DO NOT COUNT NATURAL GAS / GAS TURBINES OUT YET
2030 & 2050 TARGETS
ECONOMICS WILL GOVERN

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Abstract

As the concern about global warming intensifies, many countries have embarked on ambitious plans to limit CO2 emission and replace fossil fuels by Renewable Energy plant aided by Energy Storage and Green Hydrogen to cope with the intermittent production of these plants to meet 2030 and 2050 targets. While Solar and Wind technologies have reached reasonable maturity, thus, can be factored in the plans on large scale sound bases with satisfactory levels for investors and financial institutions. In the opinion of the author, Energy Storage and the Green Hydrogen technologies for large scale adoption appear to be lagging (as discussed in the paper) and hence comes the impetus for this paper addressing; ***What backup means we can depend upon****, in the immediate / short term while time is allowed for further development of Energy Storage such as Battery systems and Green Hydrogen (to reach economical Capital and Operational costs without government's support or at minimal support). The author turns to the Natural Gas Infrastructure and the power plants that use Natural Gas yielding least CO2 emissions compared to e.g. oil etc. The paper addresses the advantages of building on the well-established technologies of Natural Gas power plants. It discusses Carbon Capture and utilization and storage "CCUS" as a necessary factor that must be included in the proposed backup plan and advocated this as the most viable solution in the short term. Improving the economics of the Carbon storage and utilization should be top priority. The author opted not to address the key and important topic of regulations and support as other presentations in the symposium will deal with different aspects of this topic including updated information.*

Key Words

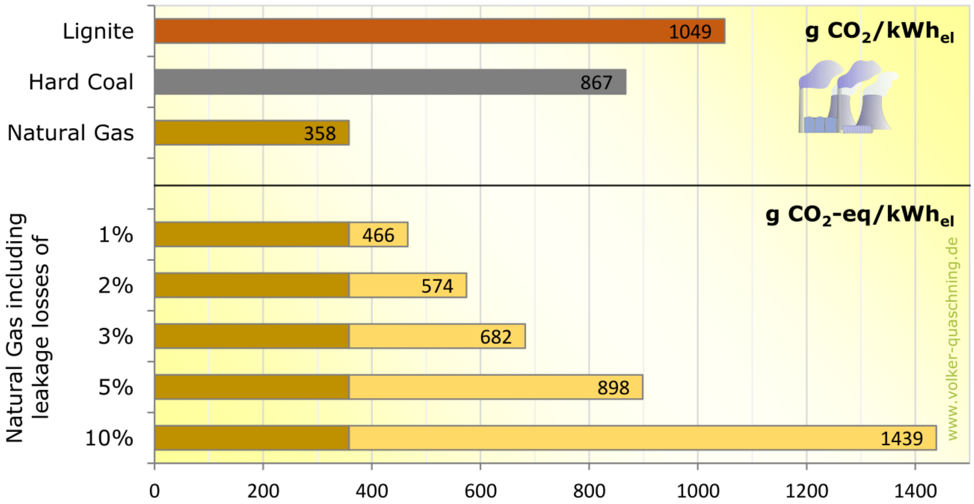
Green Hydrogen, Blue Hydrogen, Energy Savings, Electrical Energy Storage, Natural Gas, LNG, Gas Turbines, Carbon Capture, CO2 transport and storage.

Impetus

The World is geared to combat the excessive increase of the earth's temperature due to Carbon Oxide emissions resulting from burning fossil fuels with the aim to limit the temperature rise to 1.5 C. Please refer to the latest IPCC report Intergovernmental Panel on Climate Change (2023). A global perspective has emerged since the Paris Accord Paris Agreement (2015*)*. This together with the UN sustainability agreement & targets Paris Agreement (2015), energy target #7. Then COP series of meetings with the latest "Dubai Roadmap to Net Zero" (2023). Now globally the World is moving in an overall direction Net Zero 2030 -2050 with countries setting target goals for the reduction of CO2 to specified levels by 2030 and by 2050. Europe and the USA are taking the lead Energy European Commission (n.d.) & Commission proposes 166 cross-border energy projects for EU support to help deliver the Green Deal (Nov. 28, 2023*)* and the inflation Reduction Act (2022) & 7 billion dollars for USA's first clean hydrogen hubs (2023), respectively. Please refer also to IRENA'S Energy Transition To Strengthen Climate Action Report – Insights to Impact (2023).

Recognizing that the World has built its economies on the use of fossil fuel with related infrastructures in various countries accordingly since more than 100 years in many countries. For each country the energy uses span industrial, transport, and the electricity system. In the industrial sector burning fossil fuel provides most of the required energy together with a small percentage electrical energy that has shown increased trend in many countries. For transport in general we deal with aviation, marine and onshore transport. For aviation the dominant fuel the jet fuel, for marine over many years heavy fuel oil and more recently LNG for some transport ships. For onshore transport, trucks and locomotives commonly used Diesel as the fuel of choice and in the last two decades Natural Gas "NG" as CNG "Compressed Natural Gas" gained popularity. Electricity gained large penetration in trains a and public transport. In the last ten years we saw positive trend of increased electrical vehicles. This trend can also be seen in private cars. In the onshore transport, we can see two directions that are directed to reduce CO2 from transport, i) Electric Cars – where batteries are charged from the electricity source (on the Electrical System) through EV charging stations, ii) Hydrogen cars - vehicles are modified internal combustion engines to burn Hydrogen and a new Hydrogen filling stations. The concern about CO2 was behind moving away from coal and oil and increased dependence on Natural Gas. This can be easily understood from Figure 1 that shows the approximate emissions from different fuels. Among fossil fuels Natural Gas has the lowest emissions.

Figure 1 extracted from Volker-quaschning Germany CO2 from different fuels (n.d.)



Please note the bottom part of the figure which underlines the importance of avoiding Methane leakage (addressed later under section 4.4).

So far, we concentrated on burning fossil fuels for industrial and transport applications. We note the form of energy released from burning fuel is the chemical energy in the fuel a fossil fuel is a hydrocarbon fuel and the. Carbon content is giving the undesirable CO2. This energy is a lower grade energy compared to electrical energy which is versatile and have been a dependable means for populations of most countries in their daily life and in all enterprises.

Let us turn to the Electrical System "ES" in a country or a region. An ES is composed of three subsystems, generation, transmission, and distribution. The generation is where the power plants are and in the last century typically fossil fuels were burned in steam plant, internal combustion engines (reciprocating, and, gas turbines and combined cycle configurations. Mostly, we saw central generation i.e. the electricity was the prime output of the power plant. In the last part of the 20th century, we saw cogeneration (use of heat from the exhaust gases for district heating or desalination) and distributed generation where smaller capacity power plants were installed in locations close to load centers. Also, hydro power plants and nuclear plans were included in the generation subsystem. ES's emerged to robust and dependable means for the economies, with the unidirectional flow of electricity from the generation to the High Voltage "HV" Transmission. The HV include main transmission lines and substations to lower the HV to medium voltage that could supply major users. The Transmission subsystem connects to the distribution subsystem. In the latter the users (residential, commercial, and industrial etc.) are connected at medium voltage "MV" or low voltage "LV", the subsystem is LV electrical cabling and substations to reduce to MV level. An ES has an extensive safety, security, and monitoring & control features. It is noted that for nearly 3 decades now, private power generation (power plants owned and operated) has flourished. Also, in many countries the distribution subsystem has been privatized. With the emergence of wind and solar electrical generation, because of the intermittent operation of these Renewable Energy source, a lot of changes have taken place in ES's, the unidirectional characteristic now has been replaced by multi electricity direction flows as now renewable energy connects to distribution and transmission lines. Also, electrical storage energy storage systems. These changes required substantial digitization. These features have had a profound change in the electrical system that has led to considerable expenditures and required funds.

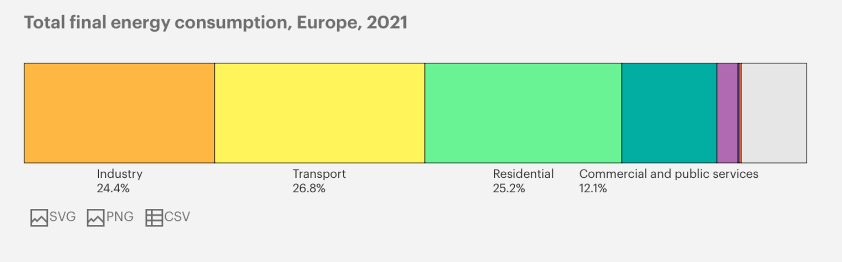
In parallel due to the interest in Natural Gas "NG" that grew in the last fifty years, we see NG Systems "NGS's" that have been constructed transporting gas to users such as power generation plants. They take similar forms like the ES's NG comes in at certain nodes (terminals) and through main pipes it flows to reduction stations then to distribution piping onwards to the users e.g. industrial, commercial, residential, and power plants. The NGS's have compression stations and pressure reduction stations in different

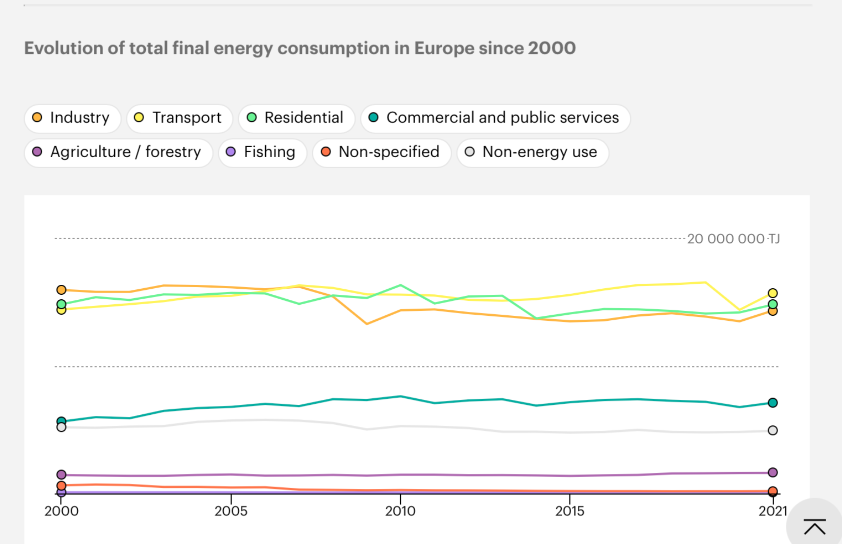
points similar to the substations in the ESs. In some instances, storage of Natural Gas in large Vessels or caverns is included. Also, CNG compressed natural gas produced at compressing facilities became available for distribution to support vehicles and other purposes. Further, the interconnections of the national systems from different countries allowed import and exports across national borders. One can say the ES's are dealing with transport of electrons and the NGS's transport molecules, both are supporting the energy needs in a country or a region. The ES's and the NGS's have grown to be robust and quite dependable in supporting critical needs of energy for the economy of countries.
From the foregoing one can see that in the big picture, we want to replace the fossil fuel generation by renewable electrical "RE" plants. Another objective is to use hydrogen as fuel instead of fossil fuels that contain carbon. In this regards the following options have been identified and are being investigated on different levels, I) Green Hydrogen based on electrolysis of water splitting it into Hydrogen and Oxygen, II) Blue Hydrogen that is produced from chemical plants that use Natural Gas as Feedstock and produce Grey hydrogen as part of its operations (e.g. some fertilizers plants), the Blue Hydrogen plant incorporates a Carbon Capture Storage "CCS" scheme to avoid emission of CO2 in the air, III) Biogenic Hydrogen from Municipal waste, woody and waste water. for this solution CCS is needed.
The bold text sums up what the World is trying to accomplish by 2030 – 2050. Because of the multitude of interdependences and the details of implementing these general directions in relatively short times (less than 6 years till 2030 and about 25 years till 2050), to effect significant modifications in the ES's infrastructure that took the order of 100 years to build and develop. Significant challenges in new regulatory laws and provisions to deal with a lot of new circumstances. RE technologies wind and solar have reached a good maturity over the last two decades, with ESS making good progress for short duration battery storage. New technologies (particularly in Hydrogen production, CCS need to be refined to reach commercial large-scale level that get the acceptance of the financial institutions and earn confidence of developers to undertake projects with plants lifetime of 20-25 years under reasonable risks.

