HYDROGEN IN GREECE
The state of play

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Hydrogen at a Glance

Hydrogen is the lightest and most abundant chemical elements in the universe. On Earth, hydrogen is found in great quantities combined with other elements, such as in water and hydrocarbons. It can be produced using a number of different processes. The feedstock and the source of energy used define whether it is classified as **"grey", "blue" or "green"**.

Grey hydrogen is produced from fossil fuels via carbon intensive processes, such as steam methane reforming and coal gasification. Currently, 96% of hydrogen produced globally is grey hydrogen. Blue hydrogen is also produced from fossil fuels via carbon intensive processes but CO_2 emitted during production is sequestered via carbon capture and storage (CCS). Green hydrogen is produced via water electrolysis fueled by renewable electricity. To this day, the deployment of green hydrogen projects has been limited to demonstration projects.

Today, hydrogen is mostly being used for crude oil refining and for ammonia and methanol synthesis. However, hydrogen is expected to be part of global emissions' mitigation efforts in the coming decades, through several applications, such as hydrogen used as a fuel in fuel-cell heavy duty and passenger cars and hydrogen injected into the gas grid, decarbonizing heat to a certain extent.

EU Green Deal & the EU Hydrogen Strategy

Regarding the most recent developments on the European Union's emission reduction targets, following the **European Green Deal**, the European Climate Law entered into force on 29 July 2021 and set a legally binding target of **net zero greenhouse gas emissions by 2050**. The law also set the intermediate target of reducing net greenhouse gas emissions by at least 55% by 2030, compared to 1990 levels.

Within Green Deal, one of the most prominent EU Strategies is the **Hydrogen Strategy** which highlights the importance of producing **renewable hydrogen** (green hydrogen) and using it as feedstock, fuel or energy carrier to reduce greenhouse gas emissions across industry, transport, power and buildings sectors. The Strategy set intermediate targets of 6GW of renewable hydrogen electrolysers in the EU producing up to 1 million tonnes of renewable hydrogen by 2024 and of at least 40GW of electrolysers producing up to 10 million tonnes of renewable hydrogen by 2030. From 2030 onwards, renewable hydrogen will be deployed at a large scale across all hard-to-decarbonize sectors.

Also, in late 2020, the Commission published its legislative proposal for the **revision of Regulation (EU) No 347/2013 on guidelines for trans-European energy infrastructure (the TEN-E Regulation)** which envisages the exclusion of oil and natural gas network infrastructure from the projects eligible for the PCI status and the inclusion of hydrogen and smart gas grid projects.

Greek National Energy & Climate Plan (NECP): CO2 Mitigation Targets & The role of Hydrogen

Following the EU Green Deal directions, Greece published its **National Energy & Climate Plan (NECP)** setting ambitious goals for climate change to be reached by 2030. In particular the country announced its intention to **reduce greenhouse gas (GHG) emissions by more than 42% compared to emissions in 1990 and more than 56% compared to emissions in 2005**, thus exceeding even the core EU targets. Greece also set **a target of 35% share of renewable energy sources in gross final energy consumption**, once again higher than the core EU objective for RES of 32%.

Greece's 2019 National Energy & Climate Plan, views **hydrogen as a future solution** and does not include any specific quantitative targets or roadmaps for the deployment of hydrogen as a fuel in the short term. In more detail the Greek NECP:

- Recognizes as a key priority of research and innovation the "*production of*

renewable hydrogen from electrolysis of water and electricity from RES (installed electrolytes at renewable hydrogen refueling stations)".

