's "New Green Deal" and plans to cooperate in the "European Clean Hydrogen Alliance". Specifically, in the short term, it emphasises its role as provider of hydrogen through the production and export of natural gas and acceptance of returned CO_2 to be buried underground (CCS), with Norwegian value creation only through technology development. For the time being, the concept is not to export blue hydrogen as no business case has yet been identified. Another option addressed, is to potentially blend natural gas with hydrogen in the existing pipeline grid for export. Major cooperation partners for blue hydrogen (via the CO_2 return option) in Europe are the UK, Germany, and the Netherlands.

Target sectors and infrastructures

In a 2019 study for the Norwegian government [DNV-GL 2019], the following Norwegian hydrogen demand has been estimated for 2030 based on inputs from Norwegian industry and on today's total annual hydrogen production:

- methanol production: 112 $kton_{H2}$ (46%)
- ammonia production: 70 $kton_{H2}$ (28%)
- new industry use: 8 $kton_{H2}$ (3%)
- fuel cell trucks: 29 $kton_{H2}$ (12%),
- maritime use: 18 $kton_{H2}$ (7%)
- fuel cell city buses: 7 $kton_{H2}$ (3%) and
- fuel cell trains: 2 $kton_{H2}$ (1%).

or adding up 190 $kton_{H2}$ for all industry and 56 $kton_{H2}$ for all transport applications and 246 $kton_{H2}$ in total. According to this study today's total annual H_2-production from industrial processes is 225 $kton_{H2}$. These figures can only be taken as indicative since they have not been specifically supported by the national hydrogen energy strategy report, even though the report has been explicitly cited. The resulting annual CO_2 emission reduction for the transport sector would then be in the order of 500 $kton_{CO2}$, or only 1% of Norway's total GHG emissions.

The Norwegian hydrogen energy strategy does not foresee any hydrogen export in the short term, even though the underlying study by [DNV-GL 2019] had suggested potentially large export capacities as blue hydrogen as early as 2030[46].

As in 2018 the Norwegian maritime business (ship owners, maritime service, shipyards and equipment manufacturers) made up 8% of the national value creation and 17% of all export, it has been recognised as a focal sector for energy innovation according to

[46] Given the theoretical hydrogen export capacity of 25 $Mton_{H2}$, if total amount of natural gas exported today were converted to hydrogen.

[Handlingsplanen 2019]. Battery drives are already in operation and fuel cell drives will soon be tested.

For road transport the government's fact-based plan towards 2025, which is relevant for all alternative drive system options, is as follows:

- all new light-duty vehicles shall by zero emission operated by 2025;
- all new city buses shall be zero emission or use biogas by 2025;
- new heavier delivery vans, 75% of all long-distance buses and 50% of all new heavy-duty trucks shall be of zero emission type by 2030;
- goods distribution to the largest city centres shall be close to zero emission by 2030;
- public spending shall be used for biofuel, low- or zero emission technology in its own or rented vehicles and ships to the largest possible extent;
- by 2050, the whole transport sector shall be close to zero emission and hence climate neutral.

Until now, Enova has supported hydrogen infrastructure development for alternative fuels in the early development phase. In total, 9 hydrogen refuelling stations have been funded as well as the infrastructure for the ASKO hydrogen/ heavy-duty fuel cell truck project[47], adding up to ca. 82 million NOK (ca. 10 M€) in total. For the future, the Transport Ministry has decided in July 2019 that the further build-up shall be on commercial grounds and will not receive any further funds, to be aligned to the build-up of vehicle fleets.

Even though the multiple potential contribution of hydrogen in industrial use has been identified by the hydrogen energy roadmap, e.g. in the refinery, steel, fertiliser or chemical industry, with single projects also being supported by Enova, the Norwegian government judges further short-term activities as challenging and connected with high uncertainties. Therefore, further support for hydrogen in these applications is currently not foreseen.

In the electricity sector, little use of hydrogen is foreseen for load balancing due to the high non-fluctuating hydropower share. On the other hand, ample onshore wind resources in the very north of Norway (Raggovidda) could be explored by using hydrogen as an energy transport medium at large scale[48]. This is an alternative option to costly electricity transport grid and has led to a pilot project now under development[49].

47 E.g. as reported in [Scania 2020].

48 [DNV-GL 2019] has estimated the excess power produced to grow from 5 TWh per year in 2018 to 20 TWh per year by 2030.

49 Berlevåg community received funds for a feasibility study based on using excess electricity from the local wind park by electrolysis. With input from a pre-project Varanger Kraft and SINTEF have now received Horizon 2020

Contributing 8.6% to Norwegian value creation and 16% to Norwegian exports, the plan is to put one focus on sustainable energy technologies for the maritime sector, hydrogen, ammonia and fuel cells specifically addressed among others. Taken from Norway's 2019 Activity Plan in [Handlingsplanen 2019], following declarations of intent for this sector can be summarised:

- Stimulate further towards green growth and competitiveness in Norwegian maritime business, and prepare for increased imports of low- and zero emission technology in the maritime sector
- Stimulate zero- or low-emission technology in all vehicle categories
- In future revisions of cost positions in the income system for local communities (fylkeskommune), consider cost increases following the communities' requirements on low- and zero emission solutions in connection with the operation of ferries and speedboats
- Follow up the decision to introduce zero emission claims for tourist ships and ferries in the World Heritage fjords as fast as technologically realisable, but by 2026 the latest, and approach the government (Stortinget) in time
- Consider transferring the environmental requirements for ships from the World Heritage fjords to other Norwegian fjords
- Consider environmental regulations for zero- and low-emissions in the Norwegian International Ships Registries NIS (Norsk internasjonalt skipsregister) and NOR (Norwegian Ordinary Ships Register)
- Make sure that the Maritime Directorate (Sjøfartsdirektoratet) and Coastal Department (Kystverket) develop sufficient capacity and competence for new approaches in green shipping, among others to develop regulations for the use of hydrogen in maritime applications
- Consider developing requirements for low- and zero emission solutions in the public ferry and speedboat programs, where applicable
- Consider the development of requirements to introduce zero- and low-emission for service ships in ports
- Consider introducing requirements zero- and low-emission solutions for new ships servicing the oil production sector

funds from the EC in the order of 50 million NOK (ca. 6 M€) to build a hydrogen factory commencing hydrogen production in 2020.

Measures and H_2 requirements

Norway's hydrogen energy strategy targets specifically the research and development of hydrogen and fuel cell research focusing on blue and green hydrogen. Commercialisation shall be supported by pilot- and demonstration projects. The developments shall be supported by accompanying measures such as the acquisition of relevant equipment by authorities (annual grand total budget of 500 million NOK, including all other sustainable energy technologies and focus on transportation) and the development of relevant regulatory frameworks. Here specifically the activities towards a certification (technologies and alternative fuels) to allow the operation of hydrogen and derivatives (ammonia and methanol) as well as fuel cells (responsible: Sjøfartsdirektoratet) in the maritime sector are mentioned. Target is to contribute to the compilation of a "hydrogen handbook" as basis for hydrogen rules and standards[50]. Both hydrogen and ammonia applications for coastal maritime applications are supported through Statens Vegvesen/Sjøfartsdirektoratet and hydrogen for rail applications through Det Norske Statsbane (DNB).

Recent public spending to support pure hydrogen have been coordinated by the PILOT-E program in 2019 and amounted to 71 million NOK[51].

Three programs support Norwegian research and industry: the Norwegian Research Council (Norges forskningsråd), Innovation Norway (Innovasjon Norge) and Enova support funds for the development and demonstration of energy- and cost-effective methods and supply chains for the production, transport, storage and end-use of pure hydrogen, through the common funding platform PILOT-E among others [Strategi 2020]. In addition, these programs will be combined with the "Klimaplanen for 2030" to develop and use hydrogen energy in Norway, the focus of which is on projects of excellence and potential for value creation in Norway. Through the zero emission-fund (Nullutslippsfond), founded in 2019, Enova will in addition fund both road and maritime vehicles along with the ripening technology.

As already today, the waiver of renewable electricity taxes for the production of hydrogen by electrolysis (today 16.13 øre/kWh or ca. 2 ¢/kWh) will be extended. In the last years the

[50] Norway contributes to the development of IMO rules by the "Interim Guidelines for Fuel Cells" through UN's Maritime Security Committee (MSC) by 2021.

[51] One consortium managed by BKK AS/Bergen develops a large hydrogen liquefaction unit to become a first step for a nationwide H_2 infrastructure. The other consortium is coordinated by Flakkgruppen AS for the Hellesylt Hydrogen project, developing a fully sustainable hydrogen supply in the Geiranger Fjord (Nord-Vestlandet) (http://min.e24.no/hellesylt-hydrogen-hub-far-37-6-millioner-fra-enova/a/Qo2RzR). In 2016, 2017 and 2018 further funds were provided for several projects, for ships and land transport (trucks: Next Nordic Green Transport Wave – Large Vehicles (Next Wave project: https://www.hydrogen.no/hva-skjer/aktuelt/fikk-ja-til-hydrogensatsing-pa-lastebiler), and industry among others.

Norwegian government has funded hydrogen technology development by ca. 500 million NOK, mostly through the energy research program ENERGIX. An extra 120 million NOK has been decided as immediate COVID-19 related support measure, hydrogen being one but unspecified solution among other measures.

A central element of the Norwegian strategy seems to be the technology development for the production of blue hydrogen which promises cheaper than through electrolysis (green hydrogen) in the short term. This pathway is understood to be of specific Norwegian value also for future technology export to other countries across Europe, both adding value creation by technology leadership as well as by offering the CO_2 storage capacities in old oil and gas fields under the North Sea. However, direct export from Norway as blue hydrogen is not foreseen.

On the other side, fuel cell vehicles will experience the same prioritisation as battery electric vehicles (until 2025 and up to 50,000 vehicles). Detaxation (VAT), which is significant in Norway and up to the same level as the vehicle price, specifically for high value (such as fuel cell) cars. Following an EFTA Surveillance Authority (ESA) decision, fuel cell vehicles will remain de-taxed until at least 2023. Also, fuel cell vehicles in commercial use will be specifically funded. The following support mechanisms are now being applied.

Taxation

- Like battery electric vehicles (BEV), fuel cell electric vehicles are also waived traffic insurance taxes and (re-)registration fees from 1st January 2018.
- In 2020, a 40% rebate on catalogue price is considered when calculating the advantage for commercial car as compared to ordinary car purchases.

Operational incentivisation

- Until recently, zero emission vehicles did not have to pay any fees for city access ferries and parking and had admission to drive on public lanes. Today, it is up to local authorities to decide about the free use of limited traffic zones and free parking. But national rule is that ZEVs must not pay more than 50% of the normal city access and ferry fee. Currently, new rules are established for parking.

In 2019, the Environmental Ministry established a fast ferry program (25 million NOK), extended by 80 million NOK in 2020 to accelerate ferry development contracts in short-term. The use of ammonia as well as hydrogen are fuel options to be supported for the onshore infrastructure (Kystverket) for maritime transport. And finally, it is planned to enforce sustainable investment rules for all public "innovation-friendly" purchasing in the order of 500 million NOK annually, with a focus on mobility applications[52]. Also, the military considers acquiring fuel cell-based equipment for remote electricity supply based on hydrogen as well as a fuel for fuel cell operated submarines. However, no indication is provided how much of this amount will be spent for each purchase sector.

Based on the government of Norway's insights, electrolytic (= green) hydrogen is too expensive today. It therefore opts to develop blue hydrogen (SMR with CCS) in the short-term (based on CO_2 returns), also by supporting the neighbouring European Member States (UK, NL, DE) with know-how and the potential to store CO_2 in depleted oil and gas fields under the (Norwegian) North Sea.

Between 2009 and 2019, the Norwegian Research Council (Norges Forskningsråd NFR) has funded hydrogen, fuel cell and electrolysis related R&D (ENERGIX-program: materials, production, conversion, transport, storage, end-use, modelling) by ca. 550 million NOK (ca. 70 M€). In addition, the CLIMIT program has funded CCS-based hydrogen production from natural gas.

For the future, it is envisaged that funds are directed towards know-how development on technology readiness and specifically cost efficiency for various hydrogen applications, public acceptance of hydrogen energy in known and new applications and the role of the public to develop hydrogen's contribution in the energy system further.

