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Hydrogen supply chain and its impacts on energy storage and carbon neutrality

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Abstract

As a clean and efficient secondary energy, hydrogen energy is of great significance for energy transition and carbon neutrality. However, hydrogen development faces big challenges of high cost, unclean in production process, insecurity in transportation and storage etc. This paper tries to build a theoretical framework of hydrogen supply chain which contains whole life cycle of production, transportation, storage, utilization, and recycle of end use. Our study shows that a hydrogen supply chain can enlarge the scale of hydrogen production and reduce the cost, improve its efficient and safety, and obtain a stable, sustainable, and zero-emission energy system. We expect a hydrogen energy supply chain to play the roles of a security guard for energy security and a bridge for the transition from fossil energy to renewable energy and these will help to reduce CO_2 emissions, promote carbon peaking and neutrality through energy technological innovation and rapid energy transition.

1. Introduction

1.1 Background

- Hydrogen energy is of great importance for carbon neutrality due to its excellent characteristics of wide sources, clean and pollution-free, high combustion heat value
- Hydrogen energy storage provides a path choice for energy storage technology progress and renewable energy development due to its clean, efficient, extensive sources and controllable security

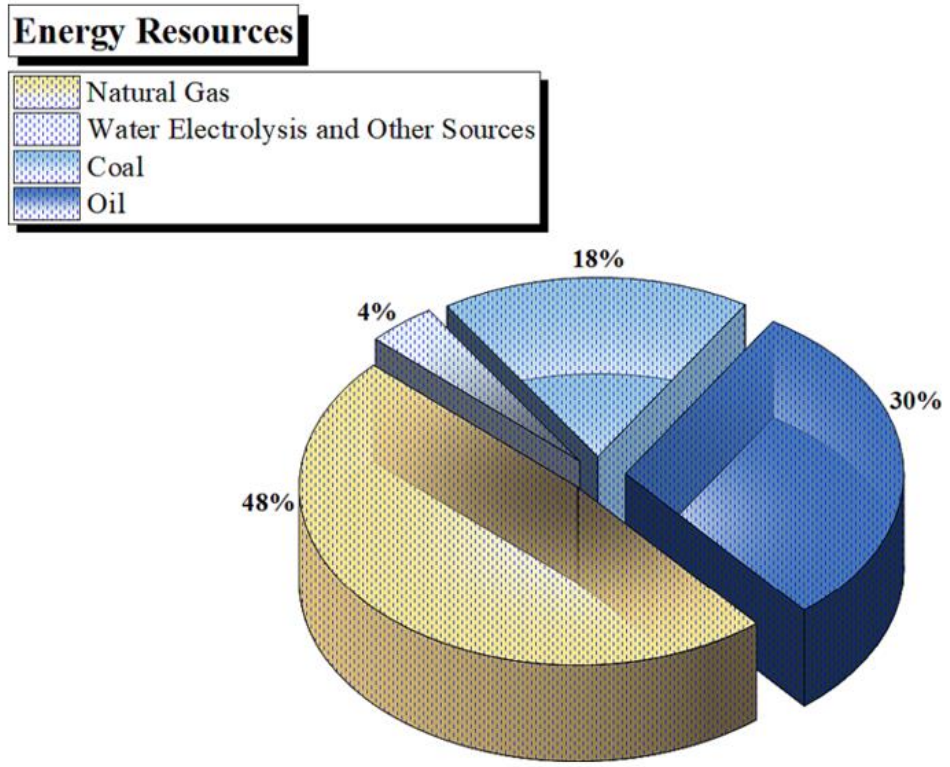


Fig. 1. Sources of current hydrogen gas products (Adapted from [25]).

Source: Analyzing the hydrogen supply chain for airports: Evaluating environmental impact, cost, sustainability, viability, and safety in various scenarios for implementation

1.2 Previous study

- **Hydrogen energy is important for future energy and reduce carbon emissions**. Yong etl. (2023) find that the integrated energy system with hydrogen storage and heat storage tank can reduce carbon emissions
- **Technological innovation is a key to solve the problems of high cost and pollution in the process of hydrogen production and transportation.** Angelo etl (2023) presented a Multi-Technology Microgrid case to indicate that technologies of producing hydrogen by gas, water etc. are necessary in hydrogen energy storage system.
- **Green and clean hydrogen production and consumption by renewal energy are expected in the future.** **Li, Khademi etl (2022)** presented the latest approaches on green hydrogen as a potential source of renewable energy towards sustainable energy and showed that recent innovations of clean hydrogen energy such as green fuel and renewable energy can contribute to reducing greenhouse gas emissions.
- **Hydrogen energy can play role of energy storage.** Kwon etl (2020) designed and optimized a hydrogen supply chain using a centralized storage model and the results show that a hydrogen supply chain with a centralized storage structure advances the phase transition of central hydrogen production plants and reduces the total annual cost of the entire supply chain in 20 cities of South Korea.

Research gap:

- The roles of hydrogen energy in energy transition and the guarantee for energy security
- The role and position of hydrogen in energy storage and the functions of energy storage in energy efficiency and carbon neutrality
- lack of a good framework and methodology to cover the multiple dimensions of hydrogen energy
- How to reduce the cost and guarantee the safety of hydrogen energy

