# BRIQ
## Belt & Road Initiative Quarterly

Volume 3 Issue 3 **Summer 2022**

BRIQ is a scholarly journal of international politics, economy,
and culture. The languages of publication are Turkish and English.

ISSN 2687-5896


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**Editorial Office**

Esentepe Mah. Yüzbaşı Kaya Aldoğan Sk. No: 4 İç Kapı No: 209 Şişli-İstanbul
www.briqjournal.com • editor@briqjournal.com
+90 (212) 401 13 33 +90 (212) 401 13 34 +90 (532) 525 91 56

**Publication Type** • Scholarly Journal

**General Manager** • Ayhan İlhan

**Owner**

Emine Sağlam on behalf of Turkish-Chinese Business Development and Friendship Association

**Printing** • Özkaracan Matbaa
Evren Mah. Gülbahar Cad. No:62 Güneşli / Bağcılar - İstanbul

This Journal is indexed INDEX COPERNICUS INTERNATIONAL and CiteFactor Academic Scientific Journals

/briqdergisi

## Principles of Publication

At a time when US ambitions for a unipolar world order have lost their appeal, a new order is taking shape thanks to the multipolarization of world politics and the acceleration of cooperation between developing countries, rejecting the globalism of imperialist states. Under these conditions, the new agenda of global cooperation should respond to the needs and aspirations of developing countries seeking joint development and solidarity under the guidance of public-driven projects. In particular, the Belt and Road Initiative (BRI) -put forward in 2013 by Xi Jinping, President of the People's Republic of China- provides a suitable opportunity and a sound foundation for the implementation of this new agenda of global cooperation.

BRI is an epoch-making move to re-implement the concept of the Silk Road, which dates back 2,000 years, to a time when China was immensely contributing to global prosperity and the development of trade and cooperation. The revival of this concept entails a much more comprehensive approach that also incorporates rail and sea transport, and digital systems.

BRI proposes to bring together over 60 countries across Asia, Europe, Africa, and Latin America –together accounting for nearly half of the world's gross domestic product– for prosperity and development at the initiative of China. Unlike the Western-centered world order, BRI seeks peaceful collaboration for improving global trade and production towards common goals for humanity. It firmly rejects crude imperialist exploitation. Two thousand years ago, the Silk Road was a conduit for the flow of gunpowder, spices, silk, compasses and paper to the world. Today, it offers artificial intelligence, quantum computers, new energy and material technologies, and space-age visions to developing countries. In addition, the New Silk Road provides incentives and opportunities for the development and implementation of bio-economic schemes in stakeholder countries against the threat of climate change and other environmental threats that bring the entire ecosystem to the brink of extinction.

Turkey has a significant role –real and potential– in accelerating South-South cooperation. Turkey is conveniently located as Asia's farthest outpost to the West. It assumes a critical position as a pivotal country on BRI's North-South and East-West axes. However, China's development and BRI's contribution to the future of humanity have remained to a large extent underrecognized and superficially evaluated in Turkish academia, media, and politics. This is mainly because Turkey's academics, media professionals, and policy makers have been observing China using Western sources. In the same manner, China and BRI's other potential partners have been viewing Turkey through a Western lens.

BRIQ has committed itself to developing an in-depth understanding of the present era, with a particular emphasis on the new opportunities and obstacles on the road to the New Asian Century.

BRIQ assumes the task of providing direct exchange of views and information among Chinese and Turkish academics, intellectuals, and policy makers. In the meantime, this journal will serve as a platform to bring together the intellectual accumulation of the whole world, especially developing countries, on the basis of the Belt and Road Initiative, which presents a historic opportunity for the common future of humanity.

BRIQ is also devoted to publishing research and other intellectual contributions that underline the transformative power of public-driven economies, where popular interests are upheld as the basic principle, ahead of individual profit. The fundamental tasks of BRIQ are to demonstrate how BRI can contribute to the implementation of this public-driven model, and to help potential BRI partners -including Turkey- to realize their real potential.

BRIQ stands for the unity of humanity and a fair world order. It will therefore be a publication for the world's distinguished intellectuals, especially those from Eurasia, Africa, and the Americas: the defenders of a new civilization rising from Asia on the basis of peace, fraternity, cooperation, prosperity, social benefit and common development.

## Submission Guidelines

BRIQ features a broad range of content, from academic articles to book reviews, review essays, interviews, news reports, and feature articles.

The Editorial Board can issue calls for papers for special issues and invite authors to contribute manuscripts; however, it also welcomes unsolicited submissions.

Submissions are invited in English or Turkish. All submissions are to include a short biography (150-word limit) and should be sent as Microsoft Word attachments to briq@briqjournal.com Articles or other content that have been previously published or are under review by other journals will not be considered for publication.

BRIQ follows American Psychology Association (APA style, 6th edition, https://www.apastyle.org) and uses American English spelling.

BRIQ applies a double-blind review process for all academic articles.

Academic articles should be between 5000 and 9000 words in length, including abstracts, notes, references, and all other content. Please supply a cover page that includes complete author information, and a fully anonymized manuscript that also contains an abstract (200-word limit) and five keywords.

Book reviews should not exceed 1,000 words; review essays covering two or more works can be up to 3,000 words.

News reports consisting of brief analyses of news developments should not exceed 1,500 words; feature articles combining reporting and analysis can be up to 3,500 words.

Please contact the Editorial Board for interview proposals.

# EDITORIAL

## The Energy of A New Civilization

Through democratic revolutions, humanity had rediscovered equality, freedom, fraternity, solidarity, and humanity. With a huge leap in solidarity, sharing, communitarianism, and collectivism, national liberation struggles and socialist practices in various countries enabled humanity to transcend the limitations of the 20th century. Meanwhile, imperialist capitalism attempted to eradicate these humanistic attributes, which were the motor of progress.

The following ordering can be accepted if the civilizations on Earth were to be ranked according to the main energy sources that they used in different historical periods: Wood was the main source of energy after the discovery of fire. The 18th and 19th centuries can be described as a civilization built primarily on coal, thanks to the invention of steam power and the industrial revolution. The twentieth century and the early twenty-first century were characterized by a civilization dependent on oil and natural gas.

Controlling the world's key energy resources has always been at the center of global power struggles. In their attempt to dominate international politics, imperialist powers devote special efforts at controlling the world's finite traditional fossil fuel supplies.

There can be no doubt about the severity of the crisis of neoliberal globalization. Even the proponents of globalization do not fail to acknowledge this problem and are working to reform the current policy setting. In the meantime, developing countries, which are suffering from the destructive effects of the neoliberal globalized economy at first hand, are voicing their demand for a more just international order with ever increasing persistence and force.

Neoliberal globalization, which used to provide the general framework for the unipolar international order led by the United States, has corroded the basic human values on social, economic and cultural levels, and damaged the environment at the expense of our planet's vitality. Worthy of special emphasis is that neoliberal globalization was predicated on a fossil-fuel-based model of development, which has eventually resulted in a broader "civilization crisis."

This system, which threatens planetary survival, is in an ever deepening crisis. In these circumstances, the only way out is to build a new civilization predicated on the principles of sharing, solidarity, egalitarianism, international collaboration, and environmental sustainability. This new civilization, which can be referred to as the “ecological civilization”, will be necessarily based on renewable energy sources. In this perspective, green hydrogen produced from renewable energy sources stands out as a crucial source of energy.

Energy must be rendered abundant, affordable, accessible, renewable, and ecologically friendly, if an ecological civilization is to be erected. Green hydrogen energy might be a viable solution at the the current stage of scientific and technological progress.

It is well known that China does not only place a high priority on the development of renewable energy sources, but it has also emerged as a world leader that promotes international collaboration under the Belt and Road Initiative (BRI). The BRI, whose agenda is shaped by developing countries, proposes a fair model of international relations, which serves as the foundation for a sharing and solidaristic new civilization built on human-nature harmony. Developing green energy cooperation among Belt and Road countries will enhance the BRI, while also speeding up the growth of these countries.

**FİKRET AKFIRAT**
Editor-in-Chief

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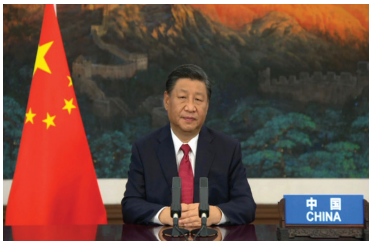



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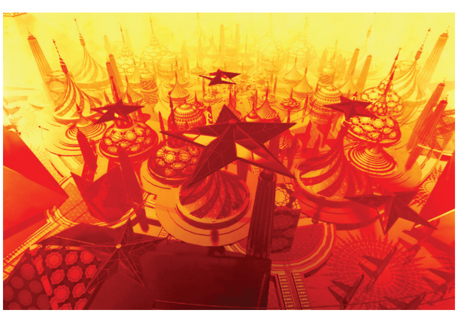

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# Green Hydrogen: The Common Thread Of The Belt And Road Initiative

BİROL KILKIŞ
Prof. Dr.
OSTIM Technical University

*Mr. Kilkis was born in 1949 in Ankara. He received his Ph.D. degree in Mechanical Engineering with high honors from Middle East Technical University. He graduated in 1972 with an honors degree from von Karman Institute for Fluid Dynamics in Belgium- a NATO Research Center. He completed his master degree in 1973 and PhD degree in 1979. Dr.Kilkis who received the Science Encouragement Award from TUBİTAK in 1981 retired from the METU Mechanical Engineering Department as a professor in 1999. Currently, Dr. Kilkis is the member of ASHRAE Building Performance Metrics Steering Committee and the member of ASHRAE Research Journal Sub-Committee. ASHRAE has elevated him to Fellow Grade in 2003 due to his outstanding services and has been named distinguished lecturer. In 2008, he received Distinguished Service and Exceptional Service awards from ASHRAE. He is the author of more than 500 papers in several journals and proceedings on a large variety of topics, and has several patents pending on green buildings, solar trigeneration, heat pump coupled cogeneration, and low-exergy HVAC systems. Dr. Kilkis has been appointed to the Executive Committee membership of the European Union Solar Thermal Technologies Platform in 2015. Since his commencement of this duty in 2018, he became the Vice Chair of Renewable Heating and Cooling Committee (RHC). He also served Turkish Society of HVAC and Plumbing Engineers at a capacity of President between 2017 and 2019.*

*E-mail: birolkilkis@hotmail.com* *https://orcid.org/0000-0003-2580-3910*

**Received:** 25.04.2022
**Accepted:** 06.05.2022

How to cite: Kılkış, B. (2022) Green hydrogen: The common thread of the Belt And Road Initiative. *Belt & Road Initiative Quarterly (BRIQ)*, 3(3), 6-20.

## ABSTRACT

This paper responds to the Sixth Assessment Report of the Intergovernmental Panel for Climate Change (IPCC), showing how global warming may be kept below 1.5°C by a trend of global greenhouse gas emissions to peak before 2025 and be halved by 2030 on the Belt and Road Initiative (BRI). This paper states that conglomerations of cities need to be prioritized for decarbonization as an integral vector among all other environmental parameters and emission resources in the form of net-zero carbon. In this quest, the BRI bears a great responsibility and opportunity at the same time because all major cities and urban areas are on or near the course of the BRI, and they must be interconnected and incorporated mainly from energy and exergy points of view. The main motive is that almost a quarter of global Gross Domestic Product is produced in the BRI countries. The paper presents a novel hydrogen link designed from East Asia to Europe, connecting BRI countries on a single green hydrogen line transporting, storıng, and interchanging both heat and power to strongly support the BRI towards the Paris Agreement goals for 2050.

**Keywords :** climate crisis, combined transport of power and heat, fuel cell, hydrogen belt road, renewable energy

## Introduction

IPCC'S SIXTH ASSESSMENT REPORT ON Climate Change shows that limiting global warming to around 1.5°C requires global greenhouse gas emissions to peak before 2025 and be halved by 2030. In this respect, cities need to be prioritized for decarbonization as an integral vector among all other environmental parameters and emissions resources in the form of net-zero (IPCC, 2022; Kilkis S., 2022). In this respect, net-zero exergy districts and urban areas must be established against global warming (Kılkış, Ş. 2012; Kılkış, Ş., 2014). Exergy is the useful work potential part of a given energy flow and plays an important role in recognizing the nearly avoidable $CO_2$ emissions due to exergy mismatches between supply and demand exergy of a given system or equipment. These emission responsibilities also hold for 100% renewables, as shown in Figure 8 in the following sections.

In this quest, the BRI bears a great responsibility because all major cities and urban areas are on the course of the BRI and they must be interconnected and incorporated mainly from energy and exergy points of view. Almost a quarter of global GDP is produced in the BRI countries.

Therefore, decarbonizing the BRI becomes even more critical. The main question is whether economic or technical instruments play the dominant role in decarbonization.

The report by Vivid (2019) for decarbonizing the BRI envisions the key solution starting from a `green finance` roadmap (Vivid, 2019). However, standard economic rules like the linearized Pareto principle and green financing instruments, the so-called sustainable funds proposed by IEA, cannot satisfy the Paris Agreement goals alone. The reasons are far beyond the comprehension of classical economics, and this article reveals that technical issues are dominant for sustainably potential solutions, which stretch far beyond today`s anticipation of politicians and even scientists.

**The greening of the BRI must seek solutions beyond economics with innovative engineering solutions to be collaboratively developed by the BRI countries.**

By this token, the greening of the BRI must seek solutions beyond economics with innovative engineering solutions to be collaboratively developed by the BRI countries. Obviously, renewable and waste energy resources play the biggest role in decarbonization. However, the big question is how to be implemented and sustained in the BRI countries with the challenge of transporting heat and electricity over several thousand kilometers. Ibrahim Kolawole Muritala reveals that 72% of the global primary energy consumption is lost after conversions. In further detail, 63% of the considered waste heat streams arise at a temperature below 100°C, in which electricity generation has the largest share, after transport and industry (Forman vd., 2016: 1568-1579).

