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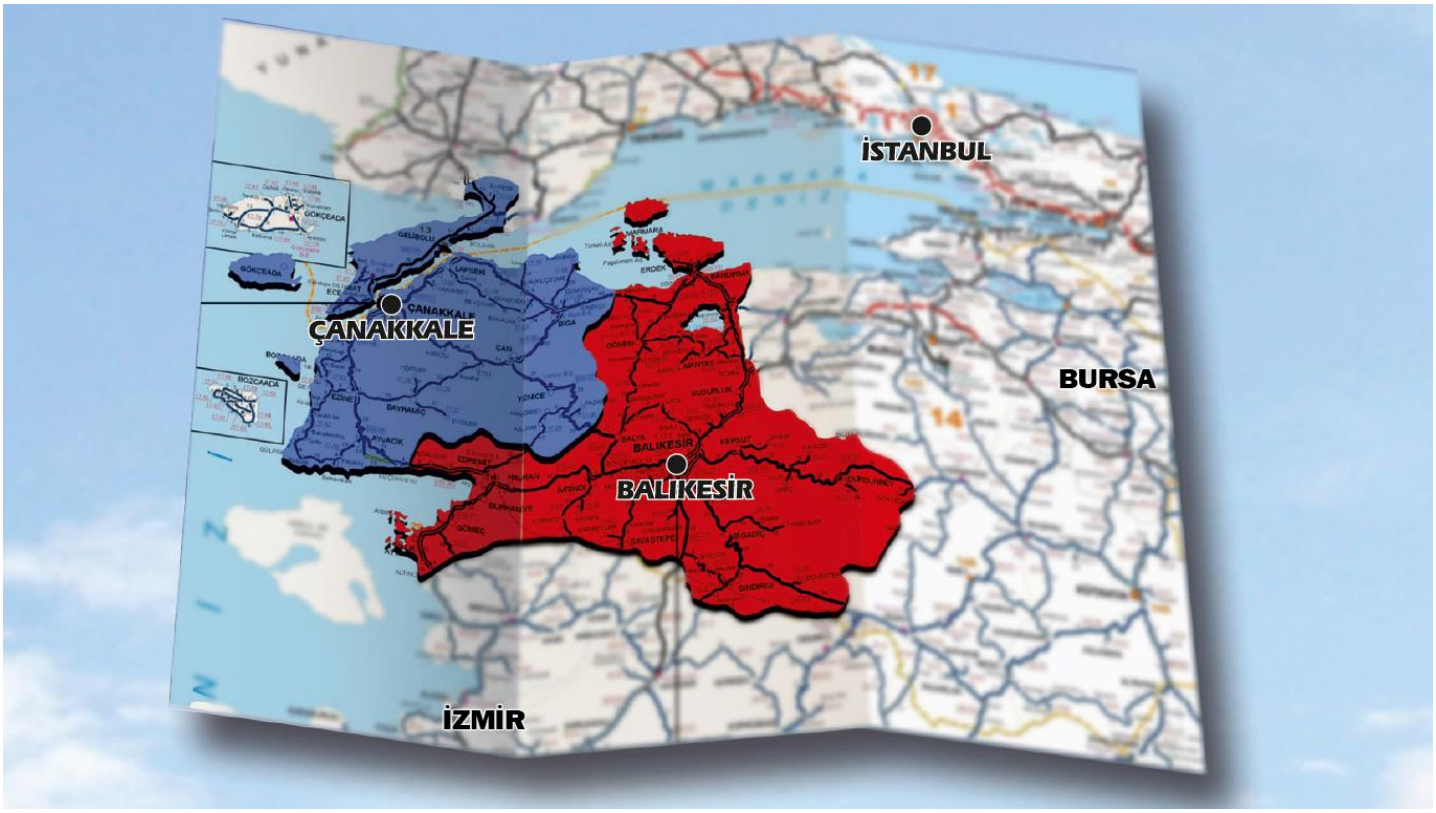

Green Hydrogen Valleys: South Marmara Hydrogen Shore A Model for Türkiye in Hydrogen Economy

