INSTITUTE OF ENERGY
FOR SOUTH-EAST EUROPE

SE Europe Energy Brief - No 328 | February 23, 2021

Monthly
ANALYSIS

> The Case for Hydrogen in SE Europe

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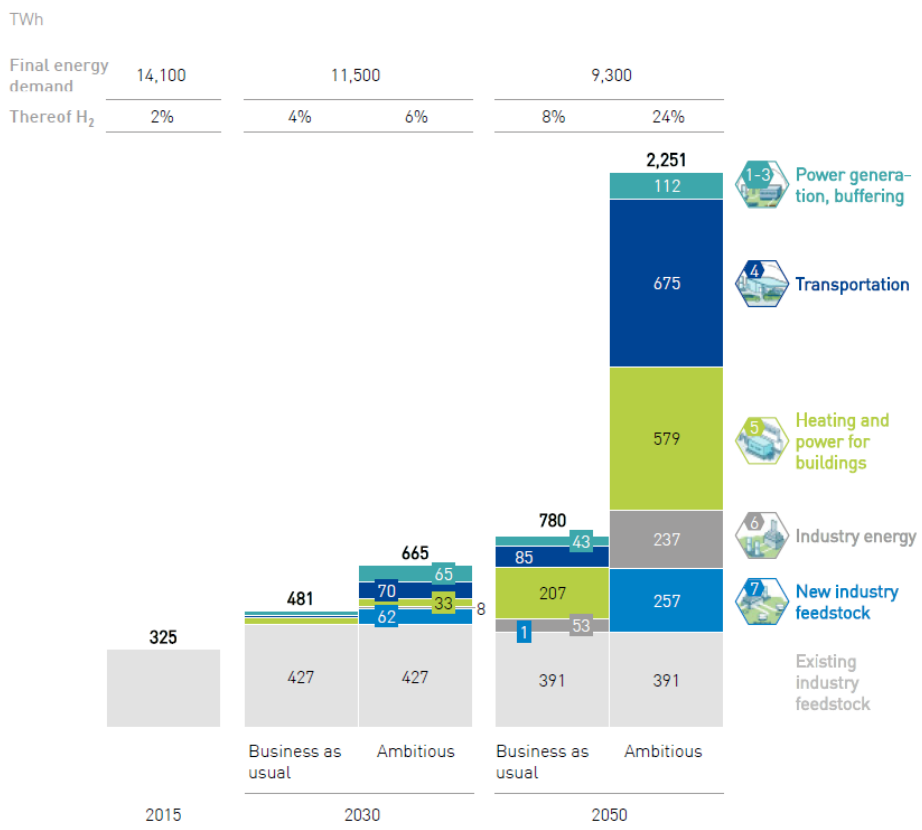
In late 2019, the European Commission presented the European Green Deal **(1)**, outlining the main policy initiatives for reaching net-zero greenhouse gas (GHG) emissions by 2050. The Green Deal identifies clean hydrogen as a priority area for achieving carbon neutrality by 2050. There are two aspects to consider in this major European policy initiative: firstly, the European Union currently uses approximately 9.7 million tonnes (Mt) of hydrogen annually **(2)**, mainly destined for industrial processes, and these hydrogen quantities need to be decarbonised. Secondly, hydrogen is considered a key input to the future energy system as a flexible energy carrier for industry and transport, helping to reduce GHG and particle emissions.

The targets for the Green Deal should be broken down in two phases: phase 1: From now until 2030 and phase 2: 2030 until 2050. In the short term, the EU's dependency on fossil fuels for transport services will only marginally decrease, according to the long-term scenarios (LTS). However, according to the EU's hydrogen strategy **(3)**, at least 6 GW of electrolysers powered by renewable energy sources (RES) should be installed between 2020 and 2024. Depending on its utilisation, such capacity could produce up to 0.8 Mt of clean hydrogen, annually. This number should then increase to 40 GW by 2030. By that time, hydrogen demand in EU plus UK will be 665 TWh or 16.9 Mt, according to the 2019 Hydrogen Roadmap Europe's ambitious scenario **(4)**.