Therefore, it is evident that today, the most abundant form of global heat is low-enthalpy (low-temperature, low exergy) renewable and waste heat resources below 100°C, which may not be used to generate electricity. On the other hand, if a sustainable and rational energy corridor will link the BRI countries at large, such heat resources must also be transnationally collected, stored, transported, and exchanged among several countries. However, it is quite impossible to transport heat and cold through hydraulic pipelines for long distances due to pumping electricity demand exergy and thermal power distributed and transported. Thermo-mechanical losses on the way further make the transport and distribution of low-exergy thermal power for the BRI, spanning thousands of kilometers, impossible. The unit exergy of electric power is 0.95 kW-hexergy/kW-henergy, whereas the unit exergy of thermal power distributed in a district energy system is less than 0.10. Therefore the unit exergy imbalance makes it critical to limit the pumping capacity and heat transport to shorter distances, depending on the amount of energy and exergy transported (Kilkis, B., 2020c).

Despite this fact, ignoring the exergy issue, this is one of the main reasons why the EU (European Union) is considering total `green` electrification with heat pumps and district energy systems on the demand side of the built environment by converting part of the electricity back to heat and cold by heat pumps, thus eliminating long-distance transport of thermal power (EU, 2018). However, according to the second law of thermodynamics (exergy), the coefficient of performance of the heat pumps, *COP*, must be greater than eight in heating and ten in cooling, respectively, using conventional HVAC (Heating, Vantilating, and Air-Conditioning) systems to benefit the environment. Otherwise, nearly avoidable $CO_2$ emissions responsibilities will arise because there will be a negative mismatch between the electrical power value-adding potential and the value-adding potential of the thermal outputs of the heat pumps. Today, such high *COP* values are not possible even if heat pumps are cascaded (Kılkış, B., 2021a). This fact brings us to the question of whether total electrification, especially on a trans-national scale, is environmentally rational and sound or not. If not, what are the alternatives?

## Electric Power Grid or Hydrogen Grid on a Trans-National Scale?

The biggest remaining question is whether renewable and waste energy sources should be transported as 100% electricity. There are four conflicting handicaps to transport electricity and heat in the BRI. These are summarized below:

### Challenge 1

Since electrical power lines cannot transport thermal energy, a second or even a third pipeline (transporting cold) will be necessary for the BRI. Therefore, it may seem rational to transport only electricity and leave behind renewable and waste energy sources. However, this will mean that abundant energy sources are untapped and left behind.

### Challenge 2

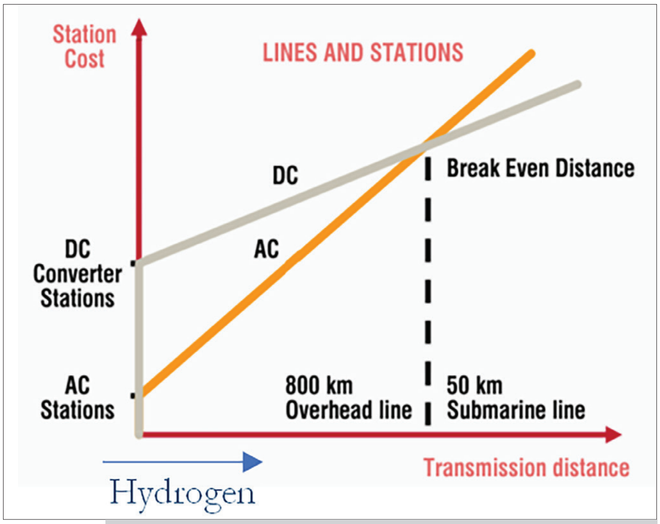
While global thermal demand is more than electric power demand in terms of energy, renewable and waste energy sources, abundant globally, must be utilized for minimum $CO_2$ emissions.

Furthermore, renewable energy storage and connecting to the existing grids are major problems. Different heat sources are difficult to mix and match in terms of their enthalpy (temperature; exergy). Added value potentials may be lost. Consequently, because low-enthalpy heat (below 100°C) cannot be efficiently converted to electricity, these globally abundant energy sources will remain unutilized at the source side and wasted on the environment, thus also contributing to global warming. For very low-enthalpy heat sources, an option may be residential water heaters using absorption technology, which may peak the temperature above the Legionella risk mitigation level of 65°C. However, they have a high initial cost and working fluid challenges.

### Challenge 3

Converting electricity on the demand side site back to heat and cold with electrically operated heat pumps with *COP* values less than eight for heating and ten for cooling means emissions responsibilities. Trying to heat and cool only by electricity on the demand side with power-to-heat systems will overload the existing grids unless costly and time-consuming retrofits and upgrades are made and new transmission lines are deployed. These actions mean that most existing AC grids have to be replaced/retrofitted/appended. Although, HVDC (High-Voltage DC) power makes sense because renewables (wind and solar) already generate DC power. This convenience eliminates AC to DC and DC

**Figure 1. Hydrogen and Electric Power Transmissions**




Source: EEP, 2021.

to AC inverters, provided that all household units are also converted to DC, which is another costly issue. Most EU officials have drawn total electrification of the EU roadmap, and at least 80% of them own shares in electric power companies (Private communications during 2019 Helsinki ETIP RHC Meeting). However, a recent study claims that HVDC is the cheapest and easiest way to use existing AC grid lines (EEP, 2021). Holland is one of the pioneering countries (IEC, 2022). Hydrogen does not need AC-DC conversions because it is not electricity and is not subject to any distance break-even point (Fig. 1). Hydrogen may be transported to any distance.

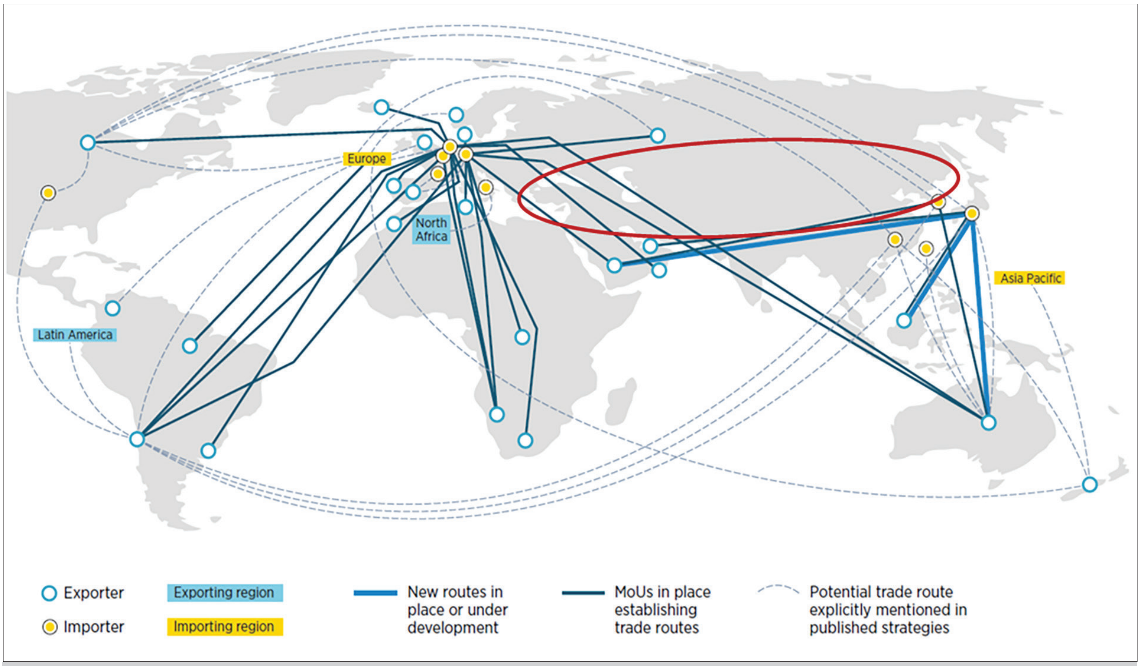
### Challenge 4

Rather than converting part of the electricity back to heat or cold, generated electricity from renewables should be used for more rational applications like lighting, mass transport, and industry.

These challenges indicate that electricity must remain as electricity and must be used as electricity (in applications with no other options like lighting, communications, electric mobility, and industry). At any rate, there is a definite optimum point average regarding total electrification and hydrogen mix distribution, which depends on the technology, supply-demand, population profile, climate, and availability of renewables. These variables need to be considered in a case-by-case analysis for every country and region. Therefore, even with renewables, the EU goal of `total` electrification is a dream that will never come true.

To mobilize the low-enthalpy and waste energy sources in the quest for decarbonization, total electrification and long-distance thermal power transportation do not seem rational candidates for problem-solving, so another transport medium must be sought. Plainly stating, electricity cannot transport everything. We need more elegant solutions. As this paper shows, hydrogen is the best way to store and transport energy over long distances, provided that some precautions are taken and maintained: hydrogen has small but non-zero global warming potential (*GWP*), which requires leakage management over long distances, and flammability must also be considered. Furthermore, transport by liquefaction or compression of hydrogen is energy-intensive, and these must also be provided from green systems with optimized designs. At any rate, there is a large distribution gap today in terms of hydrogen over the BRI course across the continents. Figure 2 shows that there is no hydrogen trade route yet on BRI leaving a large gap on the energy transition map of the initiative.

**Figure 2. Hydrogen Trade Routes**



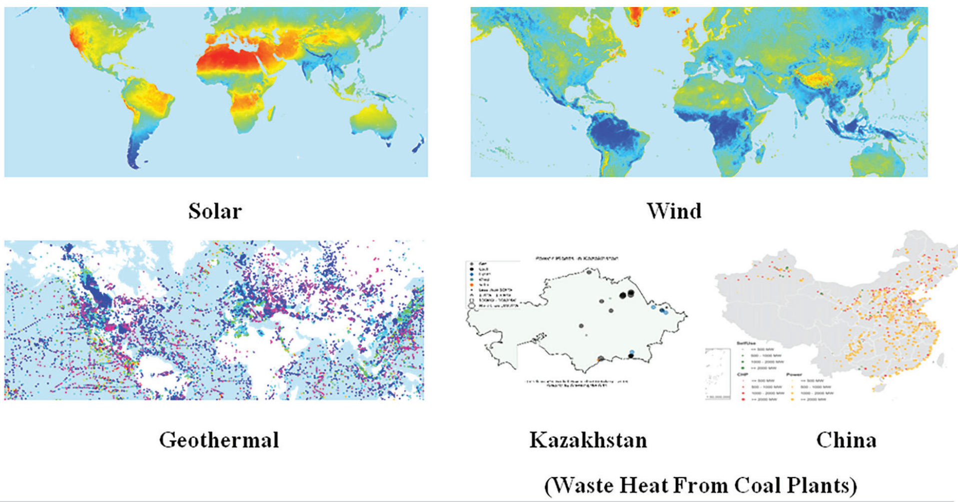

Source: IRENA, 2022.

If all combined into one singular medium of energy and then stored and transported within the same medium for long distances and then converted back to heat, cold, and electrical power with high efficiency in any dynamic proportion of demand, the useful work potential of the original energy constituents might increase. This route will link collective farms and cities on a single hydrogen pipeline over long distances.

With the advent of superconductivity, hydrogen at cryogenic temperatures may replace the use of precious helium gas, provided that cryogenic hydrogen is produced from renewables.

Such an energy gap is not a coincidence for the BRI. Although relatively rich in renewables, power generation with renewables and transmission systems are quite weak. Coal is still used extensively and may be made greener by capturing and mixing the coke/coal flue gas and mixing with hydrogen or via biogas. Coke/coal flue gas is rich in hydrogen at about 55 % and methane at 27% (coke oven gas) (İlbaş, 2017). Therefore, rather than recovering the heat of the flue gas, utilization of it as a fuel mix is more efficient and effective, as it can be readily mixed with hydrogen. The lower heating value (LHV) of coke oven gas is 3678 kcal/m3, whereas hydrogen has an LHV value of 2583 kcal/m3. LHV of biogas is about 3800. Hydrogen seems to have the lowest LHV, but this is due to its lowest density. Mixing may be achieved at the starting point of the B&R in eastern China, where most coal consumption occurs in industry and power plants (see Figure 3) or along the road with local biogas and other coke/coal gas sources. Furthermore, coal may be transported in coal-water slurry, yet water spending, quality degradation, and

**Figure 3. Renewables and Major Waste Heat Sources on the Belt and Road Initiative**




Source: IRENA, 2022.

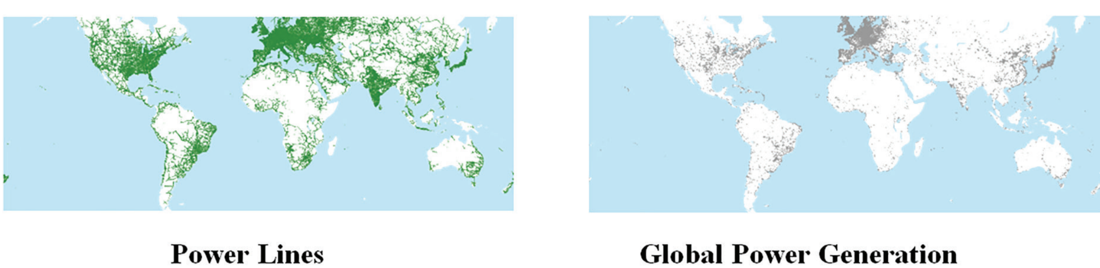
associated environmental concerns must be addressed. Pumping exergy demand must also be optimized for minimum emissions responsibility.

The B&R region is rich in renewables and waste heat (Figure 3) yet relatively poor in power transmission and generation (Figure 4). Transnational collocation and conglomeration are a compound problem, except for geothermal and waste heat from fossil fuel power plants. Renewables are intermittent except for biogas and geothermal. Therefore, energy storage in terms of electricity, heat, and cold is necessary. Although thermal energy storage is simpler and cheaper, electrical energy storage is still expensive and environmentally costly in terms of battery storage. Hydrogen is a more suitable energy storage medium without requiring energy conversions prior to the final use. It is stored as hydrogen upstream.

What is missing for the BRI is a common thread that unifies all forms of energy on a single thread. Hydrogen seems to be the only feasible thread.

B&R with hydrogen may reverse this trend shown in Figure 4, where hydrogen eliminates the necessity of collocation and coexistence of renewables and waste heat sources and fills

**Figure 4. Global Power Lines and Power Generation Maps**




Source: IRENA, 2022.