1.3 Contribution

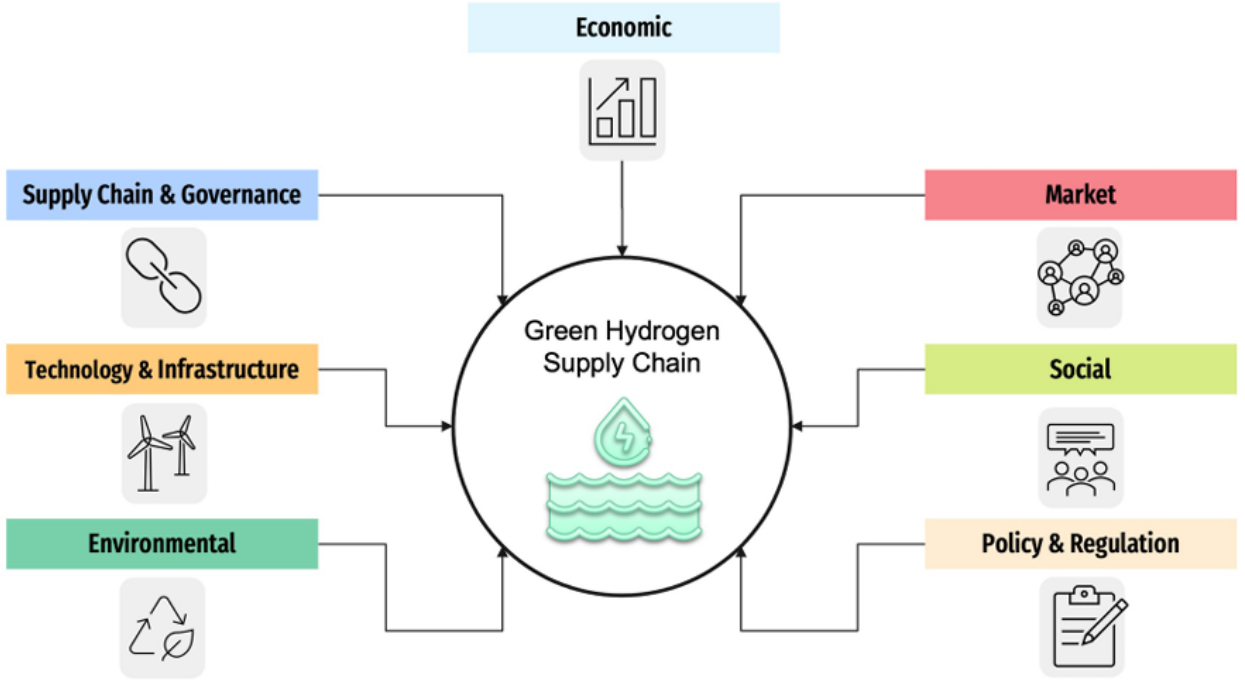
- Proved a full supply chain system for hydrogen energy from whole life-cycle prospect covering all aspects from production, transportation, storage, end-use and final recycle ;
- Discuss the roles of hydrogen as an potential future energy and its importance to energy security;
- Analysis the ways to produce green hydrogen from renewal energy and design a clean hydrogen energy supply chain
- Clarify the role of large scale hydrogen energy storage in bridging energy transition from fossil fuel energy to renewable energy and its contributions to the doble targets of carbon peaking and carbon neutrality
- Giving some technological options to reduce the cost and insure the safety, stability and sustainability of hydrogen energy development

2. Challenges and Opportunities to hydrogen

2.1 Challenges

- Construction cost: high
- **Infrastructure：insufficient**
- Construction cycle: long
- Supply and demand market: mismatch
- Relevant technology: immature
- Policy measures: incomplete

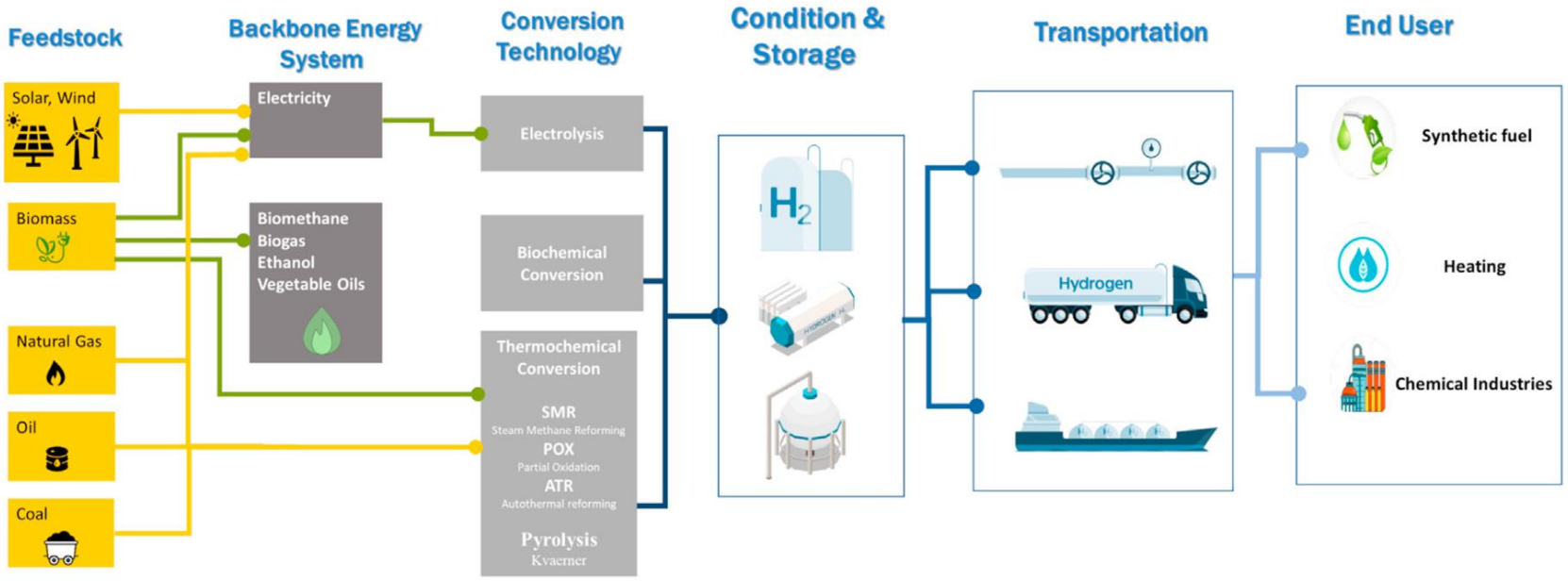
China has strong infrastructure capabilities, so the problem of insufficient infrastructure can be solved. The biggest problem facing the hydrogen energy industry chain is the high cost



Source: Green hydrogen supply chain risk analysis: A european hard-to-abate sectors perspective

2.2 Opportunities

- The commitment of all countries to net zero emissions and the global energy crisis have further accelerated the development of the hydrogen energy industry
- China needs to change its mode, and shift from a resource-dependent and extensive expansion of high-carbon development mode to an innovation-driven and enhanced low-carbon development path

