Erasmus University Rotterdam

MSc in Maritime Economics and Logistics

2020/2021

Penetration of Ammonia in Greece by 2050

By

Nikolas Alefantos

Acknowledgements

I would like to express my deep and sincere gratitude to my research supervisor, Dr. Michele Acciaro, Associate Professor of Maritime Logistics at Kühne Logistics University (KLU), for giving me the opportunity to do this research and providing invaluable help throughout the whole process. Even though the difficult times that we live in, his efforts to explain everything in the best possible way in order to better understand this new subject and his extremely detailed guidelines help me complete this work. It was a great privilege and honor to work and study under his guidance.

To my fellow colleagues, it was a privilege sharing all those unforgettable moments of laugh, stress, and hard work with you. I would like to wish you all the best in your careers. This is only the beginning and hopefully our paths will cross again within the maritime industry.

Last but not least, I am extremely grateful to my parents for their love, caring and sacrifices for educating and preparing me for my future.

Abstract

As the world turns into an eco-friendlier mode, so does the maritime industry with the decarbonization process. Among other future fuel options, green ammonia and hydrogen provide the healthiest balance. The main objective of this paper is to study the possibilities of using ammonia as a primary fuel and source of hydrogen in the maritime industry while following the green economy approach. Broad research has been made in order to collect information about ammonia that would help to better understand the feasibility of the argument. As a specific case study, Greece has been selected as the country to focus and conduct the modeling of forecasting by estimating the future consumption of ammonia in the Greek market by 2050.

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CHAPTER 1: INTRODUCTION

Ammonia and hydrogen are carbon neutral marine fuels and are likely to be the most important in the future, according to a new series of reports from the World Bank. According to them, these two green fuels are currently "the most promising" for the world of shipping.

According to reports, liquefied natural gas will play a minor role in the decarbonization process. Analysts said green ammonia and hydrogen provide the healthiest balance among other future fuel candidates, including biofuels and synthetic carbon-based fuels. Ocean-going ships could move using ammonia within a decade, as the shipping industry is active in reducing carbon emissions. Although the creation of ammonia itself produces large amounts of carbon dioxide, according to a new report, this problem can be solved thanks to new technologies.

The challenge is great, as shipping produces about 2% of international carbon emissions - about as much as the entire Greek economy. Ammonia production is also a major source of carbon: According to a report by the Royal Society, ammonia production currently generates 1.8% of the world's carbon dioxide emissions, more than any other chemical industry (Oh et al., 2021).

Greece plans to introduce ammonia as the main fuel to the shipping industry and make it commercially available by the end of the 2020s as part of its efforts to reduce carbon emissions by 2050, Offshore Energy reported. This became known during a meeting of the Ammonia Fuel Council. Ammonia is expected to be introduced as a commercial fuel for heat generation by the end of the 2020s. Ammonia joins renewable energy sources like solar, wind, geothermal, and hydropower because it does not emit CO2 even when burned. Another advantage of this type of fuel is that ammonia can be stored at higher temperatures in liquid form (Senda & Harumi, 2018).

However, ammonia is less energy-intensive than, for example, oil; this means that ships will consume five times more fuel by volume. According to the International Chamber of Shipping, ammonia production is set to grow by 440 million tons - more than three times the current production - which will require 750 gigawatts of renewable energy. Green ammonia has been recognized as one of the most promising fuels with minimal emissions. Industry experts predict that its use for transporting goods will reach 130 million tons by 2070, which is double what was used globally for fertilizer production in 2019.

The purpose of this paper is to review the applications of the prospects of the use of ammonia as the main fuel and source of hydrogen in the maritime industry using the green economy model. The development of direct energy conversion systems and the production of green ammonia (NH^3) energy carriers from locally generated wind energy are of central importance. Ammonia has a number of advantages over hydrogen, another fuel of the future, as it is easier to transport, is less flammable, and more economical than many other types of fuel, while ammonia has specific energy 1.8 times more than hydrogen. Also, Ammonia needs to be stored at -33 Celsius, compared to the more logistically challenging -253 Celsius required to store hydrogen.

In terms of pricing, the ammonia energy used in ocean transportation should come from green ammonia, that is, using renewable and sustainable sources to justify its use in shipping. This means that ammonia must be cost-competitive as a marine fuel. One of the ways to achieve this goal is to expand the scale of renewable energy and lower the price of green electricity so that the price of green ammonia is between US$300-500 per ton, which can compete with traditional fuels. The added value of clean transportation must be considered. One solution is to impose a carbon dioxide tax on traditional fuels, which will require international cooperation to ensure a level playing field. In addition, whether the shipowner is willing to pay for cleaner energy is the key (Kim et al., 2021).

It was explored through a poll, that is, whether marine ammonia fuel is feasible only in the context of strict control of carbon dioxide emissions throughout the life cycle. 73% of the respondents agree or strongly agree with this—one argument. The balance point for the interviewees seems to be to find an acceptable life-cycle cost (Kim et al., 2021).

Cesaro et al. (2021) pointed out that it is not currently necessary to use pure ammonia power directly. Ammonia energy can be used with other marine fuels (as pilot fuel), and with the development of technology, it can also be used with hydrogen energy produced by ammonia cracking on ships. He said: *"The fuel cell technology is not mature enough, so the internal combustion engine will be a compromise solution. Diesel can be loaded on the ship as a backup fuel in an emergency. When using ammonia as a shipping fuel, what we have to do is to close the gap, including gaps in cost, supply assurance, safety and receiving facilities, and technology. In general, our goal is to promote the future through the production of green ammonia products."* The companies expect to achieve climate neutrality by 2050 and to achieve the first batch of green ammonia production by 2030 (Hansson et al., 2020).

For shipowners, this is a major project as hydrogen energy is facing some challenges in storage; this is why we have to consider ammonia energy to solve the storage problem. The research on fuel cells has led us to a lot of interesting things. Contrast, in terms of unit weight, hydrogen is a very efficient fuel, but hydrogen per unit volume is inefficient. Unit volume is the most important parameter in ship design because we need to consider the fuel containment system. In this project, NETSCo researched various ammonia control systems. Compared with liquid hydrogen, the scope of the ammonia safety enclosure system is relatively wide. When comparing the energy density per unit volume of various fuels, the extra space required to meet safety standards is not considered. For fuels like liquid hydrogen, a lot of extra space is required to ensure safety. Ammonia is relatively mild, and we can easily store ammonia in Type B tanks; compared with LNG, this will save more space (Cesaro et al., 2021).

At present, the research and development of ammonia-powered ships are not limited to Greece and the United States. The NCE Maritime clean technology ship fuel cell project is partially funded by the European Union (Hansson et al., 2020).

Various methods for developing a low carbon economy have been proposed. However, there is a remaining gap in the literature to view the trend of adoption of ammonia fuel as an option in the near future. This study intends to fill this gap.

Prospects for the maritime industry in Greece

As the maritime industry is committed to reduce atmospheric emissions and meet the International Maritime Organization (IMO) greenhouse gas emission reduction strategy, alternative fuels have emerged. Classification society DNV GL recognizes that the international rules for alternative fuels other than LNG are still blank. Therefore, it has formulated new classification rules and the classification symbol "Gas fueled LPG" for liquefied petroleum gas (LPG) fuels to meet Growing industry interest (Lamas Galdo et al., 2020).

Except from liquefied natural gas, all gases and low-flashpoint fuels currently follow the “alternative design method”, which means that only when the safety, reliability, and reliability of their systems are shown to be equivalent to those of new and comparable traditional fuel engines, and these fuels can only be used in the case of auxiliary engines. This process is time-consuming and costly and may hinder the application and expansion of lower-emission alternative fuels (Hansson et al., 2020).

It is hoped that through the new rules and class symbols, we can provide shipowners interested in LPG with an intuitive approach and an alternative design method that complies with the IGF rules. As the fuel situation in the maritime industry has become more diversified, it is very necessary for us to continue to expand the scope of implementation of norms and regulations to support these new options. These specifications and class symbols are based on DNV GL's specifications for ships using LNG fuel while taking into account the differences in attributes and phases between LPG and LNG. The "Gas fueled LPG" label covers pure gas fuel and dual-fuel internal combustion engines, boilers, and gas turbines. It also includes the requirements for ship fuel supply, considering the requirements of equipment and installations from the filling connection to the LPG user (main engine and auxiliary engine, boiler, etc.) (Kim et al., 2021).

LPG fuel can reduce ships' atmospheric emissions, including greenhouse gases and other pollutants. Compared with HFO or MGO fuel, LPG can eliminate sulfur emissions and reduce greenhouse gas emissions by about 17%. LPG can also be used as a transition fuel for ammonia because, in most cases, the materials used in LPG tanks and systems are also suitable for ammonia. Through advanced planning methods, the adjustments required to switch from LPG to ammonia can be minimized. The production and related supply chain of ammonia energy has been improved, which has improved its feasibility as an alternative fuel for shipping (Schönborn, 2021).

Ammonia can be injected with pilot fuel as internal combustion fuel or as a hydrogen carrier for fuel cell cracking to generate energy and heat. These characteristics help ammonia as an alternative fuel. In a poll in July 2020, about 60% of respondents believed that ammonia would become part of the fuel market by 2025. A higher proportion of respondents expressed interest in using ammonia energy, and 65% of respondents expressed their willingness to become early adopters (Lamas Galdo et al., 2020).

Research purposes

The purpose of this paper is to study the feasibility of whether ammonia can be used as ship fuel and to determine the direction of the supervision of ammonia-fueled ships by identifying the characteristics of ammonia as a renewable energy source and a source of hydrogen production. This compound of nitrogen and hydrogen is an excellent energy store and can fuel new emission-free ship propulsion systems. Therefore, it will revolutionize the maritime movement Gas emissions. For the purpose of the paper, Greece has been selected as the country to focus on the practical part of this study.

Research Questions

- What are the prospects of renewable energy sources as Ammonia to serve as the main marine fuel in Greece?
- What would it take to establish Ammonia as a main marine fuel by 2050?
- What is the projected consumption of Ammonia in Greece by 2050?

Methodology

In order to pursue the established goals, the study intends to make use of a mixed methodology. A qualitative research part will be conducted by reviewing the existing literature revealing desired insights into the phenomena under investigation. Meanwhile, exponential smoothing on past data is being used to forecast future consumption of Ammonia in Greece will be conducted for the quantitative part of the study.

Data collection

As inclusion criteria for the selection of studies, studies containing the descriptors, addressing the subject under analysis, having been published between 2009 and 2021 and being available in full on the investigated databases were considered. Then, articles that were distributed over a decade of publication, during the period from 2009 to 2019, were selected regarding the countries of publication. After this phase was completed, the process of classifying articles regarding the potential of ammonia as maritime industry fuel in the anticipated future. This part of the research required a qualitative approach, in which content analysis was used, that deals with a set of analysis techniques of texts or communications, aiming to obtain, through systematic and objective procedures of the description of its contents, quantitative indicators or not, which makes it possible to infer knowledge regarding the conditions deduced from these texts.

For the primary study, data set was obtained from knoema.com which is a global platform for statistical data sets particularly related to fuel consumption. The consumption of Ammonia fuel for past few years was taken in order to predict the future trends.

CHAPTER 2: LITERATURE REVIEW

According to Valera-Medina et al. (2021), Ammonia has the potential to be the basis for future sustainable energy development; but until recently, the production of ammonia consumed a lot of energy. At the heart of every ammonia plant is a steel reactor, which still uses the Haber-Bosch process, a 100-year-old ammonia production recipe.

As per Oh et al. (2021), in this recipe, a pressure of up to 250 atmospheres is generated to break the chemical bonds that bind the nitrogen molecules and combine the atoms with hydrogen to produce ammonia, according to the estimates of professionals, by the middle of the century, all-new sea vessels will operate on environmentally friendly ammonia fuel, the worldwide trend towards cleaner energy sources than traditional oil and gas is picking up steam again after becoming clear that the coronavirus pandemic is fading into the background (Oh et al., 2021).

Experts believe that in the near future, new opportunities will be opened in the field of green energy. So far, the main focus of clean energy advocates has been on lithium, which is the base cell for batteries in electric vehicles. However, it is becoming increasingly clear that lithium is not capable of providing sufficient capacity to fully transition the industry towards clean and sustainable energy sources. Therefore, they are looking for an alternative, one of which can be ordinary ammonia. So far, the main use of ammonia - at least for the time being - is in fertilizers. But it can quickly turn into a potentially game-changing source of clean energy (Senda & Harumi, 2018).

Experts believe that it is he who will be able to provide a large amount of energy for industrial production and become a key "fuel of the future" - this is exactly what Chemical & Engineering News experts called him, saying that ammonia batteries can contain nine times more energy than lithium-ion. So far, shipowners have shown the greatest interest in the new type of fuel.

According to experts, by the middle of the century, ammonia can account for 25% of the marine fuel balance in world maritime transport, and starting from 2044, almost all new ships will run on ammonia. Ammonia is expected to play a key role in the decarburization of cargo ships, which aim to reduce emissions by 50% from 2008 levels by 2050. More than 120 ports in the world are already equipped with ammonia trading facilities (Valera-Medina et al., 2021).

According to De Vries (2019), ammonia has a number of advantages over hydrogen, another fuel of the future as it is easier to transport, is less flammable, easier to transport, and more economical than many other types of fuel and ammonia has specific energy 1.8 times more than hydrogen. Also, Ammonia needs to be stored at -33 Celsius, compared to the more logistically challenging -253 Celsius required to store hydrogen. The publication reports that today, one of the enterprises of the oil-rich Saudi Arabia announced plans to invest $5 billion in a hydrogen-based ammonia plant that operates on renewable energy sources.

Highlighting the necessity to leverage the potential of ammonia as a carbon-free fuel, Hansson et al. (2020) proposed its usefulness. According to them, most of the world's ammonia is used as fertilizer. Plants need nitrogen for growth and fruiting, and ammonia provides that nitrogen in a more biologically usable form. Companies around the world produce $60 billion annually in ammonia, primarily as fertilizer. However, the current method used to produce ammonia, the Haber-Bosch process, has changed a little since its development in the early 20th century. It consumes a large amount of fossil fuel and causes air pollution. Studies show that the total energy density of ammonia is almost twice that of liquid hydrogen, which is a major competitor as a clean alternative fuel. Ammonia is also much easier to transport and distribute. Given the potential of ammonia as a clean, environmentally friendly, carbon-free fuel, experts are currently working on the concept of an ammonia economy.

As per Oh et al. (2021), ships contribute to air pollution with a variety of gaseous pollutants, including carbon dioxide (CO_2), soot (C), sulfur oxides (SO_2), or nitrogen oxides (NO_2), and nitrous oxide (NO). These pollutants contribute to global climate change either by acting directly to trapping heat in the atmosphere or indirectly by helping to create additional greenhouse gases. Another category is suspended particles (PM_{10}), ozone hole-related gases (NO_2 and VOCs - Volatile Organic Compounds), and finally, gaseous pollutants that cause acid rain, SO_2 (sulfur oxides), NH_3 (ammonia), and NO_x, which also cause acid rain.

A key issue that also concerns the shipping community is CO_2 from shipping. Climate change is a matter of great concern to the scientific community and will undoubtedly have decisive consequences for the future of mankind. It is now known that climate change is a phenomenon which is growing rapidly in recent years and is a major problem on a global scale, taking an important place in the foreground due to its negative consequences. Starting from the era of the industrial revolution, the progress of humanity through technology and science has brought huge changes in all aspects of industry and society, which has assimilated technological achievements and made them an integral part of its daily life. In addition to the undoubted benefits, it has also had negative consequences, one of which is the depletion of natural resources and the pollution of the environment, which directly threatens the planet's climate (Liu et al., 2020).

According to a report by the Intergovernmental Panel on Climate Change (IPCC), the effects of climate change are already being felt on all continents and in all oceans. The global community, in most cases, is unprepared for the dangers of climate change. The report concludes that there is potential for people to respond to these risks, although it will be difficult to manage global warming due to emissions. An increase between 2 and 4 degrees Celsius will lead to the desertification of many areas and increasing drought, while in other areas, there will be heavy rainfall and floods, resulting in soil erosion and the simultaneous occurrence of catastrophic hurricanes. In the extreme case of rising global temperatures above 4 degrees Celsius, there will be catastrophic consequences for environmental ecosystems, international relations, and the global economy (Dimitriou & Javaid, 2020).

On many routes, rising storms will increase shipping costs, forcing it to do so: either take additional security measures or lead to the adoption of longer routes. If storms disrupt supply chains, transportation costs will increase, or new routes will be sought. Also, increased storms can make delays more frequent due to bad weather and will certainly increase the cost of maintaining ships and ports (Senda & Harumi, 2018).

Another part of shipping that will be affected by climate change, higher temperatures, rising sea levels, and the most intense and increased storms are, of course, the ports. For this reason, it is necessary to properly train port staff in order to begin the adjustment process. Further, acidification of the oceans by increasing amounts of carbon dioxide is putting endangered coral reefs and other calcium carbonate-producing organisms in shells. This could lead to the collapse of many important food chains, including those on which people depend. Marine ecosystems and ocean circulation is disrupted by the melting of sea ice and rising sea levels, caused by the continuing rise of the temperature in oceans (Senda & Harumi, 2018).