**Figure 5. Major Cities on the Belt and Road Initiative**


Source: ALEPH, 2020.

an important gap of energy transit shown in Figure 2.

Major cities are already on the BRI on land. Therefore, the energy corridor must be on the same line. However, there is not any renewable energy corridor yet, except in Europe. The main pipeline must follow the transnational railroad.

Figures 5 and 6 imply that a singular hydrogen line should follow the same route, especially close to the railroad link with an under-the-sea passage in the Caspian Sea. Rich natural gas reserves in Azerbaijan may also be mixed with hydrogen for optimal cost-effectiveness.

## Problems with Renewables

There are problems with singular solar and wind applications:

All singular applications for generating electric power, like PV panels, have waste heat. Even large wind turbines. PV panels generate electric power but reject the solar heat that they absorb. The nacelle of large wind turbines generates heat due to electro-mechanical system inefficiencies. Flat-plate collectors

**Figure 6. The Railroad Link on the Belt and Road Initiative**


Source: Uysal, 2019.

**Figure 7. Singular Solar Photovoltaics on the Ground and Wind Turbines. Waste of Land**

Source: Freepik, n.d.

generate heat but miss the opportunity of generating power with higher exergy. Therefore, the latter (FPC) must be avoided except for some local applications. Figure 7 shows a single wind turbine atop a bare tower where individual solar PV panels occupy the land. This arrangement is not efficient for land use (land use effectiveness, *LUE*). The individual solar PV panels could be mounted on the bare tower to improve LUE (See Figure 16 in the following sections).

## The Problems with Waste Heat and Power Plants

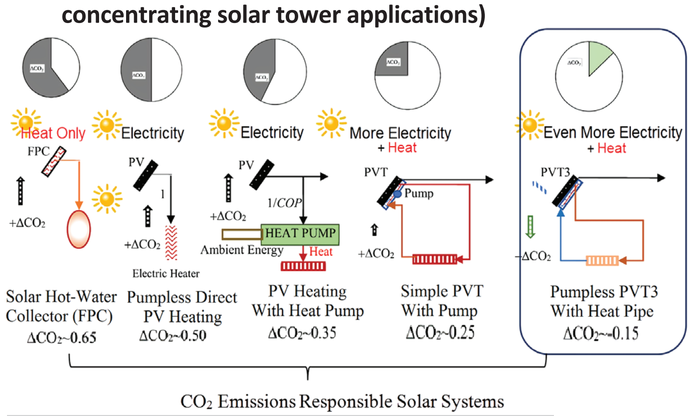
Besides the unutilized waste heat available from solar systems, wind turbines, and geothermal power plants, major heat waste occurs in thermal power plants through their cooling towers, which also spend water and release water vapor into the atmosphere. City municipal wastewater also carries low-temperature heat. These are important energy sources, but the electro-mechanical systems like pumping motors and heat exchangers must be carefully designed so that power exergy does not exceed the thermal power exergy obtained. For example, the fan motor capacity must not exceed the heat claimed from the stack gas of a coal-fired power plant (Kılkış, B., 2019b). Combined heat and power systems using biogas must also be carefully designed and operated to provide the maximum exergy, sum of electricity, heat, and cold (Kilkis, B., & Kilkis, S., 2007).

## Solar Energy

Figure 8 depicts that even PV panels actually have unutilized waste heat. When this heat is not utilized, someone else will produce the same heat again possibly by consuming some fossil fuel, rather than using this lost heat. This reveals the fact that the PV panel is responsible for a carbon dioxide emission, albeit indirectly ($\Delta CO_2$). In Figure 8, it is seen that a sample PV panel has a $\Delta CO_2$ responsibility as much as the $CO_2$ it draws from its carbon stock because it produces electricity, and as a result, this PV panel does not actually make a net contribution to the environment. The planar collector, on the other hand, is responsible for more than it absorbs from the carbon stock. The use of heat pumps is also not a solution unless the Coefficient of Performance (COP) exceeds eight.

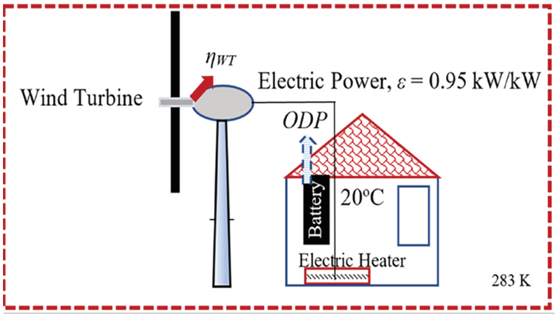
## Wind Energy

**Figure 8. Different Solar Energy Systems (Except concentrating solar tower applications)**




Source: Kilkis, B., 2022b.

**Figure 9. Direct Electric Resistance Heating in a Chinese Building with Wind Energy**

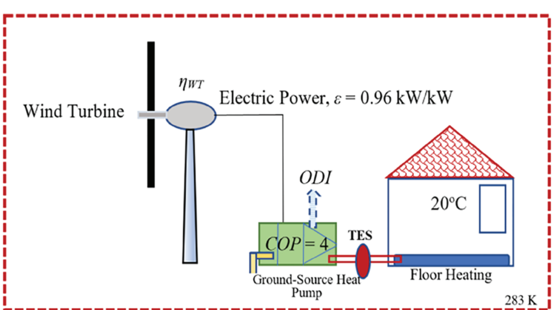



Source: Kılkış, B., 2021c.

Heating in cold climates of the Northern provinces of China is considered to be accomplished by wind energy to replace coal and lignite by using electricity directly for heating through electric coils (Figure 9). If this alternative is used for buildings in cold climates in China, the result will be disappointing or, better to say, catastrophic for the environment. The exergy difference between electricity and electric heating for comfort is about 0.90 kW-hexergy/kW-henergy, almost equal to a coal stove in terms of $CO_2$ emissions responsibility (Kılkış, B., 2021a).

In the nacelle for moderately-large-sized wind turbines, the nacelle heat is wasted. In addition, any electric battery will be responsible for ozone depletion potential (*ODP*) (Kılkış, B., 2019a). Figure 10 shows an apparent improvement by using a heat pump to utilize part of the wind power to generate heat for comfort heating. This alternative works only if the *COP* exceeds eight and adds too much cost. Otherwise, the coupling of a wind turbine with a heat pump is not carbon-free. In addition, the refrigerant leakage will be responsible for the ozone-depletion index, ODI, which is a combination of *ODP* and global warming potential (*GWP*).

**Figure 10. Wind-Driven Heat and Cold Supply with a Heat Pump**

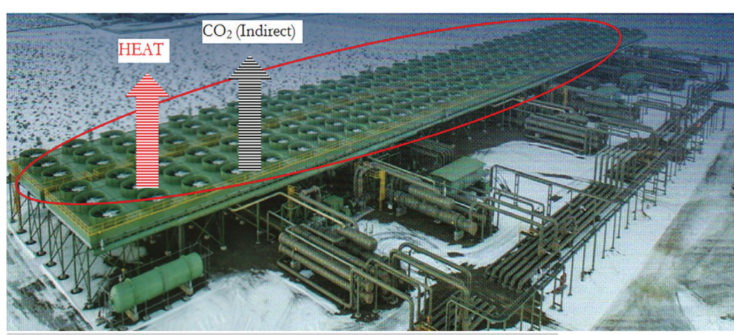



Source: Kılkış, B., 2021c.

## Geothermal Energy

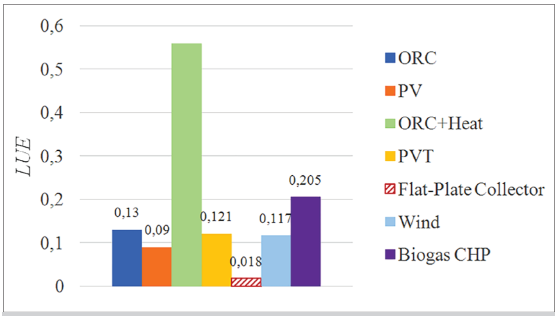
About 80% of the geothermal energy reserves are close to or below 100°C, leaving only a small margin of power generation with organic Rankine cycles (ORC). Figure 11 shows a large array of dry cooling fans, occupying much more area than the plant itself. It rejects heat from the atmosphere. Fans consume electric power. Even the electricity is green for the geothermal plant; this means nearly voidable emissions responsibility, because this amount of electrical energy could be supplied to the grid, reducing the power load on thermal power plants. Land

**Figure 11. Only Power Generation with Organic Rankine Cycle in Geothermal Field with Wasted Heat, $CO_2$ emissions responsibility, and Excess Land Use**




Source: Jesdergi, 2022.

**Figure 12. Land Use Effectiveness of Different Renewables**




Source: Kılkış, B., 2021c.

use is also important. ORC+heat is the best utilized, and the fans shown in Figure 11 are eliminated.

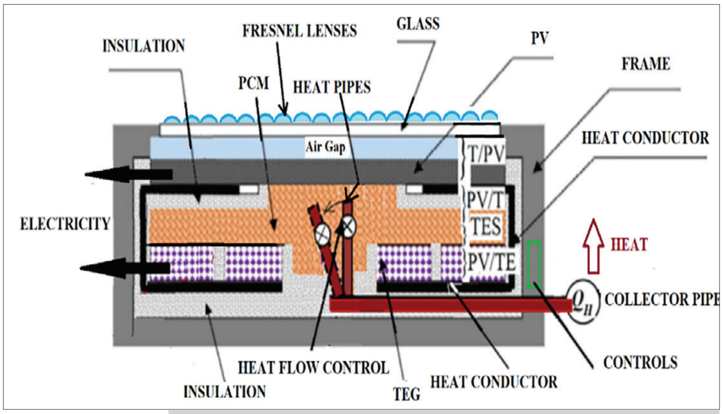
## Solutions

Solutions will pave the way to new technology and international collaboration with concerted R&D and P&D, new Jobs, new technologies, and a better economy besides the hydrogen economy.

### Solar

Figure 13 shows the aforementioned new generation PVT3 system. Only such a system can have negative carbon characteristics.

**Figure 13. Advanced Photo-Voltaic-Heat Systems with high Efficiency**



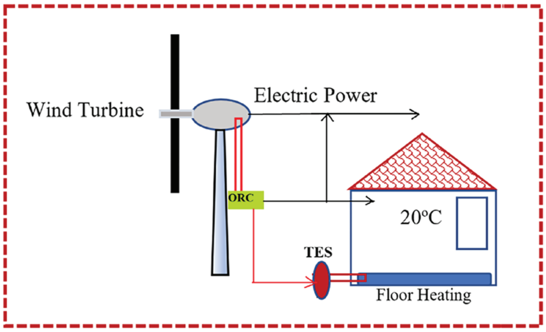

Source: Kılkış, B., 2020d.

### Wind

The wind turbine of moderate size in the range up to 1 MW in rural areas with domiciles may utilize the electro-mechanical waste heat in the nacelle with ORC for additional power and low-temperature heat.

### Geothermal

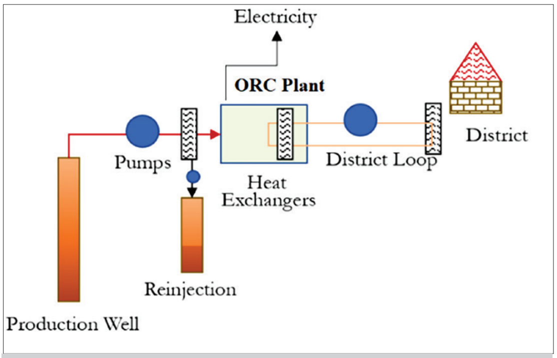
**Figure 14. Cogenerating Wind Turbine**




Source: Kılkış, B., 2020b.

From a low enthalpy geothermal well A district heating that can be realized is depicted in Figure 15. No heat pump is used

**Figure 15. Utilizing Waste Heat from ORC for District Heating and System**




Source: Kılkış, B., 2020.

for temperature peaking, however, heat pipe radiators or floor heating systems that can operate at temperatures as low as 35°C are used.

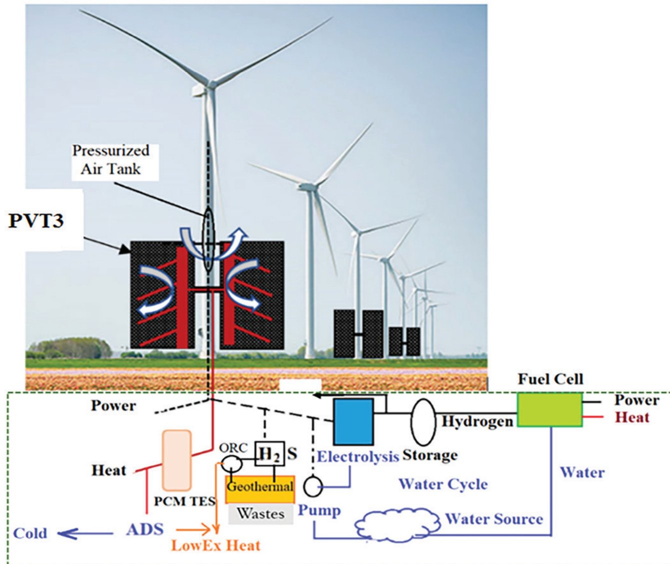
## Equipment Side

In district energy systems for heating, the biggest challenge is the temperature incompatibility of low supply temperatures and the higher temperature demand of the existing heating equipment. The solution is low-exergy heating and cooling equipment with heat pipe technology (Kılkış, B., Çağlar, & Şengül, 2021).

## Compound Renewables

Renewables above and below the ground are combined to form an all-in-one 100% power generation and storage medium based on hydrogen. This arrangement also improves *LUE*.