- Advocates the development of "*pilot applications for the energy utilization of wave energy and of RES hydrogen production"*
- Mentions that "*To this end, the corresponding legislative and regulatory framework for the operation of these projects should also be developed, and it is extremely important to develop or update, where necessary, the necessary support schemes and mechanisms for their operation."* And that "*the development of RES (especially hydrogen) fuel for large-scale energy storage is estimated to be small by 2030 and is expected to grow further in the long run".*
- Notes that "*by 2030 the first electrolysis systems are expected to operate, allowing the electricity generation sector to be coupled with the hydrogen generation sector for energy storage."*
- Considers important for the country's scientific potential to "*monitor and participate in relevant programmes promoting hydrogen as a fuel in shipping, in the more specifically targeted areas applications where this is appropriate (e.g., barges in terminals or hydrogen-powered ferry boats with an electric motor)."*
- States that "*the application of hydrogen is not attractive to seagoing vessels as it involves a significant reduction in the useful capacity of ships and is a complex and expensive investment."*
- Finds that "*the options for coupling the electricity and gas sectors (power-to-gas) through storage applications that include conversion of electricity into renewable gas, such as hydrogen, are [equally] important".* And that "*The gas produced by using RES energy may be fed into the existing gas network and used as fuel for heating in buildings or in transport*", while "*the sustainability and efficiency of such a scheme will be considered initially through pilot applications and, if deemed positive, appropriate measures and policies will be promoted with a view to expanding the scope of these technological applications".*
- Supports the EU's argument that "*The introduction of guarantees of origin for biogas and hydrogen from various forms of energy and the coupling of guarantees of origin systems for different forms of energy (electricity, fuel gas, thermal and cooling energy) will help increasing the penetration of renewables in final consumption*."

Opportunities for Hydrogen Deployment in Greece

Moving towards a net-zero emissions era, the role of hydrogen is not yet clear. Admittedly, hydrogen is the route to cutting emissions in sectors where carbon-free electricity cannot, such as Road transport, Heavy industry, Ammonia, Steel, Shipping fuels, Aviation.

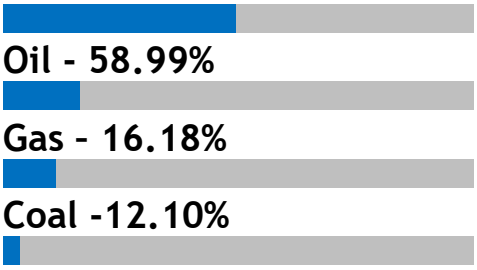
The widespread deployment of hydrogen in national economies will depend on hydrogen availability and cost and performance relative to alternatives for each potential application. For the case of Greece, the country's fuel mix, the energy needs and GHG intensity per sector as well as certain country-specific characteristics, allow us to identify opportunities and bottlenecks for the deployment of hydrogen.

To begin with, in Greece the **most energy intensive sector is Transport,** accounting for the 36.7% of final energy consumption in 2018, followed by Households which -for the same year- were responsible for the 24.3% of total consumption and Industry which consumed the 22.8% of the country's cumulative consumption. Trade and Services accounted for the 13.1% of total energy consumed, while the energy share of the Agricultural sector for year 2018 was only 1.7%.

As per the share of energy consumption by source in Greece, since oil covers the 98% of the Transport needs, the country's final energy consumption is dominated by oil. The share of energy consumption by source in Greece in 2019, as depicted in the Figure 1, reveals that **fossil fuels covered the 87.27% of the country's total energy needs**. It should be noted that while Greece is self-sufficient in coal, it has very little indigenous oil production and no production of natural gas. Thus, the demand for these fuels is covered by imports.

In terms of gross electricity generation in Greece, in 2019, **Natural gas-fired units provided the 42.4%%, Oil-fired plants the 10%, Lignite plants the 22.6% and Renewable energy sources produced the 25%**. However, the domestic electricity generation is not sufficient for the country's energy needs. In order to close the gap between domestic electricity generation and consumption, Greece is a net importer of electricity, with **net imports covering a low share of approximately 16% of total supply**.

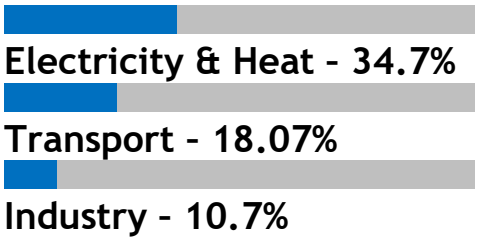
FIGURE 1: GREECE - SHARE OF ENERGY CONSUMPTION BY SOURCE IN 2019



The share of Greenhouse gas emissions (GHG) per sector in Greece in 2016, is depicted in Figure 2.