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According to a new study by the FCH JU, "**Hydrogen Roadmap Europe: A sustainable pathway for the European Energy Transition**", hydrogen is an essential element in the energy transition and can account for 24% of final energy demand and 5.4m jobs by 2050. At scale decarbonisation of key segments such as the gas grid, transport, industrial processes that use high-grade heat and hydrogen as chemical feedstock require the use of hydrogen in large quantities. Türkiye hasn't released its green hydrogen strategy document yet. But TENMAK which is affliated to the Ministry of Energy and Natural Resources, is expected to release Türkiye's first hydrogen roadmap titled "Hydrogen Technologies Roadmap and Action Plan" at the end of 2022. Most of the developed countries has released their strategy documents on green hydrogen. The fact that Türkiye has not created a clear vision and set its goals for green hydrogen up to now is a serious shortcoming. But South Marmara Region may serve as a model for Türkiye thanks to its advantages that can't be found easily in other regions of the country.

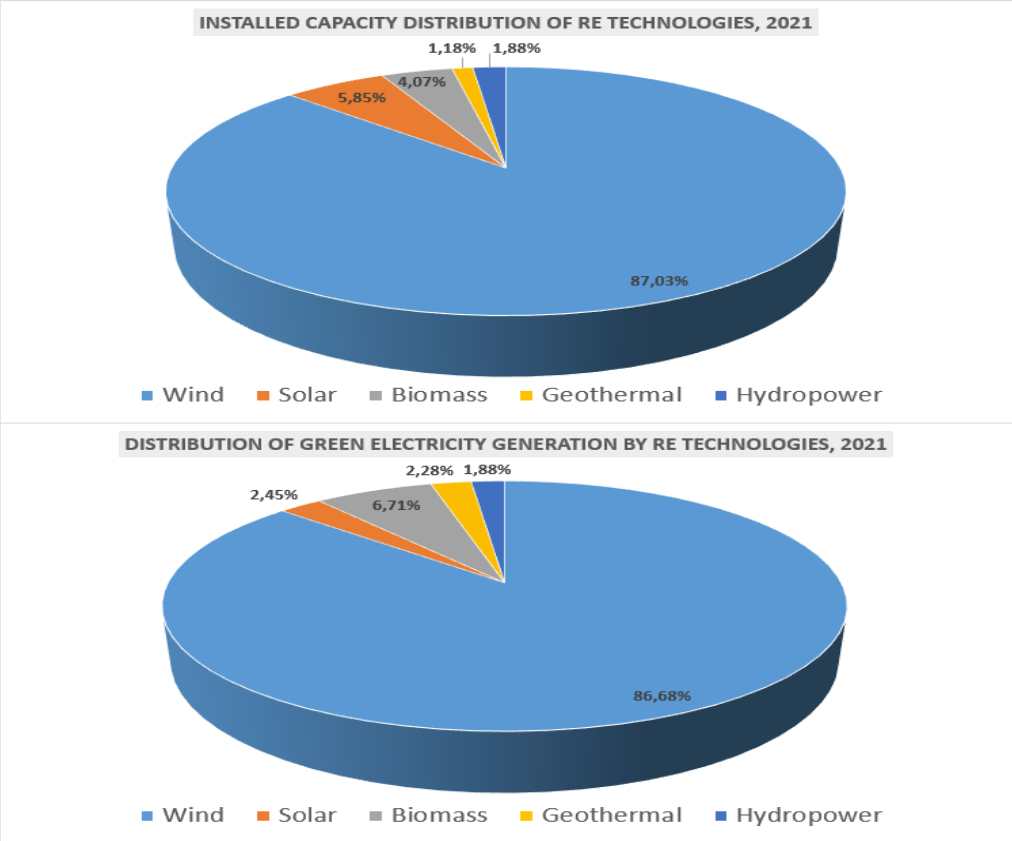

Chart 1. Renewable Energy Data of South Marmara Region, 2021

South Marmara Region has one of the most developed energy infrastructures when it is compared with other NUTS2 Regions. All the power plants located in the region generated 42.500 GWh electricity which covers approximately 13 % of the total electricity generation in the country. When it comes to green energy, South Marmara is the leading region in green electricity generation through modern renewable technologies in Türkiye. Although it covers only 3 % of Türkiye's total land area, the electricity generation capacity of South Marmara in renewables is pushing the 3 GW limit. In 2021, renewable power plants in the region generated around 8200 GWh of electricity. Most of this generation came from wind energy. Installed wind capacity accounts for 87 % of all the renewable capacity in South Marmara which is also Türkiye's leading region in installed wind capacity with a share of 21 %. All the WPP's are onshore type but also a new phase is coming for the region: offshore wind energy. Some of the near shore and offshore zones of South Marmara Region has the highest potential in wind enery compared to other regions. Türkiye will probably install its first offshore wind farms in the zones which border with South Marmara Region.

Figure 1. Off-shore Wind Zones in South Marmara

By the end of 2021, electricity generation from renewables is 1.8 times higher than the consumption of all sectors in the region. The renewable energy potential of the region is the most critical instrument for the green transition of industry. Regarding hydrogen economy in the region, there are large-scale facilities which are currently using significant amount of grey hydrogen and its derivatives in their processes. Those companies are mostly operating in chemical industry. Besides that there are also other critical sectors in the region which will face obligations brought by EU Green Deal in terms of GHG emmissions such as; steel production, cement production, energy generation. The most logical response of the companies to EU's CBAM is the green transition of their energy-intensive processes. So green hydrogen will play a critical role in this path.

Figure 2. Türkiye's Natural Gas Grid