**Figure 16. Compound Renewable Energy Utilization Below and Above the Ground**

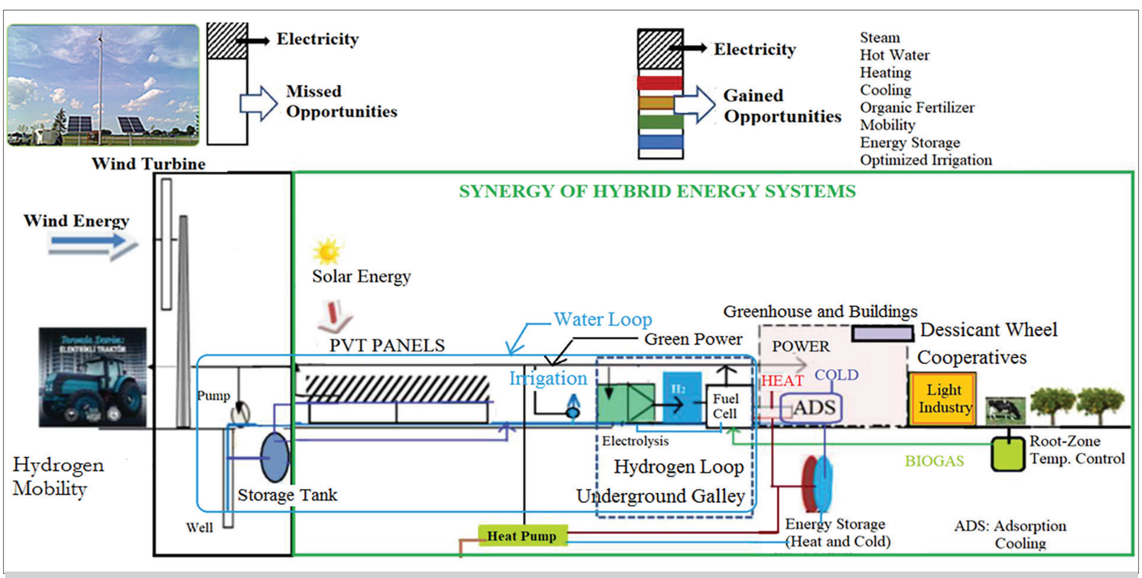



Source: Kilkis, B., 2022a.

## Energy, Water, Food, Farms, Cities, and Economy Nexus: An Example

Figure 17 shows a hybrid farm, small agricultural industry, and habitat (Kılkış,

**Figure 17. Green Hydrogen-Based Collective Farm Model**



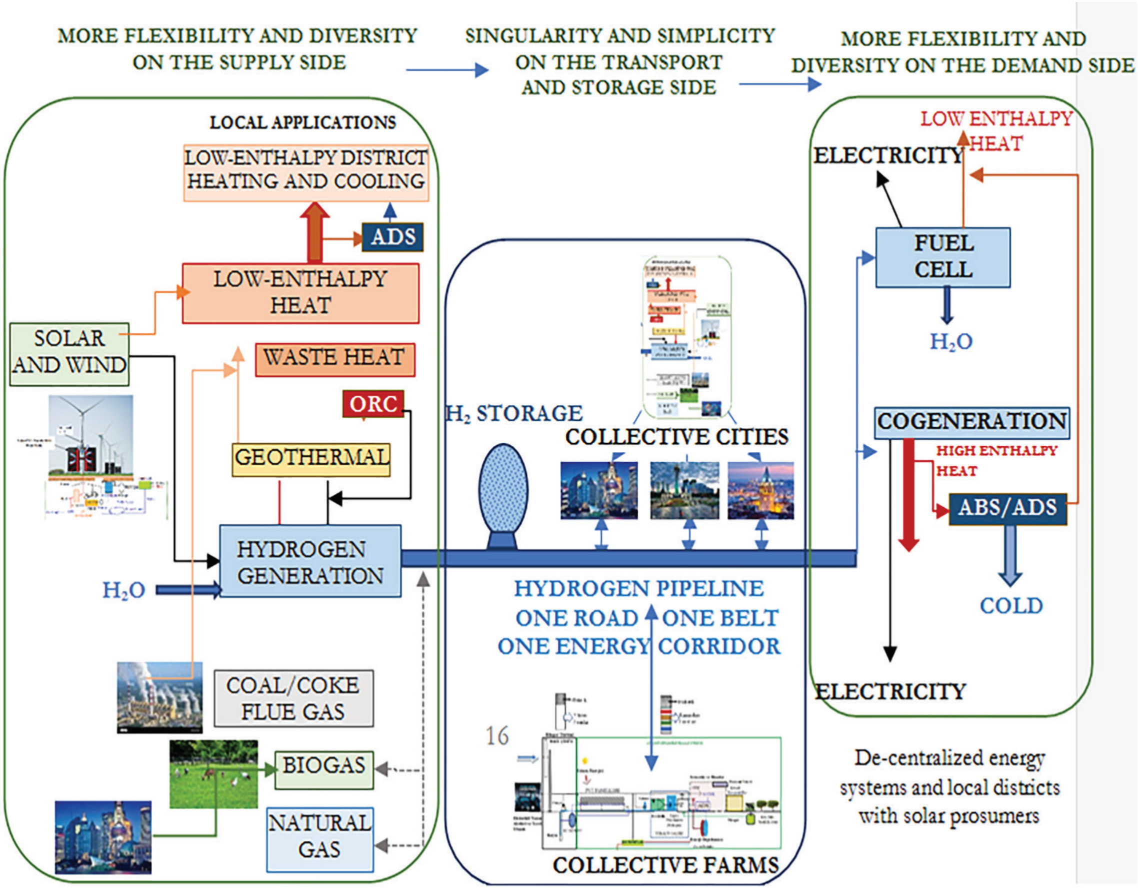

Source: Kılkış, B., 2020a.

B., 2020a). In this model, the irrigation is performed by DC-powered pumps from the wells. Power is collectively generated by the on-site wind turbines and PVT panels, which at the same time keep the PV cells cool to maintain their rated efficiency. Hydrogen generation by water electrolysis, heat pumps, hydrogen storage, adsorption cooling, greenhouse operations, small industry like agricultural product drying, food packaging, hydrogen mobility, desiccant moisture control in the buildings, fuel cells, waste heat recovery are the main features.

## Conclusion

Hydrogen is the best alternative to harness renewables and store and transnationally transport energy. The key innovation is shown in Figure 18. This innovation comprises condensing all energy forms into hydrogen, transporting them with hydrogen, and then expanding hydrogen again to different forms of energy on demand. On the hydrogen route, cities, farms, and industry exchange energy similarly on their minor-scale hydrogen economy.

**Figure 18. Ultimate Solution: One Road, One Belt, One Energy Corridor, On a Singular Meeting Line of Green Hydrogen**




Source: Kılkış, B., 2022.

**Figure 19. Global Map of Natural Gas Pipelines**

Source: IRENA, 2022.

The prerequisite to such a success is developing innovative technologies concerning renewable energy systems and utilizing the abundantly available and waste energy sources and ambient energy sources. It also requires more diversity and flexibility in one energy transport medium (hydrogen). Hydrogen may mix natural gas, coal flue gas (may also replace them with a ratio of 1 to three approximately), and biogas, making it highly flexible. Additionally, it is not rational to recover heat from flue gases of power plants (Kilkis, B., 2019b). Better these gases should be used as a fuel. However, attention must be paid to the fact that although this is waste, it may make the hydrogen green hydrogen grey, although LHV is increased after mixing per meter cube of gas. Coke oven gas is the best and makes the industry relatively cleaner. In conclusion, hydrogen is the best-combined heat and power transport, storage, and utilization medium.

Greener and hydrogenized B&R is expected to bring unprecedented benefits for jobs, R&D, P&D, science and technology, economy, social welfare, and political unity. Figure 18 concludes how the BRI may be implemented for a green energy belt for a sustainable future and potentially the largest positive impact towards satisfying the Paris Agreement goals with 126 countries that B&R covers (Vivid, 2019). A primary transnational infrastructure is already available. According to Figure 19, there is already a natural gas pipeline on the main B&R route. It may be used for hydrogen transport by reversing today's natural gas flow.

## Acknowledgement

Assoc. Prof. Dr. Şiir Kılkış, the lead author of IPCC, has provided the most valuable material, knowledge, and deep insight during this research. Her unique contributions and dedicated support are greatly appreciated.

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# The Ultimate Solution for Turkey's Energy, Water Shortage and Climate Change Problems: Hydrogen Fuel

İ. ENGİN TÜRE

Prof.Dr.

*Mr. Türe was appointed as the Head of Energy Systems Department at TUBITAK Marmara Research Center in 1992 and served as a founder there for five years. He received TÜBİTAK-MAM The Personnel of the Year and Project Achievement Awards. While working as the Head of the Physics Department at Mimar Sinan University, where he was appointed as a professor in 1998, he gave lectures also at Yeditepe and Haliç Universities for 4.5 years. In 2005, he first served as vice-president and then chairman until 2008 at the United Nations International Center for Hydrogen Technologies. Prof. Dr. Türe who was appointed as the Rector of Haliç University in 2008 maintained this position until 2010. In the same year, he founded Arentek Energy and Technology Company and provided consultancy to many companies. Prof. Türe who is continuing his duty as a lecturer at MEF University since 2017, is also carrying out work as the founder and former president of the Clean Energy Foundation. Prof. Türe has more than 50 publications, mostly in international journals, and his publications have been cited 600. Prof. Türe has given more than 40 conferences as a guest speaker in 30 countries including Japan, China, the USA, England, France, Italy, and Norway, and chaired many international meetings until today.*

*E-mail: enginture@gmail.com* *https://orcid.org/0000-0002-6570-1882*

**Received:** 29.12.2021

**Accepted:** 25.04.2022

How to cite: Türe, İ. E. (2022). The ultimate solution for Turkey's energy, water shortage and climate change problems: Hydrogen fuel. *Belt & Road Initiative Quarterly (BRIQ)*, 3(3), 22-49.

## ABSTRACT

The above prediction of Jules Verne, whose many predictions have been realized in the books of "From Earth to the Moon", "Around the World in Eighty Days", "Twenty Thousand Leagues Under the Sea", is perhaps much more realistic than the others. Hydrogen fuel has already started to be used in many places. It's hard to believe, but in the 1960s, hydrogen fuel-powered tractors, golf cars, and even Volkswagen mini busses were produced and used. In these years, the interest in hydrogen has decreased due to the fact that oil was very cheap and the infrastructure was prepared quickly, and unfortunately, this technology has been pushed into the background. These days, clean energies and hydrogen have come to the fore again due to increasing oil prices global warming and climate change. The main disadvantage of clean and inexhaustible energies such as sun and wind is that it is not intermittent and reliable and alongside that cannot be used as fuel. This is where hydrogen gets involved which enables a large amount of energy to be stored. As is known, the biggest problem with energy today is that it cannot be stored in large quantities. Here, a large amount of hydrogen sulfide exists in the Black Sea also has been added to the sources and methods of hydrogen production. Boron reserves of Turkey have been taken into account for the safe storage of hydrogen and are discussed. As stated in the article title, it is explained that the ultimate solution for energy, water shortage, and climate change can be realized by using renewable energy sources, especially electrolysis of seawater, which has infinite potential.In this article, besides the characteristics of hydrogen energy, it has been shown that production technologies, costs, reliability, and hydrogen production from seawater can be the final solution to our country's and the world's energy, water scarcity, and climate change problems.


**Keywords:** energy, hydrogen fuel, hydrogen sulfide, seawater, sodium borohydride

***"Yes, my friends, I believe that water will one day be employed as fuel, that hydrogen and oxygen which constitute it, used singly or together, will furnish an inexhaustible source of heat and light, of an intensity of which coal is not capable... When the deposits of coal are exhausted we shall heat and warm ourselves with water."***

*1874, Jules Verne, "The Mysterious Island"*

## Introduction

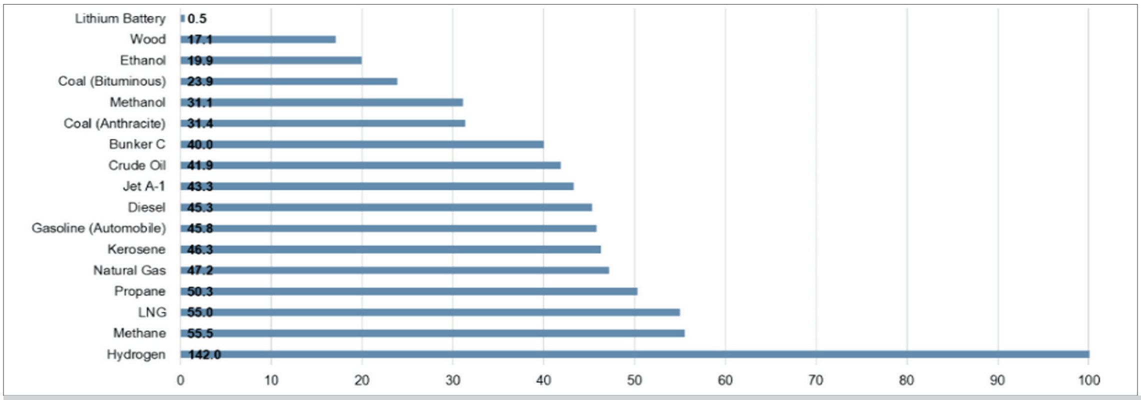
IT IS WELL KNOWN THAT, SINCE THE Industrial Revolution that started in the middle of the 19th century, fossil fuel resources namely, coal then oil and natural gas were used to meet the world energy demand. While the increase in energy use with industrialization has increased the living standards of countries, fossil fuel consumption has accelerated accordingly. Unfortunately, human beings have only been able to realize that this excessive consumption can have extremely serious consequences such as global climate change, as well as environmental pollution in recent years. Fossil fuel companies have constantly underestimated other alternatives in this well-profitable sector for their own interests and have used their power to exclude them from the decision-makers (Türe, 2021: para.3). Alternative energies such as sun, wind, and small streams, which are known as environmentally friendly are considered to be more expensive than fossil fuels. Intermittent natures of these resources were also another reason why they were not accepted by society.

**Hydrogen has many advantages over the fossil fuels currently used. In a fuel cell where hydrogen will be used as a fuel, energy is obtained with high efficiency, while only pure water comes out as waste.**

As it is known, when fossil fuels such as coal, oil, and natural gas are used, some dust particles are released into the environment along with various gases. There are carbon oxides, sulfur oxides, hydrocarbons, poly-nuclear aromatic hydrocarbons (PAH), olefins, aldehydes and some other pollutants in these released gas mixtures and particles. The effects of air pollution on the environment occur on a global, regional and local scale. On a global scale, it is possible to count climate changes such as global warming caused by greenhouse gases, especially carbon dioxide, and consequently increasing the intensity of hurricanes, extreme drought, or flooding. On a regional scale, deterioration of ecological balance as the result of acid rains, forest destruction, and increased acidity of lakes are the most important indications. At the local scale, air pollutants such as CO, $SO_2$ NOX, and $O_3$ cause adverse effects on human health, plants, structure, and materials. Currently, the total damage did by fossil fuels to the environment in the world reaches almost 8 trillion dollars per year (Greenpeace, 2020).