The **Electricity and Heat supply appear to be the highest emitters, followed by Transport and Industry**. For this sector, in 2019, the 65% of the emissions came from Coal, 19% from Gas and 16% from Oil. Aviation and Shipping hold a considerable share in total GHGs, but it should be noted that international shipping and international aviation, do not fall under national climate mitigation policies.

FIGURE 2: GREECE - SHARE OF GREENHOUSE GAS EMISSIONS (GHG) PER SECTOR IN GREECE IN 2016



Aviation & Shipping - 8.5%

Agriculture - 8.2%

Manufacturing & Construction - 6.8%

Focusing on **Electricity**, as already mentioned, Natural Gas and RES are currently dominating the electricity mix, while the use of lignite is expected to be eliminated soon. Actually, Greece released a **Master Plan for Decarbonization** according to which Greece aspires to complete the **phaseout of all lignite plants by 2028**. Greece has historically been one of the most lignite-dependent countries in Europe, because of the abundant coal resources in the region of Western Macedonia and the municipality of Megalopolis (Region of Peloponnese). It is worth mentioning that **between 2018 and 2020, the lignite share in the electricity mix declined from 33.9% to 10.3%**.

However, for Greece -which imports all of its natural gas and oil (the latter used mainly on the non-interconnected islands) and imports net electricity from abroad- the lignite reserves represented an important indigenous energy source. As a matter of fact, Greece is the seventh country in the world and third in the EU-27 when it comes to lignite production. **Since Greece possesses significant untapped RES generation potential, the production and use of green hydrogen in electricity production could end the country's reliance on fossil fuel exporting nations and thus improve its energy security, while boosting the system flexibility needs and lowering the GHG emissions of the Electricity sector.**

Moving on to **Heat**, space heating in Greece in 2017 was covered mainly by heating oil (46.64%) and low-cost solid biofuels (32.65%), and secondarily by electricity (9.74%) and gas (11.93%). Blending hydrogen with natural gas in the existing natural gas ``infrastructure would have a limited impact on the country's GHG emissions from the heating sector, due to the relatively small share of natural gas in the heating fuel mix. However, **in the long term, a dedicated hydrogen infrastructure coupled with investments to replace residential oil-fired boilers, could effectively decarbonize a larger portion of the heating sector.**

It should be noted that Greece is currently planning to invest significantly in new natural gas networks to reach new consumers and help substitute polluting oil products used for heating. This plan does not appear to consider how NG network extensions fit in the longer-term context for a net-zero energy system in 2050 or if they will have a negative impact on other policies (e.g., high costs to be paid by customers or stranded assets).

Another important characteristic of Greece is that GHG emissions per capita generated in most Greek large regions[1] are below 10 tCO_2e per capita. Only Western Macedonia and Central Greece have higher emissions per capita than the OECD average of 11.5 tCO_2e. Estimated emissions per capita in Western Macedonia -where lignite fired plants operate-are more than 18 times higher than in Ionian Islands. In the same region, three district heating networks are currently in operation which utilize the heat waste from lignite combustion. Hydrogen could replace lignite in district heating plants.

Regarding the **Transport** sector, it should be highlighted that, even though transport is in most EU NECPs considered as the first market segment to deploy hydrogen, the Plan of Greece envisages that the final energy consumption in the transport sector in 2030 will be met via petroleum products, advanced biofuels, natural gas and electricity. Also, according to the European Alternative Fuels Observatory, the 2019 Greek National report on the Implementation of the National Policy Framework for the Development of the Market as regards Alternative Fuels Infrastructure in the Transport Sector and the deployment of the relevant Infrastructure, reveals that "*In the years to come, hydrogen is not expected to be promoted as a fuel in the transport sector*".