Increased interest in Ammonia

Hydrogen has become one of the European Union's key tools in achieving its climate neutrality goals by 2050. This element can be used to store excess renewable electricity, produced, among others, by wind turbines or solar panels. As a result, the generated energy is not wasted but is fed back into the grid to balance the power system. Hydrogen is also increasingly used as an alternative fuel (Oh et al., 2021).

Ammonia also emerged as a new alternative. The issue of ammonia as one of the hydrogen fuels is constantly raised in scientific circles. Experts mention many advantages of this chemical compound that make it an attractive alternative to pure hydrogen. First, ammonia condenses at -33° C under ambient pressure. Meanwhile, hydrogen requires a much lower temperature, as much as -253° C. Additionally, one cubic meter of ammonia contains approx. 50% more energy than the same space filled with hydrogen. This unique feature would find application, especially in sea shipping, due to the limited space on board and the difficulties in refueling during the voyage (Hansson, Fridell & Brynolf, 2020).

Decarbonization is a key task

Scientists are aware of the advantages and disadvantages of ammonia; and the latter undoubtedly include corrosivity, toxicity, and flammability, as Paulus mentions. In addition, huge amounts of carbon dioxide are produced during the production of this substance for fertilizing purposes (Oh et al., 2021).

Scientists are giving ammonia a chance. However, Jutta Paulus believes that the disadvantages of ammonia do not necessarily lead to the abandonment of its use. According to the researcher, a strategy to deal with the negative properties of a chemical compound and the beneficial use of its advantages should be developed (Senda & Harumi, 2018).

Globally installed stationary fuel cell capacity has increased rapidly in the last ten years, reaching almost 1.6 GW in 2018 (chart below), although only about 70 MW uses hydrogen as fuel. Most of the existing fuel cells now run-on natural gas. The number of fuel cells installed worldwide is around 363,000, largely dominated by micro-cogeneration systems. The Japanese initiative to introduce ENE-FARM domestic fuel cells to the market (currently approx. 276

thousand) constitutes the majority, but it is only 12 percent. It has an installed capacity (193 MW). Outside of Japan, the household fuel cell market is also expanding in Greece, thanks to the KfW433 support program (Liu et al., 2020).

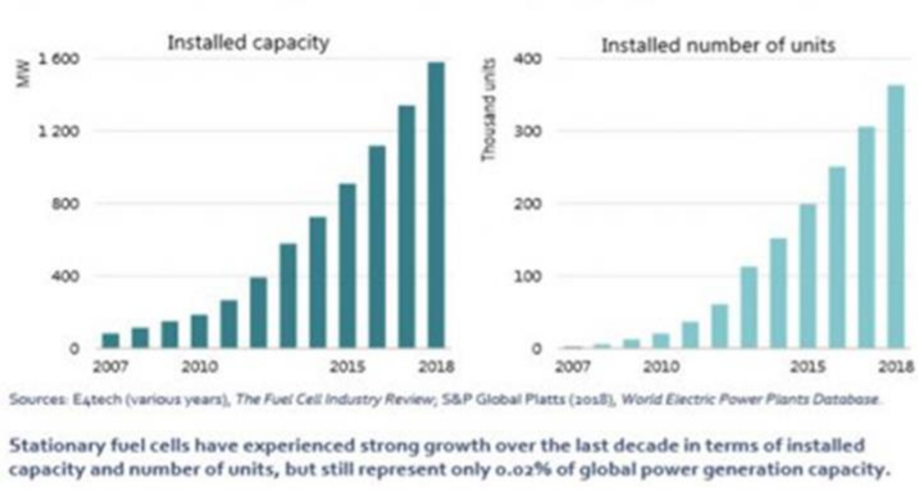


Figure 1: Development of global stationary fuel cell capacity 2007-2018

Very few countries have set clear targets for the use of hydrogen or hydrogen fuels for energy. Japan is one of the few exceptions: it aims to reach 1 GW of hydrogen-based capacity by 2030 (corresponding to an annual hydrogen consumption of 0.3 Mt) and 15-30 GW in the longer term (corresponding to an annual hydrogen consumption of 15-30 Mt). South Korea is another exception. Korean plans to use hydrogen in the energy sector set a target installed fuel cell capacity of 1.5 GW by 2022 and 15 GW by 2040. Research and pilot projects are underway in Japan, the Netherlands, and Australia to introduce hydrogen and ammonia as fuels for gas turbines and coal-fired power plants (Dimitriou & Javaid, 2020).

Ammonia as a hydrogen source

Hydrogen can be produced from different sources, divided into three main classes: fossil fuels, renewable sources, and water electrolysis. Among the renewable sources, great emphasis has been placed on biomass. When talking about biomass, it may be referring to agricultural products and their derivatives, such as ethanol, fatty acids, and glycerol or organic waste consisting of decomposing material. Producing and storing hydrogen conveniently, efficiently, and safely poses challenges to the hydrogen economy. Ammonia can be considered an excellent hydrogen store, as it is: produced at the same cost as hydrogen; it is available in large quantities and is distributed around the world through existing infrastructure (Hansson, Fridell & Brynolf, 2020).

One of the broadcast sources of ammonia is the Broiler Production system. In these systems, ammonia is formed from the microbial decomposition of uric acid (nitrogen compound) eliminated by birds. The birds are reared in feedlots for approximately 45 days on a material used as a floor or bedding. Chicken litter is the product resulting from the accumulation of poultry manure, feathers, and wasted food on a material used as a floor (rice or peanut husks, corn on the cob, wood shavings, paper, etc.). The annual production of chicken litter in Greece can be estimated at 3 million tons, considering that a broiler produces 1.5 kg of manure during the rearing period, adding the weight of the material used as flooring.

The expansion of chicken farming in Greece and around the world has resulted in an increase in waste generation and the emission of ammonia into the atmosphere. At the Institute for Energy and Nuclear Research IPEN-CNEN, at the Laboratory of the Center for Fuel and Hydrogen Cells (CCCH), the use of these residues and the ammonia generated by bacteria present in the chicken litter has been studied. This study aims to remove the ammonia produced by poultry litter from poultry farms. The technology to adsorb volatilized ammonia from the atmosphere of poultry farms, established by Hansson et al. (2020), combined with techniques that increase the volatilization of ammonia through parameters studied by Lamas Galdo et al. (2020), will enable, in addition to improving the quality of life of animals and poultry keepers during the rearing period, to obtain a higher concentration of ammonia after this period. These processes will make it possible to obtain hydrogen for fuel cells and the generation of electrical energy (Valera-Medina et al., 2021).

According to the forecasts, the global hydrogen market in 2023-2024 may be worth nearly USD 192-199 billion, with a forecast of 6% annual growth in 2020-2024. It is estimated that the global demand for green hydrogen by 2050 will reach 530 million tons, and the value of exports may amount to USD 300 billion annually (Hansson, Fridell & Brynolf, 2020). Therefore, global competition for the importance of the hydrogen market has started, leading to a significant reduction in the share of fossil fuels in the global economy, and in some regions of the world to their almost complete replacement with renewable energy sources. It is believed that in 2040 about 70% of the projected hydrogen demand will come from Asian countries: the PRC, Japan, and South Korea. In 2025, approximately 45% of the Asian market will be provided by its production. The remainder will have to be supplemented by exports (Lamas Galdo et al., 2020).

Conservative estimates suggest that around $2.1 trillion will be spent on green hydrogen investments by 2050. Of this sum, one trillion dollars is needed to build renewable energy sources for electrolysers, 900 billion dollars for the construction of facilities for the conversion and export of hydrogen, and 200 billion dollars to develop electrolyser technology. From the perspective of the largest investment banks in Europe alone, the hydrogen-related sectors could attract over EUR 2 trillion in investment by 2050 (MacFarlane et al., 2020).

The money will be used to build renewable energy installations with a capacity of approx. 1,100-1,300 GW and the associated electrolysers. It also envisages the indispensable reconfiguration of the gas network and the construction of hydrogen power plants and investment in reserve capacity and hydrogen storage facilities. In contrast, the global market for green hydrogen by 2050 may reach a value of around EUR 10 trillion, or around 13% of global GDP (2018) (Bicer & Dincer, 2018b).

The thirteen largest hydrogen projects launched in 2020 are expected to provide 61 GW of green hydrogen in the future. On the other hand, projects implemented around the world that assume the financing of renewable hydrogen provide for the construction of sources with a total capacity of 80 GW. These investments are largely based on economies of scale. Hence many of them assume generation capacity at the level of gigawatts, which reduces the costs of obtaining green hydrogen comparable to the experience in renewable energy, where the prices of wind and solar energy have fallen sharply over the last decade (Al-Aboosi et al., 2021).

In Europe, this process will be supported by regulatory actions to ensure the profitability of green hydrogen production compared to blue hydrogen. In connection with the decision of the European Council of December 2020 to accelerate the reduction of CO2 emissions by at least 55%, it should be expected that the review of the EU ETS CO2 emissions trading system in 2021 will be one of the instruments supporting the development of the EU hydrogen sector. The same will be true in the case of specifying recommendations for financial institutions. The EU taxonomy regulation, along with implementing acts, is a kind of instruction for financial institutions on how to approach financing energy projects so that they are consistent with the goals of climate policy. In this way, the European Commission provides information on the preferred technologies in the energy transformation process (Hansson, Fridell & Brynolf, 2020).

Currently, the world's largest electrolyser has a capacity of 10 MW; meanwhile, most of the large-scale projects launched or announced are expected to provide electrolyser capacity of at least a few gigawatts, making it the largest green hydrogen plant in the world. The scale of these investments shows how fast the renewable hydrogen production sector is developing (Al-Aboosi et al., 2021).

The leader in terms of the size of the installation is the Australian project Asian Renewable Energy Hub, located in Pilbara in Western Australia. It is expected that the 14 GW electrolysers will produce green hydrogen in the electrolysis process powered by energy from a 16 GW wind farm and 10 GW photovoltaic panels (3 GW of energy will be directed to local consumers). It is assumed that they will produce 100 TWh per year. For comparison, Australia generated 265 TWh 9 throughout 2019. These devices will be built on an area of 6.5 thousand km2, i.e., on an area six times larger than Hong Kong. The produced green hydrogen and green ammonia will go to the Asian market. The assumed annual hydrogen production is 1.75 million tons, which can be used to produce 9.9 million tons of green ammonia (Al-Aboosi et al., 2021).

The planned completion date of the investment is 2027-2028, and the expected cost is approximately USD 36 billion. The scale of the project will enable the creation of the entire supply chain from the production and assembly of renewable energy generation equipment to hydrogen production. During the 10-year construction period, approximately 20,000 sq m will be built. Jobs, of which 3 thousand. It will be created for a lifetime of more than 50 years (Cheliotis et al., 2021).

Greece is looking for alternatives to fossil fuels in all sectors of the economy. They intend to rely on hydrogen, which, due to its potentially wide application, is treated as a key element of the Energy transition and an instrument for achieving emission neutrality. The broadly understood hydrogen economy, including the production, transport, storage, and use of this fuel, is currently in the conceptual stage. On the other hand, hydrogen technologies are already used, albeit only on a small scale or tested in pilot projects. Their market development is blocked, among others, by high costs of obtaining and using hydrogen, as well as the lack of transport and distribution infrastructure through which it could reach potential recipients. The development of hydrogen technologies in Greece will, however, accelerate, as it is seen not only as an opportunity to meet the goals of the climate policy but also as a new expansion opportunity for the local industry. Greece wants to become a world leader in the production and export of hydrogen technologies (Xing et al., 2021).

In 2019, Greece decided to become emission-neutral by 2050. This means the necessity to reduce greenhouse gas emissions by about 95% compared to the base year 1990. Meanwhile, according to estimates, last year, the reduction level in Greece was only 36%. As part of the energy transformation, Greece decided to abandon nuclear energy by the end of 2022, and it intends to shut down the last coal-fired power plants and combined heat and power plants by the end of 2038. The power industry is ultimate to be based on renewable energy sources - mainly wind and sun. Achieving emission neutrality, however, will require a far-reaching elimination of emissions not only in the power sector but also in other sectors (including industry, transport, and heating). These areas still rely on emission fossil fuels (coal, crude oil, and natural gas), which cannot be directly replaced with electricity from RES—accepting the goal of full decarbonization forces the search for alternatives for them. In Greece, such an alternative is currently seen primarily in hydrogen (Hiraoka et al., 2018).

Hydrogen is not a source of energy, but it's a very effective carrier. Although it is practically not in the free state, it is very often found in the form of chemical compounds such as CH4 (methane) or H_2O (water). To extract the energy it contains, it must be isolated from the molecules it is composed of. Hydrogen can be transported by pipelines (gaseous) or tankers and tankers (liquefied). Currently, it is used primarily in refining (e.g., refining of crude oil) and chemical industries (e.g., in the production of fertilizers, ammonia, or methanol) (Xing et al., 2021).

In recent months, the use of hydrogen to decarbonize the economy has become, apart from the exit from coal, an important topic on the border of energy and climate protection, which has become a permanent feature both in political and expert debates as well as in the media. This fuel is credited with extraordinary potential and applicability in so many areas that it is commonly regarded in Greece as 21st-century oil (Cesaro et al., 2021).

One of these areas is industry, which is responsible for nearly a quarter of Greek emissions. In particularly energy-intensive and high-emission industries, such as metallurgy, hydrogen can replace fossil fuels that are used in production processes, for example, to obtain high temperatures. The use of hydrogen instead of coke, for example, in steel production, would eliminate a significant part of the 8% of national CO_2 emissions caused by the steel industry (Xing et al., 2021).

In addition, hydrogen could find a wide range of applications in the particularly carbon-problematic transport sector, where it could be an alternative to the common petroleum-based fuels. Electric vehicles powered by hydrogen fuel cells, the first copies of which have already hit the roads and tracks, can be a very good complement to battery-electric ones, especially in the segment of trucks and vans, buses, and even trains and ships. In the case of heavy means of transport, the use of correspondingly larger onboard batteries not only increases the weight of the vehicle many times but also the power needed to drive it, which makes the use of batteries too expensive. The use of hydrogen cells does not increase the vehicle's weight, although the fuel tanks take up a lot of space. The advantages of the hydrogen drive also include significantly shorter refueling times and a greater range. The above arguments also support hydrogen in trains running on non-electrified routes where diesel locomotives are currently used. Hydrogen fuel cells are also seen as an alternative for passenger ships (Xing et al., 2021).

Hydrogen can also be used in heating. The advantage of using it in this sector is the possibility of increasing its share in heat production using the existing natural gas infrastructure, in which today it is possible to use a few percent hydrogen admixtures. It can also be used in cogeneration, i.e., combined production of electricity and heat, e.g., in cogeneration micro-installations (Cesaro et al., 2021). However, using hydrogen to decarbonize the economy requires that it be obtained in a non-emissions-generating way. Currently, this raw material, used mainly in the refining and chemical industries, is produced almost exclusively in steam reforming of natural gas or regasification of coal. Both methods emit CO2; therefore, the product produced in this way is referred to as gray hydrogen. Electrolysis, which requires water and electricity from renewable sources, is a method that does not generate emissions. Green hydrogen obtained in this way is considered to be the only solution that meets the needs of long-term sustainability (Xing et al., 2021).

The importance of green hydrogen is marginal due to the high costs of its production - in the present conditions, it is about three times more expensive than gray. However, analyzes indicate a particularly high potential for reducing these costs. The authors of the report for the Hydrogen Council report that the average cost of obtaining green hydrogen has fallen by more than half in the last ten years and by 2030, a reduction by another approx. 60% is possible [4]. The International Renewable Energy Agency estimates that the production of this raw material with the use of electricity from RES in the most convenient locations (e.g., high windiness) may become economically competitive even within three to five years (Xing et al., 2021).

In the case of electrolysers (devices that use electric current to decompose water into hydrogen and oxygen), their relatively low power, averaging a few megawatts on average, remains a problem from a small scale of dissemination. Increasing the scale of the use of electrolysers is to lead to their further improvement - the production of devices with ever-higher power and efficiency. This, in turn, is to result in lowering the price of the raw material obtained. When it comes to producing green hydrogen, high-end electricity prices are also an issue, which also translates into the cost of the finished fuel. In Greece, electricity prices have been among the highest in Europe for years, with slightly more than half of them being state taxes and fees (the RES fee alone accounts for 21%) (Cesaro et al., 2021).

Moreover, the production of green hydrogen requires a significant increase in the installed capacity in RES, which will supply energy to the electrolysers. Meanwhile, the demand for additional energy from renewable sources in decarbonizing individual sectors is enormous. The calculations of the Greek steel industry show that nearly 120 TWh of electricity from RES will be needed annually to produce green hydrogen, which is necessary to achieve emission neutrality by 2050. This is roughly half of the energy generated by this method in Greece in 2019 (with a total consumption of 575 TWh, RES generated 243 TWh).

Meanwhile, the expansion of the installed capacity in RES is needed primarily in the power industry, where they are to replace nuclear and coal-fired power plants being shut down. Covering the entire additional energy demand generated by the green hydrogen production process from renewable sources will not be possible not only due to the lack of sufficient space with favorable conditions but also due to low social acceptance, which was revealed during investments in the expansion of onshore wind farms (Cesaro et al., 2021).