Hydrogen has many advantages over the fossil fuels currently used. In a fuel cell where hydrogen will be used as a fuel, energy is obtained with high efficiency, while only pure water comes out as waste. The use of water as a source of hydrogen constitutes one of the main advantages of hydrogen. Economical storage and transportation are still the most important problems of hydrogen technologies waiting to be solved. However, studies in recent years show that these problems will be overcome in a short period of time. Hydrogen technology is gaining importance with the continuous development of its usage area and the addition of methods to increase energy efficiency. According to the cost calculations, using hydrogen technology systems are more expensive than the existing fossil fuel systems but along with that the increasing oil and natural gas prices in the near future, equality in this regard will be achieved in the next ten years. Classified as the social cost of fossil fuels; global climate change, air pollution, oil spills, mining accidents, etc. when this damage done by the elements to the world is put on fossil fuel prices, hydrogen becomes much more advantageous in terms of cost. As mentioned above, there is no possibility that this situation will continue due to the limited fossil fuels and environmental disasters that await our world. Considering that it is not possible for people to renounce their comfort and living standards, it is necessary to find a new synthetic fuel instead of fossil fuels. This fuel should be clean, environmentally friendly, renewable, endless, ubiquitous, easily transportable, affordable, high calorific value, and efficient. Many years of studies have shown that the ideal fuel is definitely hydrogen. Hydrogen is shown as the only solution

**Figure 1. The Energy Content of Hydrogen Relative to Various Fuels (Mj/kg)**




Source: Transport Geography, 2022.

to environmental problems and is also called an "independence fuel" that can save countries from fossil fuels. As a result of the eruption of the energy crisis in 1973 and the scientific community's search for a solution to this problem, hydrogen energy came to the fore in the world.

When hydrogen gas, which is odorless and colorless under normal temperature and pressure, combines with oxygen, the most important substance for life, namely water, is obtained. Hydrogen is a very light gas; its density is 1/14 of air and 1/9 of natural gas. The density of hydrogen, which becomes liquid when cooled to -253˚C at atmospheric pressure, is 1/10 of that of gasoline. Hydrogen is the most efficient fuel. On average, it is 26% more efficient than fossil fuels. Hydrogen has the highest energy content per unit mass of all known fuels. In Figure 1, the energy content of hydrogen compared to other fuels is given. 1 kg of hydrogen has the same energy as 2.1 kg of natural gas or 2.8 kg of oil (Türe, 2021: para.6).

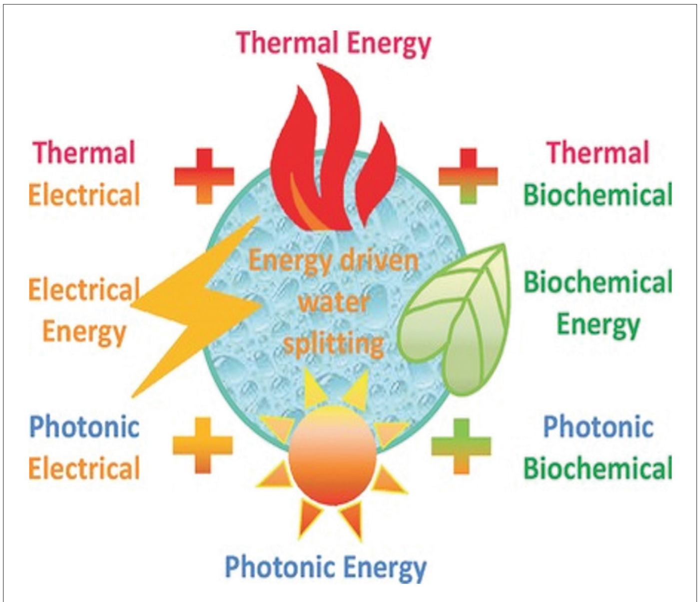
Considering that, the heat of combustion of liquid hydrogen is 120.7 MJ/kg, while the heating value of aviation gasoline is only 44 megajoules per kg, it is easy to understand the usage of liquid hydrogen as rocket fuel. However, its heating value per unit volume is low. The heating value of hydrogen gas is given as approximately 12 Mega Joules per cubic meter (Türe, 2021: para.7).

Hydrogen is the cleanest energy carrier. In view of the high efficiency of hydrogen and the environmental damage of fossil fuels, hydrogen is the most cost-effective fuel. It does not produce greenhouse gases that cause global climate change, does not cause acid rain, and does not produce chemicals that damage the ozone layer (Türe, 2021: para. 8).

Hydrogen is secondary energy just like electricity, so it is a carrier and must be produced from primary energy sources. Obtaining hydrogen from clean energy sources and water means both endless energy and the world getting rid of all environmental problems, especially global warming. For example, as a result of the separation of water into hydrogen and oxygen with solar energy, the transportation of the obtained hydrogen to the desired location through pipelines or storing, and then combusting with oxygen again, waste material of the resulting energy is again a few drops of pure water or water vapor (Türe, 2021: para. 9).

Hydrogen is considered to be the fuel not only for this century but also for the next 5 billion years,

**Figure 2. Various Methods Used for Obtaining Hydrogen from Water**




Source: Online Library, 2017.

which is estimated as the life of the sun (Türe, 2021: para. 10). Considering the fuels that humanity has used from the first days of mankind to today it is clearly seen that the hydrogen ratio in these fuels is increasing (Türe, 2001). It is certain that this fuel will be completely hydrogen in the next period.

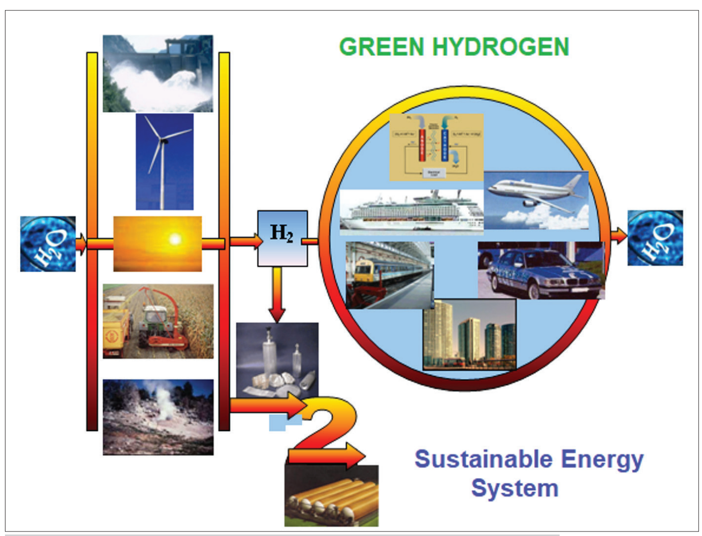
## Hydrogen Production Methods and Costs

Hydrogen can be obtained by various methods, depending on the use of different main energy sources (Figure 2). These include electrolytic, thermal, thermo-chemical, electro-thermochemical, photolytic, and mixed methods. Nowadays, the methods used for the production of hydrogen by decomposition of water are summarized in Figure 2.

Today, the most commonly used method in hydrogen production is to obtain high purity hydrogen from natural gas by the reforming method. The cost of hydrogen produced by this method is an average of 2 US dollars per kg. However, carbon dioxide gases are also released as a result of obtaining hydrogen from fossil fuels such as coal. Obtaining hydrogen from fossil fuels becomes even more expensive when the cost of the technology to store $CO_2$ by burying it in the ground is taken into account. When hydrogen is obtained from fossil fuel sources, it is called "blue hydrogen" to indicate that the source is not clean (United States Department of Energy, 2020). Since almost 95% of the hydrogen produced today is produced by these well-known and fully commercialized technologies, new technologies are mostly included here. Hydrogen obtained by electrolysis of water using renewable energy sources is called "green hydrogen" (Figure 3). The cost is approximately 3-7 US dollars per kilogram of hydrogen with this method.

As it can be seen in Table 1, although the production cost of hydrogen from renewable energy sources and nuclear energy is still higher than fossil fuels, it is clear that this cost will decrease

**Figure 3. Green Hydrogen Cycle**




Source: Türe, 2001.

**Table 1. Costs for Hydrogen Produced from Various Sources in the World**

| Hydrogen Production Source | Hydrogen Cost $/kg |
|---|---|
| Natural gas | 0.9-3.2 |
| Natural gas with storage of CO2. | 1.5-2.9 |
| Coal | 1.2-2.2 |
| Electrolysis of water with renewable energies | 3-7.5 |

Source: Statista, 2020.

depending on the development of technology. Also, hydrogen from renewable sources is still cheaper when the aforementioned social costs are added to fossil fuels. Since the usage of electrical energy to be obtained from renewable energy sources such as wind and sun is taken as the basis here, it is possible to obtain hydrogen from water using alkaline or PEM electrolyzers. For this reason, according to these technologies, hydrogen costs are given comparatively and as an estimate. As it is known, natural gas and electricity prices vary from country to country, as well as over the years. In addition, factors such as the costs of the devices used for production and the amount of hydrogen produced play an important role in the cost of the product obtained. For the cost of hydrogen, the estimated price range is given in Table-1 instead of the exact price depending on various sources.

## Hydrogen Production from Solar, Wind, Hydraulic, and Geothermal Energies

Electrolysis of water with the help of electricity obtained from all renewable sources is the basic method for obtaining hydrogen. For example, wind and solar energies are important renewable energy sources used for the production of hydrogen to be used as fuel. There are three main types of electrolytic cells for the electrolysis of water, including alkaline electrolysis, polymer electrolyte membrane (PEM), and solid oxide electrolysis cells (SOECs).

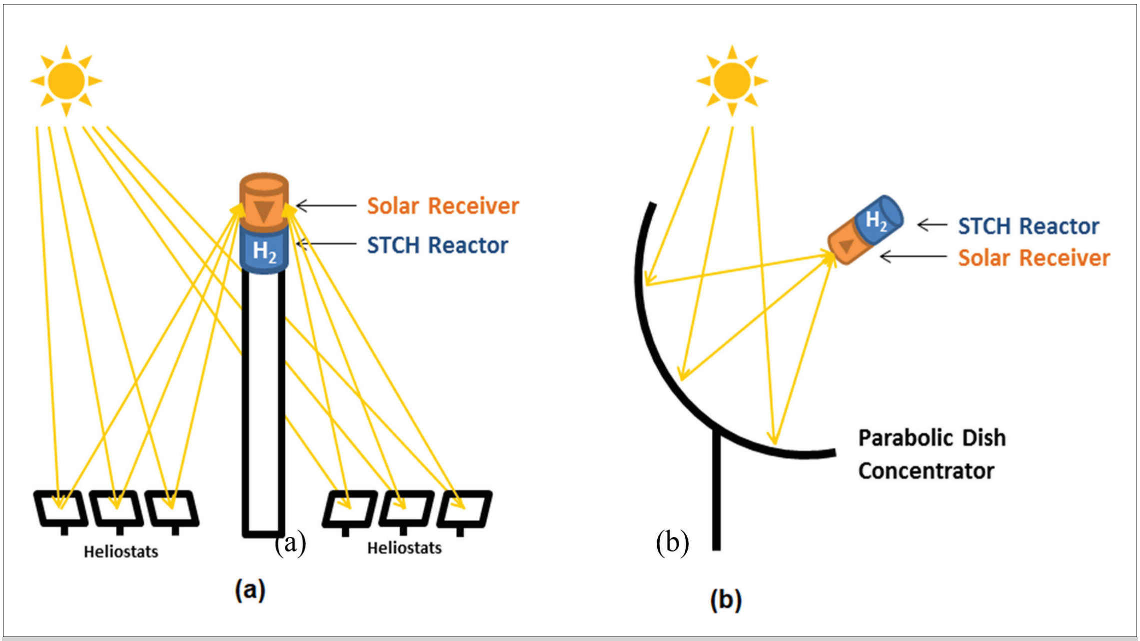
Hydrogen consumption increases by about 6% per year and, its annual production is estimated to be around 80 million tons today. As it is known, hydrogen is produced by reforming natural gas with steam which is a process that leads to greenhouse gas emissions to a large extent (Greenpeace, 2020: The Geography of Transport Systems, 2022). Nearly 50% of global hydrogen demand is covering currently through steam reforming of natural gas, approximately 30% from oil/naphtha reform from refinery/chemical industrial waste gases, 18% from coal gasification, 3.9% from water electrolysis, and 0.1% from other sources.

## Direct Decomposition Methods

### Separation of Water at High Temperature (Thermolysis)

It is the process of chemical decomposition of water into hydrogen and oxygen when a temperature of more than 2500 °C is applied. The hydrogen and oxygen must be effectively separated to prevent them from turning back

**Figure 4. Thermochemical Hydrogen Production by Concentrated Solar Energy a) Central Receiver/Reactor Tower With Heliostats b) Modular Dish-Mounted Receiver/Reactor**




Source: United States Department of Energy, 2022.

into the water due to the reaction is reversible. In this method, concentrated solar energy or waste heat of nuclear power reactions can be used as a source. Depending on the heat source used with this method, very few or hardly ever greenhouse gases are emitted into the atmosphere.

During the electrolysis of water with the thermochemical method, a temperature of (500-2000) °C is required for a series of chemical reactions at a temperature of (500-2.000) °C to decompose the water. The chemicals used in the process are reused in each cycle, creating a closed cycle that consumes only water and produces hydrogen and oxygen. The high temperatures required for the processes are provided by eco-friendly intensive solar energy (Figure 4; United States Department of Energy).