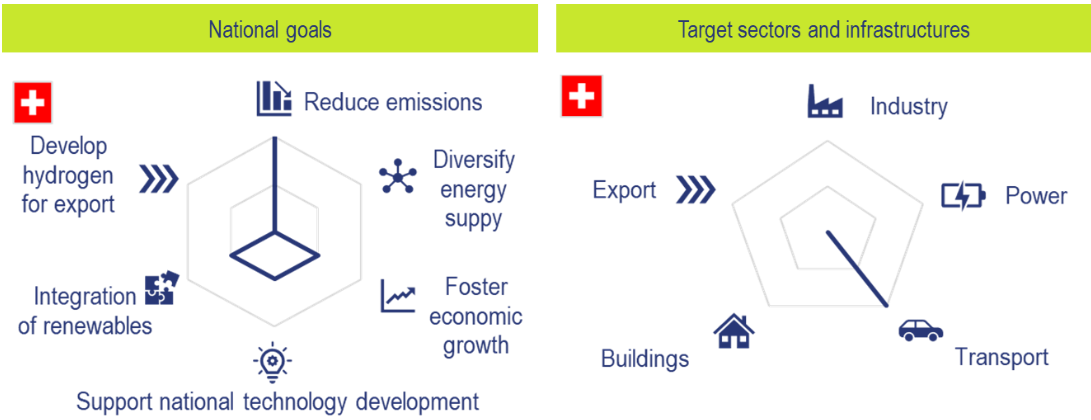
Achievements

In comparison to 260,581 battery electric cars, 7,331 light-duty batter delivery vans, 199 battery electric city buses and 21 battery electric trucks, 149 fuel cell cars, 1 light-weight delivery van and 5 fuel cell buses were registered end of 2019.

Moreover, from 2021 onward, a hydrogen-battery ferry ship will be tested on the Hjelmeland–Nesvik–Skipavik connection (Shipowner will be Norled AS). Several other hydrogen fuel cell ship projects are now in preparation with Havyard Group ASA, Samskip AS, Selfa Arctic AS and Flying Foil AS. Norwegian industry is also involved in Nordic and European cooperation projects on ammonia technologies (ShipFC).

[52] The rules for public goods acquisitions, specifically with a view to climate- and environmental friendly technology and green innovation, have been laid down in an activity plan (handlingsplan) by *"Melding St. 22 (2018-2019) Smartere innkjøp – effektive og profesjonelle offentlige anskaffelser"* As part of this program, a battery electric (Ampere in Lavik-Opedal) as well as a hydrogen-hybrid ferry have been acquired in the past. By 2021 it is expected that 80 out of a total of 200 Norwegian coastal ferries shall be operated by battery drives. Hydrogen operated ships are believed to populate the speedboat fleet (hurtigbåt) for specific weight and energy density.

Switzerland



Current situation

Switzerland has no national hydrogen strategy. A position paper by the federal energy office on hydrogen mobility dating back to 2016 [BFE 2016] recognises the general potential of hydrogen to contribute to emission reduction in the transport sector. The paper suggests supporting research and development as well as technology pilots.

Major present Swiss activities focus on green hydrogen use in road transport mainly by heavy-duty vehicles. For this purpose, the H2 Mobility Switzerland Association founded in May 2018 promotes the development of CO_2-free hydrogen mobility together with the required supply chains and infrastructures. The association has 21 members representing individual corporations which, among others, operate more than 2,000 conventional refuelling stations and 5,000 heavy goods vehicles [H2 Mobility CH 2020]. Moreover, in August 2014 a private company, H2 Energy AG, has been founded to provide hydrogen system solutions, components for non-automotive hydrogen solutions and engineering services [H2 Energy 2020]. In April 2019 H2 Energy AG and Hyundai Motor Company have signed a joint venture agreement to bring fuel cell trucks, developed by Hyundai, into the Swiss market [H2 Mobility CH 2020]. It is expected that the Swiss federal government will publish an official document which could serve as the Swiss strategy.

National goals

Major goal of the Swiss hydrogen-related developments is to reduce GHG emissions through sustainable and CO_2-free mobility. In this context renewable hydrogen supply will be needed allowing for better integration of existing renewable power generation into the energy system. Both Swiss hydrogen association and the private company H2 Energy AG aim to further develop the technology and supply chains in Switzerland to ensure clean and affordable mobility in Switzerland. In this way Swiss economy can be supported.

Target sectors and infrastructures

As mentioned previously in Switzerland the focus is on hydrogen use for fuel cell trucks. Other fuel cell related applications could be passenger cars, rail transport, ferries in inland waters as well as stationary appliances such as remote energy generation or combined power and heat supply.

Measures and H_2 requirements

In Switzerland, the national approach is to set up major general boundary conditions by the government which are intended to trigger technology-specific actions by individual private entities. There are two major regulatory and financial measures in the context of hydrogen:

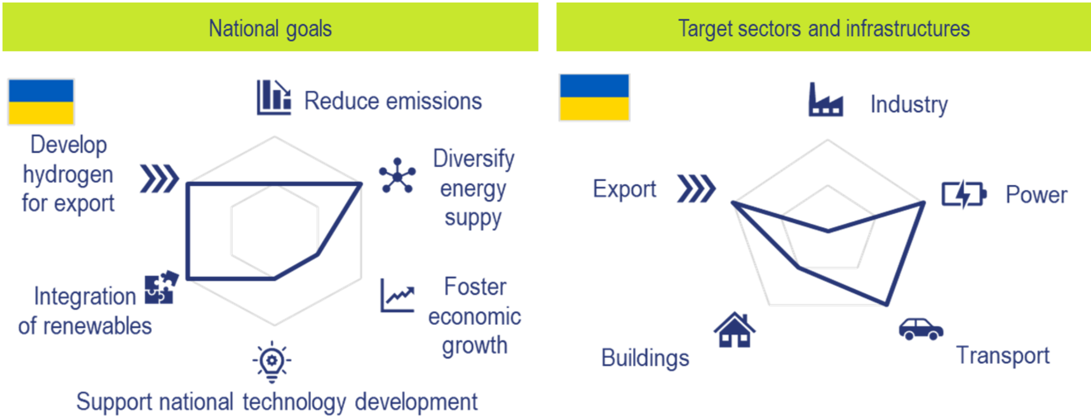
- **Road toll exemption:** fuel cell trucks as vehicles with an electric motor are exempted from the road toll for heavy-duty vehicles above 3.5 t gross weight.
- **Carbon pricing and CO_2 law:** in addition, the comparatively high carbon price of ca. 100 €/t_{CO2} provides another incentive for investments in clean technologies. Moreover, the new CO_2 law foresees the possibility to count synthetic fuels against fleet-wide CO_2 reduction targets.

Both measures are sufficient to incentivise the hydrogen-related activities in the transport sector. In line with the national goals Switzerland focusses on renewable hydrogen, e.g. based on electricity from existing hydro power plants.

Achievements

Major achievement in Switzerland is the commercial use of fuel cell trucks, renewable hydrogen supply and operation of dedicated refuelling stations in an activity between the national retailer Coop, H2 Energy AG, and Hyundai. Hyundai has delivered first ten FCEVs with 40 more to come in 2020. The plan is to bring 1,600 fuel cell trucks on Swiss roads until 2025 [Hyundai 2020]. There are five hydrogen refuelling stations in operation and five more in preparation [H2Station 2020]. H2 Mobility Switzerland aims to establish a national hydrogen refuelling station network until 2023 [H2 Mobility CH 2020]. Moreover, according to the LBST PtX-database, there are five small Power-to-X plants in operation with two additional ones in preparation.

Ukraine



Current situation

In August 2017 Ukraine has adopted the new Energy Development Strategy for the period until 2035 [ESU 2017]. However, precise targets regarding hydrogen are not set yet. At this point in time Ukraine is missing a specific official hydrogen strategy.

In November 2018, an important achievement was the establishment of the Energy Association "Ukrainian Hydrogen Council" as an autonomous association aiming at promoting the knowledge related to technologies and systems for hydrogen production and use. The association also enhances the knowledge and awareness of the hydrogen potential as an energy carrier, initiates practical programs to demonstrate hydrogen technologies and fuel cells in practice, attracts new actors with interests in the hydrogen industry, and supports economic growth and industry development in Ukraine [UHC 2020]. In 2019, the Ukrainian Hydrogen Council and the Institute of Renewable Energy of the National Academy of Sciences of Ukraine developed a roadmap for the wide introduction of hydrogen energy in Ukraine [UHC&NAS 2019_draft]. The document contains recommendations to government and industry until 2035.

In June 2020, under the chairmanship of Secretary of the National Security and Defense Council of Ukraine, a meeting of the working group on the development of the hydrogen economy was held. The working group was established in accordance with the Decree of the President of Ukraine on May 29, 2020, N° 206 "On the Council of Experts on Energy Security". It was the first official political activity related to hydrogen technologies and economy.

National goals

The Energy Development Strategy until 2035 includes ambitious targets for Ukraine: among different aspects an increase in the share of renewable energy in the total primary energy supply up to 12% until 2025, and at least up to 25% until 2035 [ESU 2017]. In the transport sector it is expected that a significant number of conventional vehicles will be replaced by electric and hydrogen vehicles in the coming decades.

The Ukrainian energy infrastructure is defined by low efficiency and high dependence on imported energy sources. Alternative sources of energy would play a significant role in the achievement of energy independence. Recent developments such as current activities of the Ukrainian Hydrogen Council show that hydrogen is becoming relevant in the Ukraine.

Target sectors and infrastructures

The Hydrogen Roadmap for Ukraine places priority on the development of hydrogen as an option for storing renewable energy to balance electricity demand and supply, followed by hydrogen in mobility and heating [UHC&NAS 2019].

To support the development of hydrogen technologies, Ukraine is active in international initiatives (e.g. 2x40 GW Green Hydrogen Initiative [Hydrogen4Climate 2020]) and collaborations with neighbouring European countries [KMU 2019], [UHC 2020b]. This can be seen as the foundation for developing hydrogen export technologies in Ukraine.

Measures and H_2 requirements

So far, there are no specific actions supporting hydrogen technologies and applications. The main targets of program of the Ukrainian Hydrogen Council are:

- "Interaction with the international energy and information organisations to involve the energy complex of Ukraine in the modern global energy dialogue
- Organisation of the international energy forums and summits
- Presentation and support of existing hydrogen energy technologies in Ukraine and the world
- Attraction of investments to Ukrainian and international hydrogen energy projects
- Modernisation of the legal environment in Ukraine and integration of legislative norms into international energy standards
- Creating an access to renewable and hydrogen energy technologies for communities through the support of energy saving programs and energy decentralisation. [UHC 2019]

In addition, in 2019 the Ukrainian Academy of Sciences has provided a budget of ca. 3 million UAH (ca. 110 thousand EUR) for research activities on wide range of hydrogen technologies [Elektrovesti 2019].

Achievements

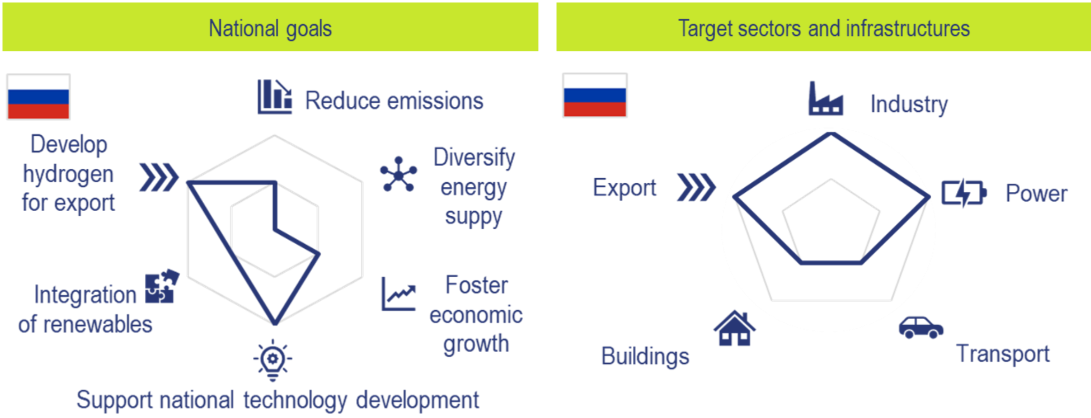
In the light of Ukrainian development towards European Union association international collaboration with Ukrainian energy generation and storage possibilities becomes a good opportunity for the European Union especially due to large wind and biomass resources in Ukraine which can be used for renewable hydrogen production [UHC 2019][53]. Moreover, in Ukraine the large-scale hydrogen production can be placed close to large-scale renewable electricity production sites. The Ukrainian hydrogen export potential to the EU amounts to ca. 118 TWh_{H2} per year by 2030 which can be transported via dedicated pipelines [Hydrogen Europe 2020], [FCH JU 2019]. In this way European electrolyser industry might have a great opportunity to develop and scale up the technology through the close collaboration between the EU and Ukraine and the development of Ukrainian market.

In this context, the largest private investor in Ukraine's energy sector DTEK plans to organise a hydrogen-related pilot project to further develop the technology [DTEK 2020]. Another project with a scale of 100 MW is announced [Repkin 2020].

The recently signed energy partnership with Germany [Energiepartnerschaft 2020] includes hydrogen as a potential cooperation area.

53 Retrieved from Atlas of energy potential of renewable energy sources in Ukraine.

Russia



Current situation

Hydrogen should play an important role in Russia's energy policy in the medium and long term. Since the end of 2019, the Russian state shows increased interest in hydrogen.