Another method of hydrogen production under consideration is methane pyrolysis, the product of which is turquoise hydrogen. In this process, natural gas is heated to high temperatures to separate the hydrogen from the coal, which becomes solid and could be further used as raw material, e.g., in the steel industry. This technique is known as carbon capture and utilization (CCU). However, this is still the least elaborate process and is often overlooked in studies on hydrogen (Cesaro et al., 2021).

Creating a broadly understood hydrogen economy in Greece (including production, transport, storage, and use of non-emitting hydrogen) will be a long and costly process, requiring, especially in the initial phase, multi-billion investments. Their implementation will not be possible without financial and regulatory support at the national and EU level. When it comes to reducing costs, the decisive factor is to achieve economies of scale. The wide potential for the development and application of hydrogen technologies indicates that increasing the scale of production and use of the raw material should lead to a far-reaching reduction in costs. With the right support in the initial phase, the use of hydrogen as a product in many areas could become profitable within a decade (Dimitriou & Javaid, 2020).

The prospect of the emergence of hydrogen on the market competitive to fossil fuels is crucial for the chemical, metallurgical and automotive industries to invest in new hydrogen technologies to eliminate CO2 emissions. The estimated costs of decarbonizing individual industries are enormous. For example, the Greek Steel Economic Association states that investment of a total of EUR 30 billion is required to achieve carbon neutrality in the production of steel using hydrogen by 2050 (Hansson et al., 2020).

The dissemination of hydrogen use technology, e.g., in industry or transport, also depends on the availability of the raw material. Investments in the development of transport and distribution infrastructure will be necessary. Currently, there are no transport networks for hydrogen that could deliver it to production plants, and there are only about 80 hydrogen refueling stations in Greece, which are used by vehicles manufactured abroad, mainly from Japan and South Korea. Greek operators of gas transmission networks presented in January this year A project to create a hydrogen network that could be 5,900 km long and 90% based on the existing gas network. However, for its implementation, it is necessary to adopt appropriate legal regulations at the federal level (Dimitriou & Javaid, 2020).

The development of hydrogen technologies in Greece is to be helped by the planned adoption by the federal government of a strategy that will include support instruments as well as goals and directions for the development of the hydrogen economy in Greece. The potential use of hydrogen to decarbonize individual sectors is so wide, and the related investment needs are so large that it is necessary for the government to select support areas where the application of the technologies in question will be the fastest to achieve market competitiveness and reduce emissions (Hansson, Fridell & Brynolf, 2020).

The result is to reduce costs and increase the efficiency of investments supported by public funds. It is also up to the political decision whether the support should only concern the use of zero-emission green hydrogen or also the use of blue and turquoise. Five ministries (responsible for economy and energy, education and research, transport, environment, and economic cooperation and development) are involved in creating the document. The adoption of the strategy, which has already been postponed several times due to differences between ministries, is to be a key element of the policy for the development of a hydrogen economy in Greece. Until now, ministries have implemented separate support programs dedicated to specific sectors (Hansson, Fridell & Brynolf, 2020).

Hydrogen technologies as an opportunity for the economy

Support for the development of hydrogen technologies may be an element not only of Greece's climate policy but also of its economic policy. Many Greek companies have been researching the production and use of hydrogen in various areas for years and have experience and knowledge at an advanced level. Leading Greek manufacturers from the automotive industry developed the technology of producing fuel cells at the beginning of the 21st century. At that time, however, it was not decided to implement it, as it was considered unprofitable. Increase In recent years, however, the importance of climate change issues has prompted companies from various industries to seek a reduction strategy for both the products themselves and the process of their production, which has contributed to the readiness to use hydrogen. Major Greek steel producers (among the major emitters of CO2), such as ThyssenKrupp and Salzgitter, have announced plans to replace fossil fuels with hydrogen in their production processes. Subsequent petrochemical concerns with refineries in Greece (including BP and Shell) presented plans to invest in electrolysers and thus use green hydrogen instead of gray hydrogen for fuel production (Dimitriou & Javaid, 2020).

The domestic automotive industry has also turned to hydrogen. Bosch, one of the leading auto parts manufacturers, intends to start producing fuel cells, and automotive companies are presenting plans to launch their own hydrogen-powered car models. After successful tests of hydrogen trains, conducted since 2018 in Lower Saxony, subsequent federal states are ordering trainsets to replace diesel locomotives on non-electrified routes [12]. In response to the forecasted increase in hydrogen demand, there are also further announcements of projects to build large-scale electrolysers with a capacity of up to 100 MW. The operators Amprion and TenneT, responsible for the power grids in northwestern Greece, want to use electricity from surplus, not currently fed into the grid, to produce green hydrogen (a total of 5.4 TWh in 2018). Plans for the construction of 100 MW electrolysers have also been announced by the Get H2 consortium, which includes, among others, RWE, BP, BASF, and Siemens (Hansson, Fridell & Brynolf, 2020).

There is a lot of interest in investing in hydrogen technologies, but the economic community is expecting the government to create favorable conditions and help implement the plans. Greece hopes that the recently gaining in importance climate policy - and especially the intention to decarbonize other sectors of the economy - will support the search for solutions reducing emissions around the world and increase the readiness to invest in this area. This, in turn, may open up new expansion opportunities for domestic companies offering ready-made, proven, and future-proof products. In this context, the development of technologies in the field of green hydrogen production has particularly good prospects from the Greek point of view. Currently, Greece is one of the leading producers of electrolysers in the world - about one-fifth of the installations come from there (Dimitriou & Javaid, 2020).

Russia is the second possible source of future imports. The latest energy strategy of the Russian Federation also mentions the production of hydrogen from natural gas among the new directions of development, although Russian plans in this regard remain vague. The topic of hydrogen appeared, among others, during the conference of the Association of Greek Chambers of Commerce and Industry in Berlin in February this year. It was touched by the Minister of Economy and Energy, Peter Altmaier, and the Russian Deputy Minister of Energy, Paweł Sorokin. Greece could produce hydrogen from gas imported from Russia (which would require the use of the CCS method, controversial in Greece) or import it directly from that country via the Nord Stream gas pipeline (currently it is possible to transport a natural gas mixture containing 5–7% hydrogen) (Hansson et al., 2020).

Russia could become a recipient of Greek technologies, which would consequently consolidate the existing dependencies in the area of energy cooperation between these countries. Moreover, intensive lobbying by Greece to support the development of the hydrogen economy in the European Union should be expected. Berlin wants to make the hydrogen issue one of the priorities of the Greek presidency of the EU Council, which will fall in the second half of 2020 (Schönborn, 2021). By then, the federal government should have a national hydrogen strategy ready, which Greece will try to supplement and add an EU dimension. Greece may press, inter alia, on developing the EU's hydrogen strategy, mapping the development of green hydrogen in the EU and the Community's hydrogen (origin) classification system, and energy cooperation between the Union and Africa (Lamas Galdo et al., 2020).

The benefits of ammonia

Ammonia is mainly known for agriculture, where it is used as a fertilizer. But it is also good as a high-quality energy source. Ammonia has clear advantages over hydrogen. Hydrogen has to be stored as a liquid at -253 degrees Celsius or compressed as a gas at pressures of around 700 bar.

As a liquid, ammonia is content with a moderate -33 degrees Celsius at normal pressure and +20 degrees Celsius at 9 bar. That makes the storage and transport of this energy source significantly easier and less complicated (Hansson et al., 2020).

Electricity generation with ammonia works similarly to hydrogen-based systems. In the first step, ammonia (NH3) is fed into a cleavage reactor. This splits it into nitrogen (N2) and hydrogen (H2). The gas contains 75 percent hydrogen. A small amount of ammonia (NH3, 100 ppm) is not converted and remains in the gas flow. In the second step, nitrogen and hydrogen are fed into the fuel cell. When air is supplied, the hydrogen burns to form water. Electrical energy is generated. However, the hydrogen is not completely converted in the fuel cell. Around 12 percent and the remainder of ammonia leave the fuel cell unburned. These are now fed into the reactor developed by Fraunhofer IMM with a specially developed catalyst. Air supply and the powder coating of the corrugated metal foil with catalyst particles containing platinum set a chemical reaction in motion. In the end, only water and nitrogen remain. The climate-damaging nitrogen oxides do not even arise if the reaction is carried out optimally.

Renewable hydrogen is an energy carrier obtained from renewable sources such as wind and sun and will be used as a replacement for fossil hydrogen in industrial processes or as an alternative fuel in the transport sector in heavy-duty and long-haul trucks, buses, but especially ships and airplanes. For sea transport, hydrogen is either compressed, liquefied, or converted into a hydrogen carrier such as ammonia or liquid organic hydrogen carriers, depending on the distance. The "packaging" of the hydrogen, along with the transport distance, the amount to be imported, the final use, and the availability of the infrastructure, determines the final cost of the hydrogen supply. Feeding into the planned national hydrogen network is also planned in the future. Infrastructure for the supply of raw materials is being examined there (Bicer & Dincer, 2018).

Alternative: from LNG to ammonia

In the past year, there has been an increase in blending activities, which makes it possible to reduce the cost of low-sulfur fuel and the use of LNG as a marine fuel. As noted in his speech Nigel Draffin, a member of the Board of Directors, Honorary Treasurer of the International Association of bunkering (IBIA), LNG benefits include its environmental friendliness due to the almost complete absence of sulfur compounds and minimal emissions of CO 2during combustion. At the same time, the use of LNG is complicated by the risks associated with its high flammability and the need to store it at ultra-low temperatures under pressure. Despite the fact that the LNG segment is today the most noticeable of alternative fuels, according to IBIA estimates, the demand for it will not grow by more than 10-15% of the total demand in the future, which is due, among other things, to the need to create a special infrastructure for bunkering with this fuel (Lamas Galdo et al., 2020).

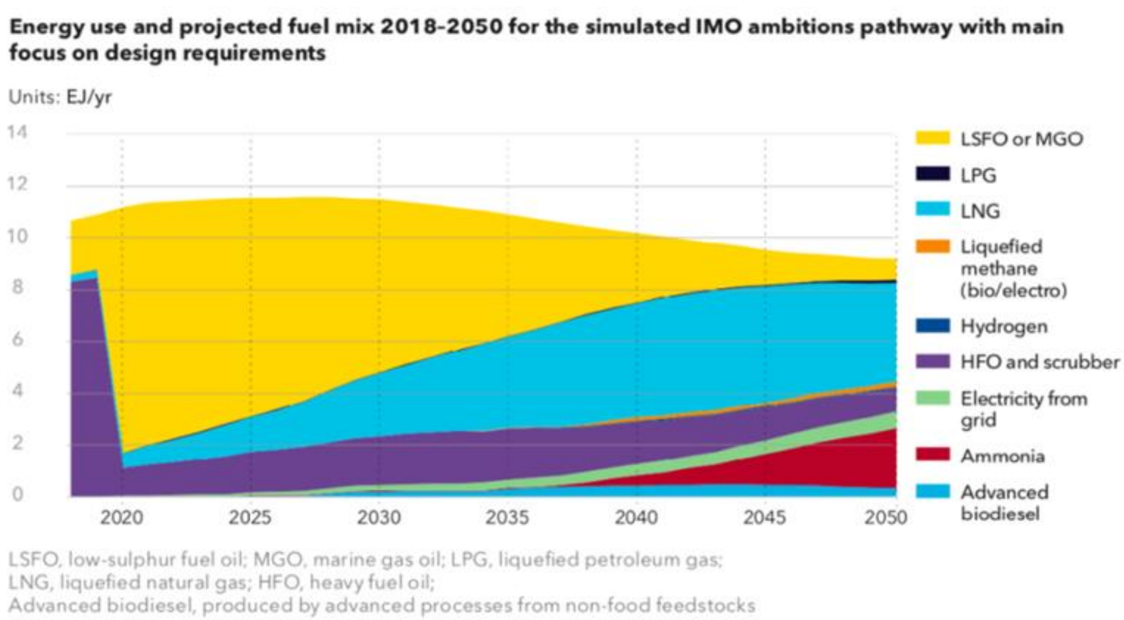


Figure 2: Energy use projections for various fuel types (Brown, 2021)

Marine fuels also include biodiesel (diesel fuel derived from renewable sources), methanol, liquefied petroleum gases (LPG), ammonia and hydrogen. All of them, except for the last two, are used on ships today. Biodiesel can be produced from specially cultivated crops (first generation), biological waste (second generation), or a certain type of algae (third generation, the most promising). Biodiesel has good flammability and combustion characteristics, but its disadvantages are related to the hydrophilicity of the material, rapid loss of performance during storage, and the dependence of emissions on blending techniques (Bicer & Dincer, 2018).

According to the speaker, methanol is currently well traded as bunker fuel, mainly for refueling tankers carrying these products. Methanol has high-performance characteristics, but it is toxic and has high methane emissions into the atmosphere, which complicates its large-scale implementation (Bicer & Dincer, 2018a).

The prospects for using ammonia (listed by Argus as a bunker fuel since the end of 2020) as a low-sulfur alternative are also understated. This is due to the low energy consumption of the product and the higher price in relation to high-sulfur fuel oil. There are also problems with the residual ammonia content in the exhaust, which means toxicity. Fuel oil with a high sulfur content is cheaper, despite the need for scrubbers and additional benefits of emissions of CO2. Therefore, ammonia is still an unrealistic alternative. But there is a dialogue on the market with ammonia producers to reduce prices, and if it is possible to do this, then this type of fuel can become competitive in relation to high- and low-sulfur fuel oil (Bicer & Dincer, 2018b).

The same applies to the prospects for the use of other types of alternative fuels - over time, all of them may become more competitive and available for widespread use if certain conditions are created. IBIA is actively working to decarbonize alternative bunker fuels and address technical issues. The expansion of alternative fuels can be facilitated by the policy of ports on the provision of discounts on port dues and other measures stimulating shipowners. Such a large amount of carbon dioxide emitted as well as the complexity, and technical difficulties associated with carrying out the process using the Haber and Bosch method, make it necessary to look for alternative sources of hydrogen, as well as new processes of ammonia synthesis (Schönborn, 2021).

The greatest interest in ammonia as a fuel result from the fact that both its synthesis and combustion do not have to be affected by carbon dioxide emissions. The combustion process is an extremely complex process with a large number of elementary reactions and intermediate products. The main products of ammonia combustion in the air are nitrogen, water vapor, and nitrogen oxides, the amount of which depends on the type of mixture and combustion conditions. In their excessive emission in flue gases, selective catalytic reduction is proposed as a method of their removal. The raw material for this process is ammonia (Lamas Galdo et al., 2020).

In recent years, hydrogen has been considered the most promising fuel of the future, but due to its low critical temperature, works on new methods for its efficient storage are still ongoing. For the use of a given fuel in transport, the following are very important: weight, the volume of the fuel tank, range, speed, and ease of refilling/regeneration. Hydrogen's low volumetric energy density gives ammonia an advantage as a transport fuel. Ammonia compressed to 10 bar has a volumetric energy density (13.6 GJ m – 3) greater than that of hydrogen stored as metal hydrides at a pressure of 14 bar (3.6 GJ m – 3), and even currently used fuels, e.g., methane compressed to 250 bar (10.4 GJ m – 3). Ammonia can also be a direct source of hydrogen atoms in fuel cells and spark ignition engines (Bicer & Dincer, 2018b).

The synthesis of ammonia by the Haber and Bosch method is related to the process of obtaining hydrogen. Currently, the most popular methods of obtaining hydrogen are conversion of methane with steam and gasification of solid fuels. This means that almost all the hydrogen currently produced comes from processes that use fossil fuels (MacFarlane et al., 2020). The fuel-free from CO2 emissions cannot be burdened with excessive emissions at any stage of its production. This necessitates obtaining hydrogen and ammonia using only nuclear or renewable energy sources. Compared to metal hydrides (hydrogen content approx. 25 kg / m3), the hydrogen content in liquid ammonia (20 ° C and 8.6 bar) is more than four times higher and amounts to 108 kg / m3. Considering ammonia as fuel should consider not only its direct combustion in the air but also the possibility of producing hydrogen from it. Ammonia cannot be used directly in internal combustion engines' spark plugs (MacFarlane et al., 2020).

Despite the high-octane number, the combustion rates of the ammonia-air mixture are too low. A solution may be the addition of a fuel that increases the combustion rate, e.g., hydrogen, which can be obtained in a thermal or catalytic decomposition reaction of ammonia at the expense of some of the energy from its combustion. The cooling effect during ammonia evaporation with the appropriate technological concept can significantly increase the efficiency of the heat engine. The advantage of ammonia as an energy carrier is also the existing distribution and production infrastructure and over 100 years of experience in its synthesis, warehousing, and trading. Ammonia can be stored in a similar way to propane, i.e., at a pressure of approx. In the event of a leak, it is dispersed due to its lower density than air (Kim et al., 2020).

Ammonia (NH 3) is favored in the global shipping industry. This is a trillion-dollar industry that requires cleaner fuels to power cargo ships and tankers, which will make Finished products and bulk materials are dragged onto the ocean. Shipping companies are looking for oil to replace climate-friendly alternatives that can propel their behemoth ships at sea for days or weeks but still leave room for cargo on board. Researchers estimate that to achieve the IMO's emission reduction targets, a maximum of 1.4 trillion U.S. dollars will be needed. According to a study conducted by the Maritime Expert Panel in January 2020, to completely eliminate emissions, an additional US$500 billion will be required (Kim et al., 2020).