Transport's final energy consumption in Greece is dominated by petroleum products - 93% in 2016- while natural gas (CNG as there is no refueling infrastructure for LNG), biofuels (biodiesel) and electricity share the remaining 7%. Road transport is responsible for the biggest part of final energy consumption in transport -87% share in 2016- followed by domestic maritime transport sector (9%), domestic air transport (3%) and rail transport (1% -most of it relying on diesel locomotives). Focusing on road transport, passenger cars consume the 57% of the total final consumption of the mode, trucks and light vehicles are responsible for the 40% of the total consumption of road mode, 4% is attributed to buses and the remaining 3% to motorcycles.

It should be noted that transport by road is the predominant inland mode for both passengers and freight partly due to the characteristics of the country's terrain and also because of inadequate railway infrastructure. In more detail, in 2015, buses and coaches in Greece transported 17% of passengers travelling by land, almost double the EU average of 9% and rail transport was used for 2% of freight inland transport and 1% of passengers land transport vs the EU average of 17.4% for freight and 7.6% for passengers, respectively.

Given the fossil-fuel based energy intensity of the Greek transport sector, hydrogen could be deployed in many ways and in conjunction with other alternatives (for example expansion of electric rail infrastructure) to decarbonize the sector. Hydrogen fuel cell technology for road-based vehicles is well established and the international practice shows that long-range trucks, vans and heavy-duty vehicles (return-to-base fees) are moving towards hydrogen fuel cell technology while battery technology is adopted for urban cars. The use of battery-only solutions in these vehicles is less attractive than the use of hydrogen which exhibits faster refueling time and higher energy density. Combining the potential of hydrogen as road transport fuel with the transport mode having the highest GHG emissions in Greece, **freight and heavy-duty passenger transport should be the first hydrogen compatible candidates**. For the Greek rail transport, any intervention today would have a small impact on the country's total GHG emissions. However, the Greek

[1] Eastern Macedonia, Thrace, Central Macedonia, Epirus, Thessaly, Ionian islands, Western Greece, Attica, North Aegean, South Aegean, Crete

government is planning to expand the railway infrastructure. In this case, the country could examine the leading option in Europe which is currently the use of hydrogen fuel cells supported by a battery pack. For maritime transport sector, the NECP promotes the future wider adoption of liquefied natural gas as a fuel for domestic shipping. As a matter of fact, the use of hydrogen in vessels raises concerns that relate to the energy density, size and cost of fuel storage systems, available cargo, and passenger space, etc. A few pilots for hydrogen-fueled ferries are taking place globally and in the long-term Greece could benefit through the maturity of relevant technologies and economies of scale.

Regarding the **Industrial** sector, existing use cases of hydrogen as feedstock/reactant which today rely almost exclusively on grey hydrogen (produced by the reforming of natural gas), are **the production of ammonia, petroleum refining and steelmaking. There can be the first industries to be considered for decarbonization by replacing grey hydrogen with blue or green.**

Additionally, hydrogen could be used for the energy needs of industrial plants and it could replace natural gas as a fuel in high-temperature heat production processes. The EU-27 has a total capacity for the industrial production of ammonia equal to about 21 million tons, of which only 1% is produced in Greece (based on 2013 data). The refineries operating in 2019 in the EU-28 (including UK), Norway and Switzerland had a primary refining capacity of 681 million tons, of which Greece accounted for 21.2 million tons (3.1%). Greece also produced the 0.9% of crude steel in the EU in 2019. Although the Greek production capacities in ammonia, steel and oil products are low compared to other Member States, the export of these goods is essential to the country's economy. Especially the Greek refineries contribute heavily to the Greek economy (nearly 37.5% of Greece's export revenue in 2012 was generated from refined products) and therefore, it is important to preserve their competitiveness (the latter is threatened by refineries outside the EU where greenhouse gas emissions are not priced). Therefore, the use of hydrogen instead of natural gas as feedstock in the aforementioned industries could have a positive effect on the reduction of the country's GHG and on strengthening its economic stance. Globally, several refineries are engaged in projects aimed at using or producing green hydrogen. One such project run by Shell in the Port of Rotterdam, transforms green electricity into renewable H_2 to be used to lower the GHG footprint of fuel produced in the nearby Pernis Refinery. As for the use of hydrogen to cover the electricity and high-temperature heat needs of industrial processes, as already mentioned, Greece has untapped RES potential which could be leveraged to produce green hydrogen for such purposes. It should also be highlighted that for the short term, the industrial processes consuming hydrogen could opt for blue hydrogen (made either through steam thermal reforming of natural gas or coal gasification, but with carbon dioxide capture and storage) before transitioning to renewable hydrogen.

