



TECHNOLOGY DEVELOPMENT FOUNDATION OF TÜRKİYE



PIONEER PROJECT INVESTMENT PROGRAM CLEAN HYDROGEN TECHNOLOGIES

DEEP DIVE STUDY - SUMMARY REPORT

May 2023



TTGV
CLIMATE
PIONEER
Projects Program





Introduction

Climate Technologies refer to technologies that serve to slow down or prevent climate change, increase adaptation and/or resilience to its impacts, or support the management of its consequences. As TTGV, it is aimed to contribute to the adaptation of climate technologies to our country, which is our primary focus in the period covering the years 2023-2028, through the Trailblazer Project Investment Program.

One of the topics that we focus on in 2023 for the development of Trailblazer Projects was determined as **“Clean Hydrogen Technologies.”** A Deep Dive study was conducted between January and May 2023 in order to understand this comprehensive area, analyze the current situation, and develop potential project scenarios. In this study, a large number of organizations and experts from Turkey and abroad were contacted and exchanged information, and in addition to that, both related technologies and legislation were examined.

In the Deep Dive Study, an attempt was made to look at the entire hydrogen technologies from a broad perspective and to demonstrate a “Value Chain” approach from the production to the consumption of hydrogen. A summary of the findings and evaluations of this study are given below.

Why Hydrogen?

1. It is considered that green/clean hydrogen, especially in the medium and long term, will play a significant role in the comprehensive transformation required to achieve decarbonization and net-zero goals in the energy portfolios of countries. Despite the fact that decarbonization is the most prominent goal, it is not the sole reason for the development of the hydrogen economy. This is because the Ukraine-Russia War that began in February 2022 and the subsequent developments have once again highlighted the importance of energy independence strategically.
2. High investments are being made and significant incentive systems are being created in clean hydrogen technologies as **a carbon-free local alternative to fuels imported from foreign countries**, particularly Europe, China, and the United States. In addition to these two reasons (decarbonization and energy independence), which are also valid for our country, various options, including hydrogen, must be considered economically due to the fact that the most significant item contributing to our country's trade deficit is energy imports. Finally, like any high-tech field, hydrogen technologies should be considered as a tool for development with the potential to create new sectors and branches of industry.
3. Considering all these factors together, hydrogen technologies, along with climate technologies such as energy production from renewable sources, energy storage, carbon capture, etc., are important technological components for meeting the requirements of **decarbonization, energy independence, economic development, and growth**.

Hydrogen Economy and Technologies

4. "Hydrogen" is a field that requires a comprehensive evaluation with different production and usage areas.
5. Currently, the most prominent topic on the agenda is **energy generation** from hydrogen. There are several methods for utilizing hydrogen for energy generation. These include burning without leaving any residue, converting to electricity and thermal power with fuel cells, or transforming it into ammonia, methanol, synthetic

methane, or other synthetic fuels. The significant advantage of using hydrogen for electricity generation is that the only byproduct is water.

6. Besides energy generation, the use of hydrogen as **a molecule in raw material/** chemical processes is widespread, especially in sectors such as oil refinery. Currently, the majority of hydrogen used as a molecule is produced by carbon-emitting processes and is known as gray/brown hydrogen. It is crucial that the hydrogen used in these sectors comes from green hydrogen obtained through methods like water electrolysis rather than hydrocarbon-based fossil sources.
7. Hydrogen also holds promise as a **chemical energy carrier and storage system** to reduce the environmental impacts of the energy value chain. One of the biggest problems with renewable energy sources is their intermittent nature. The fact that energy generation sometimes exceeds demand while at other times it cannot meet the demand requires the storage of generated energy for later use. While various alternatives for long-term energy storage (such as electrochemical/battery technologies) are being evaluated today, using hydrogen to store energy over a long period (e.g., seasonal) without generating emissions or pollution is seen as one of these alternatives.
8. In 2021, approximately 94 million tons of hydrogen were consumed as a raw material in various sectors worldwide, and the majority of this was produced without preventing greenhouse gas emissions from fossil fuels (%62 gray and %19 brown production) [1]. The future is expected to be significantly different. First of all, the quantity of production/consumption will increase exponentially along with the use of hydrogen in the energy sector. Hydrogen production is expected to exceed 500 million tons per year by 2050. [1]. It is anticipated that the share of hydrogen and hydrogen-based fuels in total final consumption will reach approximately 10% by 2050 [2]. In addition to this level of production, high-value technologies for the clean production, storage, transportation, and application of clean hydrogen must be developed and disseminated globally in order to achieve clean/green hydrogen and reduce carbon emissions.
9. Figure-1 summarizes the potential usage areas of hydrogen on the basis of various sectors.