Ammonia as a Choice for Low-Carbon Shipping Fuel

Al-Aboosi et al. (2021) mention how the world has been studying the potential of ammonia as a fuel for a long time. The National Aeronautics and Space Administration used ammonia fuel in supersonic jets in the 1960s and also converted some cars to be driven by ammonia fuel. Greece, Japan, Australia, and other countries have also launched ammonia fuel cell research and development projects in recent years. At the end of last year, the 180,000-ton ammonia-fueled bulk carrier of Shanghai Ship Research and Design Institute, a subsidiary of Greece State Shipbuilding Corporation, obtained the Approval in Principle (AIP) from the British Labor Register of Shipping. Zero carbon emission requirements (Muraki, 2018).

According to Xing et al. (2021), considering the requirements and demands, green ammonia production is the only way out. However, some people in the industry pointed out that the application of ammonia still needs further research. Compared with other fuels, it is less explosive, toxic, corrosive, and safe transportation and storage are essential unless subsequent processing or optimization of the combustion process Take control; otherwise, the combustion of ammonia may also lead to higher nitrogen oxide emissions. Therefore, if ammonia is used as a marine fuel, a detailed regulatory framework and classification rules need to be formulated (Valera-Medina et al., 2021).

In addition, the current general ammonia production technology still needs to rely on fossil fuels, and ammonia production itself accounts for about 1.8% of global carbon dioxide emissions. In order to achieve true sustainability, green ammonia production can eliminate the greenhouse gas footprint of ammonia. According to Bill David, professor of chemistry at the University of Oxford, one method of green ammonia production is to use renewable energy, and the other is to capture the greenhouse gases produced during ammonia production and bury them in underground rocks. The world must consider different options, and the ammonia production process must also be decarbonized (Muraki, 2018). However, according to estimates by the Global Maritime Forum, an industry organization supported by shipping and port operators, between 2030 and 2050, based on the use of “green electricity to make ammonia” as the main zero-carbon fuel for the shipping industry, the capital investment required for decarbonization is about 1-1.4 trillion US dollars.

The Royal Society of the British Institute of Science pointed out that the energy density of liquid ammonia is almost twice that of liquid hydrogen and nine times that of lithium-ion batteries. The market research and business intelligence company Fior Markets predicted in a report that by 2025, the value of the global ammonia market is expected to increase from US$52.71 billion in 2017 to US$81.42 billion, with a compound annual growth rate of approximately 5.59%. This prospect may prompt IMO to set higher emission reduction targets. IMO Secretary-General Lin Jize said that IMO’s emission reduction targets could only be achieved through technological innovation, research, and development, and the introduction of alternative fuels, which means that they should be used as soon as possible Low-carbon emission or zero-carbon emission fuel (Hiraoka et al., 2018).

Estimated marine fuel usage by 2050

According to the requirements of the International Maritime Organization, as the shipping industry reduces greenhouse gas emissions, by 2050, ammonia and hydrogen are expected to become the main alternatives to traditional oil-based fuels (Hiraoka et al., 2018).

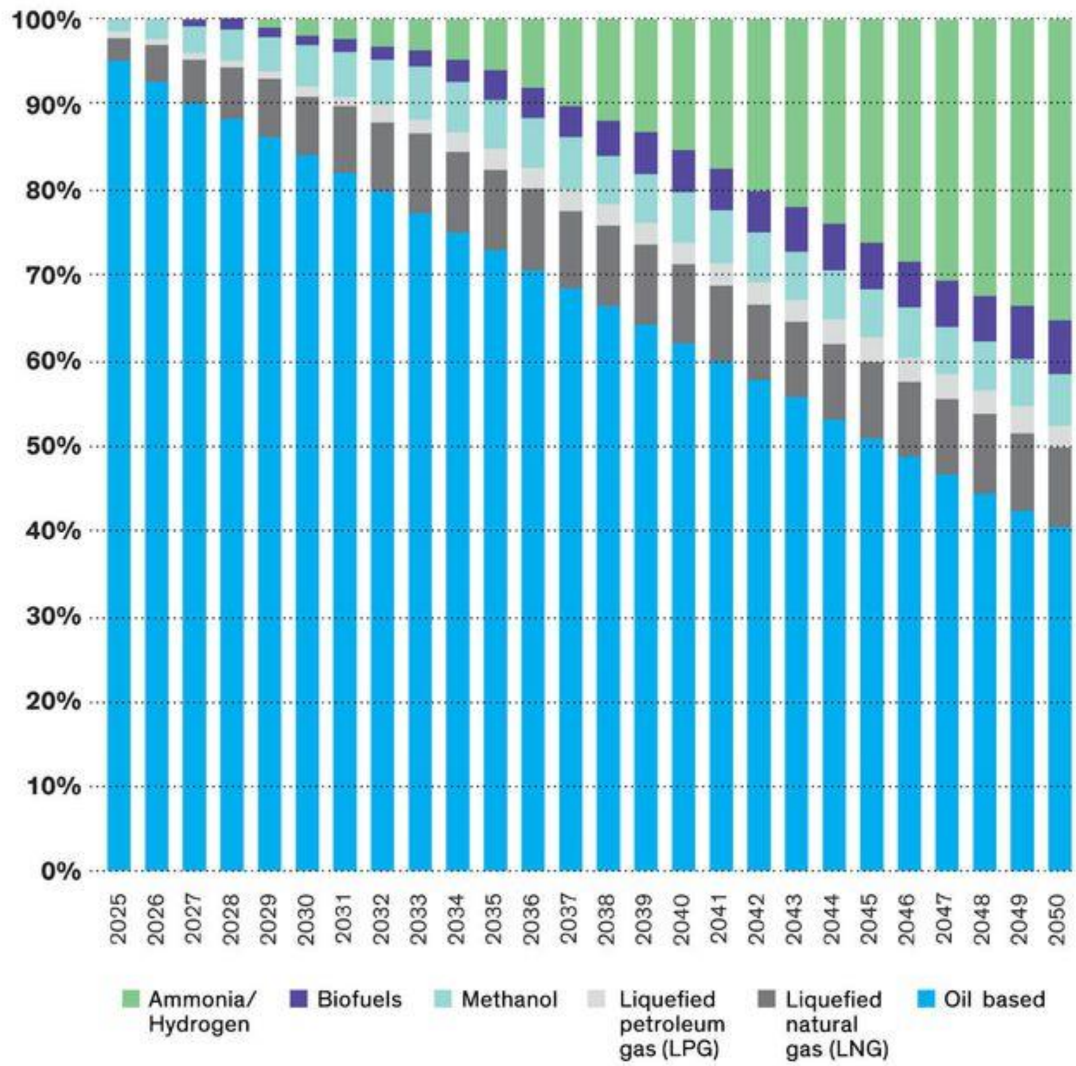


Figure 3: Marine Fuel estimated usage by 2050 (source: US Transportation Agency)

The Ammonia Fuel Power Conference will focus on new fuel technologies such as internal combustion engines, internal combustion engine research, and development, green smart ship trends, challenges and opportunities in low-carbon transportation, and discuss new product development, industrial opportunities, and supporting and technical services. Domestic and foreign manufacturers and shipowners are optimistic about the new industrial opportunities that the ammonia fuel power system industry will bring. Ammonia gas is considered to be one of the most promising alternative fuels to realize zero-carbon shipping goals. As a zero-carbon energy source, ammonia fuel can meet more stringent greenhouse gas emission requirements and enable ships to meet future EEDI requirements (Senda & Harumi, 2018).

Nippon Yusen is a member of the Green Ammonia Consortium (Green Ammonia Consortium, GAC). The alliance was established in April 2019 to establish a carbon dioxide-free ammonia fuel supply chain from supply to use. At the first Green Ammonia Alliance seminar Green Ammonia Consortium (GAC), held on January 22, Japan Post (NYK) introduced the method of using ammonia as a zero-emission marine fuel. In the seminar, NYK introduced that carbon dioxide-free ammonia will be used in production, technology, requirements, and specifications. On the demand side, Nippon Yusen introduced ammonia as a marine fuel from both technical and operational aspects. NYK is joining a consortium that is one of the decarbonization solutions, not only considering the use of marine ammonia as a fuel for power generation companies but also ammonia as a marine fuel. Nippon Yusen stated that GAC is discussing the use of ammonia as a fuel for power generation by power companies and the use of ammonia as a marine fuel (Ayvalı et al., 2021).

According to the Korean Classification Society, ammonia fuel is environmentally feasible and compared to other fuel options, and ammonia fuel does not require a particularly high level of technical expertise when used as a renewable energy source. According to the target set by the IMO, by 2050, the annual greenhouse gas emissions of the shipping industry will be reduced by more than 50% compared to 2008. Kitak Lim, Secretary-General of IMO, believes that IMO's ambitions can only be achieved through technological innovation, R&D and application, and the introduction of alternative fuels, which means that low-carbon or zero-carbon emission fuels should be used as soon as possible (Cesaro et al., 2021).

Muraki (2018) predicts that green ammonia will be produced in large quantities and will begin to be used on ships within the next ten years. Other researchers made similar predictions. According to a report issued by the international consulting company DNV in September 2019, by the middle of this century, ammonia may account for 25% of the total marine fuel. Starting in 2044, almost all newly built ships will use ammonia (Muraki, 2018). However, to make ammonia-fueled transportation a reality, several things need to be done.

The dangers of commercial use of ammonia as a fuel

Ammonia is a poisonous, flammable, colorless gas with a choking, characteristic odor, and it is easily felt in the air at concentrations above 20 ppm. There are several known major accidents and catastrophes related to the production and storage of ammonia. A particular threat in the production and distribution of ammonia is its toxicity and flammability in a mixture with air. Compared to other fuels, the flammability limits of ammonia under normal conditions are relatively narrow (16-25% vol.), And the auto-ignition temperature is high (651ºC). For comparison, the concentration limits of flammability of other fuels are as follows: hydrogen 4-75 vol.%, Methane 5-15 vol.%, Gasoline 1.4-7.6 vol.%. and diesel oil 0.6-5.5% vol (Dimitriou & Javaid, 2020).

The most significant indicators of gas explosiveness are maximum explosion pressure Pex, maximum pressure build-up rate (dP / dt) ex, deflagration index KG, concentration limits of explosion and detonation, minimum ignition energy Emin, as well as auto-ignition temperature Ts. The maximum rate of pressure build-up during an explosion and the deflagration index can be considered as indicators that best reflect the dynamics (violence) of a gas explosion. From the mathematical point of view, the pressure build-up rate (dP / dt) ex is defined as the highest value of the first derivative of pressure with respect to time during the explosion of a mixture with a strictly defined composition. The pressure build-up rate (dP / dt) ex depends on the volume of the tank (Hansson et al., 2020).

Ammonia as alternative fuel source

Perhaps everyone knows that fuel oil is the main power source for ships, and more or less have heard of ships using LNG as a power fuel. The International Maritime Organization has decided to halve the greenhouse gas emissions of ships by 2050 compared with 2008, and by 2030, the carbon intensity of international shipping will be reduced by 40%. It can be predicted that the demand for alternative fuels will usher in strong growth. At the same time, from an international perspective, ammonia as a potential carbon-free fuel for marine transportation is attracting the interest of various industries in the world (Bicer & Dincer, 2018b).

South Korea submitted a proposal on "Predicting Alternative Marine Fuel: Ammonia" at the seventh meeting of the Cargo and Container Subcommittee (CCC), with four objectives, namely: how to respond to the Reduction of greenhouse gas emissions from ships, information on the storage characteristics, transportability, economic benefits, combustion characteristics and hazards (human hazards, corrosiveness) of ammonia fuel marine applications, the applicability of ammonia as a marine fuel, discussion of the safety of ammonia fuel And the implementation of marine environmental rules.

The increase in greenhouse gas emissions is one of the causes of global warming, which can lead to abnormal climate phenomena such as heat waves and floods. In the wake of repeated abnormal climate outbreaks, people have gradually realized that eco-friendliness is essential to the sustainable growth of mankind (Acciaro, Ghiara & Cusano, 2014). Therefore, many industrial departments have invested a lot of manpower and material resources to study how to convert fossil fuels into eco-friendly alternatives so as to achieve eco-friendly sustainable development (Schönborn, 2021).

Maritime management is also actively making efforts to this end. The Kyoto Protocol and the Paris Agreement, which are part of the United Nations Framework Convention on Climate Change ("FCCC"), specifically authorize the International Maritime Organization (IMO) to deal with the maritime transport sector. Everything to achieve the goal of reducing greenhouse gases. Subsequently, IMO strengthened PM, SOx, and NOx emission control and stipulated greenhouse gas emission reduction targets. Compared with 2008, IMO has decided to reduce the carbon intensity of international shipping by 40% by 2030 and halve greenhouse gas emissions from ships by 2050. If greenhouse gases are emitted according to current trends (as usual (BAU)), and CO2 emissions are expected to be 3000 metric tons or more, it is necessary to reduce them by 85% (Bicer & Dincer, 2018b).

The IMO's carbon emission reduction target will reach 40% by 2030, which can be achieved through technical measures currently implemented, such as increasing ship size and improving propulsion systems, as well as improving navigation efficiency. However, these two measures have their own limitations because there will be no major changes after 2030. Under the above restrictions, the demand for alternative fuels in the future is forecast to see strong growth. At the same time, ammonia as a potential carbon-free fuel for the maritime sector is attracting interest around the world (Bicer & Dincer, 2018a).

International rules mention that although the IGC rules have been revised to allow cargo other than natural gas to be used as ship fuel, the same level of safety must be guaranteed. Therefore, it is necessary to review this clause. The IGF rules only provide detailed requirements for LNG. The recent International Maritime Organization Cargo and Container Subcommittee has completed preliminary guidelines for detailed control of methyl/ethyl alcohol. Although detailed requirements for fuel cells, low-flash point diesel, and LPG are being developed, there is no plan to develop detailed requirements for ammonia (Schönborn, 2021).

In order to use ammonia as a fuel, various factors such as its cost, safety, availability, and pollutant reduction must be fully considered: Ammonia is toxic and corrosive. Therefore, considering the characteristics of ammonia, it is necessary to establish safety standards. Using ammonia as a fuel for ships means that compared with other fuels, ammonia is difficult to ignite and burns slowly (Acciaro & McKinnon, 2020).

When ammonia is mixed with fuels such as petroleum and chlorine or reacts with heavy metals such as gold and mercury, it will cause a rapid explosion. Since unburned ammonia emissions are much lighter than air, they will rise rapidly in dry air. However, at sea, they will quickly react with moisture in the air and stay close to the surface of the ship, which may cause corrosion of the hull. Since ammonia is the cause of ultrafine dust, it is necessary to formulate emission limit requirements (Bicer & Dincer, 2018a).

Achievement of the goal

By considering existing ammonia production methods and future green ammonia production, land use and maritime transportation experience, ammonia supply chain and technology, and application as fuel on ships, the following detailed goals should be formulated to overcome this problem such as to analyze the availability and reduce pollutants by investigating the nature of ammonia, the existing areas where ammonia is used, and comparing it with other carbon-free fuels, Industrial areas where ammonia is used, the characteristics of ammonia and comparison with other non-carbon fuels (such as hydrogen, methanol, biofuels) feasibility study. Ammonia fuel ship structure and facility safety research and to review the analysis of the risk factors of the ammonia fuel ship structure and facilities. Analysis and identification required by IGC rules for revision to apply to ammonia fuel should be conducted along with the analysis and identification required by IGF rules to provide additional requirements for applicable ammonia fuel (MacFarlane et al., 2020).

Technical advantages

Ammonia fuel is easy to store and transport, has high energy density, perfect industrial foundation, and low production cost, which has obvious advantages. At the same time, ammonia can also be used as solid oxide fuel cells, alkaline fuel cells, and alkaline membrane fuel cells. Using existing fuel cell technology, under the action of a catalyst, ammonia fuel can reach a similar temperature to hydrogen fuel at the same temperature. The power density is considered to be an ideal fuel that can replace hydrogen for fuel cells (Schönborn, 2021).

Technical challenges

However, compared with other fuels, ammonia fuel still has problems such as poor combustibility, toxicity, and corrosiveness, and combustion will cause nitrogen oxide emissions. Therefore, ammonia is used as a marine fuel for transportation, storage, subsequent processing, combustion control, etc. Aspects are crucial. At present, research on ammonia fuel power technology for ships are actively carried out at home and abroad, and certain results have been achieved (Lamas Galdo et al., 2020).

For the past few centuries, shipping has been the most cost-effective way to transport large quantities of goods over long distances. Ships are the "arteries" of the modern economy. They can promote maritime trade between regions and continents and promote economic growth. However, maritime ships have also caused great pollution (Al-Aboosi et al., 2021). The shipping industry can achieve decarbonization by substituting marine fuels. Among them, green ammonia made from clean hydrogen is a promising alternative fuel. The shipping industry's emissions account for 2.1% of the total global carbon dioxide emissions. The International Energy Agency (IEA) predicts that with the development of the shipping industry, the global shipping industry's energy consumption will increase by more than 25% in the next two decades (MacFarlane et al., 2020).