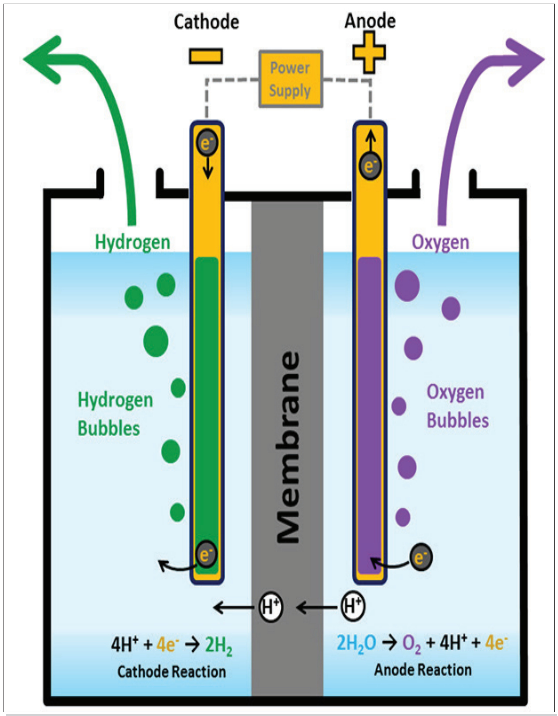
In order to reduce the high temperature required for the thermolysis process, e.g. to 1200-1500 °C, intermediates (catalysts) are used.

## Electrolysis (Alkaline)

Electrolysis of water or the decomposition of water into oxygen and hydrogen is a known and commercially used method since the 1890s. Electrolysis is basically a process that breaks the chemical bonds in the water molecule by adding a substance such as KOH or NaOH that increases conductivity in the water and passes a direct current through this liquid. It is also defined as the separation of chemical compounds dissolved in a liquid by applying an external electric current through metal electrodes immersed in the electrolytic liquid.
Electrolysis is the most essential method used

to obtain pure hydrogen. Electrodes in the electrolysis cell can be selected from different metals according to the electrolytic liquid used. This cell consists of two electrodes that are dissolved into a compound divided into positive and negative charged ions and these electrodes are adjusted by means they do not touch each other (usually 5-20 cm between two electrodes). For instance, nickel-based electrodes such as nickel-aluminum alloys are preferred in alkaline electrolysis cells. When sulfuric acid, which increases conductivity, is added to water, platinum, which is not affected by acid, should be used as an electrode. Although platinum is a highly productive electrode, it is not preferred with regard to cost. When a voltage of at least 1.23 volts is applied between the electrodes

**Figure 5. Alkaline Electrolysis Cell**




Source: Nelly Hydrogen, 2022.

from the exterior, 99.9% pure hydrogen comes out from the cathode and oxygen gas from the anode. In the case of an electrolytic cell with KOH or NaOH mixed, the reactions at the cathode and anode are given below respectively;

At the Cathode $2\ H_2O + 2e^- \rightarrow H_2 + 2OH^-$ (1)

At the Anode $2OH^- \rightarrow 0.5\ O_2 + H_2O + 2e^-$ (2)

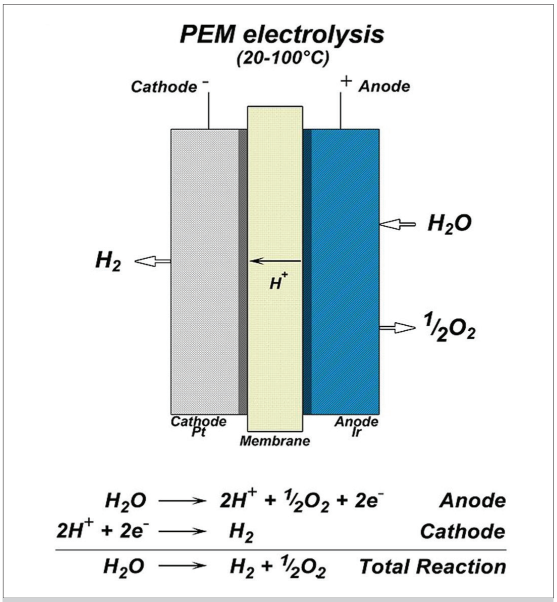
Overall reaction: $H_2O \rightarrow H_2 + 0.5\ O_2$ (3)

A schematic of an alkaline electrolyzer is shown below.

## Proton Exchange Membrane ( PEM)

Proton Permeable Membrane Electrolyzer-Proton Exchange Membrane (PEM): This type of electrolyzer is designed to produce hydrogen electrochemically at pressures of 2000 psi and with an efficiency of 85% or more. Thus, it is not necessary to use a compressor to compress the hydrogen later. The PEM electrolyzer usually uses a solid polymer-based membrane instead of a liquid electrolyte. Another advantage of this type of electrolyzer is that it can produce high purity hydrogen alongside low parasitic losses. PEM electrolyzers are one of the most studied subjects in recent years due to their simple structure and hydrogen production, as well as their ability to store gas under pressure. Today, fuel cells, which are defined as "Regenerative Fuel Cell", work conversely and act as electrolyzer, as well as can, produces electricity from hydrogen as a fuel cell, and pure water is again produced as waste. PEM electrolyzer/fuel cell diagram is given in Figure 6.

**Figure 6. PEM Electrolyzer**




Source: Kumar & Himabindu, 2021.

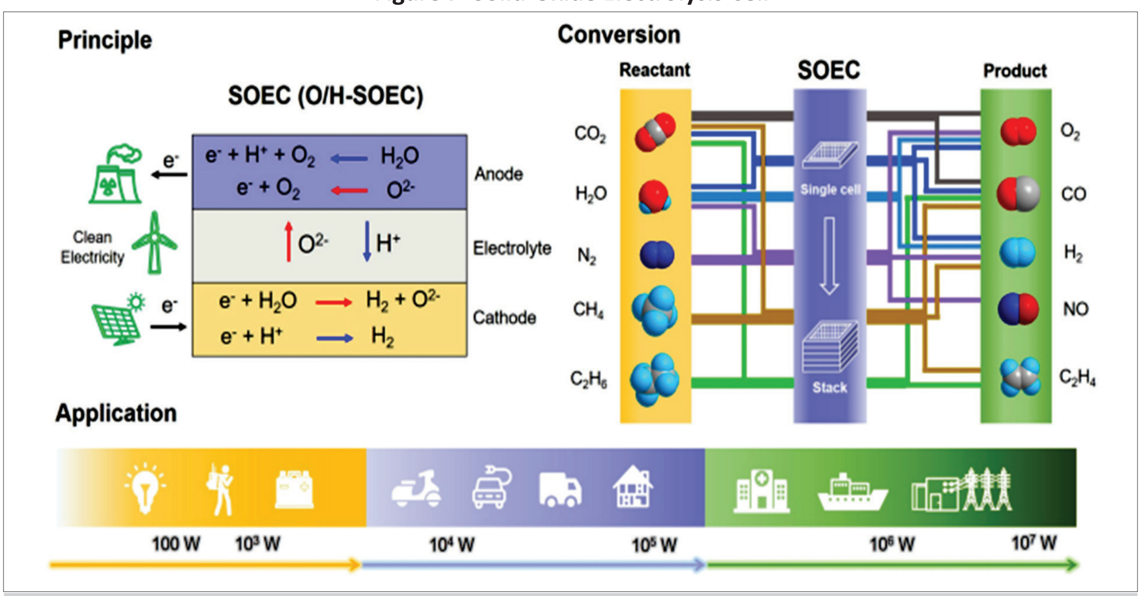
## Solid Oxide Electrolysis Cell- (SOEC)

Solid-oxide electrolyzers are electrolysis cells that selectively apply negatively charged oxygen ions $(O_2)$- at high temperatures, usually (700-1000) °C, and use a solid ceramic material as the electrolyte. In the system, firstly, electrons from the external circuit combine with water at the cathode in order to form hydrogen gas and negatively charged $(O_2)$- ions. Then, the oxygen ions pass through the ceramic membrane and react at the anode to form oxygen gas and provide electrons to the external circuit. The process can also be expressible as a high-temperature steam electrolyzer. Solid-oxide electrolyzers have much higher efficiency than proton permeable membrane (PEM) electrolyzers (Tucker, 2020; Zheng, et al., 2021).

## Photonic Energy (Photolysis)

Photolysis involves the chemical decomposition of water into hydrogen and oxygen by photonic energy. Since the potential for water separation is 1.23 eV, the wavelength of the photons equivalent to it is 1008 nm, corresponding to infrared light. That shows the separation of water is theoretically

**Figure 7. Solid-Oxide Electrolysis Cell**




Source: Tucker, 2020; Zheng, et al., 2021.

possible with infrared light, but industrial application is not available. Recently, more intensive studies have been carried out on the separation of water by the photocatalytic method under lower frequency radiation instead of high frequency (Tee, et al., 2017; Waterhouse, et al., 2013).

### Biochemical Method

Hydrogen is obtained by fermenting carbohydrates in an anaerobic (oxygen-free) environment by various bacteria. The fermentation process can produce hydrogen in the absence of oxygen by the following reaction (Tokio, 1979).

$$C_6H_{12}O_6 + 2H_2O \rightarrow 2CH_3COOH + 2\ CO_2 + 4H_2$$

## Indirect (Multi-Step) Methods

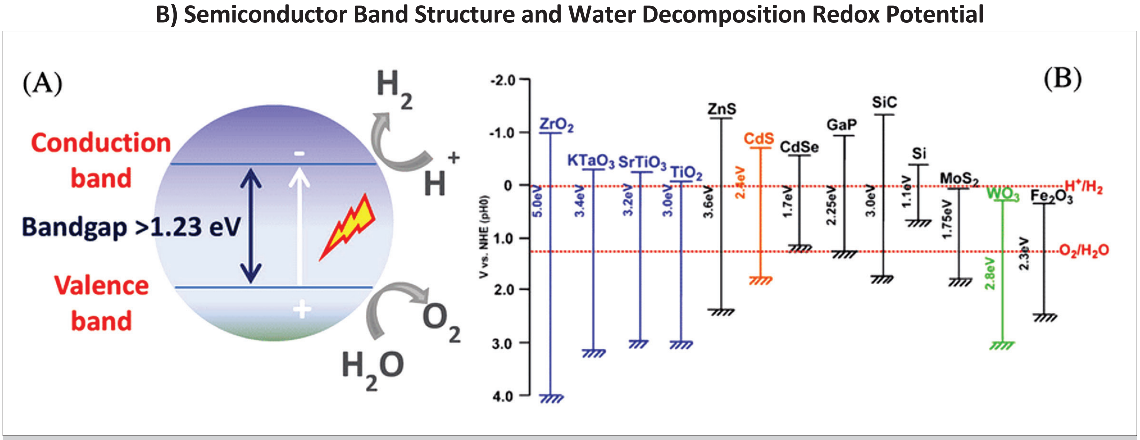
### Thermo-electrolysis

Thermo-electrolysis of water involves the chemical decomposition of water with the combined use of electrical and thermal energy. It is more efficient and economical at high temperatures because a significant part of the required energy is supplied by cheaper thermal energy, which significantly reduces the electrical energy demand and speeds up the electrolytic reaction kinetics at high temperatures. Alkaline electrolysis optimally operates at a high temperature of close to 200 °C and is used for industrial-scale hydrogen production. PEM electrolyzers typically operate below 100 °C (more efficient than alkaline electrolysis) and are increasingly available for commercial practices. SOEC electrolyzers are the most electrically efficient but least enhanced. SOEC technology faces challenges with rapid material degradation and limited long-term stability (Chao, 2019; Baniasadi, 2012).

### Biophotolysis

Biophotolysis of water involves oxygenic photosynthesis by microorganisms (i.e. green microalgae and cyanobacteria) with the combined use of biochemical and photonics energy for hydrogen production by direct and indirect methods. In direct biophotolysis, when microorganisms split water into hydrogen and oxygen ions by capturing sunlight, the hydrogen ions produced are further converted into hydrogen by the enzyme hydrogenase (i.e. $2H_2O$ + sun $\rightarrow 2H_2 + O_2$). In

**Figure 8. Photocatalytic Water Decomposing: A) Water Decomposing With Semiconductor Photocatalyst B) Semiconductor Band Structure and Water Decomposition Redox Potential**




Source: Kudo & Miseki, 2009; Hisatomi, vd., 2014; Tee, et al., 2017.

indirect biophotolysis, solar energy is captured by microorganisms through photosynthesis and stored in a type of carbohydrate $6CO_2 + 12H_2O + sun \rightarrow C_6H_{12}O_6 + 6O_2$, which is then used to produce hydrogen, then $C_6H_{12}O_6 + 12H_2O + sun \rightarrow 12H_2 + 6CO_2$ decomposes into hydrogen and carbon dioxide as a result of the reaction (Kamran & Fazal, 2021).

## Photocatalytic Water Decomposition (Photocatalysis)

The photocatalytic method is simply the production of hydrogen with the help of photon energy and a catalyst. For instance, the use of $TiO_2$ as a photocatalyst with solar energy is among the most studied subject in this field. A photocatalytic semiconductor that attracts light is needed for water to break down with photon energy. Simply, the reaction is given like that:

$$H_2O \xrightarrow[\text{Photocatalysis}]{\text{Solar}} H_2 + \tfrac{1}{2} O_2$$

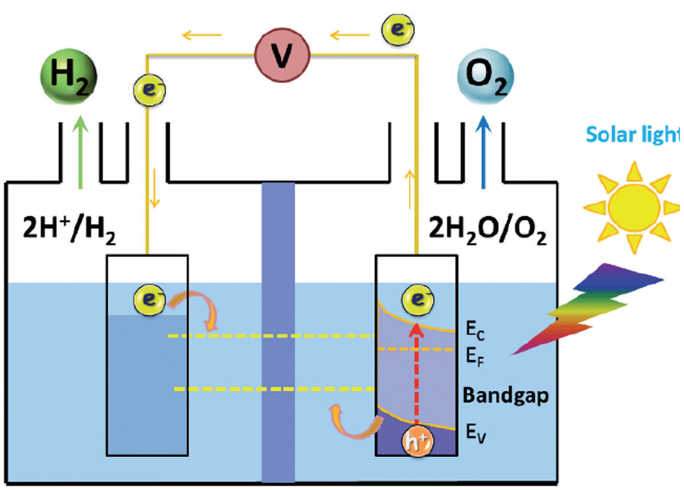
The features of semiconductors used as photocatalysts are that they provide conductivity by passing the electrons from the valence band to the conduction band with the incoming photon energy. The energy of the radiance falling on the semiconductor photocatalyst should be at least equal to the forbidden gap energy value given in eV between the valence band and the conduction band of this semiconductor. The most commonly used photocatalysts are $TiO_2$, CdS, $Fe_2O_3$, and SnO. In the photo-catalytic method, the photo-catalysts in the UV and visible region of the light provide hydrogen production by performing the reaction of reduction of water to hydrogen in the conduction band with light absorption (Kudo & Miseki, 2009; Hisatomi, et al., 2014).