In phase 2, renewable hydrogen demand will increase further, even if the demand from refineries will gradually be decreasing. Today, the biggest share of hydrogen demand comes from refineries, which were responsible for 45% of total hydrogen use (3.7 Mt) in 2018, followed by the ammonia industry with 34% (2.8 Mt), based on data provided by Hydrogen Europe **(5)**. As the implementation of the Green Deal advances, it is expected that oil product demand will decline along with the associated hydrogen consumption.

However, the deep decarbonisation of industries, such as the chemical or steel industry, are expected to outbalance this decline. By 2050, the Hydrogen Roadmap Europe report indicates that hydrogen could provide up to 24% of total energy demand corresponding to ~2,251 TWh of energy in the EU plus UK, as shown in Figure 1. By sector that means, 675 TWh in transportation, 579 TWh in heating and power for building, 391 TWh in existing industry feedstock, 257 TWh in new industry feedstock, 237 TWh in industry energy, and 112 TWh in power generation.

Figure 1: Definition of Hydrogen Production Types by Availability



Source: Fuel Cells and Hydrogen Joint Undertaking

EU's Hydrogen Supply and Demand

Today, around 120 Mt of hydrogen are produced **globally** each year, of which two-thirds is pure hydrogen and one-third is in mixture with other gases. This equals 14.4 exajoules (EJ, equivalent of 4,000 TWh or 102 Mt), about 4% of global final energy and non-energy use, according to International Energy Agency (IEA) statistics **(6)**. Around 95% of all hydrogen is generated from natural gas and coal. Around 5% is generated as a by-product from chlorine production through electrolysis. In the iron and steel industry, coke oven gas also contains a high hydrogen share, some of which is recovered. Currently, there is no significant hydrogen production from RES **(7)**.

Looking to the future, the IEA reports a global economic potential for 19 EJ (5,277 TWh or 135 Mt) of hydrogen from renewable electricity in total final energy consumption by 2050, whereas others (for example, the Hydrogen Council) see this number increasing to around 80 EJ (22,222 TWh or 568 Mt, not necessarily all from RES). Hydrogen can be produced from a variety of processes associated with a wide range of emissions depending on the technology and energy source used **(8)**. Renewable hydrogen (or green hydrogen) is produced exclusively through electrolysis using RES and it is a near-zero carbon production route, with its cost at \$6.00 (€5.09) per kilogram in 2020 **(9)**. It is projected to cost \$2.50 (€2.12) per kilogram by 2030 under average European wind energy productivity.

However, the recent rapid cost reduction for RES electricity opens up new opportunities. Renewable hydrogen has a significant decarbonisation potential and is therefore the most compatible option with the EU's climate neutrality goal. Electrolyser CAPEX, the utilisation factor (operating hours) and electricity price are the main parameters determining the cost of producing green hydrogen. Electrolyser costs are projected to halve by 2050, from \$840 per kilowatt in 2019, while renewable electricity costs will continue to fall as well, according to IRENA. Fossil-based hydrogen with carbon capture and storage (CCS) will be an additional option when the technology scales and reaches market maturity (blue hydrogen). Future projections of steam methane reformer (SMR) production[1] with CCS in Europe show production cost at €1.50/kg in 2030, according to Hydrogen Council. However, such hydrogen is not necessarily CO_2-free. CO_2-capture efficiencies are expected to reach 85%-95% at best, which means that the other 5%-15% is leaked.

Fossil-based hydrogen is produced from conventional SMR or coal gasification, representing currently the primary sources of global hydrogen production (grey hydrogen). This practice is not sustainable and it is associated with 830 $MtCO_2e$ emissions per year, 2.3% of total global CO_2 emissions are released during the production **(10)**. SMR has an emission factor of 8.9 kg CO_2/kg H2, while coal gasification's emission factor is even higher, at 29.33 kg CO_2/kg H2 **(11)**. Today around 8.2 Mt of fossil-based hydrogen are produced in the EU, its vast majority by SMR from natural gas **(12)**. The cost of such grey hydrogen was \$1.60/kg (~€1.35/kg) in 2020. Lastly, hydrogen can also be produced by using nuclear energy but some argue that this route is linked to high socio-economic risks. However, it may prone just as expensive as green hydrogen produced from RES.