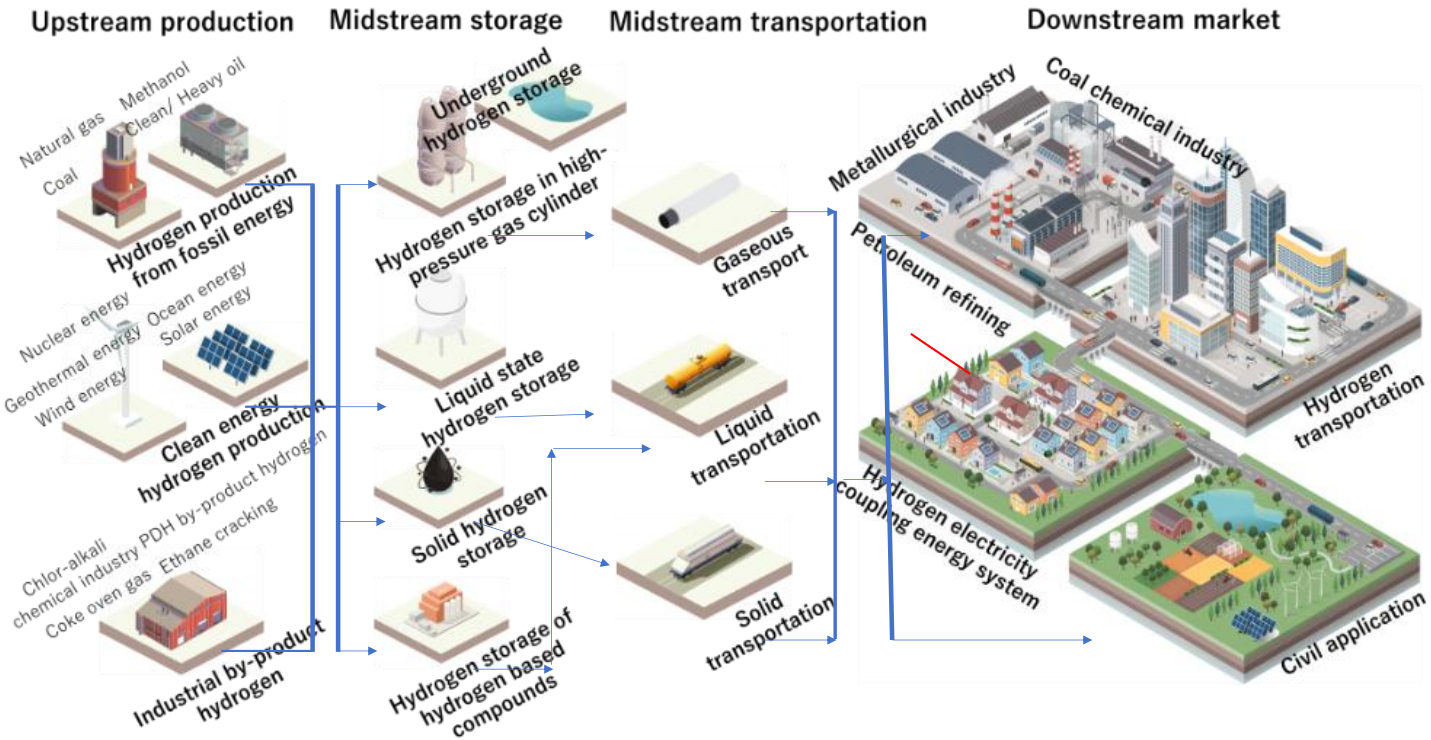


Source: Optimization of low-carbon hydrogen supply chain networks in industrial clusters

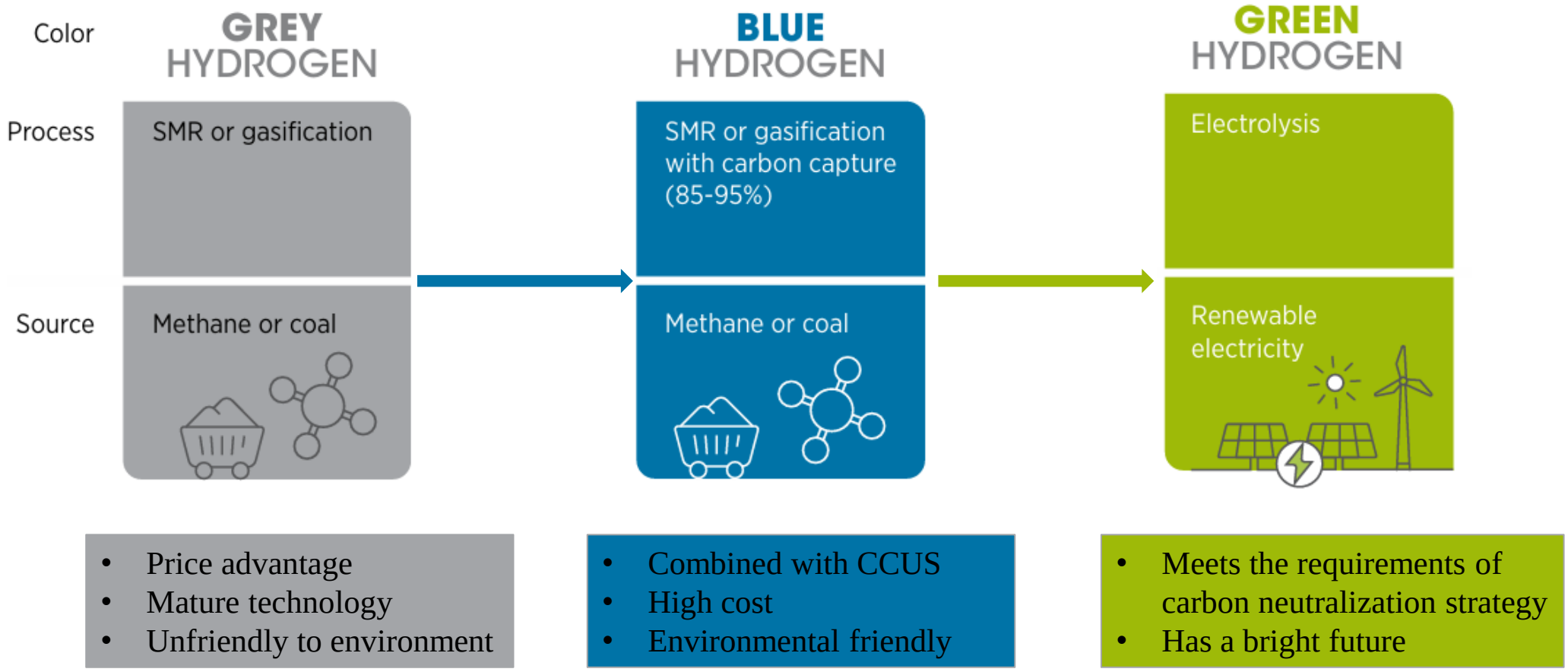
3. Hydrogen Supply Chain is the key to develop hydrogen power