So far, most of the photocatalysts reported are active only under ultraviolet light radiation. However, ultraviolet light (<400 nm) accounts for only 4% of total solar energy, while visible light (400-800 nm) and infrared light (>800 nm) account for 53% and 43% of total solar energy, respectively.

## Photo-Electrochemical Decomposition

Photo-electrochemical systems decompose water molecules using solar energy and hydrogen is obtained as a result of a chemical reaction. The biggest advantage of photo-electrochemical methods is that they only need water beside the sun as an energy source and they have serious potential for the future (Fujishima & Honda, 1972; Nozik,1978; Chen, 2010). Photoelectrochemical systems consist of three basic parts: photo-anode, photo-cathode, and electrolyte (see Figure 9). The photo-anode becomes electron-hole pairs with the sunlight falling on them, and the water molecule that comes into contact with the surface of the photo-anode is oxidized, resulting in an oxygen molecule and a positively charged hydrogen molecule.

**Figure 9. Photoelectrochemical Electrolysis Cell Diagram**



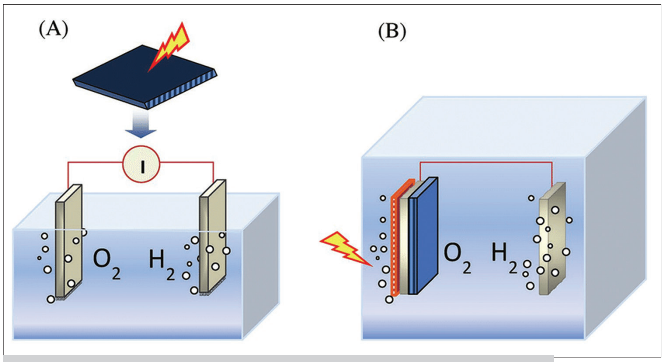

Source: Fujishima & Honda, 1972; Nozik, 1978; Chen, 2010; Ruth et al., 2017.

## Photovoltaic Integrated Photo-Electrochemical Water Decomposing

As it is known, photovoltaic cells are electronic devices that convert solar energy directly into electricity and can provide the necessary electrical energy to the electrolyzer to obtain hydrogen by decomposing water. Such a system is given in Figure 10 below. A crystalline silicon-based photovoltaic cell has an efficiency of 18% and when integrated with an electrolyzer with an efficiency of 80%, the combined electrolyzer system which is solar-powered operates with an efficiency of ≈14.19%. With the separate structure of the solar cell and the electrolyzer, the solar cell does not require immersion in the electrolyte and therefore does not cause corrosion. Photovoltaic integrated solar water decomposition uses a direct renewable source of solar energy and does not emit greenhouse gases during hydrogen production.

Current and future estimated costs for hydrogen production from commercially used Alkaline, PEM, and Solid-oxide electrolyzers are given in the tables below (Türe, 2005).

**Figure 10. Water Decomposition System with Photovoltaic Integrated Electrolysis**
**A) Photovoltaic System and External Electrolyzer**
**B) Photovoltaic İntegrated Solar-Driven Water Splitting Device**




Source: Kudo & Miseki, 2009; Hisatomi, vd., 2014; Tee, et al., 2017.

## Hydrogen Production from Hydrogen Sulfide ($H_2S$)

Studies conducted for many years show that there is a huge amount of hydrogen sulfide in the Black Sea, and this amount is increasing by 2.73 x 106 metric tons every year. This reason is that the five great rivers Kuban, Don, Dnieper, Nistru, and Danube still drain their organic compounds into the Black Sea.

**Table 2. Electrolyzer Costs**

**Electrolyzer Efficiency**

| Type | 2020 | 2040 |
|---|---|---|
| Alkaline | 70% | 80% |
| PEM | 60% | 74% |
| Solid oxide | 81% | 90% |

**Electrolyzer Lifetime**

| Type | 2020 (hours) | 2040 (hours) |
|---|---|---|
| Alkaline | 7500 | 125,000 |
| PEM | 60,000 | 100,000 |
| Solid oxide | 20,000 | 85,000 |

**Investment Costs**

| Type | 2020 $ | 2040 $ |
|---|---|---|
| Alkaline | 571 | 354 |
| PEM | 385 | 239 |
| Solid Oxide | 677 | 420 |

**$H_2$ Production Costs**

| 2020 $/kg | 2040 $/kg |
|---|---|
| 5.13 | 2.90 |

Source: Türe, 2005.

**Table 3. $H_2S$ Concentrations in the Black Sea at Different Depths**

| Depth (m) | Average $H_2S$ Density ($g/m^3$) | | | | |
|---|---|---|---|---|---|
| | (Türe, 2004) | (Brewer, et al., 1974) | (Lein & Ivanov, 1990) | Weber, et al., 2001) | Calculated |
| 100 | | 0.27 | 0.08 | 0.3 | 0.05 |
| 200 | | | 0.14 | | 0.20 |
| 300 | | | 2.55 | | 2.05 |
| 500 | | | | | 5.44 |
| 1000 | 5.27 | 10.3 | 8.0 | | 9.18 |
| 1500 | 5.62 | 12.9 | | 9.4 | 9.52 |
| 2000 | | 13.6 | | 12.2 | 11.56 |
| 2100 | | | | | 12.08 |
| 2200 | 8.9 | | | | 12.75 |
| 2200-Bottom | | | | 16.1 | 13.6 |

Source: Türe, 2004; Brewer, et al., 1974; Lein & Ivanov, 1990; Weber, et al., 2001.

The extremely organic matter is too much for the bacteria that would normally break it down aerobically, it renders the anaerobic bacteria dominate via consuming the dissolved oxygen supply. These organisms form $H_2S$ as residual gas in the process, by taking oxygen from sulfate ions which is a component of seawater. It has been found that the $H_2S$ concentration in the Black Sea conforms to two different regimes, one from the surface to 700 m and the other from 700 m to the bottom (Türe, 2005; Dimitrov, P., & Dimitrov, D., 2004).

The currently existing $H_2S$ reservoir in the Black Sea is estimated to be 5.27 x 109 metric tons. Decomposing hydrogen from this high amount of $H_2S$ in the Black Sea will both contribute to the economy and prevent future environmental disasters. According to the results obtained, the hydrogen acquired by the electrolysis of hydrogen sulfide is 3 times more economical than the electrolysis of water (COSIA, 2017). Hydrogen sulfide, $H_2S$, is a colorless, poisonous, and responsible for the rotten egg odor, flammable gas. Because hydrogen sulfide is heavier than air, it tends to accumulate near the ground in poorly ventilated areas. It usually occurs when organic matter breaks down in the absence of oxygen, such as bacteria, swamp, and sewer. It also occurs in volcanic gases, natural gas, and some well water. The odor in the gas produced as a result of the activities of $H_2S$ producing bacteria in the human large intestine is substantially the result of trace amounts of $H_2S$ gas. This type of bacterial action can contribute to bad breath in the mouth. About 10% of total global $H_2S$ emissions are due to human activities (Rubright, et al., 2017). $H_2S$ production takes place mostly in oil refineries by the hydro-desulphurization process, and it decomposes sulfur from petroleum by the action of hydrogen. The obtaining $H_2S$ is converted to elemental sulfur by the Claus process and partial combustion. The Claus method is also used for the production of hydrogen from hydrogen sulfide, but some steps of the method have been changed here. It is a two-step process, generally thermal and catalytic reactions.

(a): Thermal Step: $H_2S$ is partially oxidized with air. This is executed in a high temperature (1000-1400) °C reaction furnace. Sulfur is formed, but some $H_2S$ remains unreacted, and small amounts of $SO_2$ are produced in these reactions.

$$H_2S + 3/2\,O_2 \rightleftarrows SO_2 + H_2O \qquad (1)\ \text{step}$$

$$2\,H_2S + SO_2 \rightleftarrows 3/n\,Sn + 2\,H_2O \qquad (2)\ \text{step}$$

General reaction for the process.

$$3\,H_2S + 3/2\,O_2 \rightleftarrows 3/n\,Sn + 3\,H_2O$$

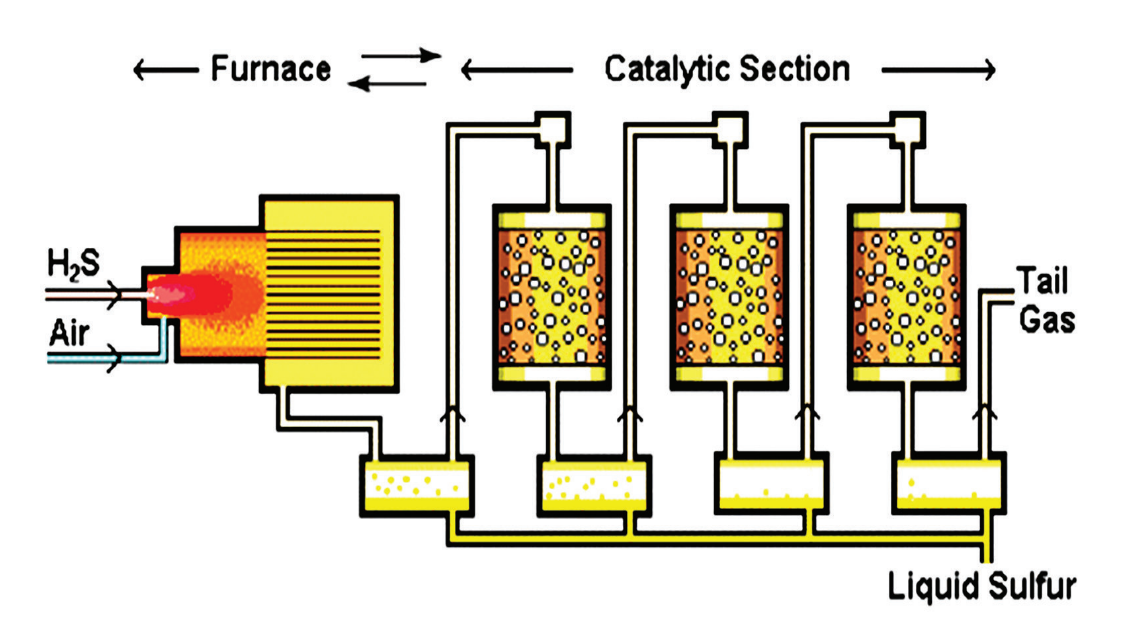
(b): Catalytic Step: The remaining $H_2S$ reacts with $SO_2$ to make more sulfur, the rate of that is approximately 99.8%. The Claus method used for hydrogen production is simply shown in Figure 11.

Due to the presence of hydrogen sulfide dissolved in seawater, it is necessary to pump sufficient density of $H_2S$ from the deep water to the surface before it is separated from water. Details of this highly complex system are given in the related publication (Naman, et al., 2008).

## Hydrogen Production from Biomass

Biomass sources such as wood, manure, organic wastes, etc. can be converted into hydrogen with gasification, steam reforming or biological conversion like biocatalyzed electrolysis or fermentative technique. Studies have shown that hydrogen can be produced from biomass sources more economically. This resource, especially obtained by energy agriculture, by growing energy crops such as fast-growing sorghum on relatively barren lands that do not compete with agriculture, is extremely useful for hydrogen production. In addition to methods such as pyrolysis, heterotrophic, and photo fermentation, bacteria are also used to obtain hydrogen from biomass. In case of hydrogen is produced from biomass, the $CO_2$ balance in the atmosphere will not change and there will be no environmental damage since $CO_2$ that was previously absorbed through photosynthesis while the plant was growing will be released.

**Figure 11. Classic Claus Process (Method)**



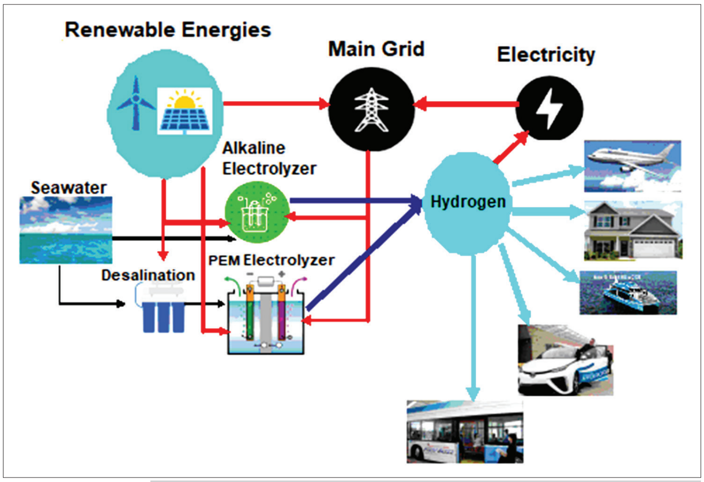

Source: Naman, et al., 2008.

## Hydrogen Production from Seawater

Considering the amount of water in the seas, and the potential of wind and solar energies, billions of tons of hydrogen could be produced and that will be the ultimate solution to the world's environmental, energy and water shortage problems (Türe, 2021: para.14). At this point, since chlorine gas causes pollution of the electrodes in electrolysis due to the salt (NaCl) in seawater, either the water must be purified first by known techniques such as reverse osmosis or making some new technological development on the electrode is required. This two-stage technique which can be realized using renewable energy sources is schematically given below.

Apart from water ($H_2O$) and salt (NaCl), sea water contains many minerals such as magnesium and calcium. The reactions that will take place at the electrolysis of pure molten salt are half-cell reactions that neutralize the salt ions. Whereas, two reduction and two oxidation reactions of both water and salt will compete at the cathode and anode

**Figure 12. Hydrogen Production Alternatives from Seawater**




Source: Türe, 2021.

in the electrolysis of the sodium chloride solution in the brine which is remaining from seawater treatment. Along with the ions formed by trace elements, except for Na+ and Cl-, are neglected at the first stage, it should not be ignored that they are also matter of economic importance and may also affect the operating life of the electrodes. The standard half-cell potentials of the reactions which are compared with the standard hydrogen electrode have indicated by E0.