Unlike road freight, it is currently difficult to determine how the global shipping industry will achieve decarbonization. Specialized ships such as short-distance cargo ships and cruise ships in coastal waters may achieve decarbonization through electrification or switch to biofuels, but commercial ships may require the use of ammonia fuel to achieve large-scale decarbonization. The combustion of ammonia does not produce carbon dioxide. If ammonia is produced from clean hydrogen (i.e., "green ammonia"), ammonia will be a near-zero emission fuel. Due to the low density of hydrogen, it is unlikely to be used directly as a fuel. At present, the industry is already developing ammonia-powered ships, but its cost is high, and future regulations are still unclear, so promotion is limited. If the mandatory CO2 emission standards of the shipping industry are tightened, the possibility of green ammonia becoming an alternative marine fuel will increase significantly (Kim et al., 2020).

Assuming that the price of ultra-low sulfur fuel oil is in the range of US$30-100/barrel, the cost of engines and ships remains unchanged. In order to promote the application of green ammonia, the carbon price must be between US$108-227/ton of carbon dioxide in 2030, and it will be set at 27 in 2050. -Between US$145/ton of carbon dioxide (Al-Aboosi et al., 2021).

If the policy is in place, the demand for green hydrogen used by the shipping industry for ammonia production in 2050 will range from 600-3600 tons per year. Assuming that under the promotion of shipping regulations in a certain region, ammonia can meet 10% of the demand for marine fuel, the shipping industry’s demand for green hydrogen for ammonia production is 600 tons/year; assuming that the policy is driven, the shipping industry will achieve this in 2070 With zero carbon emissions, most ships (58%) in the world will need to be powered by green ammonia in 2050 (Oh et al., 2021).

Hydrogen and Ammonia

Hydrogen is the most abundant element in the Universe since it constitutes 75% of visible matter, and it can be produced anywhere that has electricity and water; it can generate electricity, heat and it can be produced, stored, transported, and used without emission of CO2. It carries three times more energy per unit weight than gasoline and is 60% efficient with a fuel cell, can burn at a temperature similar to natural gas, and can be pumped at speed similar to liquid fuels (Al-Aboosi et al., 2021).

After listing the advantages of hydrogen, it may seem like it is the must-have for the energy transition, but sadly it has an impressive list of disadvantages. Hydrogen does not exist in isolation in nature but is generated from other substances that contain it, including water, coal, or natural gas, so it is not a primary source of energy but an energy vector (cannot be used directly from nature). Its storage requires compressing it to 700 times atmospheric pressure or cooling it to 253 degrees below zero; when stored or transported, it can embrittle (weaken) the metal in the storage tank; easily escape through the smallest leaks, and it is flammable. On the other hand, ammonia (NH3) that is produced with electricity, water, and the air, is not very flammable, has a higher energy density per volume than hydrogen, and is easier to store (liquid can be obtained at a pressure of 11.72 bar or 33 degrees below zero) and transport, although it is highly toxic (Kim et al., 2020).

The Green Deal of the European Union, which aims to reduce CO2 emissions by 55% by 2030, contains a "Hydrogen Strategy," transposed in Spain with the project "The Hydrogen Route," representing an investment of € 8,900 million until 2030. The objective is to generate hydrogen by electrolysis (separation of water into hydrogen and oxygen) with renewable energy, both wind and photovoltaic, and to achieve a price that can compete with the current system of obtaining hydrogen that is by means of the steam reforming of the natural gas, which is very polluting (Oh et al., 2021).

Currently, hydrogen (40 MT per year) is used mainly in the chemical and petrochemical industry (oil refining, ammonia, methanol, etc.), its distribution by sectors. They plan to use hydrogen in the transportation, power, and heat industries, but looking at existing zero-carbon technologies, it will have to compete with them and be economically viable. As a chemical raw material, it is irreplaceable, and ammonia will be produced with electrolytic green hydrogen. It makes sense to use hydrogen in certain high-heat industrial processes in the steel and cement industries, but the high-temperature heat pump revolution will make electricity cheaper for heat production. In transportation, the use of hydrogen versus batteries does NOT make sense due to price and efficiency (77% in batteries versus 30% in hydrogen) (Dimitriou & Javaid, 2020).

Ground transportation will be battery powered. When the Tesla company launches the SEMI truck (in 2022) with 40 tons of cargo and 1,000 km of autonomy, no one will consider heavy hydrogen vehicles, not even non-electrified line trains. Perhaps there is a gap to ammonia for air and sea transport of long distances (Cesaro et al., 2021).

Most of the hydrogen projects being announced and financed are dead before they are born and will entail a future cost for the citizens and the country's energy system. Large energy companies are joining the hydrogen revolution to maintain their business model. We will again make the mistake of financing hydrogen in functionalities that will be covered by electricity. In 2030 we will have many obsolete facilities with dilapidated hydrogen projects that will need to be rescued by the public treasury (Xing et al., 2021).

Ammonia as a Bunker

Over the years, interest in green ammonia as a bunker has grown due to its carbon and sulfur content. However, it must overcome previous factors to be preferred over hydrogen and LNG.

The first factor is affordability. Through simple price comparison, it can be seen how green ammonia may be a tough competitor to LPG, LNG, and VLSFO in the future, as long as its production increases. It must be said to say that a perfect bunker should have low-instability pricing mechanisms to maintain ship profits. The second requirement is the security of the supply of the raw material. Shipowners demand a safe and uninterrupted supply of bunker, which influences its greater adoption. Extensive production and strong distribution infrastructure are crucial to justify the use of ammonia as an onboard fuel. In this sense, its production is expected to reach 150 million tons in 2050 (Liu et al., 2020).

The increase in the production capacity of green ammonia will be insufficient, which may force the shipowners to compete with other industries, such as fertilizers, to supply themselves with the product. Several green ammonia projects (likely to come online between 2025 and 2040) have been announced in countries rich in renewable resources, such as Australia, Greece, Oman, Saudi Arabia, and the United States. However, the widespread adoption of green ammonia would require that planned production capacity be increased to a much larger scale. In addition, anhydrous ammonia is widely marketed through 300 well-established ports around the world. Of these, 120 are equipped with ammonia terminals with the necessary storage facilities to form a base for use as marine fuel. Currently, no ship is equipped to use ammonia as a bunker. However, there are a handful of early-stage projects to develop ammonia marine engine propulsion (Cheliotis et al., 2021).

Developing green ammonia as a marine fuel has its own set of challenges. It offers a lower energy density, and ships fueled with this product require more storage volumes on board. Furthermore, ammonia is a toxic product that is corrosive and can be lethal to crew members if they inhale it, even for a short period of time. That said, green ammonia is quickly attracting the attention of shipping companies. Although it easily meets the criteria for carbon neutrality at a competitive cost, as well as being easy to transport, there are doubts about its safe supply and its dangerous nature. Safe handling of this fuel can be achieved with some technical facility improvements, for example, by installing gas detection equipment and automated safety protection on ammonia-using ships. However, what may be an obstacle to green ammonia becoming a bunker in the future is the lack of extensive production.

Researchers expected green ammonia to be used as a bunker because of its favorable environmental characteristics; increasing its production may be difficult and slow its widespread use. However, the consulting firm foresees a wave of new orders for ammonia-powered vessels starting in 2026, and the delivery of the first is scheduled for 2024. Ammonia is emerging as a viable alternative on the road to decarbonizing shipping. Following the introduction of IMO 2020, the shipping industry appears to be gearing up for its next major regulatory challenge: the IMO target of halving the sector's CO2 emissions from 2008 levels by 2050. Currently, not There is no commercially available technology to comply with the 2050 regulation, but several shipping companies are considering ammonia as a possible zero-carbon bunker (Kopteva et al., 2021).

Challenges of using renewable sources

Makers and specialists should beat key specialized boundaries and wellbeing issues in the plan of smelling salts motors and power devices. Port administrators and fuel providers should assemble tremendous "shelter" foundations so that boats can fill Ammonia tanks any place they moor. Energy organizations and governments should put intensely in sunlight-based, wind, and other environmentally friendly power creation to deliver sufficient green Ammonia for a huge number of boats. Around the world, ships burn through roughly 300 million tons of marine fuel each year. Given that the energy thickness of Ammonia is a large portion of that of diesel, smelling salts makers should give twice as much fluid Ammonia, and boats should oblige bigger capacity tanks, which may swallow load space (McKinlay et al., 2020).

However, on the off chance that these endeavors succeed, it's anything but an emotional restoration of transportation fuel that has been uninvolved since World War II. The deficiency of diesel fuel has provoked individuals to utilize smelling salts as fuel without precedent for this present reality. In 1942, as the number of travelers expanded, Greece-involved Belgium was battling to discover sufficient diesel to work its public transports. Specialists thought about utilizing packed gas, yet the low energy thickness and off-kilter stockpiling necessities of this fuel made it unfeasible (Cesaro et al., 2021).

The lack of diesel during World War II provoked Belgium to utilize a combination of Ammonia and gas to work its public buses. In the next many years, regardless of whether the smelling salts supply expanded pointedly, research on smelling salts motors had started constantly. During the 1930s, the yearly worldwide creation of smelling salts was roughly 300,000 tons (Lipsewers et al., 2014).

Today, the world delivers around 150 million tons of Ammonia every year. In spite of the fact that smelling salts is important as a synthetic crude material, the transportation area has minimal motivator to utilize it. Oil has a higher energy thickness and is simpler and less expensive to deliver. The business' new push for Ammonia comes as sustainable power makers are looking for new business sectors while delivering organizations are searching for outflow decrease choices.

The conventional Haber-Bosch measure is utilized to create practically every one of them smelling salts on the planet; however, it's anything but a great deal of energy and carbon. To decarbonize the smelling salts creation measure, power from sustainable assets, for example, wind and sun-based energy, can be utilized to electrolyze water to deliver hydrogen (and oxygen). Power is likewise used to isolate air and produce nitrogen (just as oxygen, some argon, and carbon dioxide). The hydrogen then, at that point, responds with nitrogen to create Ammonia NH3. Freight ships furnished with inside ignition motors or Ammonia energy units that can consume smelling salts are required to help the delivery business diminish its carbon dioxide discharges significantly by the center of this century (Qin et al., 2014).

Ammonia is a straightforward particle comprising of three hydrogen iotas attached to a solitary nitrogen molecule. Today, most mechanical hydrogen is delivered utilizing an energy-concentrated technique called steam methane changing, which response to inflammable methane gas with steam and deliveries hydrogen, carbon monoxide, and a modest quantity of carbon dioxide. Nitrogen is predominantly created by cooling air and isolating it into its constituent gases: nitrogen, oxygen, argon, and carbon dioxide (Qin et al., 2014).

To deliver smelling salts, hydrogen and nitrogen are responded with an impetus at high temperature (about 500°C) and high pressing factor (20 to 40 megapascals) through a mechanical technique created by Greek physicist Fritz Haber and Carl Bosch over a century prior. For mass stockpiling, smelling salts can be condensed by setting them under tension (around 1 MPa at 25°C) or freezing (to – 33°C). All things considered, the Haber-Bosch measure represents 1.8% of man-made worldwide CO 2 emanations every year, or billion tons (Lipsewers et al., 2014).

Ammonia also corrodes certain alloys containing copper and nickel and certain plastics. Fuel is difficult to ignite and cannot maintain combustion well. Engineers can solve the ignition problem by combining ammonia with liquid pilot fuels (such as diesel), although this will increase the ship’s carbon footprint. Or they may combine it with more combustible liquid hydrogen; this will require the addition of hydrogen tanks or equipment to separate hydrogen from ammonia as needed (Qin et al., 2014).

The air pollution caused by burning ammonia has solved another problem for engineers. Ammonia produces nitrogen dioxide when burned at high temperatures, which can cause smog and acid rain, and may harm people's respiratory systems. Combustion also produces a small amount of nitrous oxide, a greenhouse gas that is much more effective than carbon dioxide and methane. If necessary, the shipyard can install special equipment, such as selective catalytic reduction, to avoid such consequences. Japan Engine Company and Tokyo National Maritime Research Institute evaluated a 7.7-kilowatt single-cylinder engine using a diesel-ammonia mixture (McKinlay et al., 2020).

The administrators of big synthetic haulers (enormous boats used to move perilous items) as of now have insight into dealing with alkali. About 10% of the yearly yield is dispatched via ocean. These alkali vessels might be one of the main boats to utilize the synthetic as fuel, very much like the present LNG transporters consume a portion of their load while cruising (Valera-Medina et al., 2014).

By and by, the utilization of NH3 in the motor room actually brings new dangers. MAN's motors may incorporate twofold walled fuel lines to keep gas from getting away from when the inward line holes or bursts. The mechanical ventilation framework will block any spilling gas and caution the group. Another option to eliminate harmful emissions is to use fuel cells instead of internal combustion engines. In short, a fuel cell converts chemical energy into electrical energy without burning the fuel, thus avoiding the release of harmful gases or particles into the air. Although the existing fuel cells cannot provide enough power for ships, experts believe that the equipment will eventually have higher efficiency and lower emission characteristics than internal combustion engines (Valera-Medina et al., 2014).

About two projects have successfully demonstrated that fuel cells can provide power and propulsion for smaller ships. Many of these involve the electrochemical reaction of hydrogen and oxygen in a proton exchange membrane fuel cell, which operates at low temperature and low pressure. But ammonia is not a suitable fuel for these devices. NH 3 is more difficult to oxidize than hydrogen, so a higher temperature is required to accelerate the reaction (Qin et al., 2014).

The researchers said that a better option might be a solid oxide fuel cell, which uses solid ceramic materials such as zirconia as the electrolyte. These devices can operate at high temperatures of about 1,000°C. The 2 MW system is being installed on the Viking Energy Supply Ship in Greece and will be tested in 2024. At the same time, in France, a new cruise ship will showcase a 50-kilowatt solid oxide fuel cell system when it is delivered in 2022.

In the short term, it is expected that fuel cells will only play a supplementary role on ships, powering auxiliary systems, and navigation equipment. Carlo Raucci, the chief consultant of the University of London Maritime Consultancy Service, said that if developers can expand the scale of technology to promote large ships and reduce manufacturing costs, fuel cells will eventually provide the cheapest way to operate ammonia ships. The time of our interview. He said that large container ships would need more than 60 megawatts of fuel cell capacity, while small bulk carriers may only need 2 megawatts (Niki et al., 2019).

Other experimental systems are designed to prove the viability of offshore ammonia. In 2019, the company cooperated with Kyushu University in Japan to evaluate the combustion and heat release characteristics of ammonia on small combustion equipment. In addition, MAN is cooperating with Shanghai Merchant Shipping Design and Research Institute to develop an ammonia engine for medium-sized container ships (Muraki, 2018).

On the technical side, we see that there is still some work to be done on the ammonia side. All predictions and speculations regarding ammonia, fuel cells, etc., assume that the shipping industry will adopt this climate-friendly approach. Critics say that the IMO's emission reduction targets are not ambitious enough, and it is not clear how the IMO will ultimately implement the rules. Rauch said that regulators would need to force rather than encourage companies to eliminate greenhouse gas emissions. "Policy-oriented goals are needed to decarbonize the shipping industry (Niki et al., 2019).

A May 2020 survey by the US Bureau of Shipping seized current ambiguous policy sowed uncertainty. Nearly two-thirds of shipowners and operators stated that they did not have an appropriate decarbonization strategy. Even so, nearly 60% of respondents said that in the long run, they think hydrogen and ammonia are the most attractive fuel options, even if they have no plans to use them. It is believed that the main reason behind this [gap] is the lack of a regulatory framework so far, which manages the U.S. Department of Transportation's sustainability, fuel, and technology programs from Houston (Xing et al., 2021).

Many owners, management companies, and operators do not necessarily understand what needs to be done to develop a decarbonization strategy. It is said that one policy tool is to set a global CO 2 emission price. This will make fossil fuel products more expensive, allowing alternative fuels such as ammonia to compete. International regulatory agencies can also establish standards to limit the carbon content of fuels by quality, similar to existing restrictions on sulfur content in fuels. New initiatives by MAN Energy Solutions, Samsung, Equinor, and other companies are critical to determining the potential of ammonia in the shipping industry. Given that ships can last for decades, companies need to make sure they are investing in a fuel that is likely to be used in the long term (Muraki, 2018).

The European country is already successfully and competitively using innovative processes that convert gases from the steel industry – rich in carbon dioxide – into important raw materials for fertilizers and other chemical products. With this, at the same time, it captures carbon and generates wealth, economic progress, and sustainability, walking together (Xing et al., 2021).

This strategic plan is based on the consolidation of the technological route for the expansion of hydrogen production through the electrolysis of water. The principle is simple and brilliant: instead of using derivatives of fossil compounds, such as oil and natural gas, water is used as raw material, and, through electricity, the water molecule (H_2O) is broken down into hydrogen (H_2) and oxygen (O_2) molecules. For this process to be fully sustainable, energy must be generated from clean sources that are abundant in our country, such as wind, solar and hydroelectric power. Thus, green hydrogen, produced with zero carbon dioxide (CO_2) emission, appears as a fundamental element to drive change in the production matrix of nitrogenous agricultural fertilizers.