3.1 Structure of hydrogen energy supply chain

- hydrogen energy production
- hydrogen energy storage and transportation (hydrogen storage technology is an important link in controlling hydrogen energy costs)
- hydrogen energy application



3.2 From gray hydrogen to green hydrogen



The direction of hydrogen energy development in the future should adhere to the principle of green hydrogen priority, blue-green counterparts, and gray hydrogen withdrawal, from gray hydrogen to green hydrogen.

Source: IRENA_Green_hydrogen_policy_2020.pdf

3.3 Hydrogen energy production

Hydrogen production method	Mechanism	Characteristic
Thermochemical method	Use heat to destroy the bond energy in the ready-made compound to reorganize it into hydrogen molecule	Thermochemistry is the most widely used method of hydrogen production. At present, 96%~97% of hydrogen in the world is produced by thermochemical methods of fossil energy
Electrochemical method	Electric energy is used to destroy the bond energy in the prepared compound, so that it can be recombined into molecules.	**Due to the wide range of sources of electricity, the purity of hydrogen production from electrolytic water is high, and the purification requirements for hydrogen generation are low.**
Plasma method	The ready-made compound is made into plasma by using electric energy to destroy its original bond energy and reorganize it into hydrogen molecule.	The hydrogen containing compound is formed into plasma to improve the hydrogen production rate.
Biological method	Through photosynthesis, with the participation of sunlight, CO_2 in the air will become hydrogen containing organisms; Or decompose water into hydrogen and oxygen through the action of bacteria.	Mild reaction, no impact on the environment, is an important cycle of nature.
Photochemical method	With the participation of catalyst, water is changed into hydrogen and oxygen through the action of light	The reaction is mild and has no impact on the environment. There is a distance from industrialization.

Green hydrogen production technology, especially hydrogen production from electrolytic water splitting technology, still needs to continue to progress to overcome the challenges posed by high costs

3.4 Hydrogen energy storage and transportation

- Storage

Hydrogen storage	Advantages	Disadvantages
Underground hydrogen storage		
High-pressure cylinder hydrogen storage	low cost, mature technology, fast hydrogen charging and discharging	low volume hydrogen storage density
Liquid hydrogen storage	high hydrogen storage density, suitable for long-distance transportation	complex dehydrogenation technology and large energy consumption
Solid hydrogen storage	low pressure, good safety and wide application scenarios	low mass density, high manufacturing cost, low hydrogen absorption and desorption efficiency
Hydrogen based compound hydrogen storage	safe, convenient, high hydrogen storage density	in the development stage

So far, there is no perfect hydrogen storage and transportation technology, which is the biggest obstacle to the development of the hydrogen energy industry and requires revolutionary breakthroughs

3.4 Hydrogen energy storage and transportation

- Transportation

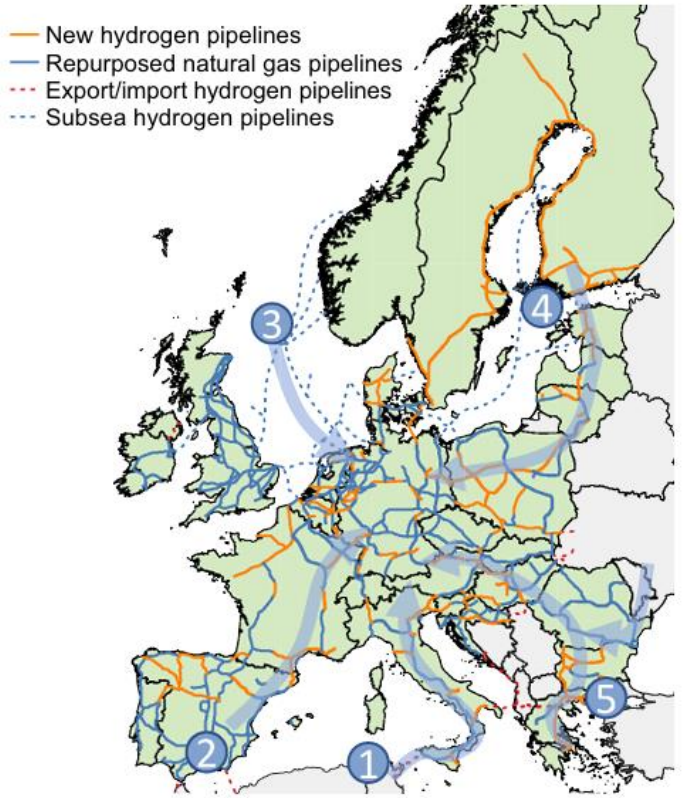
✓ High-pressure long tube trailer: most mature

✓ Low temperature liquid hydrogen transportation mode: large volume, energy consumption and loss, only used in military and aerospace fields

✓ Pipeline hydrogen transmission mode: high cost, with bright future

✓ Transportation mode of natural gas mixed with hydrogen: use the existing natural gas pipeline

✓ Hydrogen transport by hydrogen based compounds: large hydrogen transport capacity, mature technology and high safety