South Marmara Region has a developed natural gas grid comparing to the other regions in Türkiye. As it is shown in Figure 2 all the largest Natural Gas (NG) pipelines coming from Russia, Iran and Azerbaijan are combined in South Marmara and pass through European countries by connecting to TAP pipeline. In the short term; the existing gas grids may be used to inject green hydrogen for domestic utilization by repurposing them. Repurposed gas grids will also provide oppurtunities in exporting green hydrogen to European countries. Regarding export of green hydrogen and its derivatives; the region has another critical advantage of having around 1000 km coastline. South Marmara borders with both Sea of Islands (Eagean Sea) and Marmara Sea. On this coastline there are many large industrial plants with their port facilities which have the capacity to store and ship green hydrogen derivatives such as green ammonia and green methanol. Also the facilities located on the coastline of South Marmara has large-scale desalination units which are very important for the sustainability of the water source to produce green hydrogen. As it is shown in figure 3, the south coastline of Marmara Sea between Biga and Bandırma where are the two districts of the region, is being planned as the Türkiye's first hydrogen production hub. Across 80 km-air distance on this coastline there are many energy-intensive industries and also there are users of hydrogen and its derivatives as a critical feedstock. So Türkiye's first hydrogen pipeline will most probably built across this 80 km distance. In the mid-term, existing NG pipelines may be used to inject green hydrogen by repurposing the grid.

Figure 3. Türkiye's First Hydrogen Production Hub

There are small-scale electrolysers operating in some of the plants in South Marmara; in fact they should be called e-hydrogen but most of the hydrogen is produced with the help of SMR process and it is called grey hydrogen. The first green hydrogen pilot production in Türkiye comprises 10 kW-electrolyser with a 20 m^3 buffer tank installed in Enerjisa Üretim's Bandırma Energy Base in 2022. Enerjisa Üretim is one of the leading private power companies in the country which ranks first in terms of installed renewable capacity among the private sector players. Moreover Türkiye's first indigenous green hydrogen pilot plant with a 30 kW capacity electrolyser will be installed and this project will be cofinanced by South Marmara Development Agency, Enerjisa Üretim and Eti Maden which are the three members of the South Marmara Hydrogen Shore Platform. These are important but small steps because there is not a single green hydrogen plant at industrial scale in Türkiye currently. Up to now companies haven't dared to invest in green hydrogen business because of the production costs. At the beginning of 2022 the cost of gray hydrogen production was nearly 2,3 EUR/kg for a 4000 Nm3/hour capacity SMR plant in Türkiye but now the cost of green hydrogen productions is almost the same as gray hydrogen production which is around 9 EUR/kg. This progress encourages the Turkish companies to transform gray hydrogen into green hydrogen in their processes. This is not the only motivation for our companies: European Green Deal and also export opportunities in green hydrogen business are the two other instruments that motivates private sector players. Maybe the last but not the least instrument will be so-called "hydrogen valleys" concept which represents a possible way to reach the short/medium green hydrogen goals. New hydrogen valley concept would be characterized by lower and decentralized production as well as reduced transportation costs, thus potentially representing a more attractive investment.