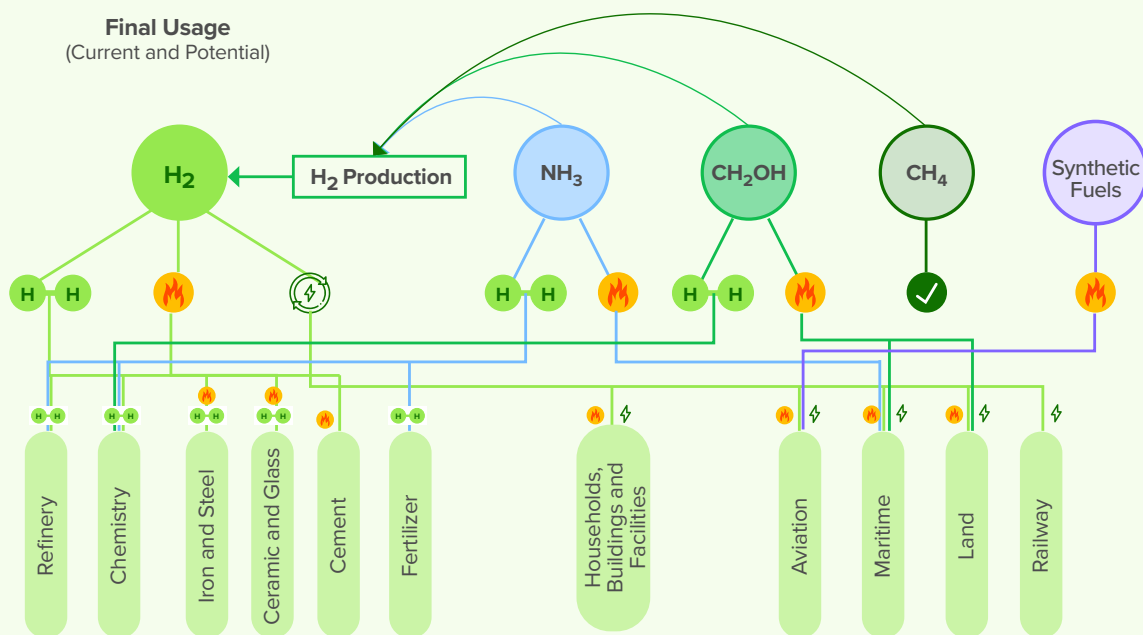


Figure 1: Potential Usage Areas of Hydrogen

10. As depicted in the figure, not only hydrogen but also its derivatives such as ammonia, methanol, synthetic methane, and other synthetic fuels have the potential to be used as both an electricity source and a thermal energy source, as well as a molecule.
11. Hydrogen has the potential to be used as an alternative or substitute heat source to fossil fuels in emission-intensive industries such as iron and steel, aluminum, cement, ceramics and glass. It can serve as an input to chemical reaction processes as well as a heat source in oil refinery and chemical industries. Additionally, it has applications in almost every aspect of the mobility sector, either by burning hydrogen or by feeding it into fuel cells to generate electricity. Besides being a heat source and a key input in the fertilizer sector, ammonia is also considered a potential fuel in maritime transport. Methanol, used in petrochemistry, is seen as a potential alternative fuel in maritime transport. Natural Gas (synthetic) is used in both industry and mobility, and synthetic fuels (diesel, kerosene, etc.) are employed

for transportation on both land and air. These indicators showcase the extensive potential of hydrogen and its derivatives in various applications.