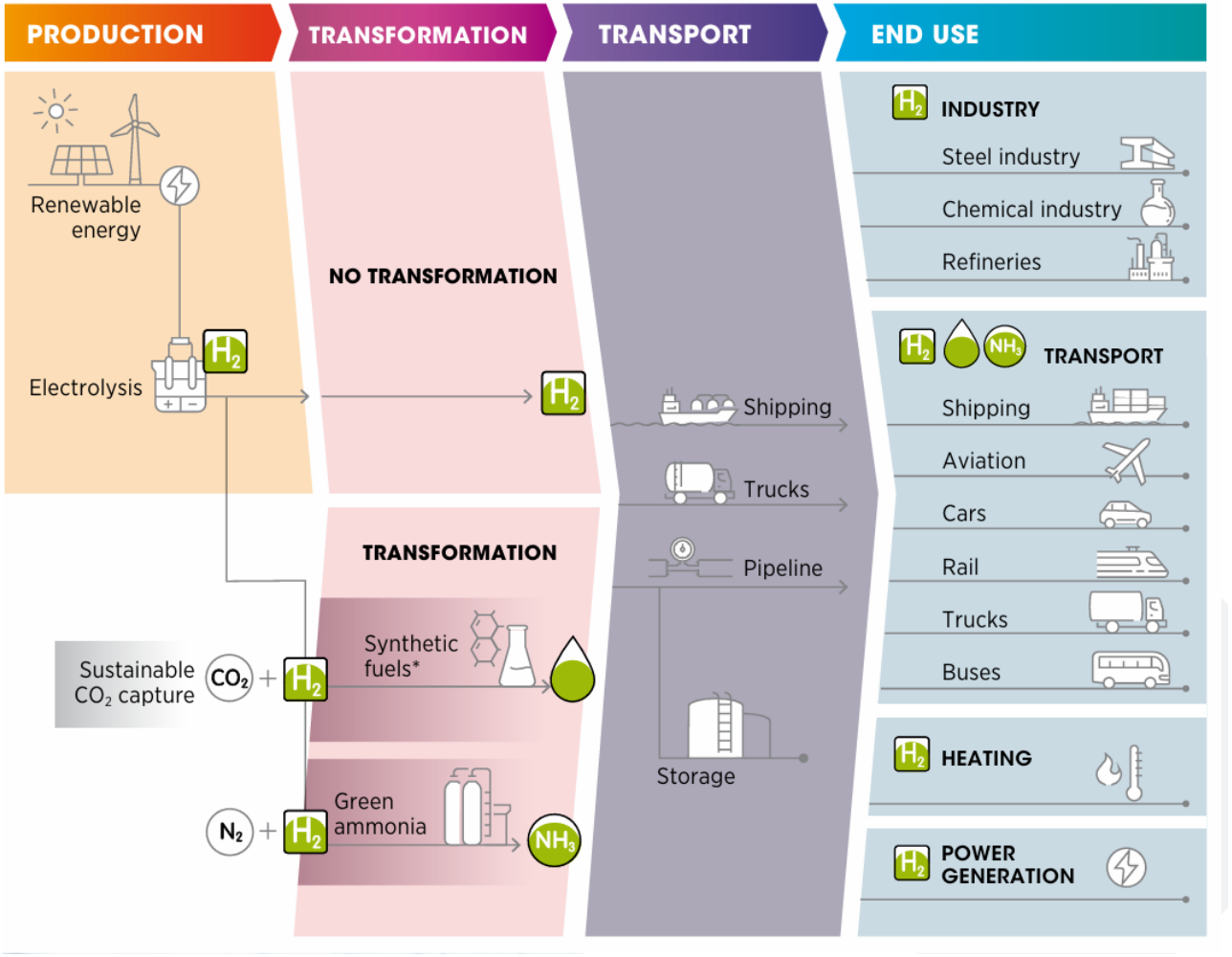


Scheme 2. Prospective hydrogen transmission pipeline network by 2040 and the five import corridors to central Europe as proposed by the European Hydrogen Backbone initiative [12,20,21].

Source: The environmental impact of renewable hydrogen supply chains: Local vs. remote production and long-distance hydrogen transport