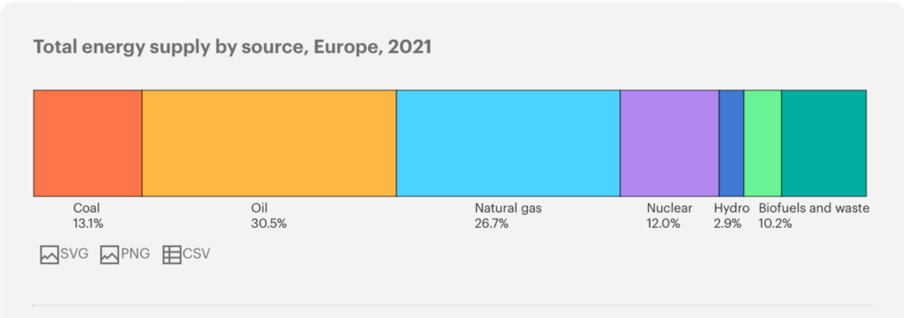
Introduction
After providing the perspective behind the investigation covered in this paper in the previous section **Impetus**, the author presents the order of the contents in this paper. In the following section some **Useful Indicative Statistics** primarily for Europe, Greece and USA are noted. Then in the section entitled; **On the path towards 2030-2050 - Where are we in early 2024? – Review,** a review of selected 14 items covering topics and concerns that have received considerable attention in the massive global effort that is underway towards defining the path of the Net Zero by 2030-2050 is summarized. The discussions concentrate on onshore Energy use and Electricity. The author excluded the coverage of policies and regulations as these topics will be covered in other sessions of the HAEE Symposium 2024.Then, building on the contents in the **Review**, the author numerates key points that leads to the thrust of the paper's theme in the two sections that follow. These are:
Natural Gas and Gas Turbines Challenges– Carbon Capture, Economics. Additional sections address comments on two topics **Waste, Economics Knowledge – Energy – Capital versus Energy Economics** follow**.** Finally, the section **Concluding Remarks** summarizes the author's outlook and presents some recommendation.

Useful Indicative Statistics
Figures in this section are organized in the following order (categories); (1) Energy Evolution / Energy Mix, (2) Electricity Evolution / Electricity Mix, (3) Intensity per GDP, (4) CO2 Emissions, (5) CO2 per Capita.
The figures are designated under common number 2 – followed by the category number. The figures are extracted from the IEA Countries (n.d.) website. For each category the data for Europe is introduced first, then Greece's data follows. For two categories #2 and #5, the USA data have been included at the end of the category.

Figure 2 (1) Europe Energy Evolution / Energy Mix







Largest sectors in final consumption in Europe, 2021

Transport
27%
of total final energy consumption

Residential
25%
of total final energy consumption

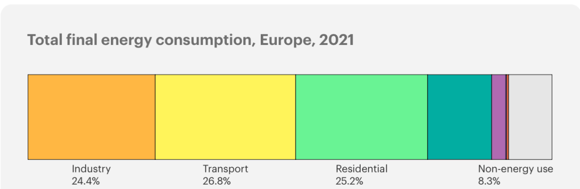
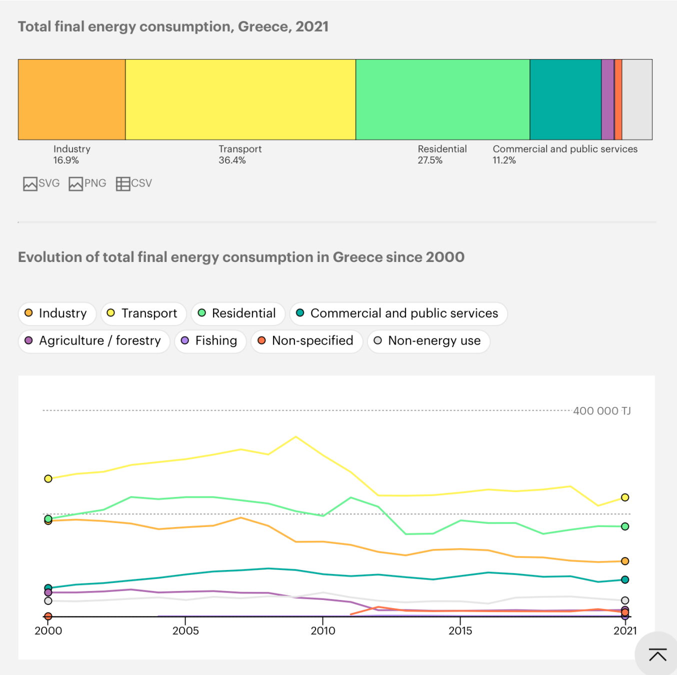


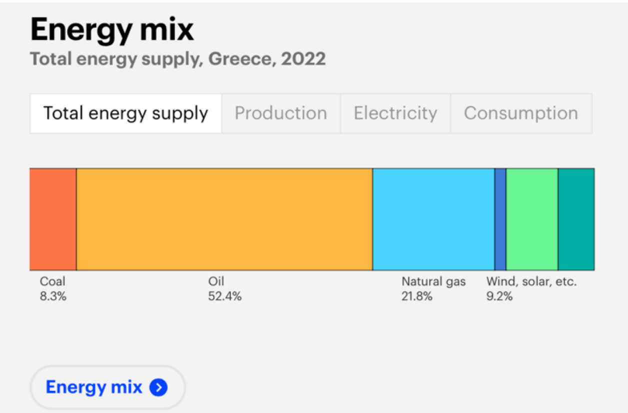
Figure 2 (1) Greece



Largest sectors in final consumption in Greece, 2021

Transport
36%
of total final energy consumption

Residential
27%
of total final energy consumption



* Figure 2 (2) Europe Electricity Evolution / Electricity Mix

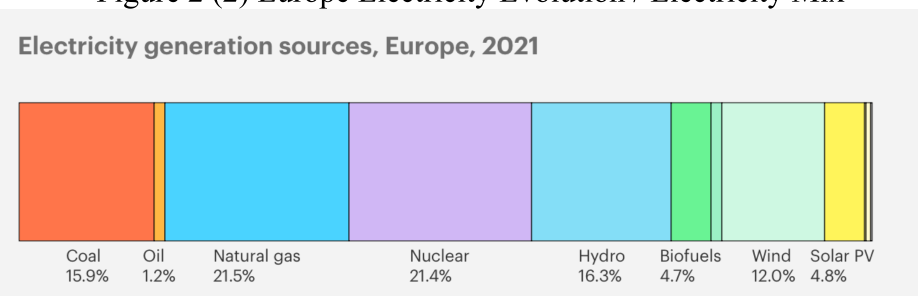
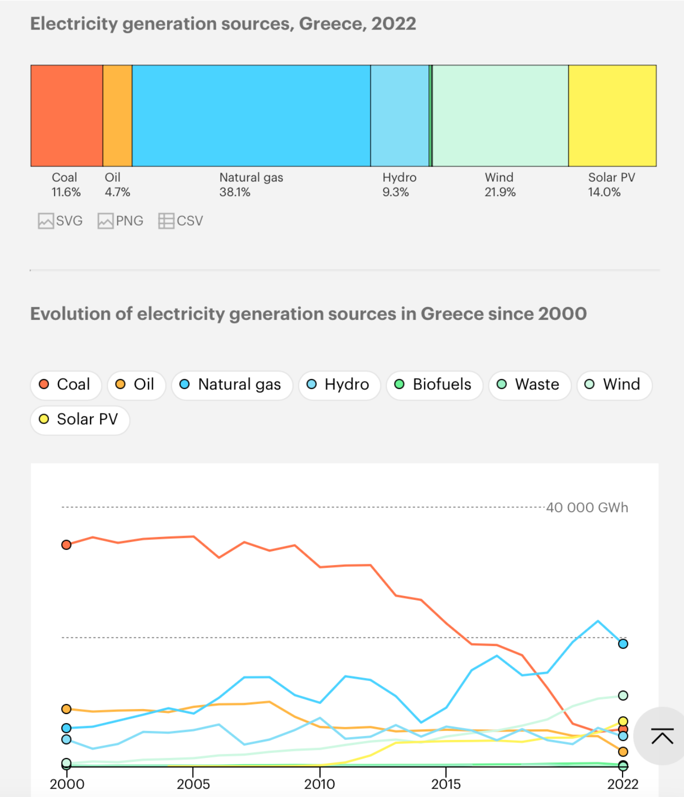


Figure 2(2) Greece Electricity



Total electricity production in Greece

Total, 2022

49719

GWh

Trend

↓8%

change 2000-2022

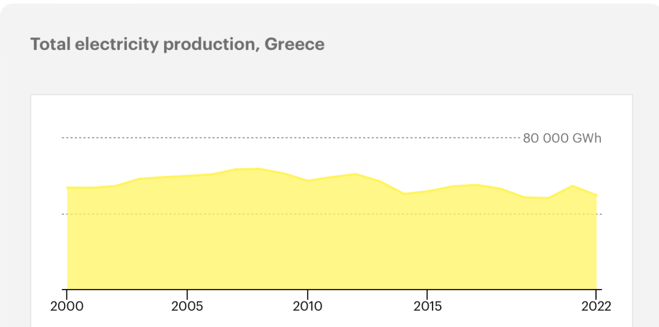
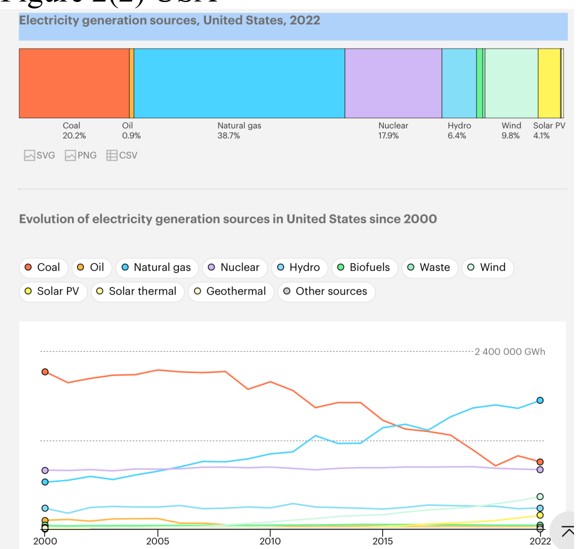


Figure 2(2) USA



* Figure 2 (3) Europe Energy Intensity per GDP

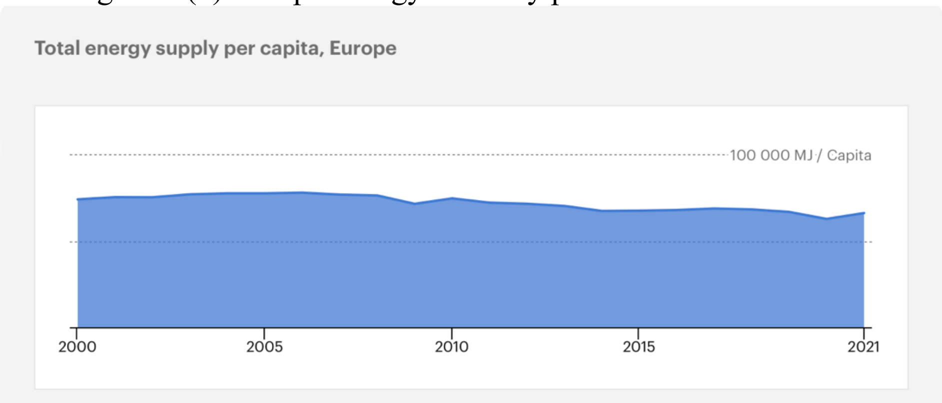
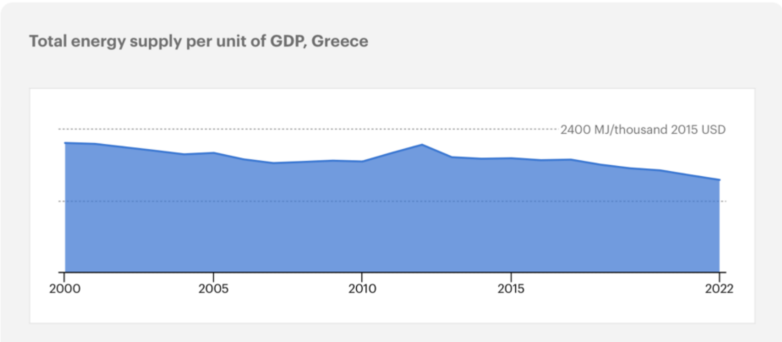