In June 2020, Russian government presented an Energy Strategy for the period until 2035 [ESR 2020]. The purpose of the development of the energy sector in the Russian Federation is, on one hand, to maximise assistance to the socio-economic development of the country, and on the other hand, to strengthen and maintain the position of the Russian Federation in the global energy sector, at least for the period until 2035. The transition to environmentally friendly and resource-saving energy is one of the main priorities of Russian energy policy.

Among other areas, the Energy Strategy explicitly defines the hydrogen sector as an important component of the Energy sector. Russia's entry into international export markets is a promising task, for the implication of which Russia has the necessary potential.

In November 2019, the Ministry of Energy officially announced the creation of a working group focused on the development of the hydrogen sector. The working group is headed by Pavel Sorokin, the Vice Minister of Energy of the Russian Federation. It also includes representatives from Gazprom, Sberbank, Rosatom, as well as from scientific community and other experts. This group is actively working on the assessment of the potential of hydrogen technologies and on building a roadmap for a hydrogen energy system in the Russian Federation. In July 2020, the first draft of the roadmap "Development of hydrogen energy in the Russian Federation" for 2020-2024 has been submitted to the government of the Russian Federation [RBK 2020].

National goals

The Russian Energy Strategy 2035 specifies main goals in terms of hydrogen energy. The development of hydrogen production and consumption, as well as Russia becoming one of the world leaders in hydrogen production and export, is a strategic objective for the development of the Russian Federation.

An indicator of achieving the goals of the hydrogen energy sector is the export of hydrogen: 0.2 Mt_{H2} by 2024 and 2 Mt_{H2} by 2035. Additional government's goals targeted with the "Russia's Energy Strategy 2035" are:

- Production of hydrogen and methane-hydrogen mixtures from natural gas for diversification of natural gas use
- Increasing the scale of hydrogen production from natural gas, as well as from renewable and nuclear energy sources
- Development of domestic low-carbon technologies for the production of hydrogen by reforming, methane pyrolysis or electrolysis, including the adoption of foreign technological knowhow
- Stimulating demand in the domestic market for fuel cells based on hydrogen and natural gas in Russian transport, as well as the use of hydrogen and methane-hydrogen mixtures as energy storage devices
- Creation of a regulatory framework in the field of hydrogen energy safety
- Development and implementation of governmental measures to support production, transport infrastructure and consumption of hydrogen and methane-hydrogen mixtures
- Provision of legislative support for hydrogen production
- Intensification of international cooperation in respect to the development of hydrogen energy and entry into foreign markets

Target sectors and infrastructures

Hydrogen is already being produced in Russia on an industrial scale. It is mainly used in oil refining as well as in the petrochemical and chemical industry.

The Energy Strategy 2035 takes into account that hydrogen can become a new energy carrier replacing hydrocarbon energy carriers in the future and form a "hydrogen economy". Technologies that play a special role in the decarbonisation of the Russian economy include hydrogen energy technologies. For example, highly efficient water electrolysers and systems for compact storage and transport of hydrogen are described as promising technologies in the energy sector.

In the Energy Strategy of the Russian Federation 2035, hydrogen is mentioned not only as an energy storage option, but also as a potential export commodity.

The potential hydrogen markets are primarily Europe and the Far East. The Russian Federation has significant hydrogen production potential (hydro, nuclear power and natural gas). According to expert estimates, hydrogen production only at existing Russian generating facilities is about 190,000 t_{H2} a year [EnergyNet 2019]. It is already possible to produce hydrogen at the underutilised Ust-Srednekanskaya hydroelectric power station in Magadan (in Russian Far East) as well as at the Leningradskaja (close to St. Petersburg) and Kolskaja (close to Murmansk) nuclear power plants. Currently, a project is being developed on a pilot electrolysis plant for the production of hydrogen at the Kola nuclear power plant [Rosatom 2020], [EEC 2020], [EnergyNet 2019]. According to preliminary forecasts by EnergyNet, in 2020–2025 Russia will be capable of producing hydrogen at a price of US$3 per kg without transport [EnergyNet 2019].

In September 2019, Rusatom Overseas and Japan's Natural Resources and Energy Agency signed a cooperation agreement for 2020/2021 regarding a pilot project to export hydrogen from Russia to Japan. The project is considering the possibility of producing hydrogen for the Japanese market by electrolysis. [Rusatom Overseas 2019]. Rosatom and Russian Railways are working together on the project to organise rail traffic with trains running on hydrogen fuel cells on Sahalin [Rosatom2020].

Gazprom is now set to boost its position in Russia’s strategic hydrogen export market. As announced on several occasions in the past six months Gazprom considers the production of hydrogen from natural gas such as methane pyrolysis. Research on hydrogen through methane pyrolysis is being conducted, though its application on a large scale will only be possible in the distant future. [OSW 2020]

On 22 July 2020, the Russian RBK daily reported, that the Gazprom will start producing hydrogen beginning in 2024 under a new government plan to develop a hydrogen economy. Rosatom is also set to launch pilot hydrogen plants in 2024. In 2021, Gazprom and other partners[54] plan to develop and test a gas turbine using methane-hydrogen fuel. Until 2024, Gazprom will study the use of hydrogen and methane-hydrogen fuel in gas installations (gas turbine engines, gas boilers, etc.) and as a motor fuel in various types of transport. In 2024, Rosatom will build a test site for railway transport using hydrogen. [RBK 2020]

Russia’s second-largest natural gas producer Novatek also announced its interest in entering the hydrogen market [oilcapital 2020]. Additionally, RusHydro is developing its own hydrogen projects, for example the construction of a hydrogen production plant by 2024 to meet Japan’s industrial demand. The power generation capacity of the Ust-Srednekanskaya hydropower plant controlled by RusHydro will be used in this undertaking [OSW 2020].

[54] Private information from Gazprom

The Energy Strategy 2035 addresses the stimulation of domestic demand for hydrogen in the transport sector (for fuel cells based on hydrogen and natural gas) as well as for methane-hydrogen mixtures from natural gas in different applications.

In this context, Europe is considered as a potential export market for hydrogen from Russia. Blue hydrogen could be transported via the Nord Stream pipeline. According to expert estimates, up to 80% of the pipeline capacity could be used for the admixture of hydrogen. [Energate 2020].

Some other developments and projects have been announced by Russian research institutes and industry. At present, the use of hydrogen in the transportation sector is limited to pilot projects. In November 2019 the first hydrogen-powered tram was launched in Saint Petersburg [GovSpb 2019], the first Russian electric car based on hydrogen fuel cells and Russia's first hydrogen-powered bus was presented at the "Open Innovations" forum held in Moscow [kalibroao 2019], [OSW 2020].

Measures and H_2 requirements

The Russian government plans to foster developments of hydrogen production and consumption through various support schemes. Their implementation is, on the one hand, stimulated by political measures (such as subsidies), and on the other hand, constrained by market condition, such as price levels for traditional energy resources.

22 July 2020, the first draft of the roadmap "Development of hydrogen energy in the Russian Federation" for 2020-2024 has been submitted to the government of the Russian Federation [RBK 2020]. The development and specification of the proposed measures will be carried out after the approval of the action plan. The work will be organised with the active participation of interested federal executive bodies: Ministry of Economic Development of Russia, Ministry of Energy of Russia, Ministry of Industry and Trade of Russia, Ministry of Education and Science of Russia, Ministry of Transport of Russia, and interested organisations. The road map envisages that the concept for the development of hydrogen energy in Russia will be adopted by the end of 2020.

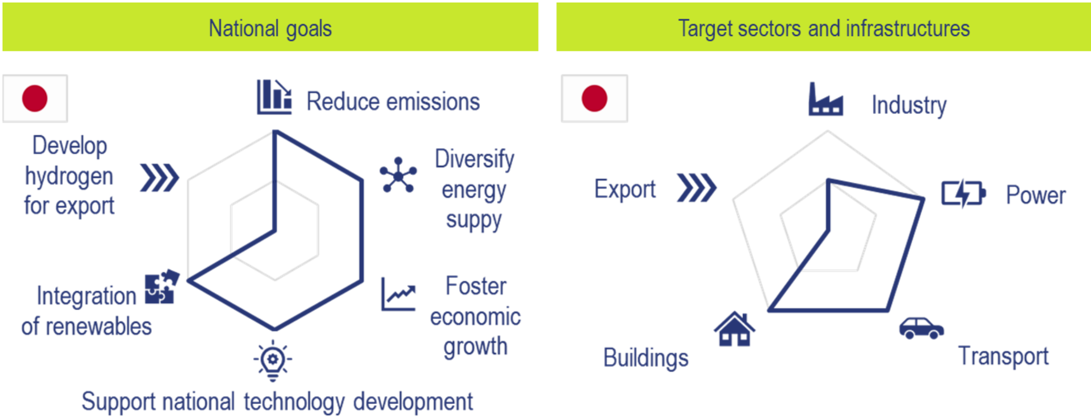
The targets mentioned in the Energy Strategy ought to be achieved.

Since 2019 Rosatom has been working on the "Atomnaja Nauka, Technika i Technologii" research program, within the framework of which the commercial production of hydrogen in nuclear power plants is promoted until 2025. Hydrogen energy based on nuclear power plants has become one of the directions of the comprehensive program for the development of nuclear science and technology proposed by Rosatom. Its financing will amount to 88.5 billion roubles until 2025 (~1 B€). About half of the funds will be allocated from the federal budget. The focus of the program is on nuclear power technologies and only a portion of it will be dedicated to hydrogen [regnum 2020].

Achievements

Based on the recent developments at Russian Energy Ministry and main energy companies Russia started to develop its own hydrogen strategy and roadmap and became active in hydrogen production mainly for export purposes, as well as in domestic areas. In this context, different colours of hydrogen (purple, blue, and green) can quickly become available and could be transported to other countries using the gas transport infrastructure. Small research projects on single hydrogen-based applications such as a fuel cell tram in St. Petersburg are also in place. July 2020 saw the opening of Russia's first hydrogen refuelling station in Russia [motor.ru 2020].

Japan



Current situation

Japan is internationally considered to be one of the leading countries in hydrogen. This is the result of continuous governmental activity and support of hydrogen and consequently resulting highly visible projects such as the planned hydrogen import from Australia or successful roll-out of small-scale FC CHP units (called Ene-Farm) over the last years. The foundations for the current status in hydrogen have been laid for many years (Hydrogen projects since the 1970s; important R&D programme from 1991 to 1999).

The 4th Strategic Energy Plan adopted in 2014 was a key document to accelerate the development of a hydrogen society. The strategic energy plan was quickly followed by the Strategic Roadmap for Hydrogen and Fuel Cells in June 2014, in which three phases towards a hydrogen society were defined. This roadmap was revised in March 2016 to now include selected quantitative targets. In December 2017, the Ministerial Council on Renewable Energy, Hydrogen and Related Issues released the Basic Hydrogen Strategy. Together with the fifth Strategic Energy Plan (2018) this led to the formulation of the most recent document, "The Strategic Road Map for Hydrogen and Fuel Cells - Industry-academia-government action plan to realise a 'Hydrogen Society'" in 2019 which supplements existing targets by defining various details regarding planned technology cost reductions and performance improvements. [Japan H2 Basic 2017] [Japan H2 Basic 2017a] [Japan H2 RM 2019] [Japan H2 RM 2019a]

National goals

Japan's interest in creating the first hydrogen society is closely linked to the so-called "3E+S" energy policy which stands for "energy security", enhancing "economic efficiency," and "environment" suitability on the premise of "safety". This policy means to address the poor availability of energy resources in Japan and the resulting structural vulnerability due to a high level of energy import dependence as well as Japan's GHG reductions commitments. A hydrogen-based society is not a goal but a means to an end. In addition, Japan aims for leadership in hydrogen technologies to enhance its industrial competitiveness and to share its achievements with other countries.

The goals to be reached with hydrogen technology and applications are therefore:

- Diversify energy imports and reduce dependencies from single countries or regions to reduce energy procurement and supply risks (avoid energy crisis like the one after the Great East Japan Earthquake and the subsequent nuclear power accident in 2011)
- Ensure that Japan becomes the first country in the world to realise a hydrogen-based society to maintain hydrogen technology leadership and enhance industrial competitiveness
- Address GHG emission reductions by substantially reducing carbon use and provide relevant technologies overseas to lead global carbon reduction
- Take advantage of unused energy resources from overseas (that Japan so far failed to use due to the fact that Japan is an island nation)
- Integration and utilisation of domestic renewables also outside the power sector and improvement of regional energy self sufficiency

Target sectors and infrastructures

The targets formulated in the Basic Hydrogen Strategy (2017) are supplemented by the strategy "Industry-academia-government action plan to realise 'Hydrogen Society' from 2019". It includes specific cost and detailed performance targets (e.g. targets for the durability of sealings inside an HRS) for various technologies. Targets set in the "fifth Strategic Energy Plan" (2018) are also considered in this document. The following table summarises the main volume targets described in these documents.