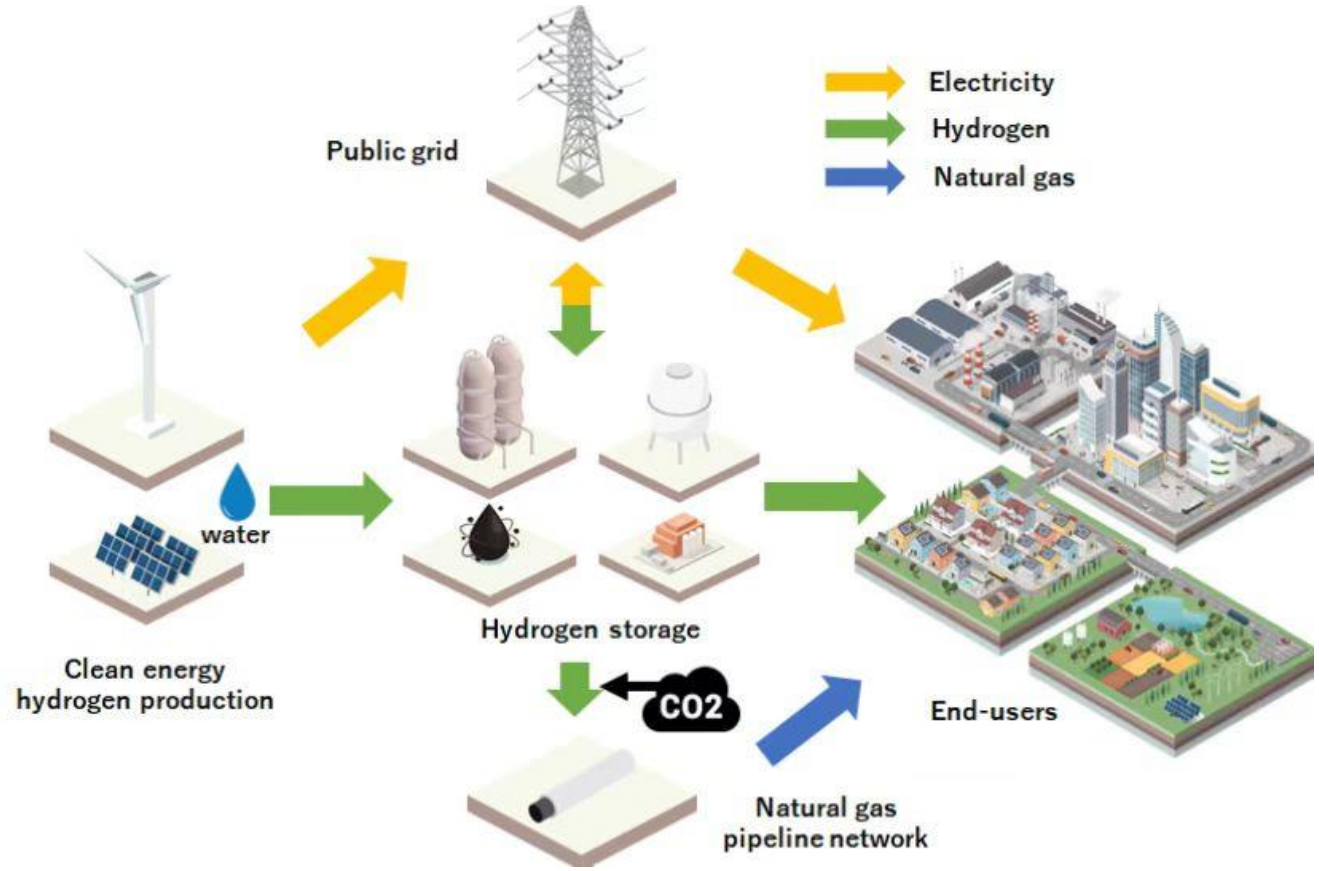
3.5 Hydrogen energy application

can be used in petroleum refining, coal chemical industry, metallurgy, industrial heating and other industrial fields, transportation, civil construction, electric power and other living fields such as agriculture and medicine



4. Hydrogen energy storage is a bridge and security guard for ensure energy transition

4.1 Hydrogen energy storage concept and technical process



Hydrogen energy storage can not only store electricity, but also hydrogen and hydrogen based compounds (such as synthetic ammonia, green methanol, green natural gas, etc.). Traditional hydrogen energy storage is based on the conversion process of "electricity to gas (P2G)"

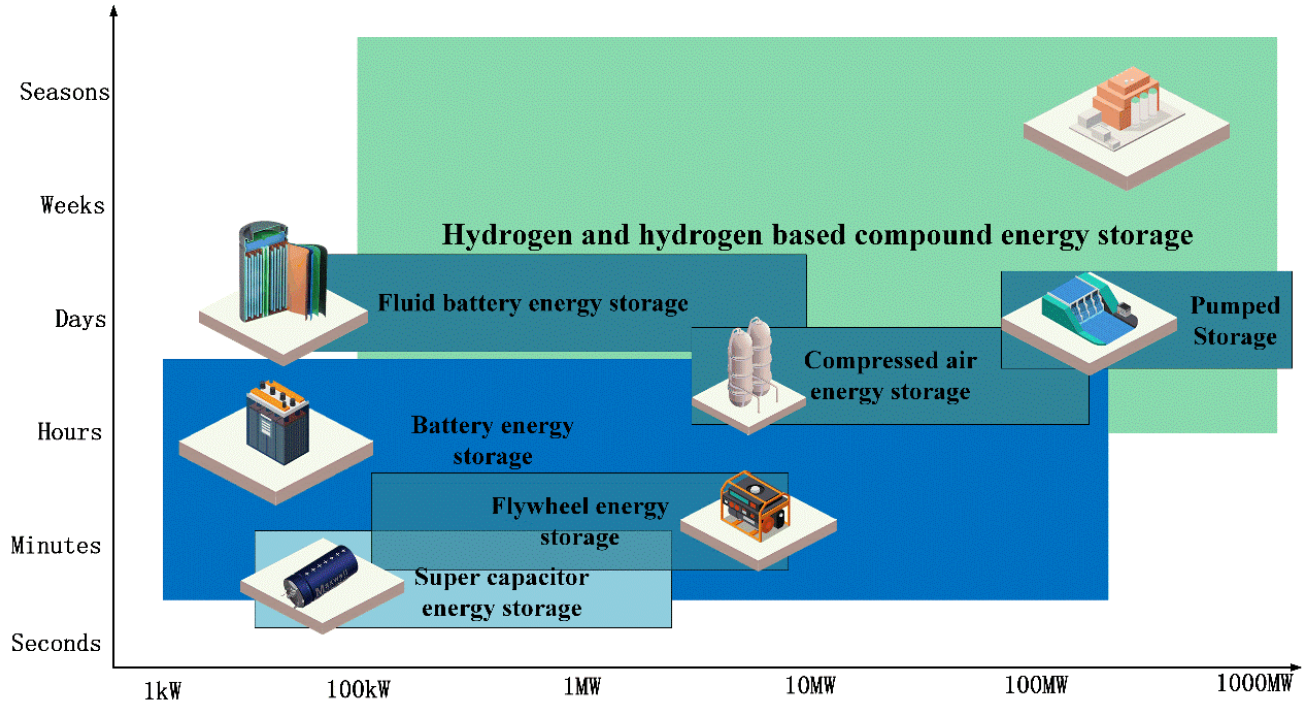
4.2 Hydrogen energy storage is a bridge for ensure energy transition

The characteristics of hydrogen, which has diverse sources and is not limited by geographical conditions, make hydrogen energy storage just play the role of bridge and link in this process, and promote the smooth transition of energy structure from fossil energy to renewable energy, so as to achieve the multiple objectives of ensuring energy security, promoting energy transformation and sustainable development.

4.3 Hydrogen energy storage is the way to realize long-term large-scale effective energy storage

✓ **energy storage time**, hydrogen energy storage can achieve a time span from hour (gaseous hydrogen storage) to quarter (solid hydrogen storage).

✓ **energy storage scale**, it can achieve a capacity storage of 100 million kilowatt hours, which is far greater than large-scale energy storage technologies such as commercial pumped storage and compressed air.