Figure 2 (3) Greece

Total energy supply per unit of GDP in Greece

Total, 2022	Trend
1551.966	**↓29%**
MJ/thousand 2015 USD	change 2000-2022



* Figure 2(4) Europe CO2 Emissions

CO2 emissions from fuel combustion in Europe

Total, 2021	Trend	Global share
7479.821	**↓18%**	**22%**
Mt CO2	change 2000-2021	of total, 2021

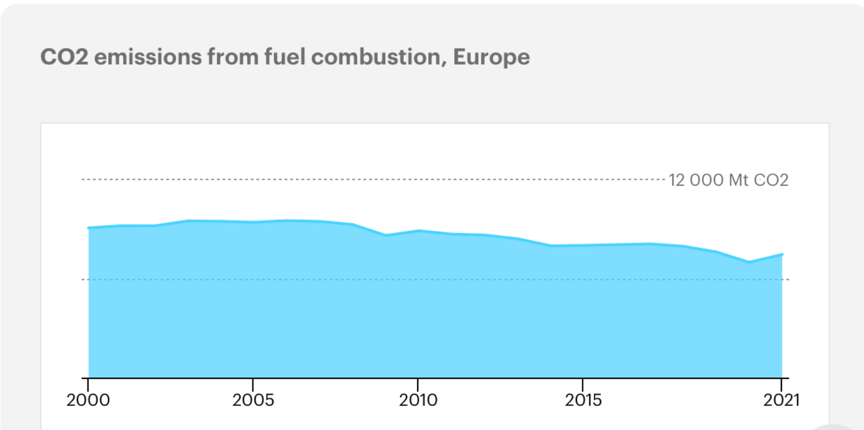
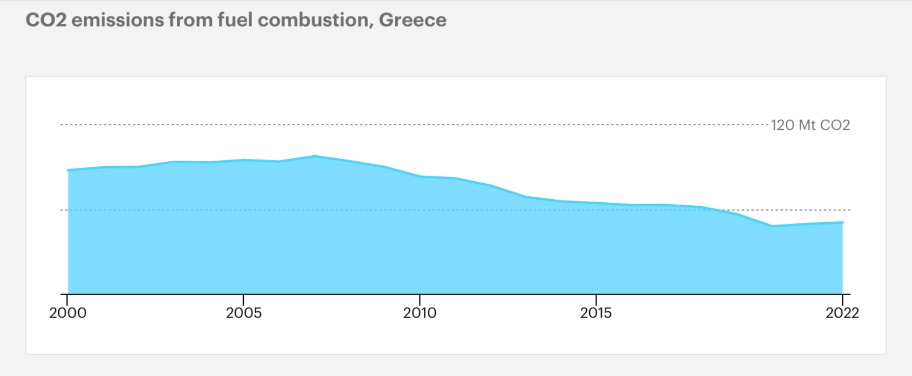


Figure 2 (4) Greece



* Figure 2 (5) Europe CO2 per Capita

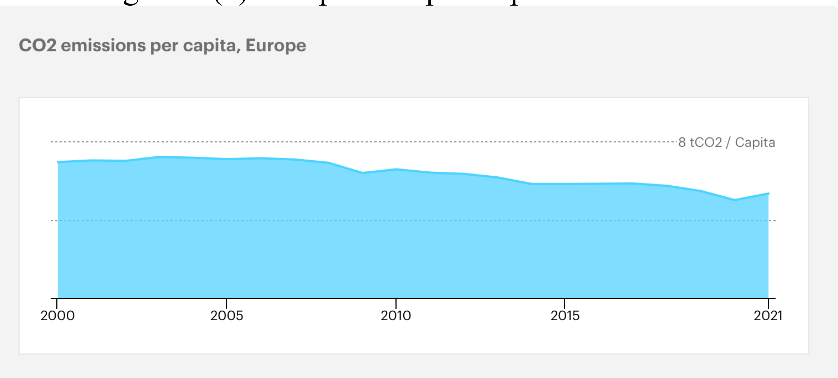


Figure 2 (5) Greece

CO2 emissions per capita in Greece

Total, 2022
4.794
tCO2 / Capita

Trend
↓41%
change 2000-2022

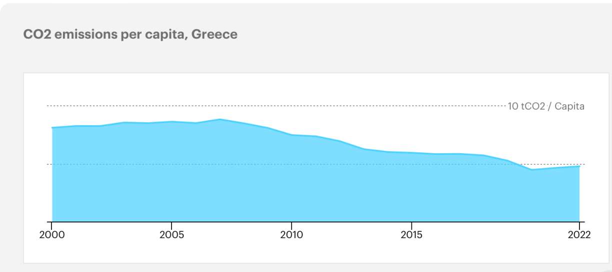
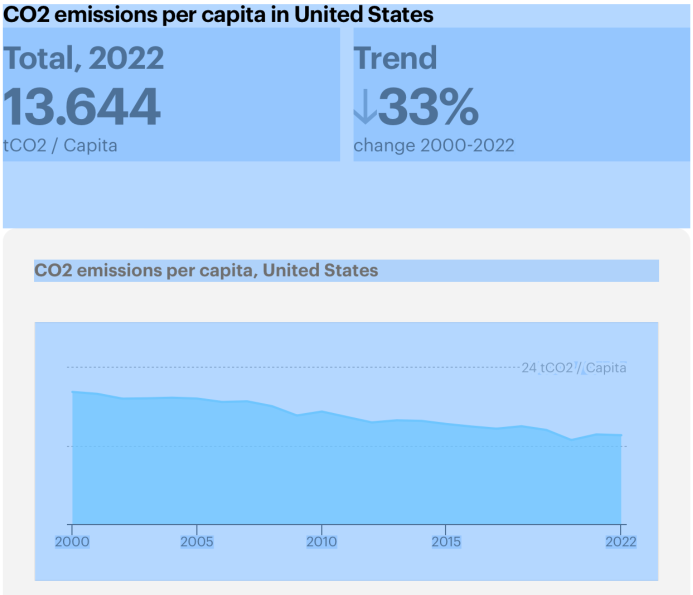


Figure 2 (5) USA



On the path towards 2030-2050 - Where are we in early 2024? - Review
The author turns to examining some details on different technologies that are under development based on information he has gathered, adding comments of his personal assessments.

1. RENEWABLE ENERGY "RE"
   CO_2 Emission: Under RE during plants operation, there is almost no CO_2 emission, very small amounts could be from getting electricity from the grid at night or times of no renewable energy received to operate systems that must keep running. There is small related (indirect) CO_2 associated in the production of the spare parts, consumables etc. and transport of these items. During the plant construction, there is CO_2 in the manufacturing of the equipment and bulks, transport of these from the manufacturing facilities (in country of production, then in marine / or air transport, and finally transport in country of the plant), plus CO_2 in the construction and testing. All effort is being made to minimize these emissions.

1.1 Solar:
Over the last 15 years Photo Voltaic "PV" made remarkable advancement, including reaching higher efficiencies for the PV panels, larger size with larger capacities. The PV panels, inverters, transformers, mounting structures, cleaning equipment, electronic controls and other components reached excellent levels. Also, the use of trackers and bifacial PV panels gained acceptance accompanied by economic advantages. All with continued reduction in prices, however, the prices, but it appears that the further reductions will not be as high.
Price volatility due to supply chain difficulties in recent years was encountered which impacted some projects schedule. The above statements are focused on stand-alone PV parks with large capacity. A drawback of PV of this type, is that large land area is required. PV parks suffer from cloudy intervals and the absence of production night-time. The variability of the irradiation during the day and in different seasons govern the electricity production (the supply) which may not match / coincide with the demand. This has underlined the storage of the electricity, please refer to ESS below. What is very positive for PV parks, now the maturity of practically all aspects for project developments are well established including site selection, permitting, EPC and dependable prediction of performance. All of this has facilitated and helped growth of wide range of project developers and investors that are also getting support from financial institutions in project financing for long term loans – 20-25 years. For large projects e.g., 100 MW capacity large areas are needed and mostly these areas with low land price are far from the electric grid giving rise to complications related to the readiness of the transmission system and the energy loss between the point of production and the point of use. In some instances, congestions in the transmission and distribution subsystems do not allow connections of new RE Plants. It is noted that the PV panels manufacturing

has grown to be dominated by Chinese Companies. Greece can evaluate Floating PV as the an application that has evolved in the last five years.

Greece is blessed with excellent irradiation among the best in Europe, yet because of the low intensity of the irradiation in central Greece where land could be available 1 MW requires about 4000-5000 m2. Not many PV parks have been built at the Greek Islands. In northern / central and south Greece one expects a specific average annual production of the order of 1200 /1500/ 2000 kWh per kW-installed.

1.2 Wind

Please refer to GWEC Global Wind Report (2024) for a compressive update of the wind industry.

Over the last 20 years, wind projects were built in many parts of the World onshore and later offshore. The capacities of the wind turbines haves grown from few kW to 10 MW.

The growth in sizes saw introduction of large turbine blades of the order of more than 50 m, the wind turbine towers reached more than 180 m. A wind turbine has a generator that converts the mechanical energy of the blade's rotation to electricity. The wind projects require choice of locations with strong wind speeds and mostly these locations are away from towns and on higher elevations top of mountains / ridges giving rise to challenges in transporting the large size components to these locations. To start a wind project, metrological measurement campaign must be undertaken, which take the order of two years. Then the engineering of the project, addressing the selection of the Turbine type / manufacturer and undertaking the design of the wind farm to avoid interference of wind turbine to another. (vortex effect), this leads to large spacing between the different turbines in the wind farm. The design of the components of the wind turbine takes care of excessive wind loads under storms. Then comes the electrical interconnections of the turbine-clusters and finally, to the medium voltage lines leading to the electricity evacuation point(s) from the wind park. Permitting takes considerable time and the connection to the grid also is complicated in some cases. Very large parks have been operated successfully and the wind industry led by world class manufacturers have established good record that has the confidence of the financial institutions. We can see in good locations load factor as high as 40-60% and in exemptional cases even higher.

In some situations, public opposition to Wind Parks was encountered because concerns of the noise and antithetic objections.

Greece has many wind parks. Some plants have operated successfully for more than 20 years. There are several projects under development. Please note in 2022. Wind contributed nearly 22% of Greek's electricity production.

1.3 Electrical Energy Storage EES

A good resource for updated information is European Association Storage Energy (n.d.)

The needs for Energy storage could be on the ES grid network, or at the generation plant, particularly, RE plants solar or wind. The ES has to supply the demand at any time, this is handled through the dispatch of the available generation units. The NG plants provide considerable flexibility compared to solar and wind that have large variations due to the variability of solar irradiation or the wind speed. Though techniques to predict weather conditions and plants now enable accurate dependable plants production help in dispatching the various available plants including RE's. The dilemma that is usually faced, is to curtail the plant output (not use a portion of the output for some duration say in the day). Obviously, to sacrifice some of the output is not a good solution. This gives an intensive to collect the curtailed energy for storage (that is charging time for an energy storage system) with the planned discharging of the stored energy when there is needed demand – usually at peak grid loads. Typically for grid supporting residential usage the early hour of the evening is hen the peak demand occurs.