Table 19: Sector targets Japan

Sector		Target volume and time horizon
Mobility	FCEV	200,000 (2025); 800,000 (2030)
	FC Bus	1,200 (2030)
	FC trucks	Explicitly mentioned but no volume target
	FC Forklifts	10,000 (2030)
	Maritime shipping	Explicitly mentioned but no volume target
	FC trains, garbage trucks only briefly mentioned	
Power and Heat	Total power generation	1 GW (2030); 15 to 30 GW (long-term)
	FC commercial and industrial use	grid parity in commercial and industrial use (2025)
	Small-scale FC CHP with NG (Ene-Farm)	5.3 million cumulative sales (2030)
Industry	Utilising CO_2-free hydrogen in the future; early discussion; no volume target	

In addition, targeted infrastructure developments include:

- Commercial-scale supply chains to massively import low-cost hydrogen (from renewable and fossil energy with CCS). Annual import of 300,000 t of hydrogen by 2030.
    - The practical use of CCS technology should be realised around 2020
    - Target hydrogen cost of about ca. 2.7 €/kg in around 2030
    - Develop and demonstrate liquid hydrogen carrier ship
    - Develop unloading facilities for liquid hydrogen
    - Develop, demonstrate and setup of technologies for the use of LOHC (Methylcyclohexane) by 2025
- From 2030 Japan will expand international hydrogen supply chains and reduce costs to ca. 1.8 €/kg
- Operation of local hydrogen networks in coastal regions from 2030
- Japan aims to commercialise Power-to-Gas systems by around 2032
- Further transport, storage, and direct-use technologies for energy carriers such as ammonia and LOHC are being developed. The production of synthetic methane is discussed as one further option to utilise hydrogen. The production of synthetic liquid fuels (hydrocarbons) is not addressed.
- Large-scale hydrogen power generation starting in 2030. Targeted electrification capacity of about 1 GW by 2030 and 15 to 30 GW in the long-term.
- National roll-out of hydrogen refuelling stations 320 (2025) and 900 (2030)

Measures and H_2 requirements

Public funding for hydrogen topics has been available in Japan for many years. Most funds are made available through the Ministry of Economy, Trade and Industry (METI). In the financial year 2018 METI budget for hydrogen and fuel cells was at about 226 M€ (260 M$-US)[55] [Ohira 2019] or roughly 3.5% of METI's energy budget [Nagashima 2018]. Little more than a half were made available for R&D projects, the rest as subsidies for HRS and residential and commercial stationary fuel cells. METI's subsidies for HRS are 50% or 67% of installation costs depending on the type of station [Valovirta 2018]. R&D budget for Power-to-Gas technology increased on a low level from 0.1 to 10 M€ (0.1 to 12 M$-US) between 2014 and 2017 [Nagashima 2018].

55 Applied exchange rate of 1.15 USD/EUR

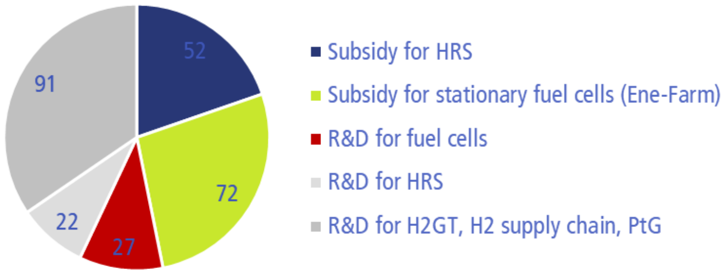


Figure 26: METI budget for hydrogen and fuel cell topics in 2018 in million USD, based on [Ohira 2019]

Some additional R&D funding was (2014 to 2018) available for energy carriers (incl. hydrogen carriers) through the Cross-ministerial Strategic Innovation Promotion Program. Annually, about 26 M€ (30 M$-US) [Shiozawa 2018] was allocated to hydrogen supply chain topics from that program via the Japan Science and Technology Agency. The Ministry of Environment further supports the subsidy for HRS [Nagashima 2018]. In 2018 additional 129 M€ (148 MUSD) in subsidies were made available by METI for clean energy vehicles (incl. FCEV, battery electric vehicles and clean diesel) [Ohira 2019].

The uptake of hydrogen technologies is further supported by the government by the revision of a variety of codes and standards for fuel cells and hydrogen infrastructure as well as by removing barriers for hydrogen use and infrastructure build-up e.g. trough adaptation of initially very strict (and thus costly) requirements for hydrogen refuelling stations. Subsidies for hydrogen fuel aim to keep costs below 10 €/kg. [Valovirta 2018]

The success in Japan is also enabled by public-private cooperation in terms of road map development, shared target setting and coordination of large demonstrations projects. The cross-sectorial advisory group CSHF (Council for a Strategy for Hydrogen and Fuel Cells) was appointed by the government agency for Natural Resources and Energy (supervised by METI) to advice the government on the hydrogen energy deployment. [Valovirta 2018]

Achievements

The continuous activities, strong (financial) support and a clear commitment for hydrogen technologies by the Japanese government as well as a profound public-private interaction (e.g. formulation of targets, development of detailed roadmap) has placed Japan in a world leading position in the field of hydrogen technologies.

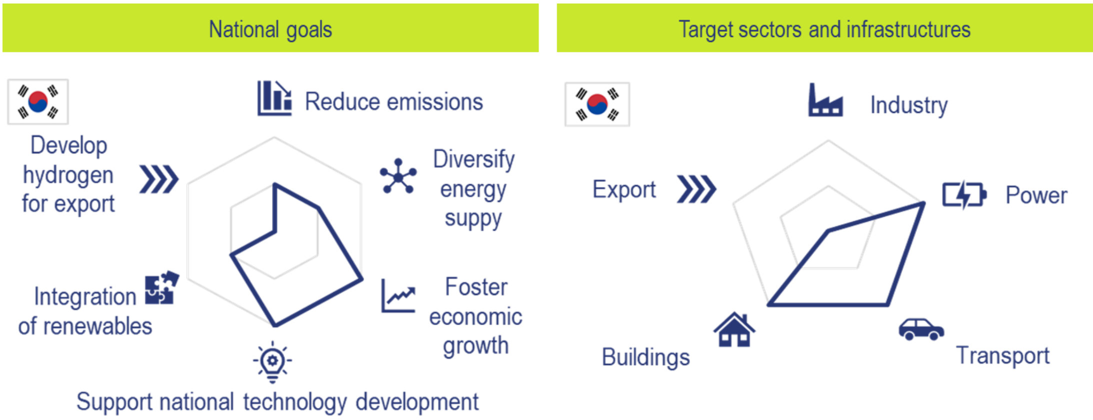
At the end of 2019, there were about 3,500 fuel cell vehicles on the roads in Japan, of which little more than 20 FC buses. In addition, there are about 160 FC material handling vehicles. The number of HRS in the country is at about 110 in 2019 making it one of the largest networks in the world.

Toyota (and partially Honda) is considered leading in fuel cell passenger cars. Toyota is preparing for mass production of 30,000 units per year for its next generation Mirai fuel cell passenger car, starting in 2020/2021 and even higher numbers with the subsequent generation expected in 2025.

Japan will be the first country importing large quantities of hydrogen via ship using newly developed technologies (e.g. hydrogen carriers ship). Until 2030 this hydrogen will mainly be fossil based with CCS technology becoming available after 2025. After 2030 low-cost renewable hydrogen will supplement the fossil (+CCS) based hydrogen.

At the beginning of 2019 around 274,000 stationary fuel cells (Ene-Farm) for households have been in use. The costs per unit were reduced by about half since their introduction in 2009. Average subsidy was also significantly reduced in the last 10 years. [Nagashima 2018]

South Korea



Current situation

Already in 2005, the Korean government released the "Master Plan for Implementation of an Environmentally-friendly Hydrogen Economy". This document had a limited focus on fuel cells in general and its application in passenger cars in particular. As the technology development was still at an early stage the initial master plan failed to reach its objective [KR H2 EC RM 2019].

In 2019, Korea released the more sophisticated "Hydrogen Economy Roadmap of Korea" and the "National Roadmap of Hydrogen Technology Development" in which the main goals and sector targets in terms of hydrogen and fuel cell technology are specified. The roadmaps cover the period until 2040. In the same year, the third Energy Master Plan was released. This plan considers hydrogen as one of the main energy carriers in the future [KR EMP 2019]. Further, "Future Automotive Industry Development Strategy" was issued in 2019, which describes concrete plans for the fuel cell vehicle industry [Yoon 2020]. In January 2020, the National Assembly passed the "Hydrogen Economy Promotion and Hydrogen Safety Management Law (Hydrogen Law)" laying the legal basis for supporting hydrogen industry and setting safety standards [Kan 2020].

South Korea has a strong automobile industry being among the world leaders in fuel cell electric vehicles. In fact, in 2013 South Korea became the first country to successfully mass produce a fuel cell vehicle (Hyundai ix35). The 2018 follow-up model (Hyundai Nexo) claims to have the longest driving range among all available fuel cell vehicles. The fuel cell industry is also amongst the world leaders due to mergers, acquisitions, and alliances with domestic and foreign companies. [KR H2 EC RM 2019]

In recent years, economic growth rates and employment rates have decreased in Korea. To stop that development, the government has announced the Innovative Platform Program (IPP) in 2018. This program focuses on the three major areas of strategic investment, one of them being the hydrogen economy [Kim et al. 2019].

National goals

The government's goals within the "Hydrogen Economic Roadmap of Korea" are:

- Increase technological competitiveness: it is expected that hydrogen will be the next growth engine for Korea creating 24 B€ in economic value and 420,000 jobs by 2040. [KR H2 EC RM 2019] [KR EMP 2019]
- Contribute towards creating a clean and safe society.
- Reduce greenhouse gas emissions: by 2040 hydrogen is expected to account for 5% of gross energy consumption and to contribute to the national emission target with a reduction of 27 MtCO2 [KR H2 EC RM 2019] [KR EMP 2019].
- Reduce the emission of fine dust: the use of hydrogen will avoid 23 Mt of fine dust by 2040 [KR H2 EC RM 2019].
- Hydrogen will contribute to South Korea's energy independence [KR EMP 2019].

The country's H_2 strategy is rather driven by economic growth and industrial competitiveness and to lower extend by environmental considerations. One reason for this might be the rather relaxed GHG emission reduction target of -37% until 2030 compared to a business as usual scenario [Kan 2020].

Target sectors and infrastructures

The Hydrogen Economic Roadmap places priority on the development of hydrogen industries especially in the automotive and fuel cell sector as well as on near- and medium-term market creation and commercialisation, followed by strong exports of vehicles and stationary fuel cells. The Third Energy Master Plan calls those periods "Preparatory phase" until 2022, "Expansion phase" until 2030 and "Leading phase" (Leadership of hydrogen economy) until 2040.

Main targets per sector are listed in Table 20.

Table 20: Sector targets Korea [KR H2 EC RM 2019], [Yoon 2020]

Sector		Target volume and time horizon
Mobility	FCEV	81,000 (2022); 100,000+ (2025); 2040: 2.9 m (domestic) + 3.3 m (export)
	FC Taxis	2040: 80,000 (domestic) + 40,000 (export)
	FC Bus	2040: 40,000 (domestic) + 20,000 (export)
	FC trucks	2040: 30,000 (domestic) + 90,000 (export)
	Hydrogen powered ships, trains, drones and construction machinery will also be supported and are mentioned in the government paper, but no further details are disclosed.	
Power and Heat	Central power generation (NG FC)	1.5 GW (2022); 8 GW domestic (2040); 7 GW export (2040)
	Decentral power generation (NG FC) ("For Home and Building")	50 MW (2022); 2.1+ GW (2040)
	Increase decentral power generation	
Overall	FCEV and stationary FC: Hydrogen consumption: 470 kt (2022); 1.94 Mt (2030) Hydrogen energy will account for 5% of gross energy consumption (5.26 Mt) in 2040.	

To satisfy domestic hydrogen demand, the roadmap formulates certain infrastructural targets. It is planned to increase the number of HRS to 310 by 2022 and to 1,200 by 2040. Further, an expansion and technology shift of hydrogen distribution is sketched.

In the near-term (2022) it is planned to develop and introduce high-pressure (700 bar and above) trailers for gaseous hydrogen transport to be able to supply hydrogen to small and medium-size refuelling stations once a day. In addition, hydrogen pipelines will be established and expanded close to existing hydrogen co-product hydrogen sources (Ulsan, Yeosu, Daesan). Hydrogen consumption of FCEVs and stationary fuel cells is expected to increase from 0.13 Mt/a (2018) to 0.47 Mt/a (2022). By that time already existing hydrogen production (co-product and extracted from natural gas) will be complemented with water electrolysis for domestic hydrogen production from renewables (solar and offshore wind). Large-scale R&D and demonstration of Power-to-Gas (with renewable electricity) will start in 2022 to prepare for increased demand in the subsequent years. Natural gas will mainly be used for stationary fuel cells. The hydrogen price target for 2022 is 5 USD/kg [Yoon 2020].