Hydrogen Production in Europe

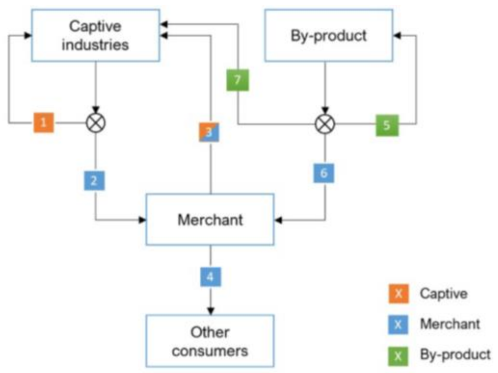
The total annual production of hydrogen in **Europe** is in the range of 9,756 Mt (merchant hydrogen and purposely produced hydrogen, and not hydrogen produced as a by-product). The majority of hydrogen consumption is associated with two industries: oil refineries and ammonia production, while the rest concerns other industrial uses. Together with methanol production and use in metal industries, these four sectors correspond to 90% of the total hydrogen consumption in Europe today.

According to Hydrogen Europe, there were 457 hydrogen production sites in the EU in 2018. These are divided into three main types: (a) merchant, which supplies hydrogen to other industrial customers, (b) captive, where the hydrogen remains on site for use and (c) plants where the production of hydrogen is a by-product of other

[1] Currently, the steam methane reformer (SMR) is one of the leading technologies for H2 production from natural gas or hydrocarbons.

processes, as shown in Figure 2. It is worth noting that more than half of the total hydrogen consumption takes place in just four countries: Germany, the Netherlands, Poland and Belgium.

Figure 2: Definition of Hydrogen Production Types by Availability



where:

(1) Captive hydrogen production on-site used exclusively for own consumption within the same facility. **(2)** Excess hydrogen production capacity in dedicated installations that can be valorised and sold to external hydrogen merchant companies for resale. This has been applied only to installations dedicated to supplying hydrogen merchants. **(3)** Hydrogen produced in large industrial installations, usually dedicated to serve a single customer or an industrial cluster. Usually produced in close vicinity to or distributed with pipelines. Whenever we could identify that the installation was serving a single customer those installations were categorised as captive. In other cases, it was categorised as merchant. **(4)** Hydrogen produced for retail purposes and sold in relatively small volumes, which does not warrant building its own Hydrogen Generation Unit (HGU). Usually distributed in compressed form, in cylinders or using tube trailers (200 bar), in a few cases liquefied, also mostly using trucks. **(5)** By-product hydrogen that is vented to the atmosphere or used as feedstock for internal processes or for onsite energy generation. **(6)** By-product hydrogen that is purified and sold to merchants for further resale. **(7)** By-product hydrogen that is sold directly to nearby captive industry.

Source: Hydrogen Europe

Grey Hydrogen

As already analysed, the current hydrogen production capacities in the EU are around 10 Mt per year, with the corresponding annual demand for hydrogen at around 8.3 Mt. As can be expected, the current state of both the supply and demand side is a consequence of historical developments in the hydrogen market, where hydrogen is mostly used as a feedstock for oil refining and the ammonia and methanol manufacturing industry. As a result, the vast majority of hydrogen production happens at large scale production plants dedicated exclusively to supplying these industries. As currently the cheapest method of bulk hydrogen production is hydrocarbon reforming, over 90% of hydrogen is produced from natural gas and other fossil fuels.

Clean Hydrogen

Clean hydrogen (renewable or low-carbon) production capacities are lower than 1% of total hydrogen production, with the new emerging hydrogen end-uses, like zero-emission mobility, having equally small shares of the hydrogen demand market. For reference, the EU Hydrogen Strategy has defined a renewable hydrogen production target for 2030 at around 10 million tonnes, the equivalent of total current hydrogen production capacities, which have been build up over decades.