1.3.1 Electrical Battery Storage

Electric battery storage systems have three components – battery stack of cells, electronic management system for the battery stack and lastly control system for the integration with the the wind plant and the grid. Lithium-Ion batteries have evolved to be the most used at this time. Good progress in reducing the prices of battery storage systems, however, more is needed. The price level per KWH has reached $ 250-500. The drawback of the Battery Storage it is only suitable for short durations say the order of 2 -4 hours. The high ambient temperature is detrimental for the lifetime of the battery, so are the deep discharges.

1.3.2 Conventional Energy Storage

In some countries, pump storage has been adopted (refer to the discussion under section 3.3). Also, Compressed Air system has been used, where excess power generated is used to compress air that is charging air in an underground cavern. When there is need for power, compressed air is taken from the cavern driving an air expander that has an electric generator thus

1.3.4 Mechanical - CO2 Dome Storage

Innovative new storage system that uses CO2 thermodynamic cycle. Dome Storage (n.d.)

Additional innovative concept: NREL USA Sand for Energy Storage (2024)

The efficiency of storing and recovering electrical energy could be of the order of 60-75%, but that is not bad if there was no direct use of the electrical energy that is stored (in case of curtailed energy) and recovering that energy at peak demand. The CO2 emission is very small (indirect CO2). These are positive, the cost is where the difficulty comes.

2. HYDROGEN

The reader is referred to Energy Efficiency Renewable Energy -USA Hydrogen Production (n.d.) for a comprehensive coverage of Hydrogen production technologies.

Hydrogen combustion produces water and with no Carbon there is no CO2 emission.

As in Item 1, there are small CO2 emissions in building H2 plants and during the operation and maintenance of the plants. For Blue Hydrogen the level of CO2 emissions is higher than that of the Green Hydrogen

2.1 Blue Hydrogen

Several industries such as Oil and Gas and Fertilizers produce Hydrogen from NG The produced H2 is based on well-established chemical processes that have been widely used in large scale production for many years. This Hydrogen is referred to as grey Hydrogen.

However, by introducing Carbon Capture to the plants (existing or new) the inherent CO2 produced from the Carbon content in the NG is not released to the atmosphere. This approach builds on solid production processes and in some countries with large facilities already existing or has low-cost NG the economies of the Blue Hydrogen will largely influenced by the backend Carbon Capture adopted. Countries in the MENA area such as Saudi Arabia and Egypt have competitive advantages for producing blue Hydrogen. Blue Hydrogen from MENA can be exported to Europe the transport considerations come in to play ad well as importation regulations.

2.2 Green Hydrogen

Produced in an electrolyzer through splitting of water into Hydrogen H2 and Oxygen O2 using. electricity produced from RE. The biggest hurdle is for the production of Green Hydrogen is the specific electricity required is of the order of 50 to 55 kWh/kg of produced H2. R&D being conducted by many companies to lower this value.

To bring close to the reader the significant challenge that Green Hydrogen faces today, please refer to the simple example below:

PV Panel efficiency (average over time)	15.00%	
Eff. of transmission of electricity in Solar Park	87.00%	
Overall Efficiency for the solar Park	13.05%	
From Solar Park to H2 plant	85.00%	

Overall Eff. From Solar Irradiation to H2 Stack	11.09%	
At Stack Input - Electrical Energy - 1kg H2	55.00	kWh
At Stack Output - Chemical Energy - 1kg H2	33.30	kWh(LHV)
Efficiency of the H2 stack	60.545%	
Overall Efficiency from Solar Irradiation to H2	**6.72%**	

One notes an overall efficiency of the order of 5%. This where the problem is.
Two major technologies are used:

2.2.1 Alkaline (operate at less than 100°C)

Producing H2 using Alkaline has been in around for many decades. In this type, an Alkaline electrolyte is used between the anode and the cathode. Alkaline electrolyzers operate via transport of hydroxide ions (OH^-) through the electrolyte from the cathode to the anode with hydrogen being generated on the cathode-side. Electrolyzers using a liquid alkaline solution of sodium or potassium hydroxide as the electrolyte have been commercially available for many years. Newer approaches using solid alkaline exchange membranes (AEM) as the electrolyte are being investigated (early development).

2.2.2 PEM (operate at 70°–90°C)

This is Polymer Electrolyte Membrane design. Near the anode water reacts to form oxygen and positively charged hydrogen ions (protons). The electrons flow through an external circuit and the hydrogen ions selectively move across the PEM to the cathode. At the cathode, hydrogen ions combine with electrons arriving from the external circuit to form hydrogen gas.

Anode Reaction: $2H_2O \rightarrow O_2 + 4H^+ + 4e^-$ Cathode Reaction: $4H^+ + 4e^- \rightarrow 2H_2$

In a H2 production plant in addition to the stacks outlined above, the plant has the BOP (Balance of Plant), there is the electric transformers / rectifiers converting received AC electricity to low voltage DC suitable for the operation of the cells of the stacks. Further there is the water supply system including water purifications if needed. On the downstream side is the H2 compression (to pressure depending on the use), and storage. Electronic Controls for the monitoring and control of operation. The offtake arrangement dictates the details of the delivery of the produced electricity. In most cases the produced Oxygen is flared, but in some instances, it is monetized (O2 economics on a case by case).

Over the last two years several companies have advanced their technology as well as manufacturing for the cells that are combined into stacks. The direction for increasing the capacity has been to add modules of the stacks. It appears that there is difficulty in scaling up the dimensions of the cells. The PEM appears to have gained momentum in the USA and Europe while the Alkaline electrolizers are being favored in China. A challenge for producing green hydrogen, is the fact that tthe electrolyzers do not tolerate fluctuating supplied electricity (being the case for PV solar or wind which has appreciable changes). Like many chemically based processes they operate under steady regime. PEM appears to tolerate some fluctuation in comparison to Alkaline electolyzers. It is noted that presently the capacities of PEM modules offered by manufacturers capacities are rather small 1 / 2.5 / 5 MW. Thus, this is a drawback in addition to the high specific power noted earlier that is hindering the Green Hydrogen growth.

2.2.3 Other Solid Oxide Electrolyzers SOE (operate at about 700°–800°C)

Other technologies that are still in early stages of development, R&D, pilot plants SOE uses a Solid ceramic material as the electrolyte that selectively conducts negatively charged oxygen ions (O2) at elevated temperatures. Hydrogen is formed: Steam at the cathode combines electrons from passthrough the solid ceramic membrane and react at the anode to form oxygen gas and generate electrons for the external circuit.

2.3Transport of Hydrogen

The transport of H2 in gaseous state represents two major challenges, i) because of its low density, its specific volume is quite high, leading to large diameter for the piping compared to the sizes of the piping for NG for the same mass flow rate, ii) Hydrogen renders the walls of the steel pipes to brittle walls. This leads to need to use of special materials and that is extra cost. The reaction of the Hydrogen with steel represents big challenges for the fittings such as valves as well for compressors. Safety considerations are noted because the explosive H_2-O_2 reaction if not controlled.

Other schemes have been proposed and are being tried at early stages of deployment. These include:

a) Liquefaction of H_2 through cryogenics – large electric consumption and need to keep the piping very well insulated because the very low temperatures of the liquid hydrogen but the liquid means smaller pipes. Yet the regasification of liquid hydrogen at the point of use is an additional burden.
b) Absorbing H_2 in compounds – solid or liquid and then regenerating H_2 at the point of receipt. This may be suitable for short distances; the recovery of the absorbents is another difficulty with additional costs.
c) In some cases, the production of Ammonia "NH_3" at existing facilities or even new ones, could make transport/export of NH_3 an economically viable transport means. Since NH_3 transport has been in wide use both onshore and via marine vessels. At the receiving end breaking the NH_3 into H_2 and N_2 through a reformer process takes place. This approach is promising, but if the source of the NH_3 is from the MENA region into Europe, there are still some hurdles to be worked out including economics, details of CO_2 accounting etc. The experiences of the chemical industry provide good resources.

2.4 Storage of Hydrogen

Similar to the 2.3 the challenges of Hydrogen storage face the same items i) and ii). The practice the chemical industry provides good base to build on. Storage for different durations, quantity, compression and if transport to other destinations involved require proper attention. Safety is of prime importance.

2.5 Hydrogen Derivatives

Under this title Sustainable Aviation Fuel "SAF" comes. SAF is a jet fuel that have minimal carbon and is produced from H_2. Many approaches are being pursued based on Green Hydrogen, Blue Hydrogen and biofuels. It is vital for reducing the aviation CO_2 emissions. This item has received considerable attention among airlines.

In the last two years, marine industry is taking serious steps to also reduced CO_2 production of ships sailing in the seas.

>>> Per IEA Global Hydrogen Review Report (2023), the overall progress for Hydrogen is lagging. and the 2030 goals may not be reached.

2.6 Fuel Cells

Fuel cells primarily use chemical energy from fuels to directly convert it to electricity without combustion. They generally command higher efficiency compared to internal combustion engines. For this paper just to complement the hydrogen brief above, we highlight one kind of Reversible Fuel Cells. These produce electricity from Hydrogen and Oxygen, let us say opposite to the electrolyzer. They can serve as electricity storage an alternate to battery storage systems discussed 1.3. The reader is referred to a comprehensive information about Fuel cells in: Energy Efficiency Renewable Energy -USA Fuel Cells (n.d.).

3. HYDRO

Hydro plants use well established technologies and proven practices. Many locations that afford the appropriate topography allowing for difference in height between a mountain and a valley plus a suitable location like lake that traps water in an upstream reservoir. From the upstream reservoir water flows into the intake of a hydraulic turbine with an electric generator. This is a very simplistic outline, In addition, there are many equipment included in the balance of plant “BOP” to support the operation of the plant.

Suitable sites generally are far from the demand location and hence similar challenges as noted under Wind (section 1.2) are faced. The permitting and environmental studies mostly take long time. Around the world, the majority of good locations for mega or large projects have been exploited already. There are issues concerning the effects on water use for agriculture and in some cases water resources redistribution between countries.

3.1 Large Projects

Suitable sites for large projects are hard to find, some may be still available in Africa, Large Hydro projects can deliver significant CO2 avoidance. Difficulties of funding hamper their development in some instances, there could be potential for conflicts among countries. These projects take long time to realize.

3.2 Medium / Small Projects

These projects require selection of the appropriate sites, in many countries only few new sites may be available. The new projects are faced with more complex social & environmental concerns. Such projects should be encouraged.

3.3 Hydro Storage

In some locations there could be site that has appropriate heigh difference together with possibility of creating economically suitable reservoirs upstream and downstream of the hydraulic turbine/pump combination T/P – electric generator/motor could be installed. The idea is to use times where electricity in the grid is more than the demand (off-peak) to pump water to the upper reservoir (in that case the T/P is running as a pump). On the other hand, when the electricity demand in the grid is high with respect to the supply, the T/P operates as a turbine.

4. NATURAL GAS

4.1 Heavy Industries

In recent years NG use replaced Oil and coal in many industries, we address the hard to abate burning of NG in the important industries, Steel, Cement, Petrochemicals, fertilizers and Glass. The NG energy is the heat of combustion that produces high temperatures that are required of the processes. For these industries there is major need to tackle the CO2 emissions. Two approaches are being investigated. Use of Hydrogen to replace NG or mixing NG with H2. The other is carbon capture scheme. Both approaches add costs to the products that need to be weighed to enable the enterprise to stay competitive.