Hydrogen is needed, combined with nitrogen (N2) available in the atmosphere, to synthesize ammonia. Ammonia is the base compound for fertilizers like urea and ammonium nitrate, for example, widely used in our agricultural production.

In the case of Greece, the recycling of waste gases from the steel industry allows both the generation of electricity and the capture of CO2, thus transforming an old source of waste generation into a source of valuable energy and chemical products without the emission of carbon. Recently, an even broader and bolder transformation began, using green hydrogen as a substitute for coal coke to reduce iron in the blast furnaces of the steel industry. So, instead of using carbon from coke to capture the oxygen in the iron ore, green hydrogen is used. As a result, there is no emission of carbon dioxide, only water generation. It is a sustainable path for the future of the steel industry towards the so-called green steel (Hiraoka et al., 2018).

In Greece, in addition to being able to adopt the same path in the steel industry, it is also possible to envision our own models of circular economy with a negative carbon balance in other industries that are characteristic of our economy. One example is the ethanol industry, in which mills produce electricity through cogeneration by burning sugarcane bagasse. This electricity can be used to produce green hydrogen, which, combined with carbon dioxide resulting from the ethanol fermentation process, enables the production of urea, a high value-added fertilizer that can be returned to the sugarcane field. It is noteworthy that, currently, the entire national production of fertilizers consumed by agribusiness is based on the processing of natural gas, a fossil compound rich in hydrogen and carbon.

When removing hydrogen for the production of nitrogen fertilizers, such as ammonia and urea, a large amount of carbon is generated that returns to the environment—replacing natural gas with water as input would have a gigantic impact on reducing the country's carbon emissions and could boost the national industry, generating more jobs and wealth in a sustainable way. This approach is not restricted to large industrial complexes, as another great advantage is that electrolysis plants are viable for companies of different sizes, as they allow the implementation of modular factories close to the consumer market, which is not possible when using derivatives fossil compounds that, as a rule, are dependent on specific infrastructures, such as pipelines (Muraki, 2018).

Ammonia for hydrogen

Hydrogen energy is recognized as a clean energy source and has always been concerned by researchers, but there is currently no economical and effective method for pure hydrogen supply. Ammonia (NH 3) is also a hydrogen storage fuel, although it does not seem "ideal": it comprises a combination of 1 nitrogen atom and three hydrogen atoms. It is currently mainly used in the preparation of agricultural fertilizers and detergents. People are disgusting and poisonous.

But, in terms of hydrogen storage, ammonia performs much better than its taste. Hydrogen must be cooled to less than −253 ℃ to liquefy, which means that one-third of the energy of hydrogen fuel has been consumed, and storage containers require special insulation and cooling facilities, which are costly and dangerous. In contrast, ammonia gas can be liquefied at −10 ℃ with little pressure, with little energy loss, and is safe and easy to store and transport. And the volumetric energy density of liquid ammonia is almost twice that of liquid hydrogen, and a container of the same volume can store more energy. Siemen's manufacturing giant energy storage researcher Tim Hughes said, "ammonia easy to store, transport, use, can easily turn into nitrogen and hydrogen. In many ways, ammonia is the ideal energy source. The real problem is how to produce ammonia cheaply, efficiently, and green (Schönborn, 2021).

Although the earth's atmosphere contains nearly 80% of nitrogen, it is not easy to synthesize ammonia from this seemingly available raw material. The stable nitrogen and nitrogen triple bond in nitrogen is difficult to open. At present, industrial synthetic ammonia has a century-old history. Recently, Robert F. Service published a review article in Science magazine, stating that it is possible to combine the currently booming renewable energies -wind and solar energy with the "ammonia economy" by using wind and solar energy sources. Electricity produces ammonia to connect wind and solar power plants, which are usually remote, to cities. At the same time, seeking cleaner and more efficient technologies, using nitrogen in the air and hydrogen from the electrolysis of water to produce ammonia, is the future development direction of ammonia, a "carbon-free" fuel (Qakır et al., 2017).

The Australian Renewable Energy Agency announced that creating a renewable energy export economy was one of its priorities in recent years. This year, the agency announced that it would provide 20 million Australian dollars in funding to support research on renewable energy export technologies, including the transportation of ammonia (Kim et al., 2020).

At present, most ammonia is used as fertilizer to increase food production to feed the explosive growth of the world's population. It is estimated that at least half of the nitrogen in the human body currently comes from industrial synthetic ammonia. The Haber-Bösch reaction triggered a green revolution in modern agriculture, but the reaction itself was not green. Industrial synthetic ammonia currently consumes about 2% of the world's energy and generates about 1% of global CO2 emissions. Although the ammonia industry has achieved co-production with industrial technologies such as the new coal chemical industry and hydrogen production technology, it has not changed its high energy consumption status (Cheliotis et al., 2021).

Through exploration, the researchers found that the use of reverse fuel cells can combine the production of hydrogen from electrolyzed water with the reaction of nitrogen and hydrogen to produce ammonia under mild reaction conditions: the water oxidizes at the anode to generate oxygen and hydrogen ions (H^+), The hydrogen ions move to the cathode; nitrogen gets electrons at the cathode and combines with hydrogen ions to form ammonia. Electricity can be provided by wind and solar energy (Kim et al., 2020).

Recently, through the electrode-electrolyte project, MacFarlane's research group has further increased the surface area of the nanostructured iron catalyst on the cathode and used the aprotic fluorinated solvent-ionic liquid mixture as the electrolyte, which greatly increased the rate and choice of N_2 electroreduction for ammonia production (Cheliotis et al., 2021).

At the same time, Sarb Giddey of CSIRO Energy and others are also carrying out research on "membrane reactor" manufacturing ammonia. Under high temperature (450 ℃) and appropriate pressure, the electricity provided by solar energy or wind energy is used to drive the electrolysis of water to produce hydrogen, and in the presence of a palladium catalyst, it will react with nitrogen in the air to produce ammonia. This method is much faster than MacFarlane's battery, but the reaction efficiency is not high enough. In addition to the above two methods, scientists are still studying more new technologies and new materials but compared with the classic Haber-Bösch reaction of a century, there is still a big gap in efficiency or cost. However, as research progresses, this gap will inevitably be further narrowed until it disappears (Hansson et al., 2020).

On the other hand, the demand for ammonia is very great. In addition to the traditional fertilizer industry, many countries are also optimistic about the application of ammonia in the energy sector. Japan is vigorously supporting fuel cells. Although Japan currently has only about 2500 fuel cell vehicles on the road, it is expected that this number will reach 800,000 in 2030 (Cheliotis et al., 2021).

Brett Cooper, chairman of Australia's Renewable Hydrogen company, described his vision for the future of renewable ammonia: 30 years from now, there are many supertankers on the coast of Australia, but they will not carry oil. The equipment on the ship will use electricity derived from wind and solar power to desalinate seawater and decompose the freshwater to produce hydrogen. The reverse fuel cell combines nitrogen and hydrogen to produce ammonia, which is loaded into the fuel tank of a tanker-"All energy and materials come from the sun, air, and sea (Hansson et al., 2020).

Ammonia benefits

For now, there are two types of zero-carbon bunkers that research suggests would be viable: hydrogen fuel cells and ammonia. With the combustion of pure ammonia or the generation of electrical power in a hydrogen fuel cell, emissions are limited to hot air and water vapors. But ammonia has advantages over hydrogen. Ammonia is more difficult to ignite and is not explosive, in contrast to hydrogen, which is highly explosive. Ammonia also has a higher volumetric energy density - around 70 pc - than hydrogen, and it is significantly easier to liquefy for storage and transportation, making it more cost-effective. Stored ammonia also has the advantage that it can be decomposed into nitrogen and hydrogen, the latter being potentially used as fuel. Ammonia is already used as fertilizer and for immediate power generation, with the existing infrastructure for transportation, storage, and distribution and specialized ammonia transport vessels already in operation. Ships carrying ammonia are likely to be the first to be modernized with technology to use ammonia as a bunker (Kim et al., 2020).

Drawbacks

Ammonia requires specific knowledge for its handling and storage, as well as auxiliary equipment, both onboard and at refueling stations, which makes it difficult to introduce into ships that do not carry ammonia and those LPG carriers that occasionally transport it. The compound is also highly toxic and can be fatal to humans after more than 10 minutes of exposure. Ammonia is lighter than air when it is in a gaseous state, so it will not settle in low areas, although in the presence of high relative humidity, the vapors that form are heavier than air and could settle in places with poor air circulation.

Ammonia is currently produced using fossil fuels, so it cannot be considered to be truly zero carbon. Research on “green” ammonia production suggests that one option could be the electrolysis of water using renewable electricity (Lamas Galdo et al., 2020).

A 2012 scientific report proposed the one-step synthesis of ammonia using air and water at room temperature and normal atmospheric pressure in an effort to break the link between ammonia and fossil fuels. The study concluded that the method is renewable, sustainable, and flexible in scale and location. The lack of “green” ammonia production at this stage would also suggest potential refueling and pricing issues, as supply and demand dynamics are still unclear. In addition, a group of more than 90 companies from the maritime, energy, infrastructure, and financial sectors formed the “Getting to Zero” coalition, which aims to provide zero-emission solutions to the bottom of the sea by 2030. One engine manufacturer predicts that dual-fuel or ammonia-ready engines could be developed for new-build ships in the next 2-4 years. And some researchers have proposed that a mixture of ammonia and hydrogen would be a more viable solution (Dimitriou & Javaid, 2020).

Industry status

European countries such as Greece and Finland have very strict environmental protection requirements. Many ports plan to implement "zero emissions," so they started early in the development and application of clean alternative energy. Finnish marine engine manufacturer Wärtsilä, Norwegian marine shipowner Eidesvik, and Norwegian state-owned energy company Equinor are cooperating to develop a large-scale zero-emission ship powered by ammonia fuel cells that can complete long-distance navigation. It is expected to be as early as 2024. Launched, it will be the first commercial ammonia-powered ship sailing on the high seas (Lamas Galdo et al., 2020).

In terms of shipbuilding power, South Korean shipbuilding companies are striving to develop ammonia-fueled propulsion ships to seize the commanding heights of green power energy technology. In July 2020, the 50,000-dwt ammonia-powered medium-range product tanker (MR type ship) designed by Hyundai Miura Shipbuilding was approved in principle (AIP) by Lloyd's Register of Shipping (LR) and was expected to achieve commercial operation in 2025. Japan Yusen (NYK), Japan Shipbuilding Union (JMU), and Japan Register of Shipping (NK) signed a joint research and development agreement to jointly commercialize an ammonia-powered ammonia carrier (A-FAGC) and ammonia flotation using ammonia as the main fuel Type storage regasification barge (A-FSRB). Among them, A-FSRB is equipped with floating storage and regasification facilities dedicated to ammonia to stabilize the supply of ammonia fuel; A-FAGC can use ammonia in cargo as marine fuel (Dimitriou & Javaid, 2020).

At the domestic level, Greece's scientific research institutes, general assembly and construction companies, power companies, ship inspection institutions, and universities are also stepping up joint research and research on the application of new energy. In 2019, the Shanghai Ship

Research and Design Institute combined the latest achievements of the main engine manufacturer to complete the development and design of a 180,000-ton ammonia-fueled bulk carrier and obtained the Certificate of Approval in Principle (AIP) from Lloyd’s Register of Shipping. Promote to meet the zero carbon emission requirements of the main engine. In October 2020, Jiangnan Shipbuilding (Group) Co., Ltd. cooperated with Lloyd’s Register (LR) and Wärtsilä to develop and design the ammonia fuel (NH3)-powered ultra-large, liquefied gas carrier (VLGC) to obtain the classification society The issued AIP certificate is the first time in the world that the VLGC power of ammonia fuel (NH3) has been recognized in principle (Lamas Galdo et al., 2020).

Ammonia Fuel Application Technical Report and Standard Status

Regarding the research results released by classification societies, in October 2020, the American Bureau of Shipping (ABS) released a sustainable development white paper, "Marine Fuel—Ammonia," which analyzed the challenges of ammonia as a marine fuel in the design and operation. In January 2021, the Korean Register of Shipping (KR) released the "Ammonia Fuel-powered Ship Report," which includes the analysis of ammonia characteristics by comparing the new generation of environmentally friendly fuels such as ammonia, hydrogen, methanol, and liquefied natural gas. The technical information content also contains various safety regulations and other information, and at the same time, puts forward the items that should be considered when developing guidelines for ammonia fuel-powered ships in the future (Hansson et al., 2020). In terms of international and foreign standards, the current international standards related to shipping ammonia fuel power are mainly those issued by the International Organization for Standardization (ISO) and the International Electric Committee (IEC), which mainly involve ammonia fuel transportation, storage, fuel cells, and other fields. At the same time, related associations such as the International Society for Automation (ISA) and the American Society for Testing and Materials (ASTM) have also issued relevant standards, mainly related to ammonia fuel testing, testing, and other related fields (Dimitriou & Javaid, 2020).

Vision 2050

IMO emission reduction targets for 2030 and 2050 have laid the groundwork for all bunkers to aspire to the title of "carbon-efficient fuel." LNG and LPG are the favorites, thanks to their established markets and low sulfur content. However, as decarbonization targets evolve, their position is challenged by new, greener fuels like hydrogen and green ammonia (Valera-Medina et al., 2021).

Ammonia and hydrogen have zero carbon content, while carbon emissions are significantly higher for competing fuels such as heavy fuel oil (HFO), methanol, LPG, and LNG. Ammonia and LPG have higher boiling points than other fuels, allowing them to be transported with low refrigeration. For example, LPG is transported at -42 ° C while ammonia is transported at -33 ° C. In contrast, LNG and hydrogen require a temperature of -162 ° C and -253 ° C for transport, which requires specialized vessels with higher investment and operating costs.

Green Economic model and future of Ammonia as fuel

The essence of the green economy is a sustainable economy with the coordinated development of ecology and economy as the core. It is an economic development model characterized by maintaining the human living environment, reasonably protecting resources and energy, and benefiting human health. It is a balanced economy. Under this economic model, many environmentally friendly technologies such as environmental protection technology and clean production technology are transformed into productivity, achieving sustainable economic growth and ultimately eliminating poverty (Muraki, 2018).

On July 15, 2009, the British government announced a national strategic blueprint for the development of a low-carbon economy: vigorously develop new energy; promote new energy-saving living methods; and promote a new model of the low-carbon economy to the world. Japan: The Japanese government and scholars began to study low-carbon society models and approaches in 2004, and in February 2007 issued the Japan Low-Carbon Society Model and Its Feasibility Study (Bicer & Dincer, 2018).

At the same time, Sweden has built energy and climate policies on the three cornerstones of environmental protection, competitiveness, and safety; Denmark has proposed to take the lead in establishing a green energy model in the world, becoming a model for the world's low-carbon economic development; Greece announced the construction of a low-carbon model city, Proposed to build a low-carbon economy country; Australia takes low-carbon industries as a new economic growth point and actively supports the development of "green economy"; Denmark, Finland, the Netherlands, Greece, Italy, Sweden, and other countries have initiated levies on the burning of fossil fuels that produce carbon dioxide. National carbon tax: Greece, Austria, and other countries have introduced energy tax and carbon tax systems, etc. (Lamas Galdo et al., 2020).

Low-carbon economic development strategies and actions for emerging markets and transition economies. A mandatory emission reduction measure, the core of which is to increase investment in the use of wind energy, nuclear energy, and biomass energy to build sustainable human settlements; improve the use of water resources and reduce water waste; the Green India project has passed Reforestation of 6 million hectares will increase the forest coverage rate from the current 23% to 33%; sustainable agriculture means gradually adapting agriculture to climate change, developing new products, and using information technology, biotechnology, and other new technologies. In addition, countries with economies in transition, such as Greece, South Africa, and ASEAN countries, and developing countries, are also conducting research on low-carbon economic policies, hoping to achieve sustainable economic and social development through low-carbon economic models and low-carbon lifestyles (Kim et al., 2020).

Thinking of countermeasures to promote the development of Greece's low-carbon economy Throughout the actions taken by countries around the world to respond to the development of a low-carbon economy, technological innovation and institutional innovation are key factors, and government leadership and enterprise participation are the main forms of implementation (Cheliotis et al., 2021).

By 2050, the new energy demand will be mainly met by clean energy, and at the same time, infrastructure systems such as smart grids that are compatible with the development of renewable energy will be established—building a low-carbon city and promoting energy conservation and emission reduction. First of all, we should change the development model and take a new urban low-carbon road. In accordance with the requirements of low carbon, cities should form a low-carbon economic development model with innovation as the main driving force, insist on energy conservation and emission reduction as a binding indicator of low-carbon economy, in energy, petroleum, metallurgy, building materials, chemicals, transportation, etc. The six major energy-consuming industries force the implementation of low-carbon economic technologies and take the road of sustainable urban development (Liu et al., 2020).

Accelerate the development and application of major energy-saving technologies, promote transformation with low-carbon technologies, strengthen the support for a low-carbon economy, encourage technological innovation and industrial upgrading, vigorously promote energy-saving technological progress and innovation in energy-saving methods, and accelerate the development, demonstration, and promotion of energy-saving technologies (Hansson, Fridell & Brynolf, 2020).