These quantities clearly show the extent of the challenge that lies ahead for the EU. Hence, a call for urgent action is required not only for the deployment of new electrolysers for hydrogen production but also for the rapid development of new RES across the EU, both solar PV and offshore wind. Furthermore, as not all current (fossil) production can be expected to be shut down in the next decade, the implementation of the EU Hydrogen strategy will require stimulating demand for Clean Hydrogen in emerging sectors such as transportation and steelmaking in addition to the replacement of current feedstock.

In addition to this, as electrolysers will in many cases be deployed near RES sites (avoiding grid congestion) and away from large scale end-users, there is also a need to develop hydrogen transportation infrastructure that would allow for large scale hydrogen trade across the whole EU. Currently, only around 1% of total hydrogen demand is subject to intra-EU trade between member states. On the other hand, the analysis of bulk hydrogen imports/exports value shows that when transported via pipelines the transportation of hydrogen can be achieved at relatively low cost.

The Case of SE Europe

Hydrogen, the fuel of the future that the European Commission is betting on in meeting its ambitious decarbonization targets, has brought several SEE industrial corporations closer, especially those of EU member states of the region, as they prepare to bid for one of the four projects Brussels will subsidize in the context of the Hydrogen Europe programme.

For instance, in **Greece**, there is the White Dragon project that provides investments of €2.5 billion in electrolytic hydrogen production by means of solar energy from photovoltaic parks with a capacity of 1.5 GW to be installed in Western Macedonia in the context of the region's decarbonization programme. The Regional Authority of Western Macedonia is coordinating the project and its members include the Public Gas Corporation (DEPA), gas grid operator DESFA, Hellenic Petroleum, Motor Oil, Mytilineos, Terna, Polish company Solaris, the Demokritos National Center for Scientific Research and the Center for Research and Technology Hellas (CERTH). The hydrogen produced will be used for district heating, as fuel to be exported via the TAP gas pipeline, and as fuel for large vehicles, such as lorries, buses, etc.

The application for the Greek project is being prepared and will be submitted in the first half of 2021, in the hope of being one of the four selected for funding by the European Commission, which would be vital for the Greek plan's implementation.

The high cost of electrolytic technology today renders the production of hydrogen through RES unsustainable; therefore, it would necessitate partnerships to achieve economies of scale and definitely some subsidies. Sources from DEPA say White Dragon ranks high in the Commission's short list, as in Brussels there is the view that the monopoly of innovative projects in Northern Europe ought to end, with such plans implemented in the continent's southeast. **(13)**

According to Greece's National Energy and Climate Plan (NECP), the country's approach to develop hydrogen as low-carbon solution comprises the following pillars: (a) hydrogen production from renewable electricity, (b) hydrogen use to decarbonize the transport sector (mainly shipping), (c) long term hydrogen storage for power generation, (d) use of existing gas infrastructure for hydrogen transport and (e) stimulate hydrogen related Research, Development and Innovation. As stated in its NECP, *"Hydrogen is a future solution, although it is currently at an early stage of development. It is noted that Greece has a significant track record in scientific investigation and research in the field of hydrogen production from RES"*. **(14)**

Greece is in a favourable starting position given its scientific knowledge and economic activity, its potential to further deploy renewable electricity production, the involvement of some regions and cities in deploying hydrogen projects and initiatives, and its activity in the maritime sector. Greece considers hydrogen as a longer-term option. Its NECP provides neither concrete hydrogen targets, nor hydrogen specific policies and measures.