4.2 Power Generation

In the last decade of the 20th century NG became the preferred fuel for new power plants and there was major growth in the Gas Turbine GT industry with advent of larger GTs with bigger output, the industry produced GTs that ha flexibility to burn different fuels and also are able to meet different dispatches with short response times enabling meeting peaking operation and intermediate operation beside the base load operation. Further Combined Cycle “CC “where steam turbines were added in which steam produced in Heat Recovery Steam Generator “HRSG” that used the hot gases in the exhaust of the GT, dominated applications in many countries. CC plants had increased the efficiency. Also, NG was used in Reciprocating Internal Combustion Engines replacing the dominance of fuel oil engines, however, the penetration of NG in Marine applications was limited except for LNG Vessels. Also, newer larger conventual steam plants used NG. Thus, we can say that NG became the fuel of choice in Electrical Power Generation. These plants reached excellent reliability that enabled the ES to meet very demanding characteristics due to the fast trends of digital controls that emerged in various uses of electricity. The robust performance of the equipment helped in bringing large investments as the confidence of the developers /investors, and financial institutions and insurance companies increased. As a result, the generation subsystems of the ES in various countries saw modern

NG plants replacing older power plants and meeting increased loads as the economies in many parts of the world saw continued growth. The inherent draw back of the CO2 emissions in these plants represent a major obstacle in the energy transition.

4.3 Gas Turbines / Internal Combustion Engines / Conventual Steam Turbines

It is worth examining the. Composition of the products of combustion in the commonly found types of NG burning power plants. The key point is the Air to fuel Ratio “A/F”, i.e. mass of in kg used per kg for NG in the flows into the a) Combustion Chamber of the GT, b) Internal. Combustion Reciprocating Engine, and c) Boiler of Conventional Steam Plant. Typically, The values for A/F are:

Gas Turbines 40 -80 – lower value is for Large GTs
CNG Internal Combustion Engines 10-20
NG Fired Boilers 10

Recognizing each of these types depending on the capacity of the plant, the capacity in MW is specified. Each plant has its own thermal efficiency, the Rated A/F, then we have deterioration with the aging of the plant, and the partial load usually is accompanied by drop in the thermal efficiency.

4.4 Methane Leakage

In recent years there were few events of significant amounts of leakages of Natural Gas from pipelines. These gases ended up burning into the atmosphere adding to the CO2 emissions.

4.5 NG Power Generation -Technical Characteristics

From the discussions above, we can see NG has evolved to a principal factor in many electrical systems in the world with a lot of advantages, exhibited by the plants noted under 4.2 and 4.3, yet all of the strengths that have been explained now are challenged because of the CO2 emissions. Thus, we examine the exhaust gases that leave the various power plants in order to investigate the CO2 capture to avoid CO2 in the exhaust gases going into the atmosphere.

Greece’s National Natural Gas System and Natural Gas fired power plants.

Figure 3 National Natural Gas System in Greece – DESFA (n.d.)

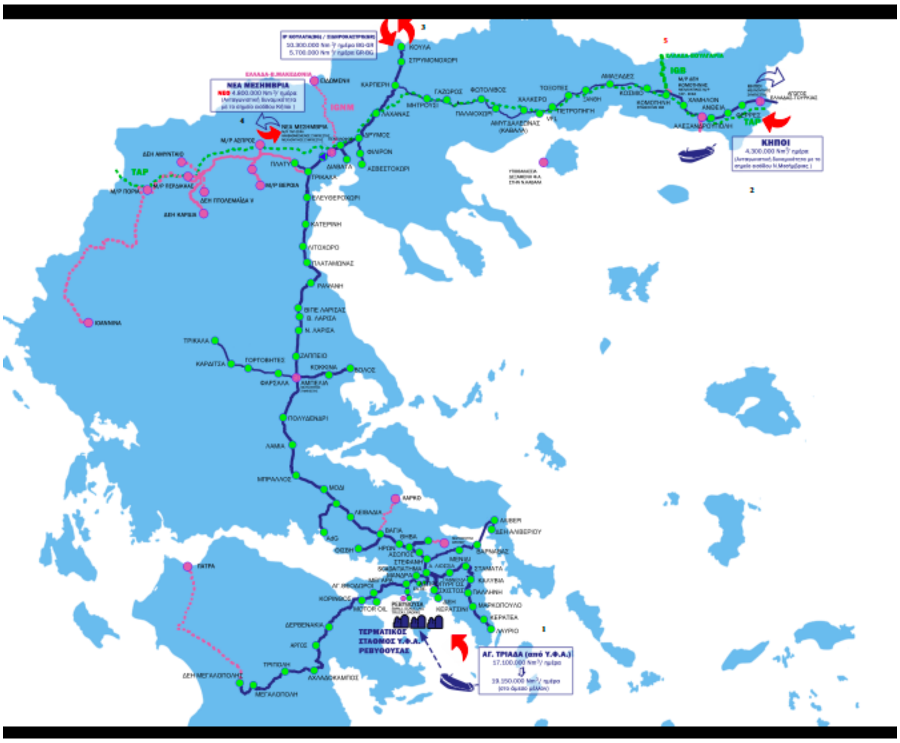
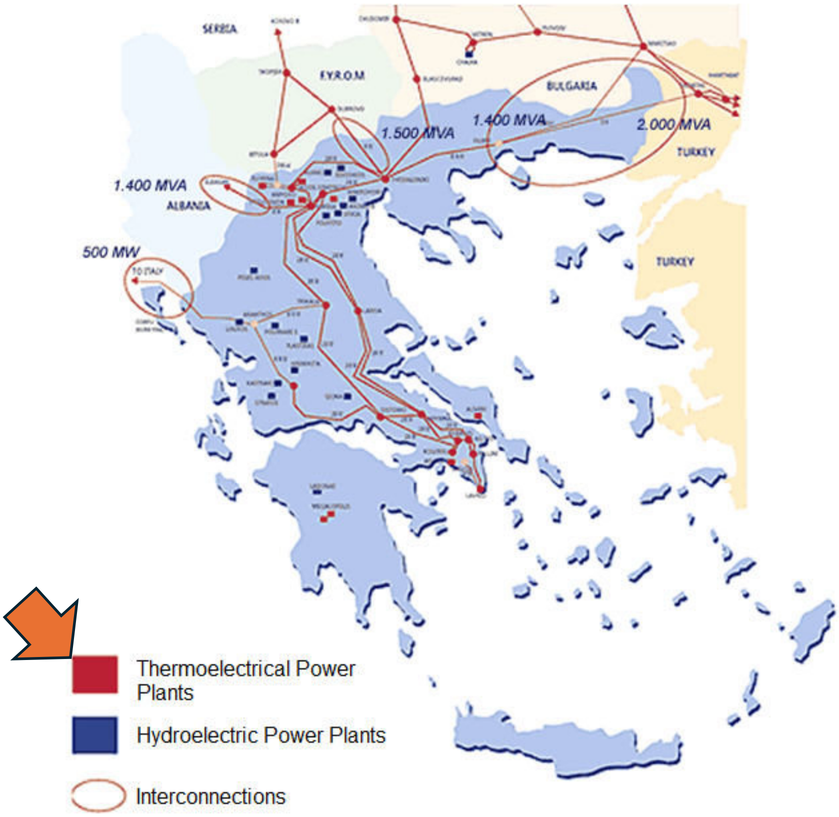


Figure 4 Electricity Map of Greece – DEI (n.d.)



5. H2 AND NATURAL GAS MIX

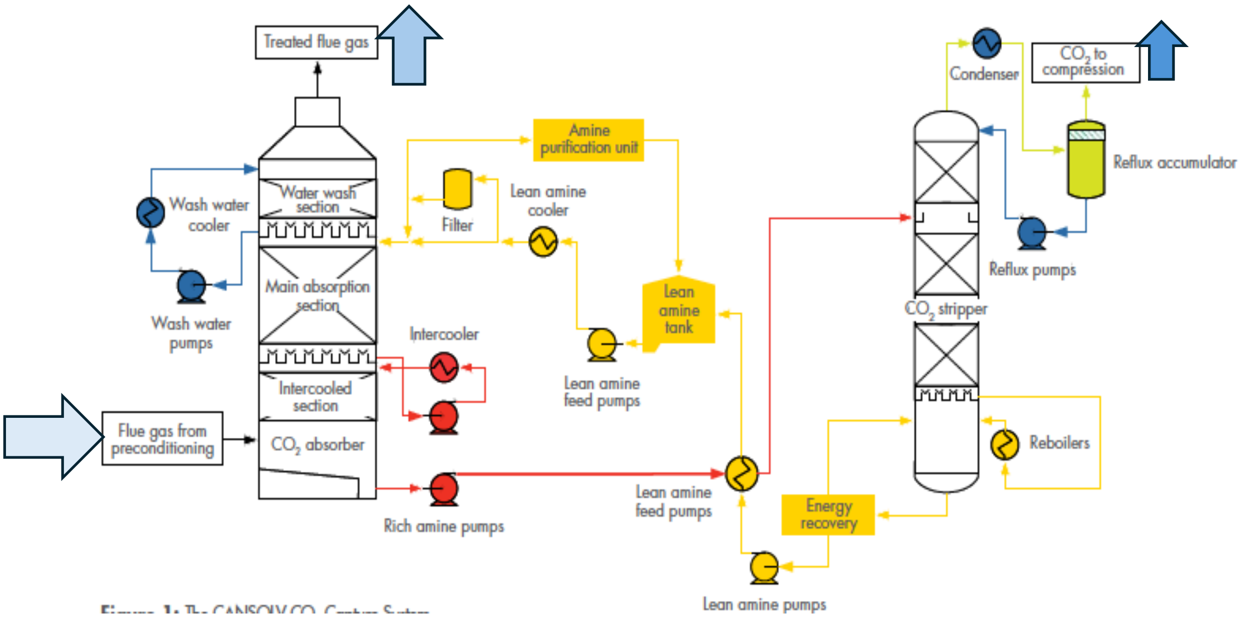
Mixing Hydrogen with NG leads to reduction of the CO2 emission when burning the mixture either in industrial applications or in power plants generation with the advantage increasing with the increase of the H2 content in the mixture. The challenges of the increased H2 manifest the problems discussed under H2 transport and storage. The leading Gas Turbine manufacturers are busy with enabling the burning of the H2&NG mixtures in the combustion chambers of GTs. Reasonable progress has been achieved to date 50% by volume. But for the H2&NG mix to gain a role in the energy supply for industry and electrical generation, the hydrogen economics addressed under 2. need to be resolved.

6. CARBON CAPTURE

6.1 Capturing CO2

Capturing CO2 from plants that use NG thus producing CO2, this is the starting point, the logic is to adopt one of two targets permanent storage: CO2 Direct Air Capture “DAC” 6.2 and 6.3 Sequestration, or Utilization 6.6. The capturing can be either from the air (where CO2 has been discharged DAC) or point source that is the exhaust gases from a plant stack (industrial or power. plant) is collected.

Figure 5- Example Schematic for Capture system
Shell Catalysts & Technologies Shell CABSOLV CO2 Capture System – Fact Sheet(n.d.)



6.2 Direct Air Capture (DAC)

Capturing CO2 directly from the air and permanently storing it removes the CO2 from the atmosphere. In the IEA Net Zero Emissions by 2050 Scenario, direct air capture technologies capture more than 85 Mt of CO2 in 2030 and around 980 MtCO2 in 2050, requiring a large and accelerated scale-up from almost 0.01 MtCO2 today. Currently 18 direct air capture facilities are operating in Canada, Europe and the United States. The first large-scale direct air capture plant of up to 1 MtCO2/year is in advanced development and is expected to be operating in the United States by the mid-2020s.

Interested readers are referred to IEA Direct Air Capture A key technology for net zero (2022) for a comprehensive report about DAC.

Breaking Trough Barriers to entry for Carbon Capture and Storage (CCS) for Power Plants (2024) gives an outline for what it takes to address CCS for power plants.