REGULATORY FRAMEWORK FOR HYDROGEN

Greece lacks a comprehensive framework for the deployment and use of hydrogen although there have been recent **developments towards this direction**:

- Following the mid-2020 release of the EU Hydrogen Strategy, **in December 2020, the Greek Ministry of Environment & Energy** announced the launch of a new Committee responsible for the development of **a National Hydrogen Strategy**. The latter will include: a roadmap for the development and use of technologies and applications for hydrogen and other gases from RES in individual energy sectors; the proposed policy measures per end-use sector; the technical and economic data on the cost for the development and operation of applications for hydrogen and other gases from RES.
- In **July 2021, the Regulatory Energy Agency (RAE)** made contact with an **external consultant for the preparation of a study concerning the formulation of the basic principles of the regulatory framework regarding the development of hydrogen infrastructure and the respective market in Greece**.
- In **August 2021**, the **Distribution System Operator** (DEDA in Greek) proposed to RAE the following addition/amendment to the Network Code: To **rename the current "Gas Distribution Network Management Code", to "Network Management Network, Network Management Code of these mixtures", with provision for further modification to include hydrogen (green and blue) in the distributed gas fuel mixtures**.
- In **May 2021**, **RAE** approved an expansion of the natural gas pipeline infrastructure proposed by the Trans Adriatic Pipeline AG, Snam Rete Gas and DESFA (the Greek Transmission System Operator), stating that: *"[..] The project of increased capacity concerning the Greek Natural Gas System, namely the new 30-inch pipeline and the new compressor in Ambeli is expected to work positively for the system as: [..] it will contribute to the achievement of its goal climate neutrality which is a strategy of the European Commission as **it is taken for granted that this new investment in gas infrastructure will support the transport of hydrogen and / or biogas.**"*
- **In early 2021, RAE** reviewing the two most important new projects included in the TSO's Development Plan for 2021-2030, namely the two high pressure pipelines, to Patras and to Western Macedonia, commented that: **natural gas should be considered as a fuel-bridge to green growth**, and that it is appropriate for the extensions of the Gas System a) to take place in the coming years, in order to have a **sufficient depreciation time**, and b) **to support the transport of hydrogen and / or biogas, always under conditions of economic efficiency**.

Infrastructure Plans

For Greece to transition into a hydrogen era, the country should consider the development of production facilities for blue and green hydrogen, the utilization of existing or immediately planned gas infrastructure for hydrogen transport and the development of dedicated hydrogen infrastructure and markets. To this end, certain initiatives are underway:

European Hydrogen Backbone

The Greek Transmission System Operator, DESFA, participates in the **European Hydrogen Backbone (EHB)** initiative which consists of a growing group of now 23 European gas infrastructure companies, working together to plan a pan-European hydrogen transport infrastructure. The EHB has drafted a proposal for a dedicated

hydrogen pipeline infrastructure of 39,700 km to be built up to 2040, to a large extent based on repurposed natural gas pipelines, stretching across 21 European countries (19 Members States, UK and Switzerland). The role of Greece-DESFA in the EHB is described as follows in the initiative's latest report, published in **April 2021**: "*By 2040, Greece's two main industrial clusters in Athens and Thessaloniki would be connected, with new pipelines following the existing natural gas route, repurposing existing pipelines can also be an option depending on market conditions. Storage could be available in the form of an aquifer near the Island of Thasos. The connection to Europe could either go through the seas using the TAP pipeline or via South East Europe. The potential hydrogen cluster in West Macedonia will also be connected to Thessaloniki, near the existing connection to TAP, through the new, hydrogen-ready pipeline in the region, which is currently under development.*"