In addition, **Bulgaria** is planning to develop a hydrogen roadmap targeting 1.1 GW of green hydrogen production capacity by 2030, according to a report presented by Angel Popov, deputy transport minister during European Hydrogen week. The country plans to produce hydrogen by electrolysis using RES and sets a goal of installing additional 800 MW of wind and 280 MW of solar capacity by 2030, according to the report. This goal is separate to the National Energy and Climate Plan (NECP), which targets 2.1 GW of solar, 250 MW of wind and 250 MW of biomass capacity by 2030. **(15)**

The Bulgarian government is working to develop a comprehensive hydrogen roadmap in the next three months that would tackle the decarbonisation challenges across all sectors, added Popov during online webinar discussions on November 27-29. The Bulgarian roadmap will fall in line with the hydrogen strategy unveiled by the European Commission in July 2020. The strategy aims to have 6 GW of renewable hydrogen electrolysers installed in the EU by 2024 and 40 GW by 2030.

Turkey aims to utilize hydrogen in several energy sector areas, including RES, heating and transportation, according to the country's Energy and Natural Resources Minister Fatih Donmez. Speaking at a recent workshop, Mr. Donmez described hydrogen as "the energy carrier of the future" and relayed that this element is at the center of current discussions to widen its use in Turkey. Hydrogen will be part of Turkey's short and long-term goal to ensure security of energy supply, Mr. Donmez said. **(16)**

In an attempt to decrease the usage of oil, natural gas and other fuels that have a negative impact on the environment and climate, Turkey has boosted efforts to add clean sources to its energy mix, which in turn will also help it become less dependent on imported fuels.

Hydrogen will have a part to play in these efforts in four different application areas, by putting "indigenousness" at the heart of its energy strategy, Donmez explained. "These include more incorporation of RES to the system - the decarbonization of the heating sector, hydrogen production from local coal and increasing the use of boron through using hydrogen as a storage and conservation material," he explained. The minister underlined the importance of producing hydrogen and liquid fuel from coal given the possibility of a reduction in emissions-free transportation costs over the long term.

Turkey's gas sector has already begun studies to use hydrogen with its first inflow to the distribution system projected to start by the end of 2021 at the latest. However, Mr. Donmez noted that this initial step would be an experimental one to test the success of a working system rather than a major start to hydrogen deployment.

Hydrogen is also of major interest to the global transport sector particularly as electric transportation is still a costly option for heavy goods transportation, Mr. Donmez said. "We have an option to provide clean transportation through producing hydrogen from our local coal. Although the costs are currently high [for this option], a bus can travel 1,030 kilometers with hydrogen that is produced from 1 tonnes of coal on top of which it would be without emissions," he said.

Looking ahead, **Croatia** also intends to deploy hydrogen as a low-carbon fuel alternative. As yet, the country has not set out formal production targets in key laws or policy documents, such as its Low Carbon Development Strategy. Hydrogen is currently only produced at INA's Rijeka refinery, the country's largest refinery, for internal use. The goal is to use hydrogen to contribute to decarbonization, so hydrogen used as a transport fuel should be green hydrogen – produced from RES **(17)**. Based on recent statements by the European Commissioner for Energy Ms. Kadri Simson, Croatia is now preparing a National Programme for Hydrogen Market Development. **(18)**

Speaking at the online conference "Energy Innovation '20", **Slovenia**'s Environment Minister Andrej Vizjak said that a period of change and innovation in hydrogen technologies, batteries and many other sectors was just beginning. He said a priority would be the use of hydrogen for energy storage. In this context, he referred to a consortium of Slovenian energy companies – Hidroelektrarne na Spodnji Savi (HESS), Geoplin Plinovodi, ELES and Holding Slovenske Elektrarne (HSE) – which are exploring the option of using hydrogen technologies to optimise the energy sector, under SLOP2G - an innovative project for the conversion of renewable electricity to green hydrogen and synthetic methane. “This is an area that has been developing for 20 years. We have a lot of know-how,” he said. **(19)**

Cyprus’s commitment for hydrogen deployment is not explicitly considered in its NECP for the period from 2021 to 2030. However, as early as 2009, hydrogen was recognised by the Cyprus University of Technology for its advantages across sectors, in terms of reduction of imported oil dependency, reduction of carbon dioxide emissions, improvement of the local air quality and the environment in general. The most sustainable path to produce hydrogen in Cyprus would be by exploiting the solar potential of the island, which is more than large enough to cover its total energy needs[2]. Cyprus is at present neither involved in European Commission’s Important Projects of Common European Interest (IPCEI) initiative, nor in projects under the EU funding programmes (FP7, H2020) related to hydrogen.