Türkiye's 5 important bodies will sign an MoU on 15 Febuary 2022 in İstanbul to pave the way towards "Carbon-Neutral South Marmara". To this end; under the leadership of the South Marmara Development Agency; EnerjiSA Üretim, Eti Maden, Tübitak-MAM and ASPİLSAN Energy will come together. This was the first step to create a hydrogen valley in the region. The name of the valley "South Marmara Hydrogen Shore" indicates that all the green hydrogen will be produced on the coastline of the region and distributed through repurposed NG pipelines at first then use new hydrogen pipelines for transport ultimately. And the offtake project of the valley will be a

minimum 4 MW capacity electrolyser. The system will be fed by a 18 MW solar power plant and a 3,5 MW hydro power plant in the production site of Enerjisa Üretim located in Bandırma. The outlet green hydrogen production will be minimum 500 tonnes/year and the whole product will be transferred via jumbo trailer trucks to 5 different location and four different energy-intensive sectors.

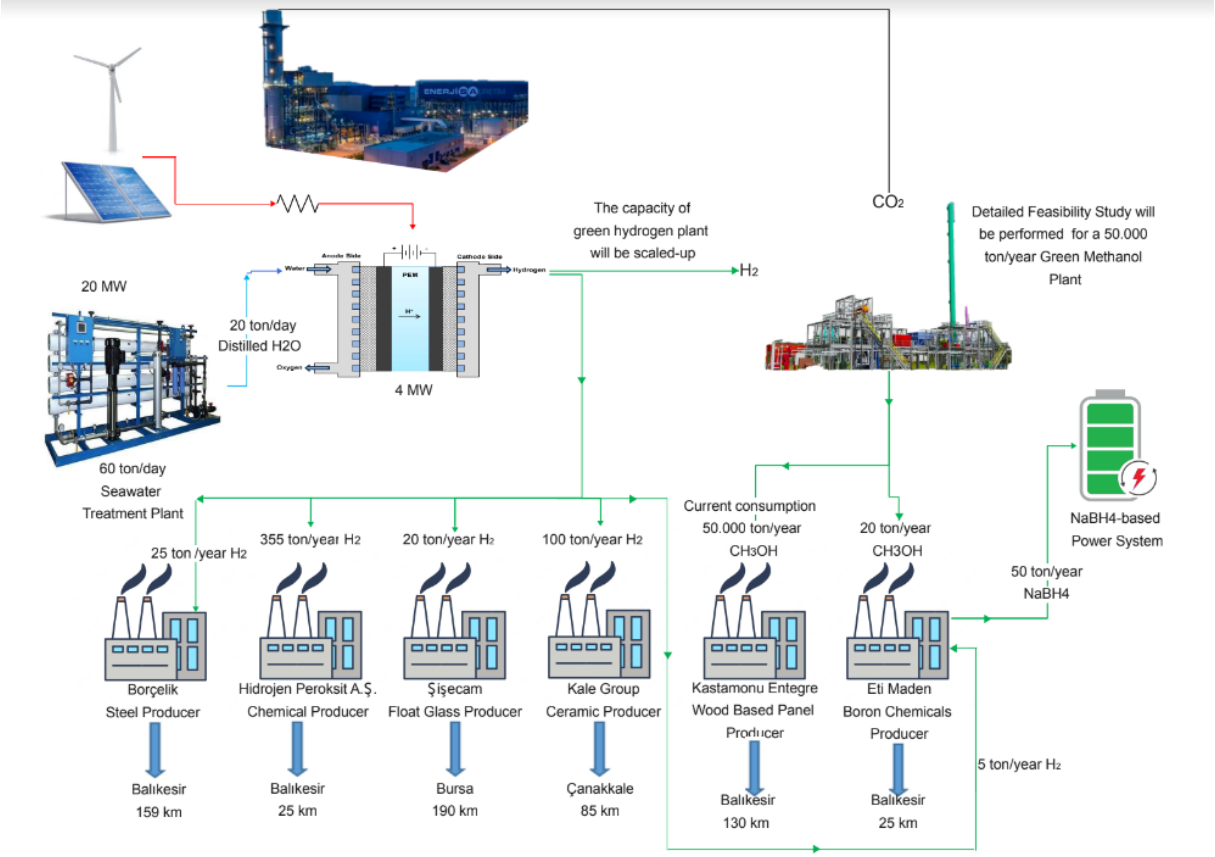

Figure 4. Project Flow Diagram

Companies from ceramic industry, glass industry, steel industry and chemical industry will be the end users. All the end users will start with a smooth transition at the beginning of the process. When the quantities of green hydrogen are compared with the total hydrogen needs of each facility; the results show that the scaling up of the project will happen in a short period of time. And the skyrocketing natural gas prices will probably catalyze the transition process. Şişecam, Borçelik and Hidrojen Peroksit are using grey hydrogen in their processes as a feedstock or reductive agent and respectively 17 %, 12,5 % and 8 % of all the hydrogen need will be met by green hydrogen in the project. But the real potential is lying under the consumption of natural gas. In that sense; the contribution of Kale Seramik to the project is very critical because in South Marmara most of the total consumed natural gas is using in industry. So green hydrogen will find a broader range of industrial applications regarding the green energy transition of the industry. Kale Seramik is one of the largest industrial consumers of natural gas in the region and the Çanakkale Plant consumed 158 million Sm^3 in 2021. The company will initiate its green transition by using 100 tonnes/year green hydrogen in a hybrid fast firing roller kiln. The roller kilns in Çanakkale Factories of