4.4 Bottleneck of Hydrogen Energy Storage

- ✓ Immature technology: The existing large-scale hydrogen storage technology is immature and in the early stage of theoretical research, experiment and industrialization, which hinders the promotion and application of hydrogen storage technology.
- ✓ The efficiency of hydrogen energy storage system is relatively low
- ✓ High cost of hydrogen energy storage: The investment power cost of pumped storage and compressed air energy storage is about 7,000 yuan/kW, the cost of electrochemical energy storage is about 2,000 yuan/kW, and the cost of hydrogen energy storage system is about 13,000 yuan/kW

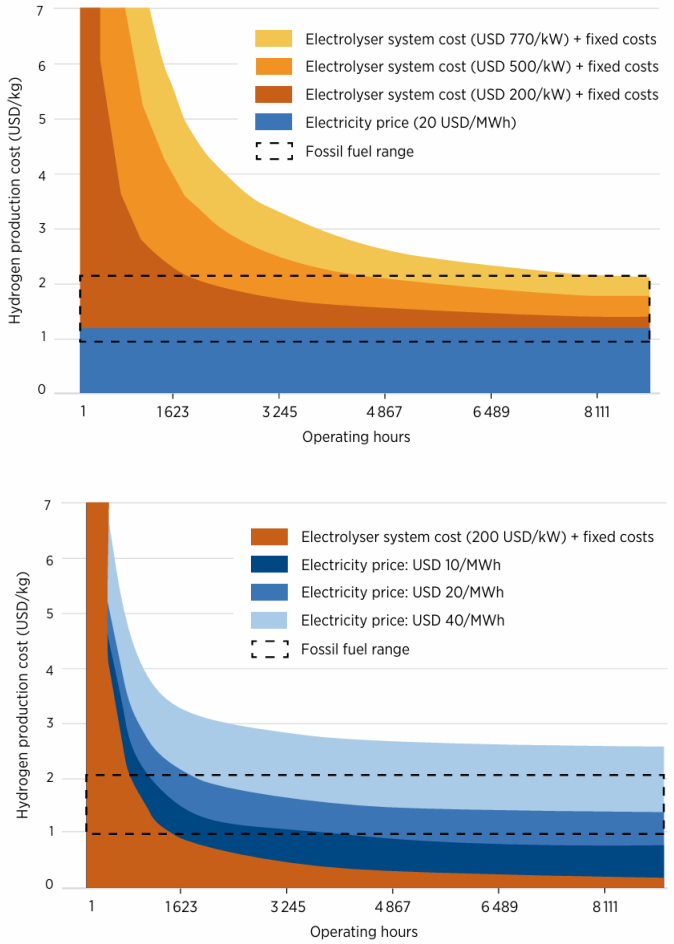


FIGURE 1.3 Hydrogen production cost depending on electrolyser system cost, electricity price and operating hours

Source: IRENA_Green_hydrogen_policy_2020.pdf

5. The future image of hydrogen supply chain

5.1 Hydrogen provides a new way for the development of renewable energy

- ✓ **Nowadays, people have an understanding of the strategic value of the hydrogen energy industry, but the development of commercial value has not yet been completed. The future commercial development of the hydrogen energy industry chain is the main direction.**
- ✓ The development of hydrogen energy storage technology plays an important role in promoting the high proportion of renewable energy consumption and ensuring the real-time balance of power and electricity.
- ✓ The development of hydrogen energy storage technology provides a new way for the consumption of renewable energy, making renewable energy not only a way to generate electricity, but also another way to produce hydrogen, which has important practical significance for promoting the development of renewable energy.

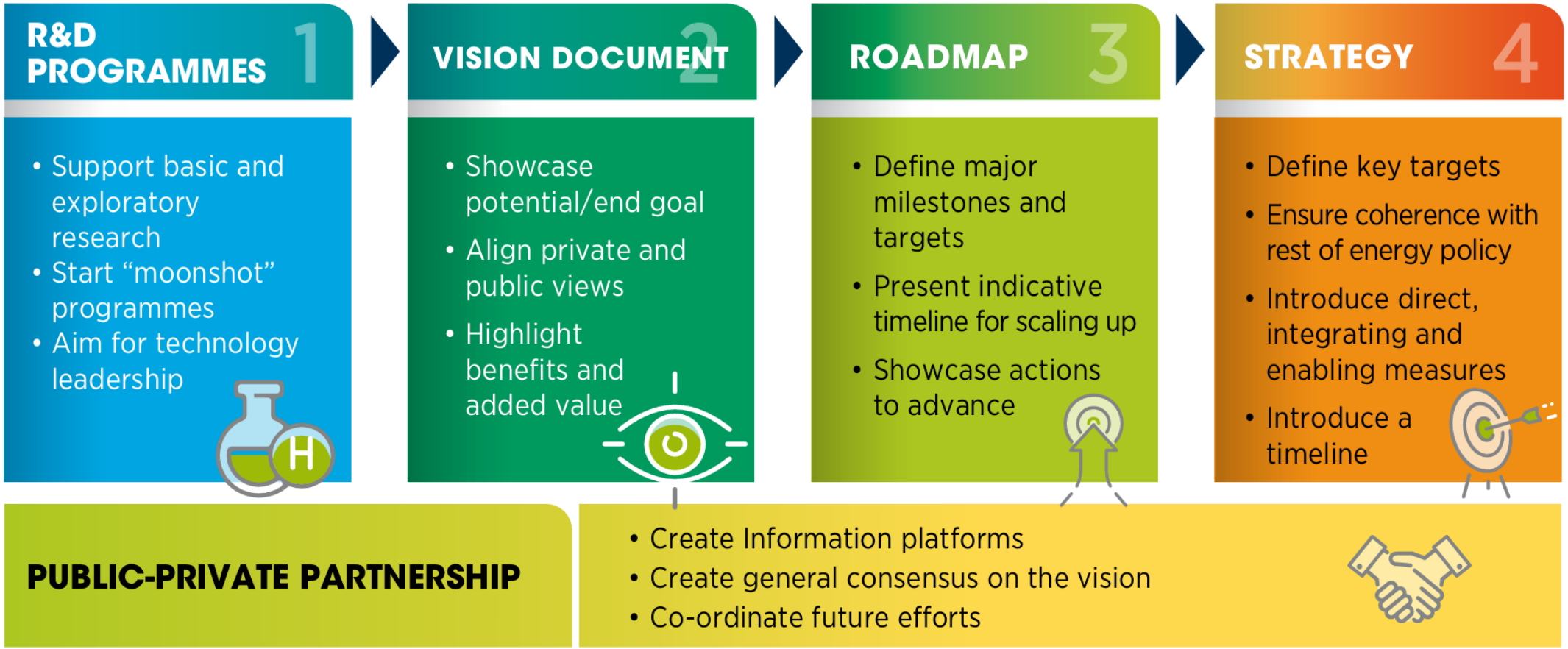
5.2 Hydrogen based compounds based on green hydrogen can be developed to provide clean industrial raw materials and intermediate products

Traditional hydrogen based compounds can produce a large amount of CO2 emissions. However, green hydrogen based compounds can be generated by combining carbon, avoiding a large amount of CO2 emissions during the preparation process. While realizing the role of energy storage, it also provides clean raw materials and intermediate products for the development of related industries.