In the medium- to long-term (2030) the government plans to support the development and introduction of new hydrogen logistic technologies, namely "liquid hydrogen" (hydrogen carriers), "liquefied hydrogen" (cryogenic hydrogen) and "solid hydrogen" (hydrides) for energy storage and road transport. Tank lorries for liquid and liquefied hydrogen for actual distribution will start in 2030. In addition, development of hydrogen pipelines for pressures at 50 bar and above are planned. First, major hydrogen sources will be connected to the pipeline, later, a nationwide network is planned. Hydrogen consumption of vehicles and stationary fuel cells is expected to increase to 1.94 Mt/a by 2030. Increased hydrogen demand will be supplied from the least costly production technology the price target is 3 USD/kg [Yoon 2020].

By 2040 hydrogen demand will increase to 5.26 Mt/a and it will be also supplied from overseas renewables and fossils sources (incl. CCS). The target is to use 70% "eco-friendly" (CO_2-free incl. CCS) hydrogen.

Measures and H_2 requirements

The Korean government is aware that substantial industry support is required to meet the roadmap targets. The roadmap does not in detail specific support measures but gives the following indications:

- "[…] the government will certainly bear some of the burden for establishment and operation of hydrogen filling stations […] in affiliation with hydrogen vehicle distribution programs at the city and province level, by providing different amounts of installation and operation assistance […]"
- "[…] in terms of fuel cells for power generation, an LNG billing system for fuel cells will be introduced, and weighted renewable supply certificates (RECs) for fuel cells will be maintained for a certain period to encourage the installation of fuel cells for power generation, thereby eliminating the uncertainty of investment and promoting economic efficiency […]
- "The distribution of home fuel cells will be supported by gradual expansion of government budgets, introduction of an LNG-exclusive billing system, provision of financial incentives such as extension of the electricity tariff specialisation system […] and mandatory installation of fuel cells at public institutions and new private buildings"

The roadmap further mentions that the government will establish safety standards and put those into law throughout the entire hydrogen economy.

A "Hydrogen Economy Promotion Committee" under the lead of the prime minister was established in 2020 (by passing the "Hydrogen Law" - Hydrogen Economy Promotion and Hydrogen Safety Management Act) to put the roadmap into action and to serve as a pan-government control tower. The committee consists of six ministries and some private companies [Ha 2019]. The "Hydrogen Law" also lays the legal basis to support hydrogen-specialised companies, education programs, prepare hydrogen related statistics, support international cooperation, reduction of taxes and levies and other support. [Kan 2020], [IPHE KR 2020], [Yoon 2020]

In 2019 the purchase of FCEVs was subsidies by central and local governments in total with about 27,300 to 30,300 USD per vehicle which was about half of the costs for a FCEV. This led to a total of 4,194 domestically produced FCEV sales that year. Fuel cell buses receive about 170,000 USD in subsidies from each, central and local government. In addition, about

250,000 USD was subsidies by the bus manufacturer (Hyundai). Unsubsidised costs for an FC bus are about 710,000 USD [Kan 2020] [Yoon 2020].

The hydrogen refuelling station network was expanded to 24 sites (September 2019) thanks to available subsidies covering about half of the investments for both, passenger car and bus refuelling station. In 2019 the company HyNet was founded by the government and 13 companies with a special purpose to build 100 hydrogen refuelling stations by 2022 [Kan 2020], [Yoon 2020].

To support fuel cell power generation, the Renewable Portfolio Standard Policy (RPS) also includes fuel cells. Under this policy (established in 2012), large power producers need to meet a minimum portion of their power generation from new and renewable technologies including fuel cells. Alternatively, they can purchase Renewable Energy Certificates (REC) to meet their obligation. Obligatory share of Renewable Energy Certificates will be increased from 7% in 2019 to 10% by 2022. They are issued per MWh multiplied by a weighting factor for specific generation technologies. Generation from fuel cells is weighted with 2, onshore wind has a weighing factor of 1 [Kan 2020].

To foster future economic growth and employment the Korean government has announced the Innovative Platform Program in 2018. Under this program, the government strategically invests in three major topics, one being the hydrogen economy. The hydrogen economy topic includes hydrogen production, storage, transport and use as well as safety aspects. The planned budget for hydrogen was about 31 M€ in 2018 and 82 M€ in 2019 out of a total program budget of 0.6 B€ and 1.1 B€, respectively [Kim et al. 2019].

Hydrogen R&D and development budgets available from the government are [Yoon 2020]:

- Development of water electrolysis and “stable” storage: 36 M€ (41.8 M$-US) (2019-2013)
- Development of power to hydrogen, methanation and LOHC: 3.8 M€ (4.4 M$-US) (2019-2021)
- Development of LH_2 technologies: 21.4 M€ (24.6 M$-US) (2019-2023)
- Development of ship using hydrogen fuel (incl. infrastructure): 13 M€ (15.1 M$-US) (2019-2023)
- Budget for the Center for Product Safety in Hydrogen Industry: 15.1 M€ (17.8 M$-US) (2018-2021)

At the end of 2019 the South Korean Ministry of Land, Infrastructure, Transport, and Tourism selected the cities of Ansan, Ulsan, and Wanju/Jeonju as candidate cities for the hydrogen economy. Each of the three cities will use hydrogen as a fuel for major urban functions such as heating, electricity and transport by 2022. The government plan calls for an investment of about 22 M€ (25 M$-US) in each city [Kan 2020], [FuelCellWorks 2020].

The roadmap sketches some requirements regarding hydrogen quality (source) for domestic use. Until about 2030 existing domestic hydrogen production facilities (by-product and sourced from natural gas) will provide large shares of hydrogen, supplemented with hydrogen from Power-to-Gas projects utilising surplus and dedicated renewable electricity. Natural gas will be the main source for stationary household fuel cells. After 2030 additional hydrogen will be imported. Overseas hydrogen produced from renewables and brown coal "produced in an eco-friendly way" will be used for that. By 2040 it is targeted that 70% of the demand will be supplied from eco-friendly, CO_2-free hydrogen (includes by-product hydrogen) [KR H2 EC RM 2019], [Yoon 2020].

Achievements

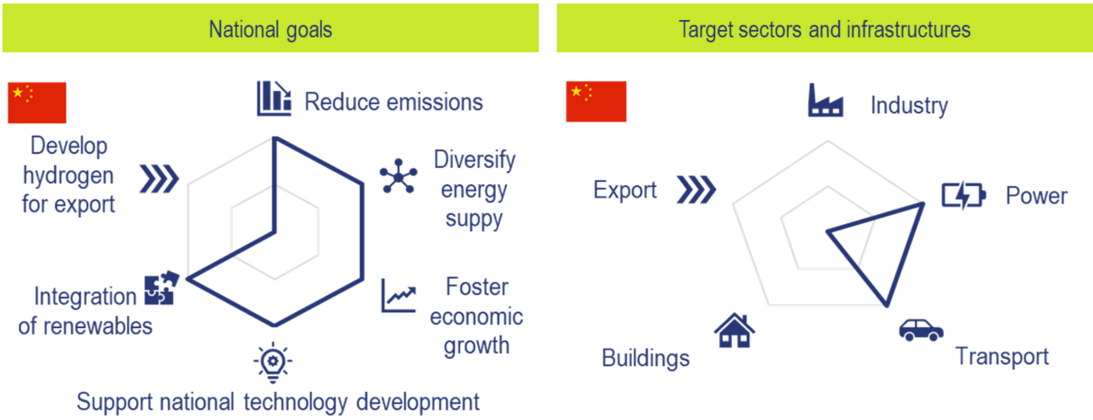
South Korea was the first country to successfully mass produce hydrogen fuel cell electric vehicles already in 2013. Since then, more than 5,000 FCEVS and 15 FC buses have been put on South Korean roads which are supplied by 34 hydrogen refuelling stations (status June 2020) [IPHE KR 2020]. In June 2020, Hyundai surpassed the mark of 10,000 FCEV produced and shipped. In addition, the first 10 fuel cell trucks are being shipped to Switzerland in mid-2020. By 2025 it is planned to bring 1,600 fuel cell trucks to the Swiss market.

In 2018 the deployment of stationary fuel cell units was already at over 3,000 small-scale units with a combined capacity of 7 MW and at a capacity of 307 MW for large-scale units distributed between 42 sites. [KR H2 EC RM 2019]

The hydrogen activities and plans formulated by the South Korean government lead to various industry plans and commitments related to the hydrogen business.

- The public enterprise Korea Gas Corporation (KOGAS) announced massive expansion plans for hydrogen infrastructure in April 2019. The company plans to construct 25 hydrogen production facilities, more than 700 km of hydrogen pipeline and to operate 100 refuelling stations and 500 hydrogen transport trailers by 2030. Investments are estimated at about 4 billion USD [Kan 2020], [IPHE KR 2020].
- Already in 2018 Hyundai released plans to expand its fuel cell production capacity to 700,000 units per year (for personal and commercial vehicles, forklifts, vessels, drones, and other vehicles) by 2030. The fuel cell production capacity is expected to increase to 40,000 units per year, by 2022 [Kan 2020].
- The construction of a large scale (about 50 MW) fuel cell power plant was announced in 2019 by Doosan Fuel Cell. Further large power plant (e.g. KOSOP's 20 MW combined heat and power plant in Incheon) already exist. In total, more than 20 plant with a combined capacity of about 167 MW exist in South Korea [Kan 2020].

China



Current situation

Already today, China is the largest producer and user of hydrogen in the world. China is developing fuel cells and hydrogen for use in road vehicles for about 20 years. First larger FCEV fleet demonstrations were performed in 2008 for the Olympic Games in Bejing and further demonstrations during the World Expo in Shanghai in 2010. All demonstrations were also equipped with hydrogen refuelling infrastructure. Refuelling technology was mostly based on foreign technology components which still often the case. Fuel cell stacks have been developed since more than 20 years by Chinese companies (e.g. SinoHytec) as well as by joint ventures with Canadian fuel cell companies (SinoSynergy/Ballard, SinoHytec/Hydrogenics). China is gradually successful in developing own fuel cell technology usually based on graphite bipolar technology (Beijing SinoHytec Co. Ltd., Guangdong Synergy Ballard Hydrogen Power Co., Ltd.) as well as first products also with metallic bipolar plates (Wuhan Troowin Power System Technology Co., Ltd).

1,000 Fuel Cell Electric Buses and 2,200 commercial trucks equipped with Ballard fuel cells are presently in operation in China. Approximately 35 million km have been achieved in FCEVs deployed in China.[56] Towards the beginning of 2022 FCEV fleets will be operational during the Winter Olympic Games Beijing in Zhangjiakou. This applies for urban buses and passenger cars in Zhangjiakou as well as bus coaches between Beijing and Zhangjiakou. Moreover, following Chinese companies are members in the Hydrogen Council documenting the commercial and strategic interest of Chinese players in hydrogen technologies: CHN Energy, Great Wall, ReFIRE, Sinocat, SinoHytec, Sinopec, Weichai Power.

[56] https://fuelcellsworks.com/news/fuel-cell-electric-vehicles-powered-by-ballard-have-now-driven-over-50-million-kilometers-enough-to-circle-the-globe-1250-times/

National goals

Originally the main reason for the introduction of so-called New Energy Vehicles (NEVs)[57] was the reduction of local pollutants in metropolitan areas in order to improve air quality and reduce smog. Recently, the reduction of GHG emissions was adopted as one of the key priorities of Chinese policy. Also in this aspect, NEVs are helpful as soon as power and hydrogen come from renewable sources, which is the case in some city agglomerations (e.g. Wuhan).

According to [NDRC 2019] among others the following goals apply for China:

- China is a practitioner of the Paris Agreement
- Renewables have to cover the future incremental energy demand
- Offshore wind power to be installed in China in the future will not be connected to the grid anymore, but will produce hydrogen directly which will be transported onshore

With respect to technological leadership, in the Made-in-China 2025 program, announced 2015, the areas mainly relevant for obtaining leadership in hydrogen and fuel cells are:

- High-end computerised machines and robots leading to industrial manufacturing of fuel cells
- New energy and energy-saving vehicles leading to FCEV commercialisation
- Energy equipment leading to new and renewable energy equipment incl. hydrogen storage

On 29 May 2020, the National People's Congress in Beijing adopted the nationwide economic and social development plan for 2020. It calls for the formulation of a "national, strategic plan for the development of the industrial hydrogen industry" and further support for "New Energy Vehicles (NEVs)" including FCEVs.