According to Battelle in the USA, the EPA will mandate by 2030 -2035 90% capture and storage of CO2 from Fossil power plants - Battelle Decarbonizing the power sector White paper (2024)

6.3 CO_2 Sequestration

CO2 is injected deep underground into deep rock formations for long-term storage. Th captures CO2 is stored in reservoirs. Thus, avoiding the release of CO2 to the atmosphere. Geologic sequestration is a proven technology and has been applied in large scale CO2 arriving to the reservoir site is injected in the reservoir deep in the order of more than 3000 m, where the CO2 is trapped through on of the following types:

- Sealed by a Caprock (Structural Trapping)
  A nonporous, impermeable caprock serves as a giant lid, isolating any CO_2 that is injected below it. This rock layer can be hundreds of feet thick and keeps CO_2 trapped securely.
- Locked in the Pores (Residual Trapping)
  These reservoirs are not large, hollow spaces. They're composed of huge strata of porous rock; more like a sponge than a cavern. When residual trapping occurs, the CO_2 is c contained within the tiny pores of the rock itself and rendered immobile.
  - Dissolved in Formation Fluid (Solubility Trapping)
  - Injected CO_2 can also dissolve into the salty brines that naturally occur within the reservoir. This process of molecular diffusion is caused by varying concentration gradients. This dissolution increases the density of brines, causing them to sink even lower in the formation—reducing upward migration of CO_2 and increasing reservoir storage capacity.
- Turned into Minerals (Mineral Trapping)
  With this form of trapping, the CO_2 interacts with minerals present in the rock formation at the molecular level via a series of geochemical reactions. These reactions result in the formation layers of carbonate minerals. The CO_2 actually becomes part of the rock. Example of this is formation of Calcium Carbonate $CaCO2$).

6.4 CO2 Transport

NERL USA Carbon Transport and Storage Atlas and Data Resources(n.d.) Depending on the point of Capture and the destination of the captured CO2 the compression pressure is determined. Setting up a CO2 hub where CO2 captured at diffidentplants can be injected into the CO2 network with the ultimate delivery to the terminal point the CO2 storage.

6.5 CO2 Storage

The CO2 collected and moved to the permeant storage location where CO2 stays for long time. The monitoring of the storage CO2 must be maintained to ensure no leakage of the CO2. Please refer to Sound of Green: A world's first in CO2 Storage(n.d.)

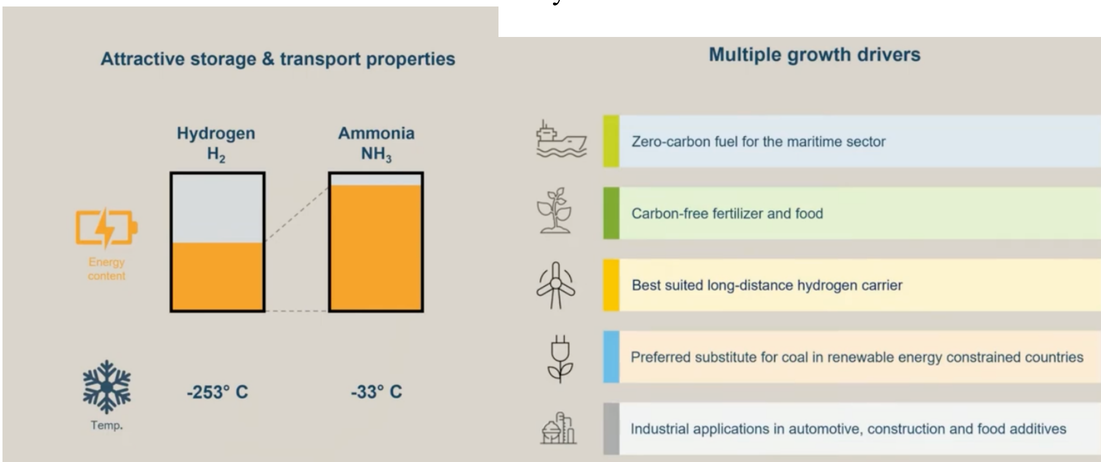
6.6 CO2 Utilization

Different uses of CO2 are being explored:

- Carbon -neutral Fuels
- Chemical Synthesis
- Carbon Mineralization
- Algae Cultivation

7.AMMONIA

Ammonia NH3 offers a possible means for transport of indirect transport of H2, e.g. Green Hydrogen is combined with N2 from the air to form NH3 that is liquidated at – 33 C, say in a MENA country which can be exported to a port in Europe, where it can be reformed back to H2.
Figure 6 From Yara Contribution in Linde Academy Session



Please refer to Yara Clean Ammonia (2022) and Yara Clean ammonia Brochure (2024) for further details on availability of Ammonia as a clean fuel. Further Ammonia is being investigated as fuel in Gas turbines. Both Mitsubishi and GE Vernova report initial progress, but it appears that there are significant hurdles to overcome.
The combustion system needs to be modified and the BOP will see large modifications.

8.NUCLEAR POWER (NP)

Between 1965 to 1985 many nuclear plants were constructed in USA, Europe, Japan, Canada, South Korea, and Eastern Europe. Fewer plants came on-line after that time. The majority of the plants used Light Water Reactors "LWR" and they ranged from 500 MW to 1700 per unit. Many sites had multiple units, mostly two units. Because of safety concerns, nuclear Plants are located far away from population concentrations, giving rise to complications and additional costs to the transmission subsystem of the ES to the grid. Since the 1990s only few new units were commissioned as the public acceptance of NP has dwindled considerably. The major concerns have been safety and the long life of the nuclear waste (hundreds of years) and where to store this waste. The three major accidents Three Miles Island USA, March 28,1979, Chernobyl Ukraine-Russia April 26,1986, and Fukushima March 11, 2011, added to the wide opposition to NP.
The operation record of the nuclear plants has been good, and NP has contributed to the mix of fuel for many countries. The characteristic of NP is high capital cost, relatively small operating costs compared to fossil plants. Because of the large size of the plants and the required Regulatory Licensing and Quality Assurance in constructing nuclear plants (particularly with larger sizes) represents hurdles to deployment of new nuclear plants. Generally, LWR plants operate ate lower pressures in the steam turbines leading to lower efficiency compared to fossil steam plants, and hence they release significantly larger waste heat. Historically, there were some attempts to utilize part of his waste heat in desalination.
The concerns with CO2 emission concerns revived interest in NP and the Nuclear Industry is responding with newer offering including smaller size plants.

The author has spent a good part in his early career at Bechtel working on NP, he believes the role of and expanded NP between now and 2030 will be minimal and the outlook beyond that from 2030 to 2050 remains to be seen.

9. ENERGY SAVING

This item has the best potential to contribute to significant CO_2 reduction in a quick way and with lowest costs and should be a target for all sectors on both the supply and the use (demand) sides, for industrial, commercial, residential, and transport. Good progress has been made over the last few years as indicated in the overall energy consumption statistics section. Modernization of equipment leads to higher efficiency and hence less energy / electrical energy. Public awareness is vital to avoid bad behaviors that lead to excessive use of energy.

9.1 Buildings

Energy savings in buildings should receive appropriate attention for existing and new buildings. Among other things, insulation of walls and use of solar water heaters should be encouraged, and use of electricity in domestic water heating should be discouraged. Heat pumps should replace the oil heating systems. Applying district heating and cooling in hotels and residential compounds should be encouraged. The use of Light Fuel Oil “LFO” for heating buildings and homes should be curbed and phase out.

10. DIGITIZATION

The Electricity Transmission and the Distribution Subsystems modernization through use of digital sensors to monitor and control the operation of these subsystems. These represent essential components to support the varying wind and solar electricity that connect into the electrical system. The possibility of consumers now providing electricity produced at their sites/homes to the network requires close monitoring round the clock.

11. STANDARDIZATIONS

In the fast-paced developments of new H_2 technology with emphasis on large-scale applications among a large number of research and OEM companies, there is a need for developing standards to enable the users to follow a common presentation of technical information. It is hoped that the sought standards will be available as the H_2 industry reaches more maturity. Various topics in the areas covered under items 1- 9, deserve updates or new standards. Safety, Health, and Environmental standards should receive the appropriate attention.

12. INTEGRATED PROJECTS & CO-LOCATION

From the discussions of the previous items, we find that contemplated solutions for dealing with CO_2 issues involve more than one project each uses a different technology, and has its own performance characteristics, and in many cases the degree of the advancement of the technology /maturity for large scale application could be significantly different. These facts represent major hurdles for the candidate off-takers, financial institutions as the risks for long term projects become quite significant. Beside the technology degree of maturity, comes the selection of the sites for the different projects of in the integrated projects. This brings not only additional costs for the transport and storage but could add to serious permitting issues. Seldomly, we could secure co-location of all the needed facilities / plants say close to the off-taker.

Unlike a project finance of for NG fired power plant or renewable plants that we have delt with in the past, now we deal with complex issues that an off-taker say of H2 needs to take into consideration, he may not be ready to assume related risks, while he needs to deal with his main activity i.e., competing in his own industry say steel or cement.

13. CERTIFICATIONS

To support the incentives and the credits for CO2 per the rules of the authorities. a dependable monitoring with measurable parameters is required. Details for such system and its working are not well established yet. The new technologies and their details and differences among manufacturers and plants make the precise delineation difficult and complex. Engaging third party could be a solution but is not an ideal because the roles may still be difficult to delineate. Some of the technologies are not mature yet, thus causing technical difficulties in contracts. The addition or factoring in the contributions of CO2 during equipment manufacturing, supply and construction, factoring transport etc. represent unknown territory. Also, during the operation phase accounting for CO2 in transport and maintenance e.g. od spare parts are examples of possible issues. To note in the USA, in accordance with the Inflation Reduction Act of 2023, the IRS was assigned the role of defining the calculations schemes for the tax credit. Yet till now the IRS has not issued its applicable guidelines.

14. CARBON INCENTIVES & CREDITS

As pointed out in the impetus section of this paper, the CO2 causing the warming of the planet is a global problem, hence, dealing with the problem requires cooperation of countries and this comes on various international levels. On the Country level, the commitments and obligations for the CO2 reduction are announced and the CO2 levels are monitored and published against the target levels. In Europe, there is a framework that the European Commission in Brussels formulates and continuously adjust as needed. For EU countries to follow in providing incentives and penalties for reducing CO2 emissions, or exceeding limits in case of penalties. These are monetary values for pricing per ton CO2.The concerned authorities administer the process in accordance with laws and clarifying guidelines and procedures.