At present, there is not much room for the reduction of energy consumption per unit of GDP in Greece. The focus of future energy conservation efforts should be on new and renewable energy. Actively develop wind energy, solar energy, geothermal energy, biological energy, ocean energy, etc., and gradually use new clean energy. Energy replaces fossil energy, accelerates the development of nuclear power, supports the development and utilization of rural renewable energy, and promotes the promotion and application of new energy and industrial development (Hansson et al., 2020).

The R&D and promotion of low-energy consumption, low-pollution, and low-emission technologies in the field will gradually establish a diversified low-carbon technology system in line with Greece's national conditions, providing strong technical support for the transformation of economic growth patterns and stimulating low-carbon domestic demand. For the promising green energy technologies, Greece should adopt the strategy of "selection and concentration" to cultivate the green energy industry as a means to ensure domestic demand and as an export industry (Lamas Galdo et al., 2020).

CHAPTER 3: RESEARCH METHODOLOGY

The research intends to make use of a mixed methodology. The qualitative research part is conducted by reviewing the existing literature revealing desired insights into the phenomena under investigation. For the quantitative part, exponential smoothing on past data is being used to forecast future consumption of Ammonia in Greece.

An exploratory study was conducted in this research for the qualitative part. This is an exploratory study of bibliographic nature, which used, for the accomplishment of the research, systematic consultation to the databases. As inclusion criteria for the selection of studies, studies containing the descriptors addressing the subject under study, having been published between 2009 and 2021 and being available in full on the investigated databases, were considered. Then, the articles were distributed over a decade of publication, during the period from 2009 to 2019, and regarding the countries of publication. After this phase was completed, the process of classifying articles regarding the potential of ammonia as maritime industry fuel in the anticipated future. This part of the research required a qualitative approach, in which content analysis was used, which deals with a set of analysis techniques of texts or communications, aiming to obtain, through systematic and objective procedures of the description of its contents, quantitative indicators or not, which makes it possible to infer knowledge regarding the conditions deduced from these texts.

Qualitative review

A detailed description of the data analysis procedure and an indication of the statistical significance of the differences between groups is mandatory. That is why such studies are often multicenter since strict selection criteria do not allow forming groups of patients in one medical institution that are sufficient to obtain statistically valid results. In developed countries, the requirements for conducting randomized clinical trials are very high. They are thoroughly tested before being published. Moreover, if any methodological flaws that cast doubt on the results obtained are revealed after the publication of the article, it can be withdrawn, about which a separate message is made.

Key features of systematic review

Specific Research question
Selection of sources based on a pre-developed system
Clear criteria for assessing the quality of research, selected for analysis
Clear and reproducible results
Meta-analysis
Conclusions only reflect research results
Any section can be easily reproduced and traced work
Methodology for preparing a systematic review

Questions should be well focused and relevant. In addition to the research question, specific goals are formulated in the second stage. Search conditions, resources for search (databases, specific journals, conference materials, etc.) are determined, search terms are formulated; independent reviewers are identified to validate search results; consultations with experts in this field of research. A set of predefined criteria (e.g., topic, time period, language, etc.) is set to identify potentially relevant publications. It is recommended that the selection criteria be tested on a subset of primary studies

Then, Researchers create a quality checklist for evaluating research (scorecard). It is necessary to determine who will evaluate the primary research, how many experts, and how disagreements between them will be resolved, if any. Forms of information/data extraction from each primary study with control elements are created; it is possible to indicate the type of data verification if assumptions are required in the analysis and formulation of conclusions. If meta-analysis is intended, it is determined which methods will be used. Lastly, the search procedure depends on the specific database provider.

Quantitative review

For the quantitative part, forecasting was conducted using Brown’s method, which will be further explain in the following paragraphs.

Rationale for choosing method

For a given average the simple exponential smoothing (SES) forecast is somewhat superior to the simple moving average (SMA) forecast because it places relatively more weight on the most recent observation. So, the slightly more responsiveness to the changes occurring in past makes Brown’s simple exponential smoothing model a suitable one for this study.

Forecasting using Brown's simple exponential smoothing

The economic model of Brown's simple exponential smoothing is used for the forecasting of Ammonia consumption by the year 2050. Exponential smoothing is a type of Univariate Time Series Analysis and Forecasting for Time Series. Since the information till 2020 is available on the production of ammonia fuel in Greece, the data is used for forecasting the share of Ammonia fuel in the market by 2050. In a time-series model, one usually uses historical and present data in order to predict future values. So, considering the current rate of production for Ammonia, its success, consumption, and adoption by major companies, one can forecast its potential future by

2050. In a nutshell, Time series forecasting is the use of a model to predict future values based on previously observed values. The annual drop in the use of existing fuels, demand for new fuel sources will be analyzed along with the rate of acceptance for ammonia to forecast the adoption by 2050.

The simplest type of time series is one in which the series values fluctuate randomly around a fixed value without showing any trend. If the time series remains constant over an average level, a simple exponential smoothing proposed by Brown (1959) can be used to predict future values of the series. The simple exponential smoothing statistical method for time series forecasting is appropriate for stationary data where there is no significant trend in the data over time.

$$\hat{Y}_{t+1} = \hat{Y}_t + \alpha (Y_t - \hat{Y}_t) \qquad 0 \leq \alpha \leq 1 \qquad (1)$$

Equation (1) indicates that the predicted value for the time period t+1 ($\hat{Y}_{t+1}$) is equal to the predicted value ($\hat{Y}_t$) plus an adjustment for the error arising from the prediction of the value in the previous period $\alpha(Y_t - \hat{Y}_t)$. The parameter is called the method's smoothing constant; which can take any value between 0 and 1 ($0 \leq \alpha \leq 1$); Y_t is the currently observed value (actual value) for the time period t and $\hat{Y}_t$ is the predicted value for the same time period t. Thus, the next period predicted value $\hat{Y}_{t+1}$ is a combination of the current predicted value $\hat{Y}_t$ and the current observed value Yt. The value of the smoothing constant α is arbitrary; the determination of its best value can be performed iteratively, using some form of comparison, such as the mean squared error (MSE). In this way, an initial value for the constant is randomly selected, from which predictions are generated. The predicted values are compared with the actual values, and the mean of the square of the differences between them is calculated; the parameter that minimizes this average is used in the final model.

Fitted exponential models assume the mathematical representation. The model takes an exponentially weighted moving average equation with the objective of producing adjustments in the random variations of data from a given time series. This procedure called simple exponential smoothing uses a different weighting for each value observed in the time series so that more recent values receive greater weights. Thus, the weights form a set that decays exponentially from more recent values

The model for double exponential smoothing of Brown can be represented as follows:

$$Y_t = \mu t + \beta 1t + at \quad (2)$$

Results

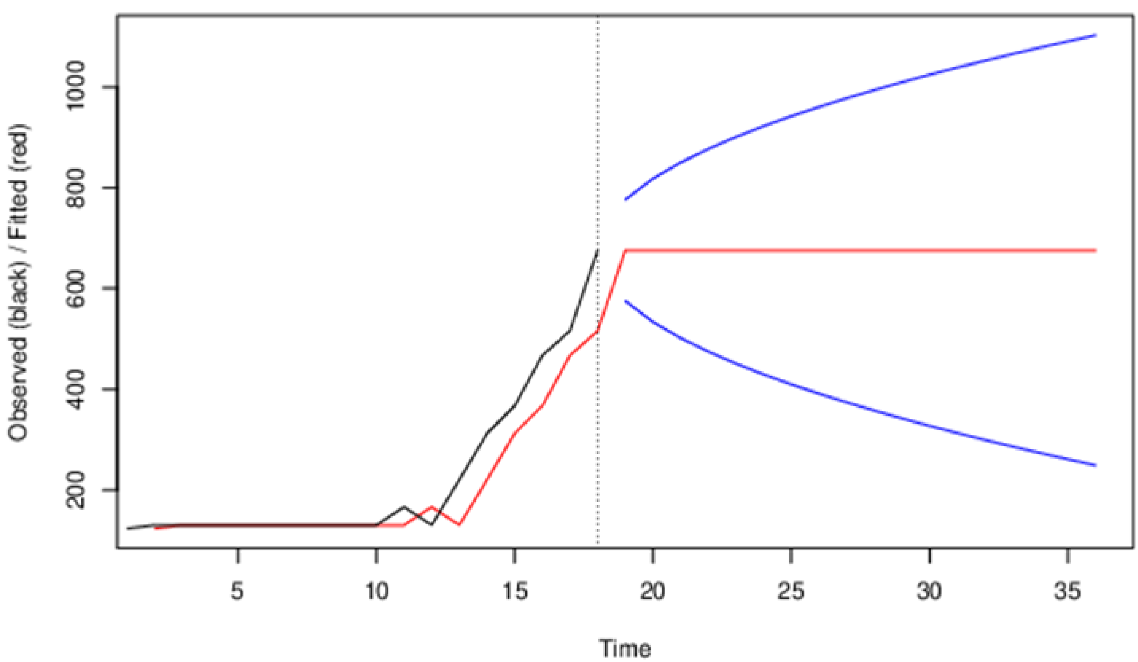
Qualitative study

Research indicates that For Greece, the development of a low-carbon economy can start from Innovate decision-making thinking and promoting transformation with low-carbon concepts. The country's mid-and long-term development strategy should actively learn from and absorb advanced concepts of a low-carbon economy and further clarify the strategic orientation for the development of the low-carbon economy. One is to take low-carbonization as one of the strategic goals of the country's economic and social development, and to explore low-carbon development models in different regions based on the actual conditions of various regions and strive to control the growth rate of carbon emissions; the second is to closely integrate the transformation and structure of Greece's development mode Transform and upgrade the actual situation (Liu et al., 2020).

Quantitative study

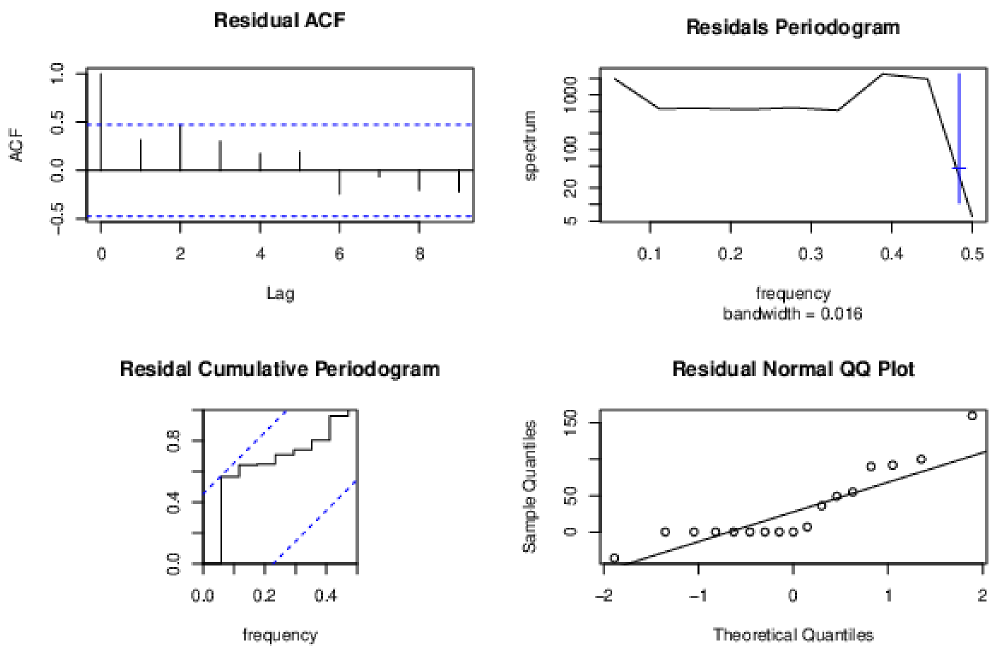
In order to conduct the desired statistical analysis for forecasting, a free statistic and forecasting software wessa.net. The online tool offers assistance in computing various exponential smoothing models and generates forecasts. In order for the results to be more accurate, the data was first forecasted till 2038 for consumption of Ammonia Fuel in Greece, and then this information was later used for forecasting Ammonia production for the next 13 years. For the fuel production by the year 2030 following results were generated.

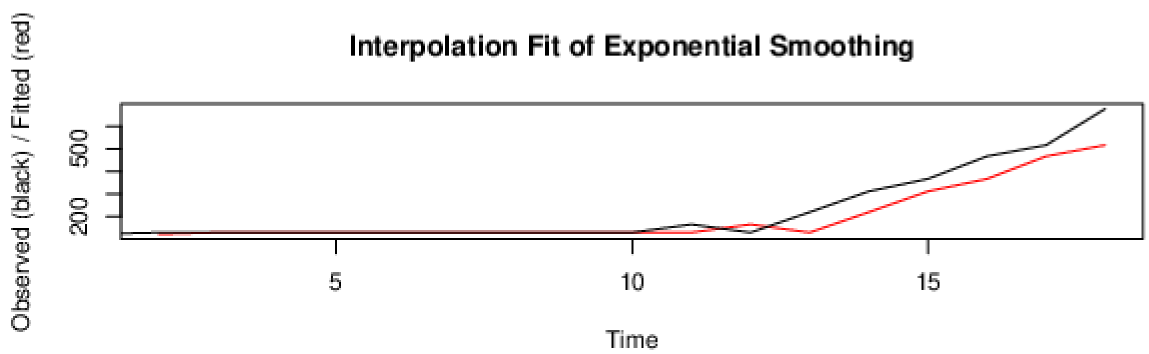
<u>Estimation by 2038</u>

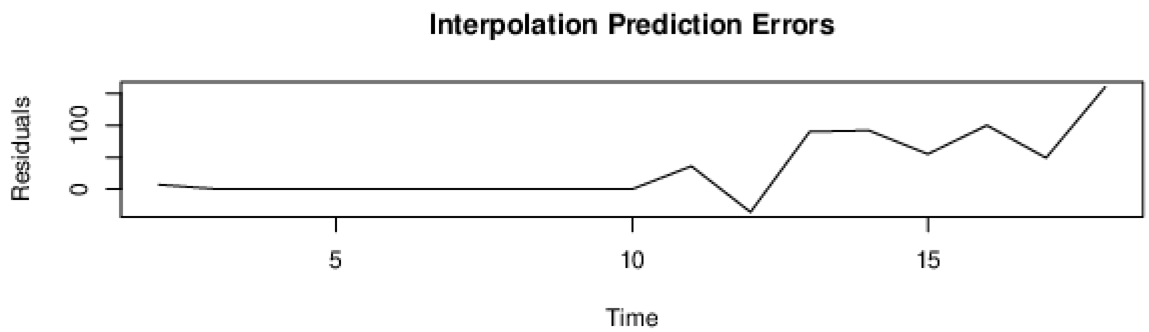


On the y-axis in the above figure, we can see the production of ammonia fuel, and years from 2005 to 2038 can be seen on the x-axis. On the basis of past values till 2020, values from 2021 to 2038 are estimated in the above graph.