Kale Seramik has 29 channels and the new roller kiln will be just one of them. The company is planning to increase green hydrogen consumption in ceramic production process incrementally. To meet the green hydrogen need of the industry, installed renewable energy and electrolyser capacity should be increased proportionally in the region. Green hydrogen produced from renewable sources, is essential on the path to a net-zero greenhouse gas emission future (Kakoulaki et al., 2021). To this end South Marmara Region will have 3 periodical targets in its Hydrogen Roadmap:

- **2023 – 2030** : Installation of additional 1 GW renewable energy capacity is aimed and electrolyzer capacity is expected to be scaled up to 300 MW to produce up to 50.000 tons of green hydrogen per year
- **2030 – 2040** : Installation of additional 1,2 GW renewable energy plus other carbon-free energy generation capacity is aimed and additional electrolyzer capacity is expected to be 500 MW to produce additional 75.000 tons of green hydrogen per year
- **2040 – 2053** : Installation of additional 2 GW renewable energy plus other carbon-free energy generation capacity is aimed and additional electrolyzer capacity is expected to be 1,2 GW to produce additional 180.000 tons of green hydrogen per year

South Marmara is expected to reach more than 300.000 ton/year hydrogen production capacity with a total of 2 GW installed electrolyser capacity. Considering the hydrogen equivalent of total natural gas consumption of the region which was around 190.000 tons/year in 2021 with future projections for 2053; it is likely that the electrolyser capacity of 2 GW alone will not be enough for the region. But energy efficiency applications, electrification and carbon-capture systems will probably help filling the gap.

Figure 5. Off-take Industries in South Marmara Region

Offtake industries shown in Figure 5, will trigger large-scale green hydrogen production and consumption in the region. At first, the compressed hydrogen gas will be transported by jumbo trailers to the production sites of Kale Seramik, Hidrojen Peroksit, Eti Maden, Şişecam and Borçelik of which the distances to the green hydrogen producer Enerjisa Üretim's Bandırma Energy Base are 80 km, 25 km, 25 km, 155 km, 195 km respectively. Of course, the ultimate goal is to distribute the compressed green hydrogen gas through hydrogen pipelines as it is in natural gas. But this is not the only focus in the South Marmara Hydrogen Vision.