12. Hydrogen technologies, due to the different technologies each encompasses, are examined under four main headings: **production, transportation, storage, and final usage**. It is still a field with a high level of R&D intensity. Despite the fact that the initial focus has been on increasing production capacity and related technologies, challenges related to green hydrogen go beyond production alone.
13. The green/clean hydrogen economy is an investment-intensive area. The Hydrogen Economy is outlined in Figure-2 below.

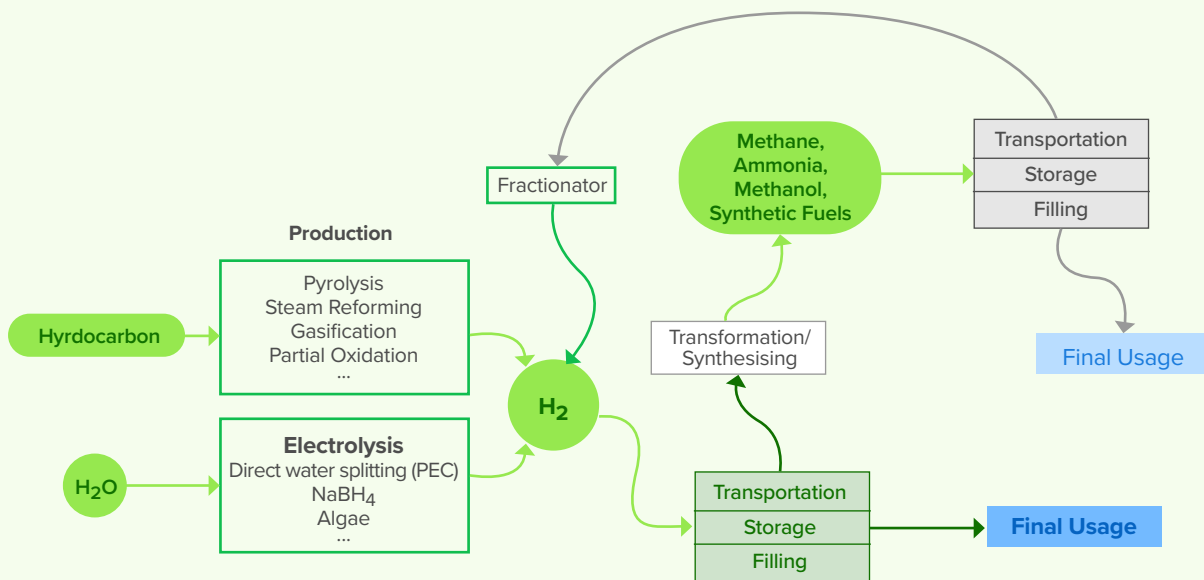


Figure 2: Hydrogen Economy Outlined

14. In hydrogen **production**, there are both ‘polluting’ methods that utilize hydrocarbons as raw materials (such as pyrolysis, steam reforming, gasification, partial oxidation, plasma reforming, etc.) and methods that utilize water as a raw material through electrolysis (alkaline, PEM, anion exchange, and solid oxide). Additionally, hydrogen can be obtained through various methods, including biological processes or direct water splitting (PEC). The **choice of production method** takes into consideration

the application area (and thus the purity and quality requirements of hydrogen), the accessibility of the raw material to be used, economic evaluations (investment cost, operating cost, incentives, and supports, etc.), and sustainability requirements, especially carbon emissions. Currently, electrolysis is the prominent technology for green hydrogen production.

15. In hydrogen **transportation**, on the other hand, the prominent approaches include transporting hydrogen by mixing it with natural gas in existing pipelines, transporting it in tanks as pressurized gas or condensed liquid, and transporting it in tanks by converting it into ammonia or methanol. For **storage**, options are available in pressurized containers, underground, in tanks by liquefaction, by binding to metal hydrides or metal amines. Storage by converting to ammonia and methanol is also an option. The safe and cost-effective transportation and storage of hydrogen are among the primary issues that need to be addressed.

Challenges and What Needs to Be Done?