<u>Estimation by 2038</u>

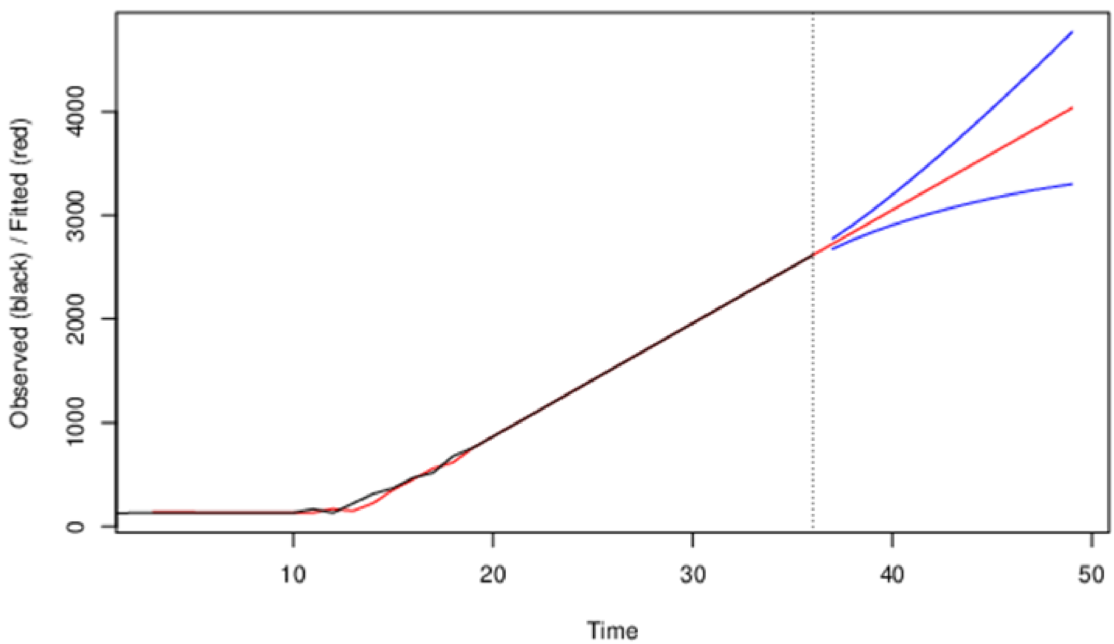




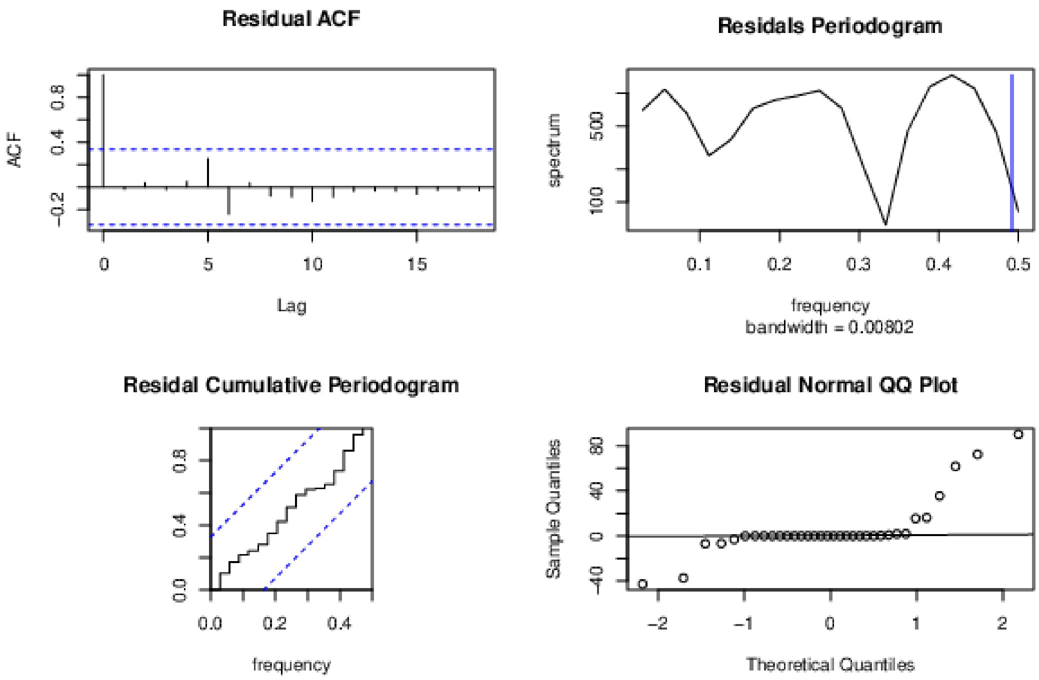


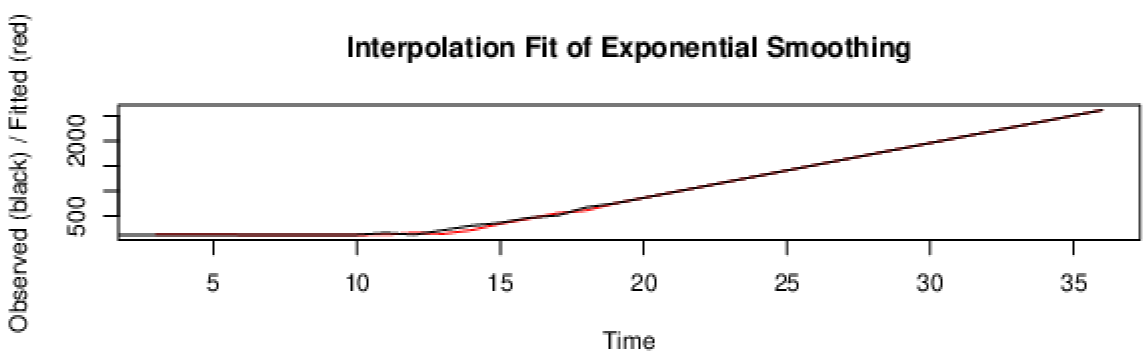
For the remaining years till 2050, double exponential smoothing of Brown was used again using the same tool, and the following results were generated.

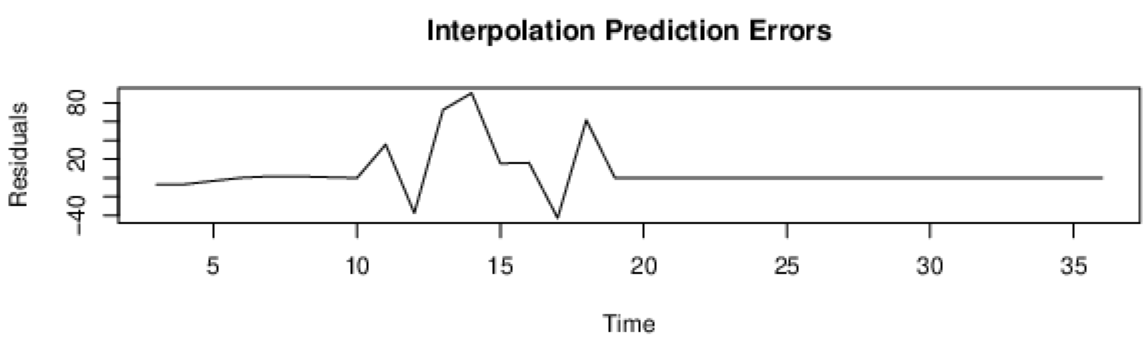
Estimation by 2050



Using the values obtained till the year 2038, the production till the year 2050 is estimated in the above graph.


Residual ACF
ACF
Lag
Residals Periodogram
spectrum
frequency
bandwidth = 0.00802
Residal Cumulative Periodogram
frequency
Residual Normal QQ Plot
Sample Quantiles
Theoretical Quantiles


Interpolation Fit of Exponential Smoothing
Observed (black) / Fitted (red)
Time


Interpolation Prediction Errors
Residuals
Time

Historical data

Historical data used in the forecasting on the production of Ammonia fuel in Greece (unit of Measure was Thousand metric tons):

YEAR	PRODUCTION (METRIC TONES)
2003	123
2004	130
2005	130
2006	130
2007	130
2008	130
2009	130
2010	130
2011	130
2012	130
2013	166

Forecasted data with 95% Lower Bound and upper bound:

YEAR	FORECAST	95% LOWER BOUND	95% UPPER BOUND
2021	755.498	684.166	826.829
2022	864.884	762.412	967.356
2023	974.27	823.677	1124.86
2024	1083.66	873.114	1294.2
2025	1193.04	913.48	1472.6
2026	1302.43	946.245	1658.61
2027	1411.81	972.306	1851.32
2028	1521.2	992.272	2050.13
2029	1630.58	1006.6	2254.57
2030	1739.97	1015.63	2464.31
2031	1849.36	1019.66	2679.05
2032	1958.74	1018.94	2898.55
2033	2068.13	1013.66	3122.6
2034	2177.51	1004.01	3351.02
2035	2286.9	990.152	3583.65
2036	2396.29	972.227	3820.35
2037	2505.67	950.363	4060.98
2038	2615.06	924.678	4305.44
2039	2724.44	2674.8	2774.09
2040	2833.83	2762.51	2905.15

2041	2943.22	2838.41	3048.03
2042	3052.6	2906.07	3199.13
2043	3161.99	2967.42	3356.56
2044	3271.37	3023.48	3519.27
2045	3380.76	3074.87	3686.65
2046	3490.15	3122.02	3858.27
2047	3599.53	3165.25	4033.82
2048	3708.92	3204.79	4213.04
2049	3818.3	3240.85	4395.75
2050	3927.69	3273.6	4581.78

Results showed that considering the increasing production in the past few years, the production in response to high consumption is likely to increase by 2050 to a great extent.

CHAPTER 4: DISCUSSION AND CONCLUSIONS

Ammonia also emerged as a new alternative. The issue of ammonia as one of the hydrogen fuels is constantly raised in scientific circles. Experts mention many advantages of this chemical compound that make it an attractive alternative to pure hydrogen. First, ammonia condenses at -33° C under ambient pressure. Meanwhile, hydrogen requires a much lower temperature, as much as -253 ° C. Additionally, one cubic meter of ammonia contains approx. 50% more energy than the same space filled with hydrogen. This unique feature would find application, especially in sea shipping, due to the limited space on board and the difficulties in refueling during the voyage (Hansson, Fridell & Brynolf, 2020).

Standardization recommendations

As a carbon-free fuel with high value and low risk, ammonia can meet the requirements of the economy and supply stability at the same time. Therefore, it has attracted the attention of the industry as one of the future marine fuels, but the related technology of ammonia fuel application is still immature. There are still gaps in supporting standards. In order to promote the coordinated development of standards and technology, it is recommended to closely integrate the development status of marine ammonia fuel power technology, strengthen the operation and safety of ammonia fuel engines, ammonia fuel power hull design, fuel supply system design, and ammonia propulsion system design, The pre-study on the standards of ammonia fuel production, transportation, storage, exhaust gas treatment, etc., provides support and guarantee for the development of Greece's marine ammonia fuel power technology (Senda & Harumi, 2018).

The European Union, Greece, the United States, Greece, Japan, and other advanced countries and regions are in a leading position in the field of marine hydrogen fuel cell propulsion technology. They have realized the demonstration and application of marine hydrogen fuel cell power propulsion devices and entered the stage of promotion and application (Hansson et al., 2020).

The application status of Greek marine hydrogen fuel cell propulsion technology

Hydrogen fuel cell propulsion technology can be used as propulsion power and auxiliary power device, applied to cruise ships and yachts in inland rivers, inland lakes, and offshore, to meet the needs of this type of ship for energy saving, emission reduction, environmental protection, and improvement of ship comfort; as a propulsion power and The auxiliary power device is used in scientific research ships to meet the requirements of this type of ship for noise, vibration and exhaust emissions; as an auxiliary power device, it is used in bulk carriers and passenger ships that frequently enter and exit the port to meet the impact of this type of ship on reducing port environmental protection demand (Hansson et al., 2020).

In recent years, investment in hydrogen fuel cell technology and supporting facilities for vehicles has continued to increase. Shanghai Automotive Group Co., Ltd., SAIC Maxus Automobile Co., Ltd., Zhengzhou Yutong Group Co., Ltd., and other well-known domestic auto companies have successively introduced various types of fuel cells as engines. New energy vehicles. The 712 Research Institute of China Shipbuilding Industry Corporation undertook the key special project of the Ministry of Science and Technology of New Energy Vehicles "R&D of Fast Dynamic Response Fuel Cell Engines" and has conquered the engineering core technology of fuel cell engines for 30 kW logistics vehicles. In general, in the automotive field, the development and application of hydrogen fuel cell systems have a good technical foundation and investment environment. In contrast, the research work of domestic marine hydrogen fuel cell propulsion technology has just started (De Vries, 2019).

There is great potential for the application of green hydrogen in the country for the production of ammonia-based fertilizers with a zero-carbon footprint. Hydrogen can be produced on a large scale through the electrolysis of water with an investment equivalent to the traditional process currently carried out from natural gas (Hiraoka et al., 2018). Two different coalitions of companies have already announced plans to introduce ammonia propulsion this year. Malaysia-based shipowner MISC, Samsung Heavy Industries (SHI), Lloyd's Register, and MAN Energy Solutions announced on January 16 that they had joined forces to that end, and a few days later, Norwegian oil company Equinor and technology operator marina Eidesvik launched a research project to retrofit Viking Energy's supply vessel to run on ammonia in 2024 (Kopteva et al., 2021).

The industry began to strengthen the overall planning, the establishment of national mechanisms to promote the development of ideas, and a clear line of hydrogen fuel cell technology ship's national development strategy and hydrogen fuel cell propulsion target device. According to strategic positioning and development goals, formulate marine hydrogen fuel cell propulsion technology development policies and overall planning, and establish a national promotion mechanism. Guide the development direction of industries, enterprises, scientific research institutes, universities, and local governments, strengthen organization and management, realize resource sharing, and reduce waste of resources and investment (De Vries, 2019).

Increase research and development of core technologies and improve the capability of independent innovation to increase investment in research and national and local governments at all levels, focus on strengthening the core technologies to promote technology engineered to marine research and development of hydrogen fuel cell: high efficiency, high reliability, and Long-life hydrogen fuel cell stack marine technology; high safety, high hydrogen storage density, high storage release reversible, and convenient replenishment of marine hydrogen source technology; highly compact, intelligent, high-power hydrogen fuel cell system integration technology. In addition, on the basis of independent enterprise innovation as the core, strengthen industry-university-research cooperation, integrate the industry's superior technical resources and industrial chain resources, create a first-class technology R&D team and technical leaders, and improve independent innovation capabilities (De Vries, 2019).

Research norms and regulations compliance, norms and regulations are recommended to establish fuel cell ship with relevant state regulations as the yardstick, the United National Maritime Bureau departments, focusing on compliance analysis, marine source of hydrogen and hydrogen fuel onboard hydrogen storage device Safety analysis and research of battery propulsion technology and research on risk assessment specifications for hydrogen fuel cell ships, and gradually establish and improve regulations and specifications for hydrogen fuel cell ships (Oh et al., 2021).

It is recommended to have demonstration run, promote market application process to ecology first green development for the lead, realize inland - Offshore - step by step demonstration of the ocean. In the demonstration operation, the reliability, safety, and environmental adaptability of the device shall be systematically assessed, the independently developed devices shall be promoted, and the construction of supporting facilities for hydrogen fuel storage and replenishment shall be accelerated. In order to accumulate experience in demonstrations across the country, as soon as possible, to promote marine hydrogen fuel cell propulsion technology to the direction of industrialization (Oh et al., 2021).

It is recommended to carry out international cooperation to promote Greece's core technological competitiveness. Focusing on the strategic positioning and development goals of marine hydrogen fuel cell propulsion equipment, actively carry out cooperation with relevant international institutions, organizations, and enterprises, and actively carry out bilateral or multilateral cooperation between governments. Comprehensively improve the quality of international scientific and technological cooperation and enhance Greece's scientific and technological innovation capabilities and core competitiveness in marine hydrogen fuel cell propulsion devices (Senda & Harumi, 2018).

Contribution of Study

The adoption of ammonia fuel in the marine industry is a phenomenon still in its infant stages and the viability of Ammonia fuel is highly being argued upon in the current academia and industry.

This paper reveals significant contributions in understanding the prospects of Ammonia fuel for the Maritime industry in Greece. The feasibility of Ammonia as an alternative fuel and its potential growth in the future is anticipated using current trends, leaving useful insights for businesses in the industry. The current trend can shape existing policies and inclinations in the industry as well as among policymakers who can form their strategies as per the emerging trends. The study has important implications for policymakers and industry players seeking the development of a low-carbon economy, who can start from Innovate decision-making thinking and promote transformation with low-carbon concepts. This research brings a useful contribution in this regard as it shows a projection of Ammonia fuel consumption keeping in view the current rise in its adoption. It offers a picture of how demand may rise if the current rate of progress persists for the adoption and use of ammonia fuel.

Furthermore, theoretically speaking, this study brings a major contribution in drawing implications for the use of ammonia fuel in the light of past literature. The literature dedicated towards the hydrogen and ammonia fuel viability in the industry is subjected to a systematic review by this study, giving a strong foundation of the area for future researchers who wish to pursue further research in the highlighted areas. A thorough understanding of the trends and practices is provided by this research which is of insightful value in future research on this area.

Practically speaking, there was a need for a study dedicated to the consumption of Ammonia fuel for the marine industry in Greece. Industry players could take useful lessons from this study if they were to pursue the path of adoption of ammonia fuel. This study contributes by filling this research gap and provide a useful projection for estimating the potential utilization of Ammonia in the marine industry of Greece. Statistics in the past have been utilized by the study for predicting consumption in the future for the marine industry of Greece.

Conclusion

It is concluded from the study that despite the criticism from some scholars, Ammonia is favored in the global shipping industry. This is a trillion-dollar industry that requires cleaner fuels to power cargo ships and tankers, which will make Finished products and bulk materials are dragged onto the ocean. Shipping companies are looking for oil to replace climate-friendly alternatives that can propel their behemoth ships at sea for days or weeks but still leave room for cargo on board.

The economic model of Brown's simple exponential smoothing was used for the forecasting of Ammonia consumption by the year 2050. Exponential smoothing is a type of Univariate Time Series Analysis and Forecasting for Time Series. From the research conducted using time series forecasting, it was shown that considering the increasing production in the past few years, the production in response to high consumption is likely to increase by 2050 to a great extent.

Thinking of countermeasures to promote the development of Greece's low-carbon economy Throughout the actions taken by countries around the world to respond to the development of a low-carbon economy, technological innovation and institutional innovation are key factors, and government leadership and enterprise participation are the main forms of implementation. For Greece, the development of a low-carbon economy can start from the following aspects: Innovate decision-making thinking and promote transformation with low-carbon concepts. The country’s mid-and long-term development strategy should actively learn from and absorb advanced concepts of a low-carbon economy and further clarify the strategic orientation for the development of the low-carbon economy.

By 2050, the new energy demand will be mainly met by clean energy, and at the same time, infrastructure systems such as smart grids that are compatible with the development of renewable energy will be established—building a low-carbon city and promoting energy conservation and emission reduction. High-tech and advanced applicable technologies transform, upgrade the production of traditional industries and traditional products, provide financial support for high-input and high-risk projects, guide and encourage enterprises to develop low-carbon technologies, equipment manufacturing, and low-carbon energy production through technology Innovation and progress improve the efficiency of input and output.

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