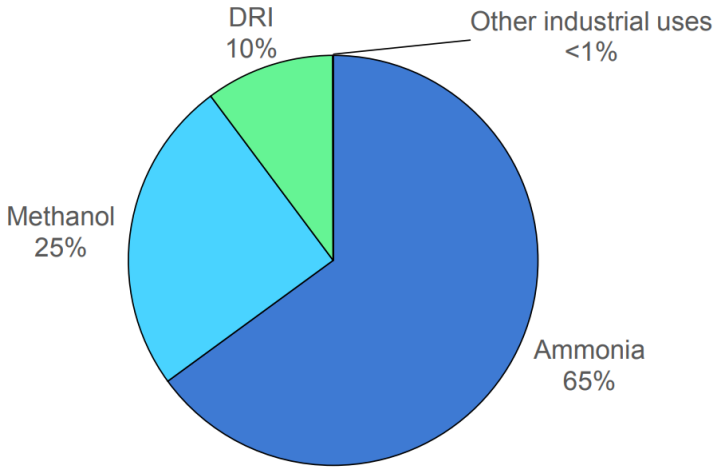

Figure 6. Hydrogen Demand in Global Industry,2020

Across global industry, 6% of total energy demand is used to produce hydrogen, which serves primarily as a feedstock for chemical production and a reducing agent in iron and steel manufacturing. Industry demand for hydrogen is 51 Mt annually (IEA, Global Hydrogen Review-2021). As it is shown in Figure 6. hydrogen demand is coming from mostly ammonia and methanol. Liquid and solid hydrogen carriers are also critical elements for the regional consumption and for exporting hydrogen to especially European countries in South Marmara. As the hydrogen derivatives, methanol and ammonia are liquid state hydrogen carriers. They are not just two of the most consumed feedstocks in the world, but also their applications in the energy sector will grow in the coming future. For a regional perspective; there are two large scale industrial plants using methanol and ammonia in their processes. One of them is wood-based panel producer Kastamonu Entegre located in Balıkesir Organized Industrial Zone which consumes an average of 50.000 tons methanol per year; and the other one is fertilizer producer BAĞFAŞ located in Bandırma which consumes an average of 450.000 tons ammonia per year. In the current global status, more than 99 % of those two chemicals are fossil-based. Because of the dependency of EU countries and Türkiye on fossil fuels, producing green methanol and green ammonia via electricity is a strategic move. Of course the real motivation comes from carbon-neutral targets of the countries. So South Marmara Region is addressed itself to have at least one industrial scale green methanol plant and one industrial scale green ammonia plant. Two feasibility studies will be conducted within the Hydrogen Valley Project for a 50.000 tons/year capacity of green methanol production and 100.000 tons/year capacity of green ammonia production. Production sites are selected on the southern coastline of Marmara Sea not just for the installed renewable capacities and desalination units of the facilities but also the companies' advantage of owing port facilities to export those critical feedstocks to Europe.

South Marmara is trying to create an another new market for green hydrogen business by planning to produce, utilize and export solid-state hydrogen carriers in the region. The region has almost 15 % of all the global boron reserves. And there are two large facilities of Eti Maden which is the Boron leader of the world with 56 % market share and a global company in mining and chemical sector. Eti Maden has a special role in hydrogen economy of the region. Its enery-intensive operations in the production of boron chemicals forces the company to speed up its green transition. But also another motivation instrument is that Eti Maden wants to take concrete steps with new boron chemicals towards its goals in energy sector. Boron is one of the promising materials to store hydrogen and the company will make an investment of 50 tons/year capacity of Sodium BoroHydride Plant with an estimated budget of 9 million EUR within the hydrogen valley project. Considering safety issues and cost-effective storage, solid state boron-hydrogen compounds may serve as a useful alternative to compressed and liquid hydrogen technologies. Sodium borohydride