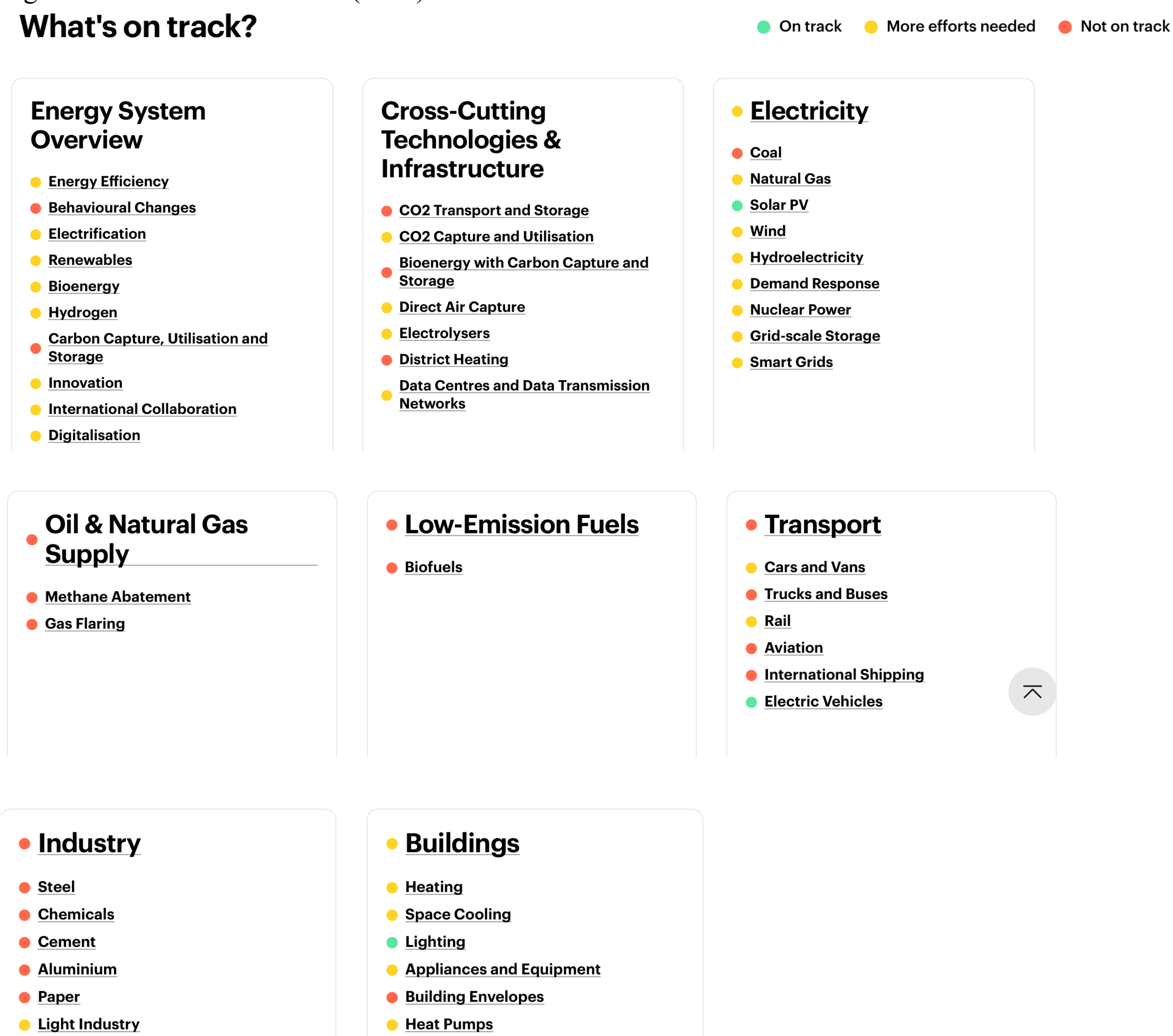
An essential element in propelling the drive towards minimizing or avoiding CO2 is the pricing assigned per ton of CO2 produced at a facility. We need to address the direct and indirect amounts. During the operation of a facility, the direct is result of the operations that take place in the facility. The latter (indirect) means whatever CO2 that is associated with all what enters the facility from outside sources to complete the product e.g. journey of the feedstock from point of production externally to the point of use in the facility.

For possible reference please refer to OECD Effective -Carbon-Rates (2021).

Take-away from Review: Where are we in early 2024?

Reflecting a bit on how the Green Hydrogen was perceived three/two years ago when the talk green Hydrogen is the answer, given where we are now, we find that the development of green hydrogen is limited and does not meet the expectations at this point and time.
As noted in the previous section, the review reflected the author's own assessments in a qualitative manner. In this section he supplements the review with information found in the IEA Tracking Clean Energy Progress (2023). Additional Information can be found in IEA clean-energy-transitions-program (2023). It is noted that the IEA perspective is for the Globe.
One sees that only three bullets are green solar PV and Lighting. The total number of bullets is 68, the red bullets add to 18, the yellow are 47. So the author's view that the overall progress is not what was perceived.

Figure 7 from IEA Assessment (2023)



In the author's opinion, given where we are, we have to build on what exists and has served the overall energy supply in an excellent way and has been reasonably dependable, this MG with its dominance use in Electrical Generation, this underlines why the author is recommending giving priority to item 4 "NG" and associated with this is Item)6. Definitely, Item 6 Carbon Capture must be supported and accelerated to enable Item 4 to prevail and fulfill the desired objective. Item 5 (mixing of H2 and NG) depends largely on the progress of H2 economics, yet it is also promising. **This brings to focus the title of this paper**.
Let us try to address possible strategies / scenarios:

A) As Energy for land transport (trucks, buses, and private cars) is still depending on fuel oil products, though newer vehicles have higher efficiencies, burning less fossil fuel and hence result in lower CO_2 emissions. The emitted CO_2 from transport can be reduced in the short term by encouraging the use of the CNG on older vehicles and accelerating the phasing out of Diesel and petroleum.

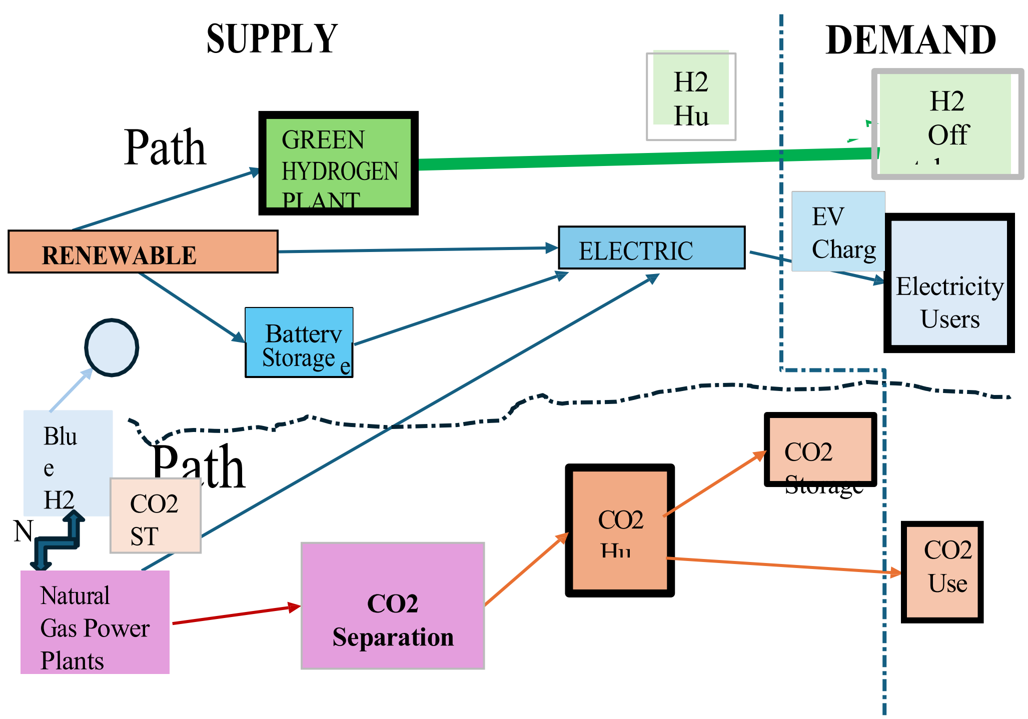
B) The CO_2 emissions from Heavy Industries and Power Plants should be main target with the objective of substantial reduction by 2030. For NG fired plants this means Carbon Capture is the possible real solution.

While A) & B) proceed other technologies should be encouraged to innovate and get to markets solutions with better CO_2 emissions.

Natural Gas and Gas Turbines Challenges– Carbon Capture
Figure 8 depicts in a simplified way the two approaches that have been envisaged towards realizing Net Zero goals by 2030-2050.

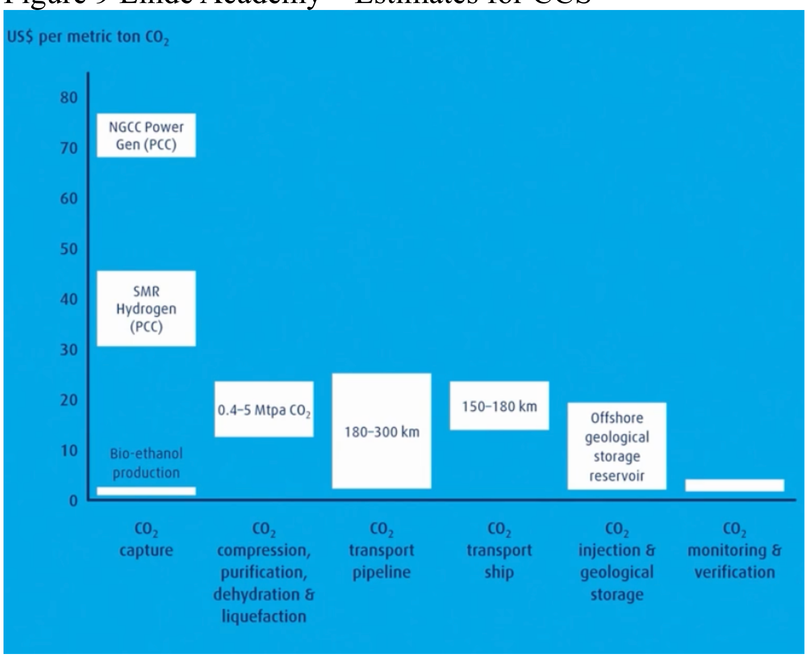
TOWARD NET ZERO

Figure 8 Simplified Schematic for the primary "Path I" and backup "Path II" to Net Zero

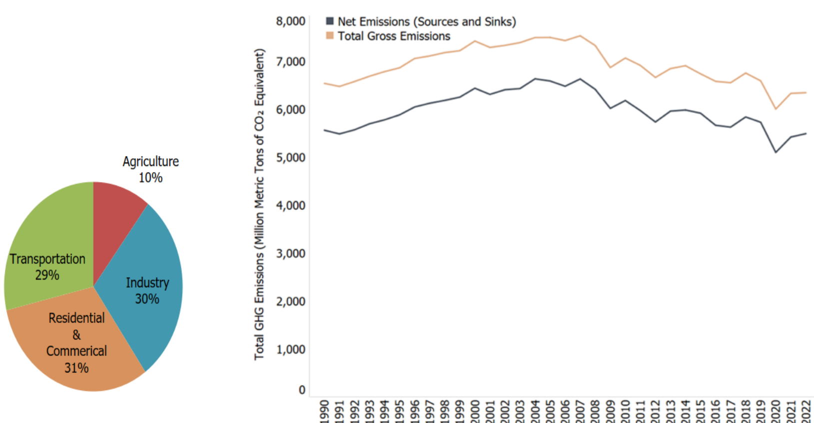


Path I is the envisioned path for the long-term objective where the supply will be primarily from RE feeding electrical and Green H2 demand (Green blocks). The inclusion of H2 hub is shown. This path supports users primarily via electricity from RE.
Path II is the near-term solution using NG to power plants (in addition to RE plants), and, heavy industries and adoption of carbon capture and storage. A CO2 hub is contemplated. At the left bottom, Blue hydrogen producing plant with an associated carbon capture and a blue hydrogen user are depicted.

Economics
The author chose the Figure 9 (as it provides a comprehensive view of the costs of the various components of Carbon Capture. Please note the high cost for CO2 capture (first step in Figure 11) for NGCC. This is a result of the very low CO2 content in the stack emissions from the gas turbine.
Figure 9 Linde Academy – Estimates for CCS



European Commission eu-action (n.d.) gives useful information on the ETS Europe's Trading System. Figure 10 From EPA (n.d.), the information below is extracted.



The above information shows the CO_2 emissions from the key sectors in the USA, the second figure shows the indirect CO_2 that need to be factored when estimating the CO_2 emission.
Based on brief survey that the author conducted, he concludes that an indicative Price per ton of CO_2 in the range of $ 50 to 150.

<u>Indicative Prices</u>
The author decided to include simple demonstrative examples for the causes of the high costs that are encountered at the moment when tackling initial developments for three propositions, i) Hydrogen Plant, ii) Battery Storage, iii) Capture of CO_2 from NGCC plant. The data chosen are typical and does not address all the elements that enter in the financial models, only the major element in each case is addressed, this represents where the main commercial obstacles stand.