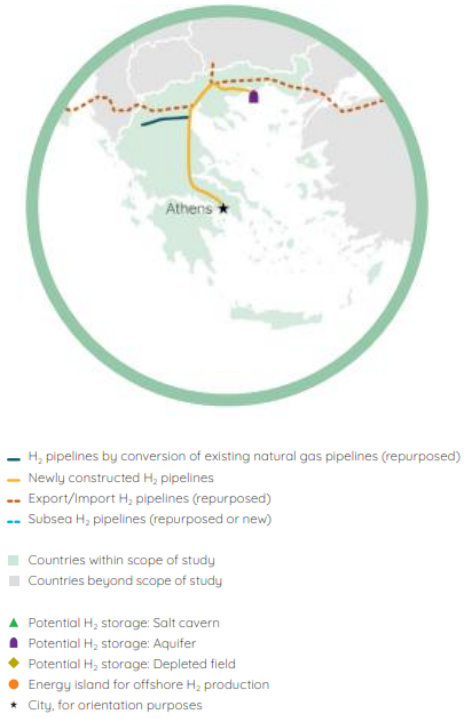


FIGURE 3: THE ROLE OF GREECE IN THE EUROPEAN HYDROGEN BACKBONE

Hydrogen Important Projects of Common European Interest (Hydrogen IPCEI)

In **September 2021**, the Greek Minister of Development and Investments and the Greek Minister of Environment, Energy, and Climate Change approved the participation of **five Greek hydrogen projects in the first wave of important projects of common European interest (IPCEI).** The projects are:

White Dragon: The project involves the deployment of large-scale renewable electricity to produce green hydrogen by electrolysis in Western Macedonia to support the phase out 2.1GW of lignite-fired capacity by 2029.

Green HIPo: This project complements White Dragon and it involves the construction of a plant to produce innovative electrolytes and fuel cells in Western Macedonia. Green HIPo will essentially produce the fuel cells that will power White Dragon's green energy plan.

Blue Med: This project dedicated to production of blue and green hydrogen, to be launched in 2025.

H2CAT TANKS: This project is dedicated to the construction of innovative high-pressure tanks for hydrogen storage, especially for the transport sector.

H2CEM – TITAN: The project comprises the production, storage and use of green hydrogen for combustion to produce energy to decarbonize the cement plants of the Greek firm TITAN.

The 5 projects need to "*prove to the European Commission they are technically and financially mature, in accordance with the IPCEI criteria*" to secure support from the European Union financial instruments.

The Way Forward

Based on the current status of hydrogen related initiatives and discussions taking place in Greece, the following priorities areas need to be addressed, in order to accelerate the deployment of hydrogen technologies in the country:

- The transposition of the **revised RED II Directive into Greek law**. This recent revision sets a new target for renewable fuels in transportation from non-biological origin (RFNBO) of 2.6% (green hydrogen falls into this category of fuels), and a new target for a 50% share of renewables in hydrogen consumption in industry – including non-energy uses.
- The **regulatory framework for hydrogen** should be developed for adaptation of the national natural gas transmission system to allow for blending of hydrogen, and the development of a dedicated hydrogen transmission system. The regulatory framework needs clear roles and responsibilities for the different actors involves, needs to enable the participation of third parties and to structure hydrogen transportation infrastructure tariffs.
- There is a need for a **National Hydrogen Strategy Plan**, providing the clarity and certainty that developers, investors, and lenders need for the widespread interest in deploying hydrogen in the Greek energy market.
- There is a need for clear and conducive **funding mechanisms** for hydrogen projects, as the lack of dedicated funding mechanisms and tools on a national level may prevent potential stakeholders from investing.
- The **technical limitations and opportunities** need to be assessed, for example: Assessment and gap analysis of the National Gas Transmission System to accept and transport hydrogen blends.

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