is one of the most versatile solid-state materials to store and release hydrogen in this regard. In this project, Eti Maden will produce sodium borohydride in Bandırma Boron and Acid Factories, the production process in which pure hydrogen and methanol will be used as hydrogen sources. Both hydrogen and methanol are the key feedstocks for the production of boron-hydrogen compounds and the utilization of their green-based alternatives becoming very critical to produce carbon-free product. Green hydrogen need will be met by Enerjisa Üretim of which production site is 25 km away from Eti Maden's Bandırma Plant. The studies has been conducted mostly on Schlesinger method up to now but there are different methods as well for the production of Boron-based hydrogen storage materials. Before the deployement starts, a pre-feasibility study will be performed by Eti Maden which comprises different production methods. And then the investment of the mid-scale industrial plant will be completed in 30 months.

As it is mentioned before, material-based solid hydrogen carriers is simplifying storage, transport and use of hydrogen in especially off-grid applications, disaster regions and emergency buildings. Traditional hydrogen use comprising compressed hydrogen gas or liquified hydrogen, require complex infrastructure and cumbersome, costly safety measures, while suffering from lower energy density. An innovative power application will be realized in the hydrogen valley project for the off-grid operations of hydrogen-based power systems. In harsh environmental conditions where grid electricity can not be supplied such as earthquakes, floods, fires, landslides, major power plant failures, regular operation of critical electrical loads will be ensured.

Sodium borohydride-based power system is another milestone of the project. By generating hydrogen from sodium borohydride, an integrated power supply and process system that feeds the PEM fuel cell will be developed and commissioned. Sodium BoroHydride will be the fuel of the integrated power supply which will be configured to operate independently from the mains power. This special boron chemical is superior to other storage options in terms of the levelized cost of hydrogen storage. The storage of hydrogen as a gas typically requires high-pressure tanks (350–700 bar while the storage of hydrogen as a liquid requires cryogenic temperatures. High density hydrogen storage is a challenge not only for stationary and portable applications but also for transportation applications. So compressed gas or cryogenic systems need a significant amount of energy but the material-based hydrogen carriers can readily store and transport and is the safer and more economical option compared to its physical-based counterpart. Since the volumetric and gravimetric hydrogen storage capacity of $NaBH_4$ is remarkably higher compared to other types of hydrogen storage materials, it is a good option for hydrogen storage and for fuel cell powered systems. Thus, an independent, reliable and low-noise electricity generation process will be realized in case of power cuts, when systems such as UPS and generator are not sufficient due to noise and/or battery capacity.

Figure 4. Logistics Warehouse of AFAD in South Marmara Region

The developed system will be used by Disaster and Emergency Management Presidency (AFAD), as an ideal solution for generating energy in off grid regions, disaster regions and emergency buildings. The first prototype will be installed in the logistics warehouse of AFAD in South Marmara. With the first on-site installation, the first step will be taken to demonstrate the usability of the system not only in the case of disasters such as earthquakes, landslides, major power plant failures but also floods and fires triggered by the climate crisis. By including this application, the project will contribute to another dimension: the social impacts of hydrogen.

The most remarkable and striking outcome of the hydrogen valley project will be the creation of a sustainable new green hydrogen business model and implementation of hydrogen valley concept which shows "the production, storage and utilization of green hydrogen in all states".