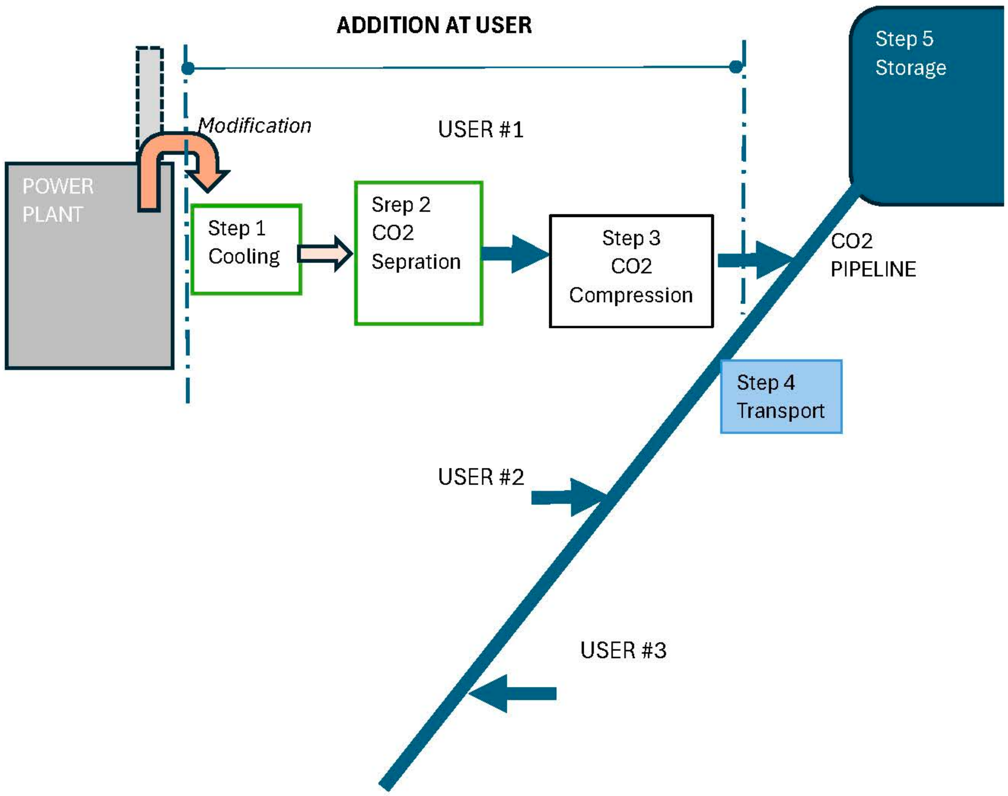
i) Green Hydrogen Plant
The most significant cost item is the electricity consumption per kg of H_2. An indicative value of 55 kWh/kg is chosen.
Assuming 35% of that energy is from RE at a priced of .04 $/kWh and 65% is from network price of .08 $/kWh. This leads to a weighted average of .066 $/kWh. Thus, only the electrical consumption amounts to 3.63 $/kg H_2.
The 0.04 $/kWh is to be negotiated with say Solar Park producer and depends on a lot of conditions in the offtake agreement. The network price is to be negotiated with the electricity distribution company per rules and stipulations dealing with clean energy because the electricity to be used come partially at peak time early night and the rest primarily nighttime.
One can see quickly from this simple example that we are far from target prices that have been talked about 1 $/kg H_2.

ii) Battery Storage
For simplicity if one uses a price of 350,000 $/MWh – (1 MW) installed and assumes that on a daily basis the battery will be charged to level 95% and discharged to 40% level, meaning .55 MWh daily. This means approximately 200,000 kWh per year. Assuming an average degradation 95% for the charging-discharging, then we have 190,000 kWh useful output per year. Assuming that battery is about 40% of the cost noted above and needs to be replaced every 10 years, the cost from the battery replacement alone is .074 $/kWh.
This is a high price without addressing the other expenses.

iii) Capture of CO_2 from NGCC plant
If one takes an example of an operating GE F4 (2GTs+1) plant with rated power of 889 MW, heat rate 5960 kJ/kWh, and using a price of natural gas 3 $/mmBTU, the fuel cost is approximately .017 $/kWh. Now, if one adds a CO_2 capture and uses the high cost of carbon capture of 75 $/ton of CO_2 (from Figure 9) , the added cost per kWh is 0.023 $/kWh. This underlines the issue of the high dilution of the CO_2 in the exhaust of the gas turbines.

Implementation of CCUS

Figure 11 depicts the steps contemplated in the implementation of CCUS for plants burning NG.
Figure 11 Simplified Schematic for the CCS adoption for NG Fueled Plants



For small users, possibly filling Carbon cylinders with high pressure CO2 then transporting these cylinders to another designation via trucks, railway or a connecting point to the pipeline CO2 hub.

Comments: Waste / Reject / Reuse
In the opinion of the author, a lesson that has been learned over and over is "to evaluate the waste, reject from the adopted schemes". This have been overlooked in several technologies in the past and has proven costly to rectify. We should not repeat the same mistake.

Comments: Economics Knowledge – Energy – Capital versus Energy Economics
HAEE is the Hellenic Association for Energy Economics, this underlines and signifies the economics of Energy. Previously, in the decades where fossil fuels dominated the power generation and the ES's was a unidirectional from the generation subsystem to the transmission and distribution subsystems, things were at least not too complicated, even when Private companies assumed large roles in the substations of generation and the role of the regulatory bodies expanded. In the last two decades, the NGNS's and the LNG supply assumed important roles in the economics of energy. This was accompanied with significant introduction of RE PV Solar and Wind plants. Diversification in the economics of the energy was accompanied with developments of tools and expertise in financial assessments and financial projections for 20-25 years for projects, to support the investors and financial institutions in making evaluations for the projects risks and ultimately reaching the investment decisions amid changing economic and political conditions.

As we entered the era of the Net Zero as a result of the global concern of the CO_2 warming, and the start of the massive effort to replace the fossil-based energy supply with RE taking the front role, economics and energy got into even closer interrelation. The author published a book "Business Economics Knowledge & Energy" Safwat (2022). In this book he proposed the concept of the knowledge & Energy Pair present in all activities and tasks of an enterprise. He added the additional factor Capital in Safwat (2023), thus the KEC model. The relevance of this thinking for the net zero era, is that it brings the need to optimize the inputs of KEC underlining the effect of the knowledge manifested by the technology with innovation.

Concluding Remarks

From the contents in the previous sections the following priorities can be deduced:

1. For 2025-2030, Energy Savings measures should be utilized to the maximum, to curb on the consumption, particularly on oil – whether in buildings, industrial, commercial, and transport. CNG should replace Diesel and petrol vehicles. Encouragement of CNG for vehicles should be priority in the immediate future.
2. While the pursue of path I (Figure 8) evolves (it will take time), path II the NG path (Figure 8) should be accelerated with major push to advance CO_2 capture and CO_2 use and storage to enable supporting economic growth in the time frame of 2027 – 2040.
3. Hopefully, path I will pick up to the attain the targets of 2050. **Substantial reduction of the specific electric energy required per kg of Green H_2 is a must.**
4. The introduction of Green H_2 into the energy supply imposes many challenges and the knowhow of H_2 production and transport & storage is at Chemical companies while in the past the electric industry depended on fuel supply from dedicated companies under fuel supply agreement "FSA" in the era of fossil generating power plants, and when solar & wind emerged the power companies concentrated on managing licensing aspects with no fuel supply agreement. **The power producer in all cases delt with the Offtake under the PPA (Power Purchase Agreement).** Balancing the risks was through the clauses of FSA and the PPA. The power plant developer played the leading role**.** For the Green H_2 plants, there are several links, a) the RE where the source of solar or wind comes, then, the feedstock for water supply agreement b) the supplement agreement for securing required electricity when the RE is not available (e.g. nighttime for PV plans), (*noting a) and b) are to ensure the right electricity at all times for the Electrolyzer continuous operation*) , c) finally comes the offtake agreement for the H_2, that depends on the end user of the received H_2 and in what form. For Blue hydrogen there is what the entity that produces Grey H_2 and the added CO_2 capture, Again the relationships must be formulated under the pertinent agreements. For Green Hydrogen, the supply of water is an issue. From these brief comments one recognizes the complexity of the interactions / interdependencies and given limited experiences and the status of the growth of large scale Green H_2 plants. How the platform of the legal project agreement will evolve remains to be seen.
5. **Path II of Figure 8 appears to hold large promise as it builds on well-established technologies in the power electric generation and the proven Natural Gas / LNG systems supported by the World major oil companies**, The CO_2 capture is an additional feature followed by the CO_2 transport & storage is a clear service that can be handled with the appropriate infrastructure (Figure 11). The optimum arrangement

will materialize once the NNGS operator decided its view on operating the CO_2 hub(s). Of course, the regulatory aspects need to be addressed.

6. The premise behind the paper title has been substantiated and **key factor must be investigated is how to raise the CO2 concentration in the exhaust of GTs.**

As the World is expecting higher interest rate globally in the coming years to curb the current high inflations, and various institutions are saying the low interest of the last two decades will not be seen for some time. This poses a very tough problem for new long-term investments, posing a major challenge for the Energy Transition.

For Greece:

The author acknowledges that the contents of this paper is primarily reflecting his assessment of where the world is on seeking paths to reach targets for Net Zero by 2030 and 2050. The underlining factor is the progress of technologies. The author addressed in the 14 items under the section "where are we" multitude of issues that remain unresolved and hence delays are coming up. For Greece, the Greek Governmental agencies, Energy Development Commission, with the aid of the Electric Utility DEI and the DEFA / DESFA responsible for the Natural Gas system the path towards Net Zero is progressing. Of course, as could be seen from the discussions of the 14 items, several of the items are interrelated. In Figure 8 one sees two paths to follow. The first one "I" is completely dependent on the advancement of the hydrogen technology. This translates to reaching green Hydrogen at acceptable commercial prices. Path II, in Figure 8 is a backup path that depends on well-known technologies that have been in use for decades. Yet to abate the CO2 emissions coming from burning Natural Gas we face some difficulties, and they lie in adopting carbon capture solutions adding to the price of the electricity and products of heavy industries.
The author recommends serious consideration of Carbon Capture system along Path II. Some specific recommendations are added below:

a) As the Transport sector produces of the CO2, the conversion of older vehicles to CNG and promoting electrical vehicles must be accelerated.
b) For Buildings and Commercial facilities energy savings schemes must be promoted.
c) The percentage of the PV solar power in Greece appears to be only half of that from wind. This should be looked into, whether the hurdles are in the electrical connection to the existing grid.
d) For the Operating Power Plants the merit of operation od the system power plants changes when the price of the CO2 is factored. As noted under item 6, the NGCC has the highest efficiency, yet it poses the most challenging cost for the CO2 storage.
e) For NGCC plants FINDING A CAPTURE TECHNOLOGY IS VERY IMPORTANT, initially some external solutions outside the core of the gas turbines could yield a small improvement on the cost of the CO2 capture. But more fundamental modifications to the combustion chamber will require some time with associated high development costs for the GT OEMs.
f) Similar to drastic change in the GT combustion chamber to burn NH3, (Ammonia burning) in gas turbines has its challenges that need to be investigated with GT OEMs to evaluate the viability as the transport of NH3 is not as complicated as transporting H2.
g) If Greece opts to explore Ammonia, it can depend on cooperation with NH3 Suppliers in the MENA region. Setting receival terminal in any of the ports of Greece can be evaluated. Good example is at the Port of Rotterdam, The Netherlands.

Adopting a group of the recommendations noted above requires assessment of the costs that need to go in each chosen item. **AT THE END THE ECONOMICS OF THE RODUCED ENRERGY / ELECTRICITY MUST BE ECONOMICALLY VIABLE TO SUSTAIN REASONABLE GROWTH FOR GREECE.**

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