Target sectors and infrastructures

The Hydrogen and Fuel Cell Roadmap published by China in 2017 already shows the focus on mainly transport applications (road, rail and ship), also on fuel cell power generation and on hydrogen production, supply and refuelling infrastructure including safety, testing, certification and RCS:

[57] NEV = New Energy Vehicle (BEV, PHEV, FCEV)

Table 21: Sector targets China (Source: [LIU 2018])

Sector		Target volume and time horizon
Mobility	FCEV	2020: 10,000 (only buses and trucks) 2025: 100,000 (mainly buses and trucks, few thousands of LDVs) [expected in revised roadmap 2020] 2030: 1-2 million (at least 50% buses and trucks)
	Hydrogen powered ships (first demo ships in 2020), trains (e.g. 50 tram lines by 2020), aircraft will also be developed.	
Power Generation	FC Power generation	2020: 200 MW 2030: 100 GW 2050: well established distributed power
H_2 Production	2020	72 billion Nm³ H_2/yr [complete demo of industrial chain]
	2030	100 billion Nm³ H_2/yr (8.9 mill t/yr) [increasing share in energy market] [expected in revised roadmap 2020: 20-40 mill t/yr]
	2050	important part in the national energy equation
Refuelling stations	2020	100 [expected in revised roadmap 2020: 50-80]
	2025	[expected in revised roadmap 2020: 800 stations]
	2030	> 1,000 [expected in revised roadmap 2020: 4,800 stations in 2035]
	2050	complete H_2 network
H_2 transport infrastructure	2030:	3,000 km H_2 pipeline (east-west extension – construction start: 2025)
	2050:	well established H_2 infrastructure

Already by 2030, China plans to have a dedicated 3,000 km H_2 pipeline infrastructure in place which by 2050 shall be well established.

In view of the planning of an almost additional 8,000 TWh of renewable electricity to be provided by 2035 a significant share of the renewable power will have to be converted into storable H_2, due to the usually non-synchronised supply and demand patterns.

This argumentation is further supported by the statements provided in the hydrogen session of the EV100 conference in Beijing in January 2020:

- In the future, Beijing only wants to rely on green hydrogen - the sector integration between the renewable electricity system and mobility will be the focus of further major project development.
- Battery electric vehicles and FCEV are to be promoted equally in China in the future. The focus for hydrogen in mobility are commercial vehicles, but passenger vehicles will also be involved in larger demonstration projects[58] in the coming years.

[58] Usually any fleet of vehicles below 1,000 units dispatched at one location is regarded as demonstration project

- Beijing sees focus on cluster/ provinces instead of the total country as the major lever in reducing costs for hydrogen technology - in the future hydrogen technology will be developed and produced on a large scale in China.
- 5,000 hydrogen refuelling stations are to be built by 2030 - 2035
- LH_2 and cryo-compressed hydrogen storage technologies are an important thrust for commercial vehicle drives, the first fuel cell trucks with LH_2 tanks are already being built.
- China should receive the world's largest hydrogen liquefiers in the coming years.

For the Olympic Winter Games 2022 a bus fleet of 1,500 fuel cell buses (175 are operational on 7 lines for almost a year already) and several hundred fuel cell cars is targeted to drive the route between Beijing and Zhangjiakou.

Measures and H_2 requirements

At present, the development of the fuel cell vehicle industry is faced with some problems such as lack of core technology and key components, weak awareness, and ability to innovate, inadequate infrastructure construction. In response to the existing problems in the industry, the current subsidy policy for fuel cell vehicles is being adjusted to select some cities that focus on the core technologies for FCEVs, and to demonstrate the industrialisation of fuel cells and an appropriate layout for the cooperation and promotion of FCEVs. Local organisations should be supported in research and development, the industrialisation of new technologies (e.g. FCEV, hydrogen refuelling stations), as well as in talent development and team building. They should be in charge of demonstration of FCEVs (at least 1,000 per location) and related infrastructures.

During the 4-year demonstration period, the central government will take a results-based approach and reward demonstration cities with a "reward replacement" method.

With the implementation of the policy in the near future, the hydrogen and fuel cell industry will be promoted as the main line. The focus is on reducing the costs of the entire industrial fuel cell chain and developing an independent commercial operation. The industrial policy was changed from "serial processing" to "parallel processing"[Jiang 2020].

NEVs in many cities were granted preferential access conditions (exemption from access ban, exemption from auctioning or lottery for acquiring a number plate, etc.). Each volume manufacturer in China has to comply with the NEV quota, which for 2021, 2022 and 2023 demands 14%, 16% and 18% of vehicle sales to be NEVs. The collection of maximum NEV points by type of NEV from 2021 onward is as follows: Plug-in Hybrid Electric Vehicles 1.5, Battery Electric Vehicles 3.4 and FCEVs 6 [NEV 2019]. Each manufacturer through the sales of NEVs aims at fulfilling the imposed quota. The nation-wide real-time monitoring system among others also verifies the type of vehicle (PHEV, BEV or FCEV) and the kilometres driven. The latter is important to prove that a vehicle has driven 20,000 km, which is the threshold for receiving the payment of any subsidies. The recognised type another important criterion for compliance with the NEV quota.

On 10 April 2020, China has released an energy law that prioritises the use of renewable power sources and aims to set future targets for both its production and its share in the country's overall energy mix. Furthermore, in its Article 115 the Chinese energy law is expanded to include "Hydrogen Energy". A consequence of this change is that less stringent requirements apply for the transport of hydrogen as a fuel than for its transport as hazardous substance, as which H_2 was previously classified. The new legislation would also make hydrogen a freely tradable energy asset and this will have significant consequences for the development of the hydrogen business in China.

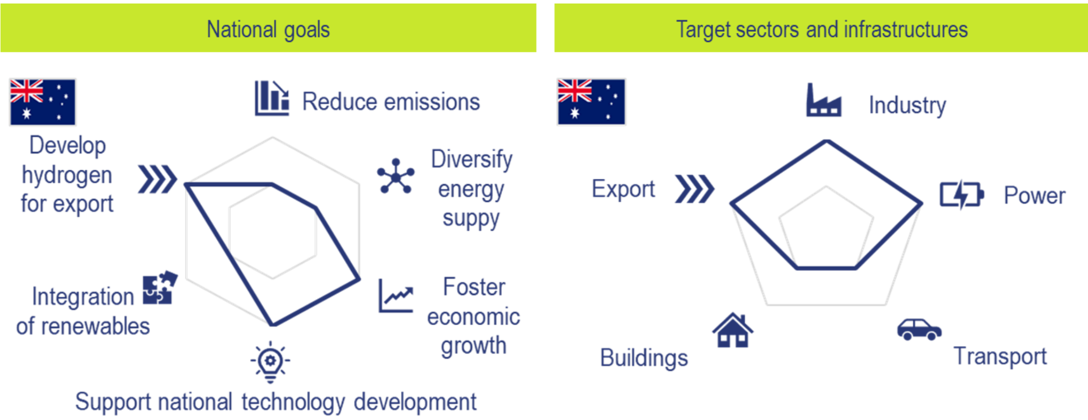
China will increasingly use abandoned solar, wind and hydrogen energy to produce hydrogen. The use of fossil energies for hydrogen production such as coal, natural gas and oil will be reduced. The future use of "clean coal" is an option [LIU 2018].

Achievements

Several manufacturing plants for fuel cell stacks and modules with graphite bipolar plates typically in the 5,000 to 10,000 units per year capacity range have been built in China: SinoHytec in Wuhan, Daton and Shenzhen, Guangdong Nation Synergy Hydrogen Power Technology Co., Ltd. in Yunfu and Weichai Power in Weifang (20,000 per year). A first manufacturing plant for metallic bipolar plate stacks has been started by Troowin Power System Technology Co., Ltd. of Wuhan.

In 2019 2,833 FCEV have been manufactured and 2,737 were sold in China. Compared to 2018 this is a growth of almost 400%. During the last four years China has started larger fuel cell fleet demonstrations of commercial vehicles (urban buses, logistics, medium duty trucks). STNE in Shanghai operates 500 Dongfeng 7.5 t logistics trucks since February 2018 (+ 600 in Shenzhen), Zhangjiakou operates 175 Yutong and Foton urban buses on 8 lines since September 2019 and in December 2019 Foshan has ordered 540 FC buses (154 Feichi Bus, 200 Yunnan Wulong Bus, 186 King Long Xianen Golden Dragon Bus) to start operation in 2020 aiming at 1,000 by the end of the year [Foshan 2019]. The same applies for 1,000 FC logistics trucks in Foshan for 2020. The company most visible in this area and combining fuel cells for FCEVs and automated manufacturing is Weichai Power in Weifang. In fuel cells, Weichai has joint ventures with Bosch as well as with Ballard (of which it owns about 20%) and runs a 50 billion RMB program on fuel cell commercialisation reaching from 2019 – 2030.

Australia



Current situation

Australian ambitions in developing a national hydrogen strategy can be traced back to 2018 when the Council of Australian Governments Energy Council officially recognised the economic and environmental benefits from hydrogen for all Australians and formulated a vision for a hydrogen industry. In December 2018, a dedicated Hydrogen Working Group led by Chief Scientist Dr Alan Finkel was established in order to develop a comprehensive national hydrogen strategy. In November 2019 Australian government represented by the Ministry for Energy and Emission Reduction and Ministry for Resources and Northern Australia published "Australia's National Hydrogen Strategy" in [COAG 2019] which was accompanied by a series of reviews, studies, research, and analyses.

National goals

As an ultimate goal, Australia aims to become a major renewable and low-carbon hydrogen exporter to global markets by 2050. The rationale is to achieve economic and environmental benefits through hydrogen deployment. In fact, Australia aims to become one of the top three exporting countries for hydrogen markets in Asia by 2030. At this point it is important to mention that the activities concern not only the export of hydrogen as an energy carrier but also of hydrogen technology as well as of corresponding knowledge and training. Nevertheless, the strategy also recognises that domestic hydrogen demand mainly in dedicated hubs (i.e. clusters of large-scale demand in ports, cities, regional or remote areas) is needed as a springboard to scale the hydrogen industry and supply chains for the future success. More specifically, the following targets are included in the strategy:

- **Reduce emissions:** Reduction of Australian GHG emission as well as air pollution in order to provide Australians with clean air limiting respiratory ailments and cancers and consequently health costs. In general, Australia aims to provide renewable and low-carbon (i.e. fossil-based with CCS) hydrogen although in the short-term transition phase fossil-based hydrogen e.g. from coal gasification will remain an option.

- **Integration of renewables:** Use of electrolysis as a flexible load to balance out renewable power supply within integrated energy market structures. In this way Australia intends to benefit from synergy effects, e.g. between the power sector and export industry, by lowering end-user power costs and hydrogen production costs.
- **Foster economic growth:** Hydrogen is providing jobs and economic benefits which flow back to communities where hydrogen industries are located.
- **Support national technology development:** Australia becomes major exporter of hydrogen in global markets and offers equipment, technology, education, training, and innovation at the forefront of developing solutions for the world. Safety issues related to hydrogen are taken adequately into account.
- **Diversify energy supply:** Provide greater choice in energy and fuel sources especially decreasing the dependency on liquid fuels imports for transport and thus reducing corresponding import costs.

Target sectors and infrastructures

Although hydrogen export is the major driver behind the development of hydrogen supply chains the strategy foresees a wide range of future domestic applications.

Industry is indicated as one of the important end-user sectors with a large potential for hydrogen. On the one hand it can be used as a chemical feedstock in different industries. In fact, ammonia production (e.g. for the fertiliser industry) is seen as jump-start for clean hydrogen supply at a large scale. In the long-term also H_2-based steelmaking might become a targeted application. On the other hand, hydrogen can also provide processes heat at least in some niche industrial applications where it becomes cost-competitive with other clean heat sources.

The transport sector is the largest energy consumer in Australia and, therefore, one of the crucial sectors. In a first step the strategy foresees hydrogen use mainly in heavy-duty and long-distance transport such as trucks, buses, trains, and ships. Hence early opportunities might arise for industrial users such as ports or remote industrial sites and public transport. In the longer run light vehicles will be introduced to the market. In addition, clean H_2-based ammonia might be used as a fuel in the maritime sector and clean hydrogen derivatives such as Power-to-Liquids might become an option for aviation. The corresponding refuelling infrastructure should be built up in line with the vehicle deployment. Therefore, the strategy expects major infrastructure development in demand centres and main corridors between them.

The use of hydrogen in gas networks, e.g. for heating and cooking purposes in the building sector, is explicitly mentioned in the strategy. At the distribution level the hydrogen blending or even a switch to dedicated 100% hydrogen networks is considered. For transmission networks, however, the strategy expresses some technical and safety concerns and does not support hydrogen. This might be adapted in the future based on new technical insights and developments. Finally, power sector is also an interesting area of use of hydrogen which can be re-electrified in fuel cells or gas turbines. In particular, off-grid and back-up electricity in remote areas and mining industry is a potential option for hydrogen. Also load balance and seasonal storage through hydrogen technology are important elements of the future Australian energy system based on renewable energy supply.