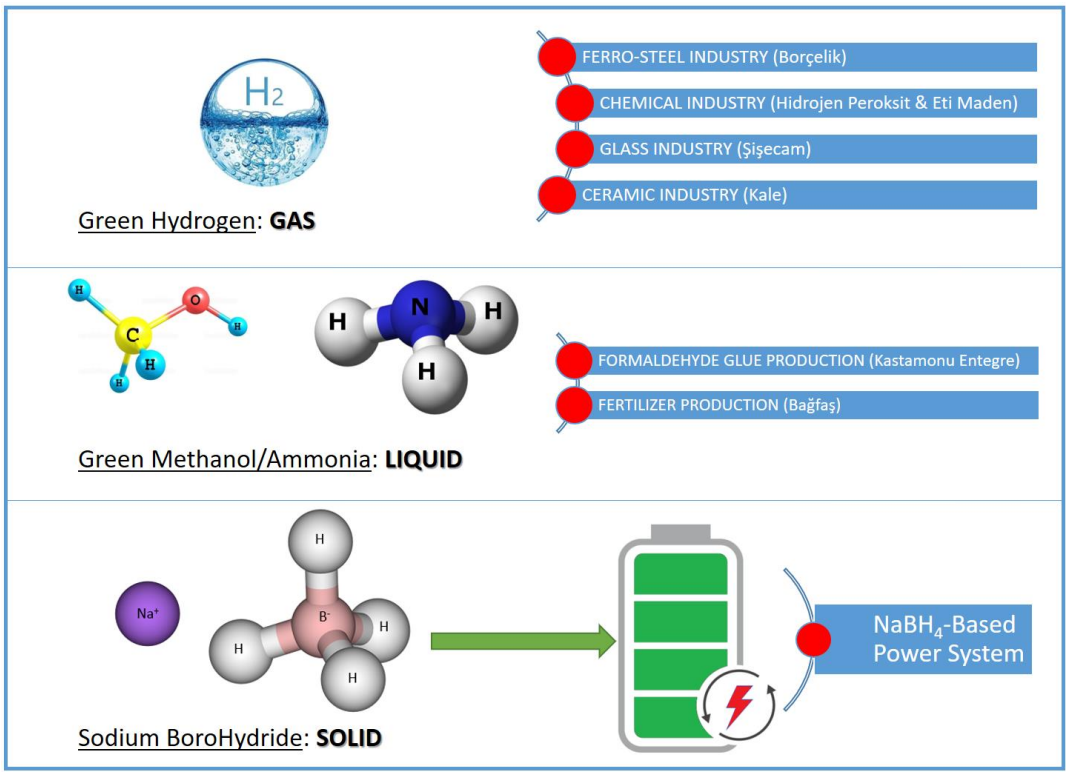

Figure 4. Different States of Green Hydrogen: Production-Storage-Utilization in South Marmara

South Marmara is one of the 26 NUTS-2 regions in Türkiye. The region is located in the middle of highly populated developed metropolitans. There are many large industrial zones around the region and also the industry of South Marmara is developing as well. Transformation of the industry is top priority because a new phase is coming with the European Green Deal and also the whole Marmara Region is environmentally under pressure. Besides all these statements, South Marmara Region has many advantages in renewable sources to counter the future risks. All the advantages of South Marmara Region mentioned in this report, will lead us to green hydrogen production which could have a key role in decarbonization of the region. Apart from hydrogen production potential, the region comprises many more advantages besides installed renewable capacity, considering hydrogen distribution-consumption domestically-export. South Marmara has a 1000 km coastline and there are many industrial facilities on this line. The plants have their own large capacity desalination units which is a must to produce hydrogen. This is one of the most important advantages to enable the sustainability of water resources. Moreover, the importance of hydrogen derivatives will increase till building new hydrogen pipelines and repurposing the

existing NG pipelines so having port facilities is a critical advantage for those companies in South Marmara to export hydrogen derivatives to European countries. Under the light of the statements in the report, it is clearly seen that South Marmara is the right region to boost the hydrogen economy in Türkiye. The establishment of a regional strong hydrogen-based economy is a very real opportunity and one that is rapidly becoming within reach when you compare it with national targets. Building good practices at regional levels in the hydrogen economy will serve as a model for Türkiye. South Marmara can be the leading region in paving the way for a carbon-neutral economy by 2053 in the country and will help the nation to achieve its net-zero carbon commitments. The region should have the right and comprehensive vision to accomplish this goal by putting South Marmara at the forefront of hydrogen innovation and capitalizing on the opportunities brought about by hydrogen technology in industrial sectors, transport and heating. Even though stakeholders are well aware of the high cost difference between “fossil-based fuels/grey hydrogen” and “green hydrogen”, the sustainability goals and carbon tax pressure motivates them to build a strategy to switch the hydrogen type as soon as possible.