16. Despite the increasing global interest in hydrogen technologies, ambitious goals set by countries, and significant efforts, it will not be easy or cheap to achieve the set targets and transition to a hydrogen economy, as changing an important component of the energy system will have an impact on the entire energy system.
17. On a global scale, numerous new technologies for hydrogen are being developed and tested, and bold promises are made regarding their outcomes. While various technologies may have a place in meeting different needs, it is currently unclear which technologies will stand out among the alternatives.
18. Currently, there are several bottlenecks, especially in the case of green hydrogen. The first is related to the increase in **production capacity** (especially for high-purity hydrogen). As of now, there is a high demand for electrolyzers, particularly from developed countries, far exceeding what can be supplied. Electrolyzer suppliers are not currently dealing with demands outside very large capacities, and even for substantial orders, delivery dates are given several years into the future.
19. The second bottleneck is the necessity for **market formation** for a healthy hydrogen ecosystem. Long-term off-take agreements are considered necessary before investment in hydrogen and its derivatives production. The increase in hydrogen

users and the establishment and support of organized markets (such as the EU's Hydrogen Bank, U.S. IRA subsidies) are essential to realize the benefits of hydrogen. As a significant note, the European Commission has announced that it will need a total of 20 million tons of hydrogen by 2030, producing 10 million tons from renewable sources and importing the other 10 million tons.

20. Thirdly, as production capacity increases, hydrogen becomes a **logistical** challenge and even a logistic **problem**. The transportation and storage of hydrogen cannot be said to be “fully” solved in a technological sense (safely and cost-effectively). Hydrogen logistics involve the construction of a series of large-scale infrastructures that do not currently exist, and this entails financing these investments. In addition to investing in transportation and storage technologies to solve the logistics problem, options such as producing hydrogen and its derivatives where they will be consumed or transporting them to locations where green hydrogen can be produced inexpensively (de-industrialization) are also being considered.
21. Fourth and finally, despite the incentives and subsidies currently in place, the production, storage, transportation, conversion, and utilization of green hydrogen are **expensive for now**. Globally, achieving a major breakthrough where the cost of green hydrogen falls below **\$2** per kg is considered a significant game-changer. Apart from investment costs, the cost of green hydrogen production with electrolyzers is heavily dependent on the price/cost of electricity obtained from renewable sources.
22. Nevertheless, postponing investments by only considering current or short-term prices may delay the formation of the ecosystem. As technologies advance, the number of suppliers increases, incentives/supports become clearer, and financial resources are directed toward this field, both investment and operating costs are expected to gradually decrease.
23. Alongside the development of technologies, investments should also be made in the formation of the ecosystem/value chain; the development of regulations, legislation, and **standards** (internationally and nationally); the regulation of **incentives**, supports, and subsidies; the formation of innovative **business models** and **markets**, and the cultivation of human resources. The effects of these investments are expected to be much clearer and comprehensive in the 2030s.

Studies in Our Country and Prominent Application Areas

24. From our country's perspective, hydrogen is anticipated to play a significant role in our carbon-free future. When combined with the facts that the European Union will impose additional taxes on products produced with high emissions under the Carbon Border Adjustment Mechanism (CBAM) starting in 2026 and that 40.6% of Turkey's total exports were to EU countries in 2022 [3], the importance of hydrogen technologies for our country becomes evident. For example, according to the analysis of the Shura Energy Transition Center, in order to achieve its net-zero goals by 2053, Turkey will need hydrogen in its energy mix at a rate of 15%. [4]. According to the Hydrogen Strategy of the Ministry of Energy and Natural Resources, it is predicted that the installed electrolyzer capacity in our country will reach 2 GW in 2030 and 70 GW in 2053. The cost of hydrogen is expected to decrease to \$2.4/kg in 2035 and below \$1.2/kg in 2053 [5].
25. Currently, various experiments related to supplying electrolyzers and hydrogen production/usage are being conducted in our industry, activities are carried out to participate in hydrogen valleys, and R&D studies on hydrogen-powered vehicles (trucks/buses/marine vehicles, etc.) are ongoing. Both public and private sector stakeholders are involved in R&D and initiatives for electrolyzers, fuel cells, storage systems, components for electrolyzers and fuel cells, and non-electrolyzer clean hydrogen technologies, thanks to incentives from public institutions such as TENMAK (Turkish Energy, Nuclear and Mineral Research Agency) and TÜBİTAK (Scientific and Technological Research Council of Turkey), as well as various R&D funds. In addition to these, numerous academic research studies have been/will be conducted. While progress has been made in these studies, it is considered that achieving production capacity on a megawatt scale may take between 5-10 years for different technologies.
26. Turkey has a significant potential for green hydrogen production, thanks to both its high renewable energy potential and lower installation costs for renewable energy sources compared to Europe. Therefore, it is anticipated that our country can be a strong player in the global hydrogen market. Taking into consideration Turkey's renewable energy potential, the country may meet its own green/clean hydrogen