Based on a scenario analysis in [Deloitte 2019] domestic hydrogen demand in Australia can range substantially from 4 to 27 TWh_{H2} per year in 2030 and from 10 to 261 TWh_{H2} per year in 2050 depending on the further development of hydrogen and other competing technologies. According to the expected development of the global demand, Australia could supply clean hydrogen of ca. 0.4-18 TWh_{H2} per year in 2030 and 4-965 TWh_{H2} per year.

Measures and H_2 requirements

The Australian national strategy includes a full range of different measures to support hydrogen technology.

Research and development is one of the areas to support future development of hydrogen supply chains. Australian strategy foresees targeted support mainly in order to reduce costs and improve the efficiency of the technology through pilot and demonstration projects which might become first nuclei for future demand hubs and production centres. In this way, the industry and general public will be able to gain experience on hydrogen which, combined with knowledge sharing, will help to reduce barriers for a broad technology introduction. The first phase until 2025, providing foundations and demonstrations for hydrogen technology in Australia, will be followed by large-scale market activation until 2030.

This support will be accompanied by a broad responsive regulation intended to provide favourable boundary conditions for the development of the hydrogen industry in Australia. In this context, the national, state, and territorial governments are expected to work together on a comprehensive review of existing laws, regulations, and standards to remove legislative barriers, ensure safety and simplify approval mechanisms for hydrogen technologies. In addition, future energy market reforms will have to take into account the specific role of hydrogen within the energy system. Cross-government working groups have been established to build up "hydrogen-ready" capabilities among the governments in a consistent and efficient way. Besides national and international collaboration the regulatory approach will be characterised by consistency with strategic goals, flexibility based on adaptive and iterative mechanisms and innovation/openness in respect to new frameworks and ideas. In order to ensure legal certainty for the industry, current taxation as well as other fees and levies will be maintained in the short-term but might be reviewed in the mid-term after consultation with relevant stakeholders. This will be accompanied by a continuous monitoring of the impact of hydrogen on consumer energy prices.

The financial support is expected to amount to ca. 400 M€ (660 million AUD) with 305 M€ (500 million AUD) at the at Commonwealth level and 98 M€ (160 million AUD) as state government funding for a broad range of projects, technologies and application. The strategy points out the need for harmonisation of timelines, application mechanisms and arrangements for future funding. In addition, hydrogen-based vehicles should be considered for new government vehicle fleets and contracts.

Public acceptance is one of the cornerstones of the Australian strategy. Hence, it foresees comprehensive education program including best practices for community engagement and addressing of concerns by industry to communicate the benefits and risks of hydrogen technology in a proactive and transparent way. In addition, training schemes for technicians, professionals, emergency services and regulators will ensure an adequate handling with hydrogen and its applications while minimising health hazards. The strategy also recognises hydrogen certification and international cooperation as key element for the market build-up.

Finally, the strategy itself is expected to remain a living document which will be adapted continuously according to global market and technology developments. In this context, the National Hydrogen Infrastructure Assessment (to be carried out in 2022 and then every five years) will monitor the required changes in the power, gas, and water supply networks as well as for the refuelling infrastructure. Moreover, the "State of Hydrogen" report will provide an additional advice at an annual basis.

Achievements

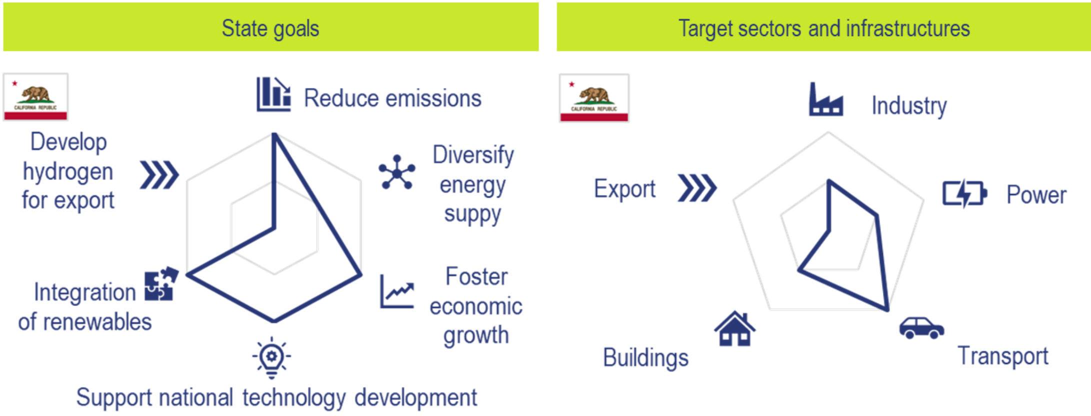
Although Australia has a comparatively new national hydrogen strategy there are more than 30 hydrogen related projects in place or under development among others:

- Hydrogen Energy Supply Chain (HESC) is a prominent project to demonstrate the supply chain for hydrogen production from brown coal in Latrobe Valle in Victoria and its transport to Japan via a LH_2-ship. It is carried out by a consortium costing of Kawasaki Heavy Industries (KHI), Electric Power Development, Iwatani, Marubeni, Sumitomo and AGL. The commercial phase of hydrogen supply from Australia to Japan is planned for 2030 including CCS technology to ensure low-carbon hydrogen production.
- Several Power-to-Gas projects for electrolytic hydrogen production (mainly from wind and solar power), its injection into local gas distribution networks and the use of electrolysis as a flexible load in the electricity system: Western Sydney Green Gas Project by Jemena; Hydrogen Park South Australia (HyP SA) by Australian Gas

Infrastructure Group (AGIG), Clean Energy Innovation Hub by ATCO as well as Hydrogen Superhub by Neoen Australia.

- Toyota is going to establish a Hydrogen Centre in Alton, Vitoria, including electrolysis, hydrogen refuelling station and an education centre to demonstrate clean hydrogen production (up to 60 kg_{H2} per day) and its use in the transport sector.
- Demonstration project for hydrogen in the transport sector including first public refuelling station and FCEV fleet in Canberra by Hyundai, ActewAGL, and Neoen.
- BOC intends to produce renewable hydrogen at its facility in Queensland to supply a FCEVs fleet operated by Queensland government.
- Demonstration project for renewable hydrogen and green ammonia production by Hydrogen Utility (H2U) in South Australia.
- Successful research at Commonwealth Scientific and Industrial Research Organisation (CSIRO) on vanadium membrane technology which allows to convert ammonia back to pure hydrogen in an efficient way.
- Low-carbon hydrogen production at the Hydrogen Park South Australia (HyP SA) will be built and operated by the Australian Gas Infrastructure Group (AGIG), one of the largest distribution companies in Australia. The demonstration project will consist of a 1.25 MW PEM electrolysis which will be used as a flexible load in the electricity system. Grid and solar power based hydrogen will be injected into the distribution grid.

California



Current situation

Based on its air quality challenges in the southern population hubs of Los Angeles and San Francisco, California belongs to one of the earliest promotors of battery electric and hydrogen and fuel cell-based mobility with a strong focus on passenger cars and city buses. Coined by this focus, California has not yet developed a state-wide public hydrogen strategy yet, which can be compared to other national hydrogen strategies, even though both state government and industry actors principally agree on the future role of hydrogen energy.

From a public perspective the three most influential bodies are the California Air Resources Board (CARB), the California Energy Commission (CEC), the state's primary energy policy and planning agency and the California Fuel Cell Partnership (CaFCP). At state-level, CARB had established the Zero Emission Vehicle Mandate (ZEV) in 1990, which has provoked major development progress on fuel cell drive systems for passenger cars by major international automakers. This was federally supported in 1993 by the establishment of the Partnership for a New Generation of Vehicles (PNGV), having a catalyst role to support FCEVs [DoE 2002].

Academically rooted by thorough analysis at UC Davis (UCD) in [Ogden 1999], the required hydrogen refuelling infrastructure and refuelling station roll-out was planned, enacted by CaFCP and CARB. The most recent documents for reporting state of art and next steps for the State of California can be found at the CEC [Newsom 2019] and CARB [CARB 2019] websites, both with a 2025 perspective.

Even though California's interest in hydrogen energy is based on its application as fuel for mobility its use for other purposes has always been co-studied. In recent reports, simulations have been carried out for California's renewable energy supply by 2045 [Wärtsilä 2020] and renewable hydrogen supply 2050 [Reed 2020]. In the latter report the contours of a holistic hydrogen energy carrier approach become visible. Other than in the most of the other 49 states, California has put a strong policy focus on renewable energies including hydrogen, a full conversion targeted within the coming 20 years.

Concluding, on one hand the State of California has not developed or published a state hydrogen strategy yet, though a wide consensus appears between relevant actors from politics and industry (power, gas, chemical industry). On the other hand, the California approach is framed by the development efforts for a federal hydrogen strategy [FCHEA 2019]. The US Department of Energy (DoE) has developed the "H_2 at scale" concept that include sectors of the energy economy beyond just transportation. In this approach, the blue H_2 concept is more advanced than in California, but not as advanced as the green H_2 concept, possibly because the DoE H_2-program is also renewables oriented. The McKinsey report for the Fuel Cell and Hydrogen Association and US DoE [FCHEA 2019] notes in its introduction that the United States has a rather fragmented state level set of regulations on many issues relevant to hydrogen, and specifically California a strong renewable orientation.

National goals

California's specific goals are multi-faceted. The initialisation happened through the air quality challenges in the bigger cities in combination with the specific local climatic conditions. Over time, California today also accepts hydrogen's contribution to the reduction of greenhouse gases in a holistic fashion. Last but not least, the economic opportunities for regional value creation from participating in the development of hydrogen and fuel cell technologies has been identified as major ambition.

In developing its green hydrogen strategy, meeting a 100% renewable electricity supply by 2045 (or 2040 [Wärtsilä 2020]) becomes a subgoal while at the same time ensuring affordable and reliable power. For the application of hydrogen as a vehicle fuel, the Clean Transportation Program by California Energy Commission lists the following major policy sub-targets:

- Reduce California's use and dependence on petroleum transportation fuels and increase the use of alternative and renewable fuels and advanced vehicle technologies.
- Produce sustainable alternative and renewable low-carbon fuels in California.
- Improve the efficiency, performance and market viability of alternative light-, medium-, and heavy-duty vehicle technologies.
- Retrofit medium- and heavy-duty on-road and nonroad vehicle fleets to alternative technologies or fuel use.
- Expand the alternative refuelling infrastructure available to existing fleets, public transit, and transportation corridors.

- Establish workforce-training programs and conduct public outreach on the benefits of alternative transportation fuels and vehicle technologies.

Target sectors and infrastructures

Today, California produces about 55 $tons_{H2}$/day of fossil-based merchant hydrogen outside of the refineries. The largest facilities are Praxair's plant in Ontario and Air Product's facility in Sacramento. This fossil hydrogen serves the non-transportation, merchant hydrogen market. In contrast, the six new renewable production projects (announced since 2017) serve the transportation applications.

Beyond the mobility sector, hydrogen's capability as energy dense and easily storable energy carrier for indefinite periods is now understood. This has recently paved the way for hydrogen's new role serving as critical foundation to electrification in a decarbonisation energy system based on renewable electricity from solar and wind energy. In that respect, hydrogen shall become complementary to the application of battery solutions, particularly well-suited for long-duration storage and transportation applications. This is specifically the case for applications requiring long-range or heavy payloads and hence large amounts of on-board energy storage. Other potential hydrogen energy applications identified are as a primary input to fertiliser production, refining, industrial processes and next-generation steel making.

In their California hydrogen roadmap assessment, UCI-APEP have generated three different ramp-up scenarios (min, medium, max). In the maximum case, approximately 3,000 out of a total of 4,300 million kg_{H2} per year or 70% are believed to be consumed by the transport sector. The other sectors to be supplied are ammonia production (ca. 2%), refining (3%), the power sector (ca. 9%) and process and room heating/cooling (ca. 13%). The analysis projects a high-case demand for renewable hydrogen of more than 400 million kg_{H2} per year (2030) and more than 10 times that amount in 2050. Given continued policy support and user acceptance, it has been estimated that renewable H_2 demand in California could then reach 4.2 million ton_{H2} per year. This would be roughly equivalent to a contribution of 2 B$ to California's state economy by 2030 and 18 B$ by 2050. As a first estimate, hydrogen would then provide about 15% of California's final energy consumption [Reed 2020].

For 1st October 2019, the CARB data analysis report indicates that 6,826 FCEVs were registered in California, up 36% since October 2018. On August 1st 2020 a total number of 8,475 fuel cell cars leased or sold, 45 fuel cell buses and 42 available hydrogen refuelling stations has been reported [FuelCellWorks 2020]. For refuelling these vehicles with hydrogen across large parts of California, allowing sufficient driving range, 100 hydrogen refuelling stations shall be installed according to the most recent plans (cars and city buses mostly in the Los Angeles, San Francisco Bay and Sacramento areas[59]), In 2018, the CaFCP had also published its vision of 1,000 stations and one million FCEVs by 2030 [Elrick 2018].