5.3 Hydrogen and electricity synergy to promote carbon neutralization

In the future, hydrogen and electricity will play an important role in the decarbonization process of the terminal energy system, but hydrogen will play a unique role in areas where electricity cannot work. For example, green hydrogen will gradually replace gray hydrogen in petroleum refining, coal chemical and steel industries. In many other traditional energy-intensive industries, hydrogen energy will also replace fossil energy as an energy carrier for energy supply. At the same time, more hydrogen energy application scenarios will be gradually developed.

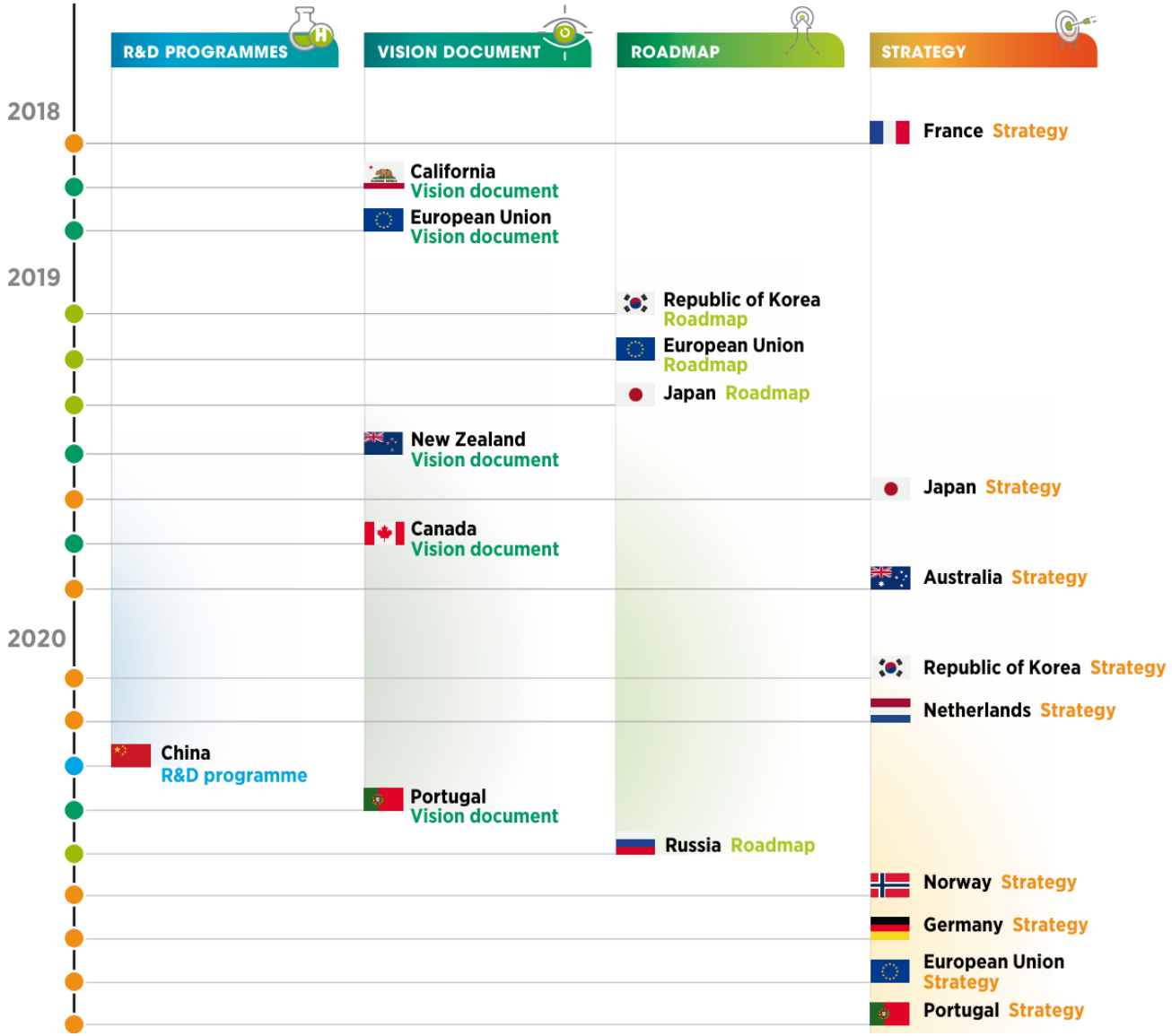
5.4 The future of hydrogen



The development of the hydrogen energy industry must adhere to market orientation, first determine the application scenarios, and then build the industrial chain, and cannot exceed the development stages of various regions.

Source: IRENA_Green_hydrogen_policy_2020.pdf

Government hydrogen-related initiatives announced between June 2018 and November 2020



- New Zealand published its vision document in 2019, which outlined the potential uses of hydrogen and explored in a non-quantitative manner some of the issues around its use
- France first published a hydrogen strategy in 2018, which was updated in June 2020
- The European Union established a High-Level Working Group on hydrogen in 2002 (with 19 stakeholders from the research community, industry, public authorities and end users), issuing its vision document one year later (European Commission, 2003).

Source: IRENA_Green_hydrogen_policy_2020.pdf

6. Conclusion and policy implication

Accelerating the development of hydrogen energy industry and building a complete supply chain of hydrogen energy industry are strategic choices to achieve the goal of "carbon peaking and carbon neutralization" and ensure national energy security. Hydrogen energy storage has the advantages of trans seasonal, trans regional and large-scale storage. It also has a certain rapid response capability, and can form an energy supply system of "hydrogen electricity coupling" with the power grid. It has strong application value. At the same time, hydrogen energy storage is a feasible option to achieve large-scale and long-term energy storage. The development of hydrogen energy storage will help to build a complete hydrogen energy supply chain, promote the adjustment of energy structure, and thus build a safe, efficient Clean energy system provides support.