needs and, at the same time, may have the potential to export both hydrogen and its derivatives and the associated technologies.

27. As a critical point, merely adopting technology, establishing facilities, producing hydrogen to meet demand, or engaging in trade will not be sufficient. It is evident that the real added value lies in the development and commercialization (and internationalization) of technologies related to hydrogen and the creation of hydrogen ecosystems and value chains.
28. In our country, beyond individual efforts for the development and commercialization of hydrogen technologies, the focus should also be on the formation, development, and sustainability of value chains and ecosystems. For this purpose, plans and roadmaps should be created, and R&D, technology, and product development activities should be supported within a roadmap framework. Markets should be created, regulations, standards, and certification/accreditation systems should be developed to align with international frameworks. Incentives, support, and sanctions should be clarified, and perhaps most importantly, the training and retention of qualified human resources that are needed/ will be needed should be ensured.
29. Turkey's annual hydrogen consumption, which is 400,000 tons, is produced and consumed as gray hydrogen, with 250,000 tons generated by the oil refinery sector [6]. The oil refinery and chemical sectors will be among the significant stakeholders in the green hydrogen ecosystem. Considering that Turkey is the world's eighth-largest iron-steel producer and Europe's largest cement producer [7], hydrogen technologies hold great potential for in emission reduction in these industries. Additionally, given the absence of commercial production of methanol and ammonia in our country, the production of these chemicals as part of hydrogen technologies has the potential to create opportunities for various sectors, including fertilizer and petrochemicals.
30. Within the scope of an deep dive study, various industries in our country (iron-steel, oil refinery, cement, fertilizer, glass-ceramic, transportation/mobility – maritime, aviation, land) have been examined in terms of their primary motivations, visions, supply bottlenecks, and levels of preparation regarding hydrogen. Potential project scenarios involving different value chains have been designed for industries with relatively higher awareness and preparedness.

31. The first of these scenarios is the **“Decarbonization with the Integration of Green Hydrogen Technologies at Ports”** project, which is thought to find faster response compared to other sectors because of regulations and requirements initiated for decarbonization in the maritime sector. This project focuses on creating an exemplary hydrogen port that reduces emissions in the maritime sector and supports green hydrogen exports in the Mediterranean basin by leveraging our country’s position on trade routes. In the second scenario, with the perspective of supporting alternative methods that will facilitate access to clean hydrogen in our country, where access to green hydrogen is difficult because of the bottleneck in the supply of electrolyzers, the **“Hydrogen Production Facility by Processing Agricultural Urban and Industrial Wastes”** project aims to produce clean hydrogen from different types of wastes by different methods such as pyrolysis and biological hydrogen production methods.
32. These project options are not limited to these. The existence of previously mentioned bottlenecks related to hydrogen and the developing awareness and motivation towards hydrogen in our country’s industries suggest the potential for other project scenarios to mature over time. While steps have been taken by the **oil refinery** sector in this direction, **mobility** (especially land transportation), **cement**, **glass**, and **ceramic** sectors are particularly prominent. In line with this, project development activities are being carried out in collaboration with the emerging ecosystem to enable a possible demonstration project.

Along with energy generation from renewable sources, hydrogen technologies (along with energy storage, carbon capture, electrification, etc.) will play a critical role in the comprehensive transformation needed to achieve net zero targets. For this purpose, while the world continues to make significant investments in technologies related to hydrogen and its derivatives, efforts are also ongoing in areas such as workforce development, market development, ecosystem creation, etc. It is anticipated that hydrogen technologies will make a significant contribution to decarbonization, energy independence, and economic development and growth for our country.



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