In 2018, **Romania** signed the Hydrogen Initiative. By signing this proposal, the country committed to continuing research and innovation into how it will use hydrogen as an energy source for the future. Hydrogen and its associated technologies are being explored for use in the electricity storage sector, the transport sector and in industry. Based on Romania’s NECP, Romanian authorities are considering the implementation of a number of pilot and demonstration projects to promote the use of hydrogen in the production of electricity and in the industrial sectors. **(20)**

Currently, hydrogen in Romania is mainly used in the chemical industry, specifically in refineries and for ammonia production. In Romania, there are now 13 industrial producers of hydrogen (all from fossil fuels) and the hydrogen market comprises of two main types of players: (a) captive producers, which produce hydrogen for their direct customers or for their own use, and (b) by-product hydrogen, resulting from chemical processes, especially the chlor-alkali industry.

Romgaz, the largest gas producer in Romania, plans to build an electricity plant that will integrate hydrogen into the production of electricity through a 200 MW gas power plant in Turnu Severin – Halanga. In June 2020, Romgaz and Liberty Galați, the largest integrated steel plant in the country, signed a memorandum for the construction of a gas plant alongside wind and solar PV capacities. The aim of the €1.2 billion project is to develop greenfield investment projects; especially, the development of gas-fired power generation and hydrogen, to be used by the steel plant. The investment should make the Galati steel plant carbon-neutral by 2030.

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[2] Panayiotou, G. and Kalogirou, S. (2009), “The introduction of Hydrogen Economy in Cyprus”, Conference on the promotion of Distributed Renewable Energy Sources in the Mediterranean region, https://www.researchgate.net/publication/264898340_The_introduction_of_Hydrogen_Economy_in_Cyprus

Discussion

The EU's strategy, presented in July 2020, calls for setting up an electrolyzer fleet of total capacity between 5 GW and 6 GW by 2025, and then another 40 GW by 2030. The strategy promotes primarily hydrogen from RES, the so-called green hydrogen. Blue hydrogen, produced from natural gas, is addressed to a lesser degree. It requires capturing and storing carbon dioxide. Also mentioned is the pyrolisis of methane directly into hydrogen and carbon.

Projects for the production and use of green hydrogen are still more political than economic. The projects aim to create a green hydrogen value chain connecting the RES capacities in SE Europe with the growing interest in hydrogen in Western Europe. Recently announced investments in (SE) Europe will undoubtedly give a strong impetus to the technologies for hydrogen production, storage and transport, as well as for its conversion back to energy.

The aim of the EU member states of SE Europe is to meet their targets for hydrogen deployment, according to their NECPs, provided they have set up such targets. In the case of the Western Balkans' countries that are not EU member states, the main goal is to develop a hydrogen strategy. Among others, a good hydrogen strategy could reduce the share of coal/lignite in the regional energy mix and cut GHG emissions. In addition, several projects for the sustainable production of both green and blue hydrogen should be promoted and the majority, if not all, of the SEE countries should join in.

One example is in the transport sector, where Bulgaria is set to take part in the 2 GW Blue Danube project **(21)**, with an estimated budget of €5.8 billion. The project includes eight countries (i.e. Germany, Austria, Czech Republic, Hungary, Slovakia, Croatia, Romania and Bulgaria) and seeks to produce green hydrogen in SE Europe using off-grid wind and solar energy and transport hydrogen via the Danube river to users in countries of Central Europe. It remains to be seen if the SEE region will understand the importance of hydrogen over the next years or it will lag behind developments in Western and Central Europe.

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IENE SE Europe Energy Brief – Monthly Analysis - February 23, 2021 - Issue No. 328 – ISSN:179-9163

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