Several California organisations are looking at hydrogen more broadly than just at transportation. The California natural gas utilities are interested in Power-to-Gas technologies and hydrogen blending to reduce the carbon intensity of gaseous fuels, and also as energy storage [NREL 2016] which has raised the interest also of the California Energy Commission. There are a handful of Power-to-Gas demonstration projects in California today, with the major utility Southern California Gas being an important actor. Also fuel cell-based CHP applications are mentioned to be used in California.

Measures and H_2 requirements

The California Energy Commission's Clean Transportation Program has funded 64 refuelling stations and has sponsored a substantial amount of R&D on H_2 for transportation and awarded funding for two projects with a total production capacity of 6,000 kg/day of 100% renewable H_2. CEC will fund 100 refuelling stations as basis for up to 1,000 refuelling stations by 2030, dispensed at H_2 price of 6-8 US$/$kg_{H2}$ (2030) and 4-6 US$/$kg_{H2}$ (2050). So far, the CEC has provided nearly 120 million USD of funding to install or upgrade 64 publicly available hydrogen stations capable of light-duty vehicle refuelling.

Financial support for renewable H_2 production and related facilities could take any of several forms [NREL 2016]: (a) a capacity credit program similar to the Low Carbon Fuel Standard (LCFS) Hydrogen Refuelling Infrastructure (HRI) credits (with a requirement that eligible feedstocks and renewable electricity be used), (b) capital grants, and (c) loan guarantees. The amount of financial support needed for the renewable H_2 production sector to reach self-sustainability depends on several factors, including the form of support.

According to the federal U.S. Alternative Fuels Data Center (AFDC)[60], rebates for the replacement of a battery, fuel cell, or other related vehicle component for eligible used zero emission vehicles (ZEVs) and near-ZEVs in California will be available through July 31, 2025. [AFDC 2020] reports on the rules for car manufacturers on ZEV in their fleet:

- 2020: 9.5%
- 2021: 12%
- 2022: 14.5%

[59] The original plans were 200 refuelling stations by 2025 [Brown 2018].

[60] See CARB Zero Emission Vehicle (ZEV) and Near-ZEV Component Rebates (Zero Emission Assurance Project) in [AFDC 2020].

- 2023: 17%
- 2024: 19.5%
- 2025 and later: 22%

Additionally, the California ZEV programme has been providing a strong incentive for vehicle manufacturers to sell clean vehicles in the State. The ZEV programme is part of the Advanced Clean Cars package of coordinated standards of the California Air Resource Board that controls smog-causing pollutants and greenhouse gas emissions of passenger vehicles. The ZEV regulation requires vehicle manufacturers to offer specific numbers of the very cleanest cars available for sale. Eligible vehicle technologies include battery-electric, hydrogen fuel cell, and plug-in hybrid-electric vehicles.

For heavy-duty trucks, public funding for the development, demonstration, pre-commercial pilot, and early commercial implementation projects for zero and near-zero emission trucks, buses, and off-road vehicles and equipment in California was supposed to be 12-20 million USD in funding annually through December 31, 2020. At least 20% of allocated funds should go towards early commercial deployment of eligible vehicles and equipment[61].

Furthermore, according to Assembly Bill No. 8 "Alternative fuel and vehicle technologies"[62], 20 million USD shall be allocated annually, as specified, until there are at least 100 publicly available hydrogen-fuelling stations in California.

Today, clean vehicle rebates are provided for up to $4,500 for fuel cell electric vehicles [CVRP 2020] and on top the State of California is co-funding the initial network of hydrogen fuelling stations, in advance of vehicle launches invests up to $100 million annually in a broad portfolio of transportation and fuel transportation projects throughout the state [CEC 2020a]. Furthermore, the Clean Transportation Program Awards as of May 1, 2020 funds hydrogen provision in two ways:

- Renewable hydrogen production: $7.93 million USD (2 projects); and
- Hydrogen refuelling infrastructure: 135.58 million USD (64 public refuelling stations, plus fleets).

In the most recent annual hydrogen evaluation, the CARB has proposed for the next funding solicitation to adopt a multi-year, network-focused approach designed to emphasise

61 See CARB Establishment of a Zero Emission Medium- and Heavy-Duty Vehicle Program 2016 in Assembly Bill AB-2415 "California Clean Truck, Bus, and Off-Road Vehicle and Equipment Technology Program." at https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201520160AB2415.

62 See funding programs in Assembly Bill AB- 8 "Alternative fuel and vehicle technologies: funding programs" at https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201320140AB8.

economic competitiveness [CARB 2020]. The ongoing investment plan allocations for financial years 2020-2021 and the subsequent years foresees the following support for hydrogen refuelling infrastructure by year:

- 2020-2021: 20 million USD,
- 2021-2022: $20 million USD,
- 2022-2023: 20 million USD, and
- 2023: 5 million USD

summing up to a total of $65 million USD by 2023.

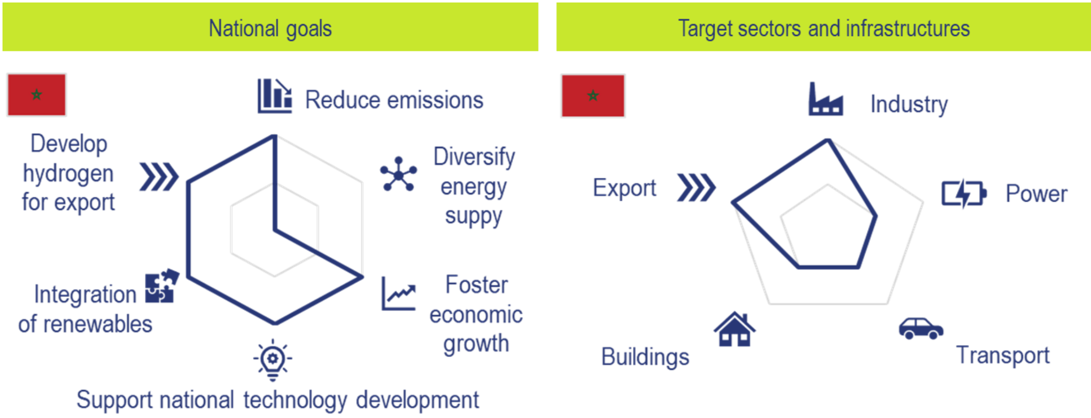
The solicitation GFO-19-602 is announcing the availability of up to 115.7 million USD in grant funds to support hydrogen refuelling infrastructure projects that will expand California’s early commercial light-duty hydrogen refuelling and FCEV markets and accommodate the 49 projected FCEV rollout in 2021–2024. Stations funded by the Clean Transportation Program so far are expected to dispense fuel with an average of 39 % renewable hydrogen content. Any stations resulting from GFO-19-602 are required to meet requirements for the LCFS Hydrogen Refueling Infrastructure (HRI) credit, which requires at least 40% of the hydrogen from renewable sources.

As a side aspect, CEC will also fund non-lithium ion technologies that can provide a minimum of 10 hours of energy storage. Hydrogen projects can potentially qualify for this funding opportunity [CEC 2020b]. At the federal level, $64 million USD funding aim to advance the focus areas of H2@Scale and support EERE's core priorities [EERE 2020]. In the San Joaquin Valley hydrogen fuel cell vehicles (HFC) receive a rebate of up to $3,000 rebate [Valley Air 2020] and in El Dorado County rebates of up to $1,000 for FCEVs are provided [AFDC 2020].

Achievements

With a focus on transportation, California has achieved world leadership in hands-on experience in the daily operation of fuel cell cars and city buses and the required hydrogen refuelling infrastructure. Concerning the other hydrogen applications, California is somewhat lagging behind, even though all topics have entered the agendas of research, the state agencies and industry (gas industry, electricity industry, technical gases industry).

Morocco



Current situation

Morocco has been the first and most active North African country building large capacities of renewable energy generation plants, based on the beneficial wind and solar conditions complemented by sizeable hydropower capacities. Wind and solar renewable electricity prices of Moroccan projects have been among the world's lowest for many years. According to the Moroccan Agency for Renewable Energy (MASEN), the country is well on track to reach its goals of 42% renewable energy production in 2020, increasing to 52% in 2030.

In November 2019, the Minister of Energy, Mines and Sustainable Development announced the establishment of a national technical commission responsible for the preparation of a "Power to X" roadmap, which is expected to be finalised in 2020 and has been involving public and private stakeholders from the outset, which hitherto has not been the norm in Moroccan strategy development. Morocco's commitment to the development of renewable hydrogen as an alternative source of energy was reaffirmed in February 2020 by Mustapha Bakkoury, President and CEO of the MASEN [Industries.ma 2020]. While the roadmap is still under development, the Moroccan and German governments have signed an agreement for the development of a green hydrogen production sector with two projects already announced, a green hydrogen production facility and a research platform. Similar agreements with other countries may follow.

National goals

The power-to-x roadmap clearly aims at positioning the country as a premier exporter of green hydrogen, expecting to be able to provide 2-4% of global demand [Eichhammer 2019], while at the same time strengthening the national technology basis. This is reflected in the working groups within the roadmap activities covering the preparation of concrete deployment projects, the requirements for a successful hydrogen export, and the establishment of appropriate research and development capacity.

Consequently, short term goals aim at reducing costs throughout the production and exploitation value chain. In the medium term, discussions focus on the development of stabilising the grid by developing adequate storage capacity for the electricity sector and the establishment of an appropriate regulatory framework for the use of power-to-x in transport. Developing a corresponding regulatory and commercial framework for eventually using it in heat production (mainly for domestic cooking) is rather seen as a long-term goal. [LesEco 2020]

Target sectors and infrastructures

While the Moroccan government is targeting to position the country as a leading green hydrogen exporter, using the technology and the low carbon fuels domestically is also a clear national aim. Applications are expected to focus on a low-carbon economy, particularly in the industrial and transport sectors. Heat production is seen as a potential long-term application sector.

With a large Moroccan fertiliser industry, dominated by the public OCP group which is a large importer of ammonia today, green and competitive ammonia production is seen as an important opportunity in the industrial sector, offering the potential for import independence as well as for diversifying the country's traditional markets. Additionally, methanol and ethanol production are also discussed.

Based on the sizeable existing ammonia handling facilities already in place, it may also become a relevant export vector. However, Morocco is also a potential bridgehead for a hydrogen pipeline between the North African region and Europe.

Measures and H_2 requirements

Short term activities include the establishment of a dedicated industrial cluster for green hydrogen production and the development of an infrastructure master plan, ensuring technology transfer through capacity building and the development of local content, as well as the creation of suitable conditions for the export of power-to-x products.

Hydrogen and green fuel production is closely tied to the low renewable energy cost in Morocco. As a result, only green hydrogen is discussed.

Achievements

With its good national framework and infrastructure for renewable energy development, notably including the Moroccan Agency for Renewable Energy (MASEN) and the solar and renewable energy research institute IRESEN, additionally supported by the German-Moroccan Energy Partnership PAREMA, Morocco builds on a strong renewable energy basis and has understood the opportunities that hydrogen and power-to-x technologies and fuels can provide for the country. The establishment of the commission with public and private stakeholders for the development of a national power-to-x roadmap and the signing of the agreement with the German government are significant achievements.

Portugal

The Portuguese national hydrogen strategy has been approved by Council of Ministers in late July 2020. Based on a draft version from May 2020 the strategy was enhanced by insights from public consultation process from May to early July 2020 as well as from six discussion sessions with input from 87 participants representing different private companies, associations and governmental institutions including several ministries.

The strategy recognises a broad range of benefits including economic benefits from the use of hydrogen technologies on the way to Portugal's carbon neutrality by 2050. In particular, the strategy claims a potential for the creation of 8,500-12,000 new jobs and the reduction of natural gas and ammonia import expenditures between 380-740 M€ and 180 M€, respectively, by 2030. In this context, Portugal is focusing on production and incorporation of renewable gases including green hydrogen mainly in sectors where electrification is not cost-effective. In addition, renewable hydrogen can be also exported to other countries in line with increasing global demand. Based on different scenarios for further development of the technology Portugal expects an electrolysis capacity of ca. 2 GW_{H2} (i.e. ca. 3 GW_{el}) by 2030. Expected investments in hydrogen technologies are between 7-9 B€ until 2030.

The strategy suggests following five pillars:

1) Anchor project for renewable hydrogen generation at seaport Sines mainly based on solar power and with an electrolysis capacity of at least 1 GW by 2030.

2) Decarbonisation of heavy-duty transport based on hydrogen and other synthetic fuels including a build-up of adequate supply infrastructure preferably with local hydrogen production.

3) Decarbonisation of industrial processes in chemical, glass ceramic and cement industries as well as in production of raw materials.

4) Creation of collaborative laboratories for hydrogen to promote R&D related to main elements of hydrogen value chain to develop new business opportunities and to build up adequate human resources.

5) Preparation and application for an Important Project of Common European Interest (IPCEI) on hydrogen in 2020.