Cathode reduction reactions: :

2 Na+(aq) + 2 e- → Na(s) E0 = -2,71 V

2 $H_2O$(l) + 2 e- → $H_2$(g) + 2 OH-(aq) E0= -0,83 V

Anode oxidation reactions:

2 Cl-(aq) → Cl2(g) + 2e- E0= 1,36 V

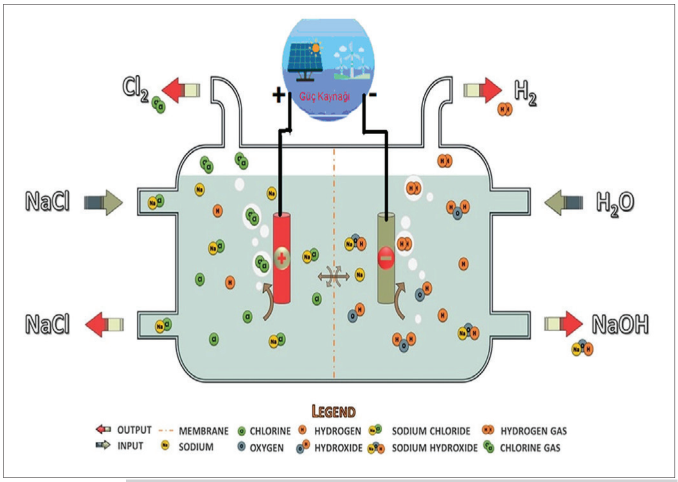
2 $H_2O$(l) → $O_2$(g) + 4 H+(aq) + 4 e- E0= 1,23 V

The standard battery potential of the electrochemical battery is equal to the potential difference between the standard cathode potential (E0cathode) and the standard anode potential (E0 anode), i.e, the half-cell potential difference between reduction and oxidation.

E0battery = E0 cathode – E0 anode

When the cathode half-reactions are examined, since the reduction of sodium is much more negative comparatively the reduction of water, $H_2$ will form at the cathode, and the Na+ ion will remain in solution. Except for some special catalysts, since the over potential of $O_2$ is higher than the over potential of Cl2, undesirable toxic Cl2 gas, not $O_2$, will be formed at the anode, although the battery potential is lower. Due to chlorine Cl2 and alkali NaOH(aq) are the two main products in the processes, apart

**Figure 13. Diaphragm Chlorine-Alkaline Process**




Source: Protank, 2018.

from $H_2$, the process is called chlor-alkali process. Cl2 is produced in the anode chamber, and $H_2$ and NaOH are produced in the cathode chamber in the diaphragm cell shown in Figure 13. The task of the diaphragm (Membrane) is to increase the yield of chlor-alkali product by preventing the formation of undesirable intermediate products such as ClO-, $ClO_3$-- and Cl- ions by preventing the contact of Cl2 with NaOH. The dissolution containing about 10-12% NaOH(aq) and 14-16% NaCl (aq) in the cathode chamber is concentrated and purified by evaporating some of the water and crystallizing NaCl(s). The final product is 50% NaOH with up to 1% NaCl(aq).

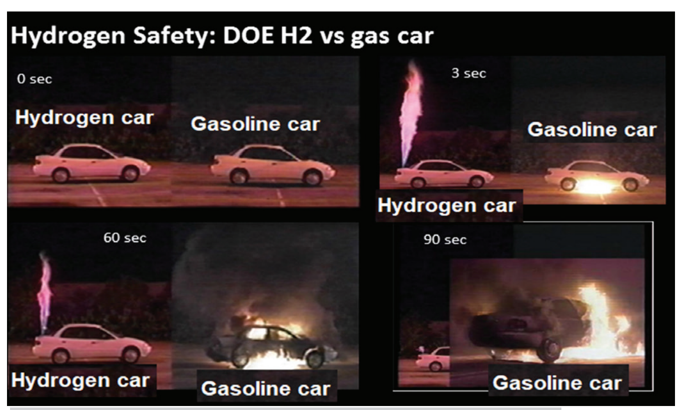
## Reliability of Hydrogen Fuel

The developing hydrogen technology remains much safer compared to the accidents that occur due to the wide use of nuclear fuels such as natural gas, oil, coal and uranium. In case of certain rules are followed in the use of hydrogen, the danger is reduced to a point where it is almost scarcely any. In fact, 50% hydrogen, 30% methane, and 7% carbon monoxide which is poisonous gas, are consisting in the gas mixture known as air gas and widely used in many metropolitan of the world (Türe, 2021: para.25). Here are the reasons why hydrogen is safe:

- Since it is 14 times lighter than air, it spreads quickly and becomes harmless;
- In case the hydrogen tank is punctured, it does not ignite before it comes close to 35-40 cm;
- When it burns, it creates only pure water;
- Concentration in the air must be at least 4% for it to burn;
- Does not emit heat such as wood, coal, or gasoline;
- Extraction of pure water instead of toxic gas and carcinogenic particles from the exhaust of the vehicles.

Considering parameters such as flammability limit in air, explosion energy, flame temperature and waste product, a higher safety factor (around 1) has found for hydrogen, although the safety factors of fossil fuels are between 0.5-0.80. These findings clearly show that hydrogen is safer than other fuels. An experiment on the safety of hydrogen is shown in Figure 14 (Türe, 2021: para. 26).

**Figure 14. Comparison of Hydrogen and Gasoline Vehicles in Case of Fire**




Source: Parsons, 2020.

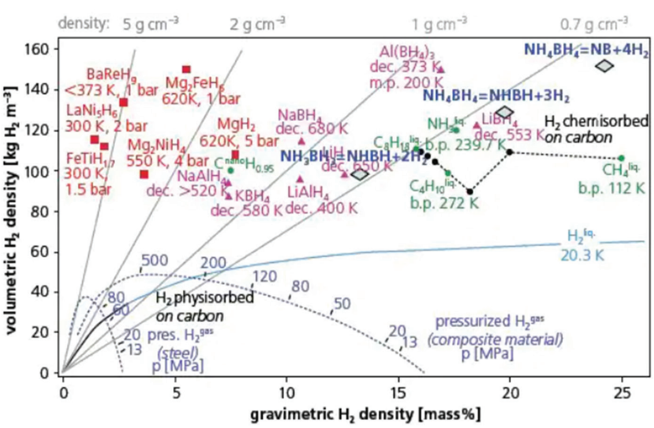
## Storage of Hydrogen

The biggest problem in using hydrogen as a fuel is the lack of efficiency in its storage. Hydrogen generally can be stored in three different ways: a) compressed, b) liquid and c) chemically bonded. Compressed and liquid hydrogen can be stored in pure form in tanks as well as physically stored in nanotubes. Chemically, it is usually in the form of hydride. Storage in the form of hydride can be in solid form in metals as well as in liquid form in sodium boron compound. Research has shown that some alloys can store hydrogen at a much higher density than pure hydrogen (Türe, 2021: para. 27). Volumetric and gravimetric hydrogen density values that can be obtained with different storage methods are given in Figure 15.

Based on the implementations that require the above-mentioned storage, the features intended for hydrogen storage in summarize;

- Recyclable storage capacity as high as possible;
- As low a desorption temperature as possible;
- Resistance to poisoning and therefore as high as possible reproducible filling numbers.

**Figure 15. Storage Types in Hydrogen and Obtainable Volumetric and Gravimetric Density Values**




Source: Ewald, 1998.

International Energy Agency (IEA) and US Department of Energy determined the target values for automotive implementation; for capacity: > 5-6%, for desorption temperature: <150 °C and for lifetime : >1000 fillings (Schulz, et al., 1999).

The importance of reliability and lightness in the storage of hydrogen highlights the storage of hydrogen in the hydride structure (Bilici, 2004). As seen in Figure 15, hydrides have a significant advantage in gas or liquid storage, especially in terms of hydrogen that can be stored in unit volume (Bilici, 2004).

### Storage of Hydrogen with Metal Hydrides

Positive results have been obtained about the storage of hydrogen as metal hydride in magnesium (Güvendiren, et al., 2004). In these studies, 6% storage capacity has reached, but the desorption temperature remained above the target values. The system needs improvements in terms of resistance to poisoning (Güvendiren, et al., 2003). Currently, studies are carried out on the basis of the Mg-Al-B system in line with the above-mentioned target values. The storage of hydrogen as metal hydride in Mg2Ni and similar systems is carried out at Osmangazi University and the studies on the numerical modeling of hydrogen storage in LaNi5 in terms of heat are carried out at Nigde University (Mat & Kaplan, 2001).

### Storage of Hydrogen with Boron Hydrides

Sodium boron hydride ($NaBH_4$) is a strong reducing agent, can react with many organic and inorganic compounds, and contains more hydrogen atoms per unit volume than other boron hydrides. Although it has been used for different purposes in various parts of the industry for years, its hydrogen carrying capacity and being a boron-containing compound have made sodium boron hydride a much more well-known compound recently (Bilici, 2004).

Sodium boron hydride has firstly obtained by the method known as the Schlesinger process, as seen in the equation below, as a result of the conversion of boric acid to trimethyl borate ($B(OCH_3)3$) with methanol and then its reduction with sodium hydride.

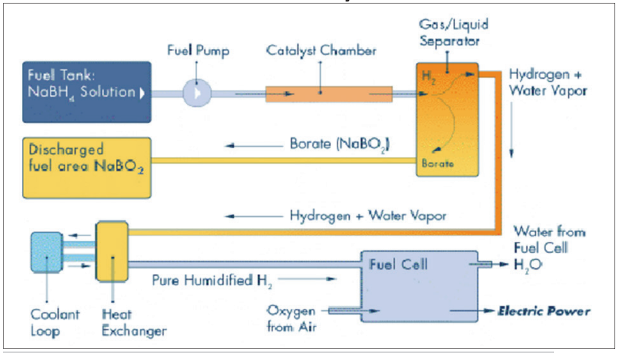
$$B(OH)3 + CH_3OH \rightarrow B(OCH_3)3 + 4NaH \rightarrow NaBH_4 + 3NaOCH_3$$

When the stoichiometric ratios in the equation are examined, it is seen that 75% of the required sodium is converted to sodium methoxide which is a by-product. This low efficiency hinders the applicability of the method on a larger scale and is the biggest factor affecting the production cost of sodium borohydride (Ortega, 2003). 66% of the world's sodium metal is produced in the USA, 14% in the UK, and the rest in Germany, France, Japan and Russia. Annual sodium metal production is 250 thousand tons. When sodium boron hydride and water react, 10.8% by weight of hydrogen is released in accordance with the following exothermic reaction and sodium metaborate ($NaBO_2$) is produced as a by-product (Li, et al., 2003).

$$NaBH_4 + 2\,H_2O \xrightarrow{\text{Catalyst}} NaBO_2 + 4H_2 \qquad \Delta H = -218\ \text{kJ.mol-1}$$

As can be seen, the amount of hydrogen released as a result of the reaction is twice that of the hydrogen bonded in the form of hydride, and 4 moles of H come from $NaBH_4$ and 4 moles of H from $H_2O$. Since the reaction is exothermic, the hydrogen obtained from the system is moist and depending on the environment in which it will be used, the hydrogen gas must be passed through a system that regulates the amount of moisture.

**Figure 16. Operating Scheme of a Commercial NaBH 4 - PEMFC System**




Source: Güvendiren & Öztürk, 2003.

Some advantages of using sodium borohydride are:

• The controllability of the reaction is ultrahigh (reaction stops when the catalyst is removed from the environment, e.g. Ruthenium, platinum, etc.);

• The reaction takes place at room temperature and pressure (no additional energy is required to liberate the hydrogen).

• It is a simpler and cheaper method compared to other methods for the production of small amounts of hydrogen.

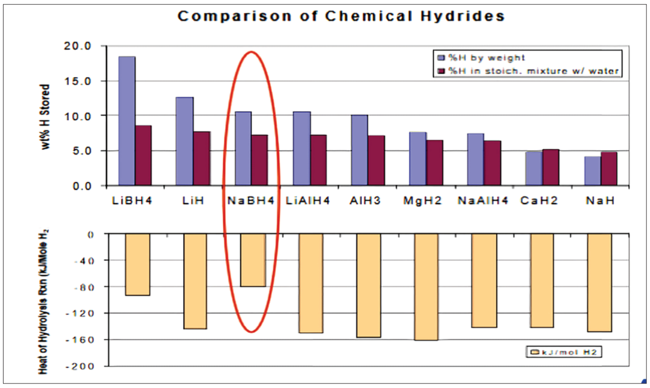
• The reaction rate is quite stable and the $H_2$ production is slow and stable. Catalysts can be used many times.

Sodium metaborate can be reused in the production of sodium borohydride.

Hydrogen gas produced in this way can be used as fuel in vehicles with a small change to be made in internal combustion engines. The flow diagram of the liquid-based sodium boron hydride system required for the fuel systems of vehicles using sodium boron hydride is shown schematically in Figure 16.

Sodium boron hydride, $NaBH_4$, is a white-looking, non-toxic, stable compound up to 300°C in dry

**Figure 17. Comparison of Chemical Hydrides**




Source: International Journal of Hydrogen Energy, 2019.

form. It can be found in powder form, granule form, or as a 12% solution in NaOH. Sodium hydroxide (NaOH) is added to these solutions in order to extend the shelf life of the sodium borohydride solution. Under normal storage conditions, the annual loss of $NaBH_4$ solution in 12% NaOH is less than 0.1%.

Sodium borohydride slowly decomposes into sodium metaborate and hydrogen when gets into contact with moisture in the air due to its hydroscopic nature. Rapid and controlled hydrogen production from $NaBH_4$ can be achieved by the addition of acidic compounds or metals that act as catalysts such as ruthenium, nickel, cobalt, and platinum. As a result of the exothermic hydrolysis reaction of sodium borohydride solution using a catalyst, 2.37 liters of $H_2$ /g $NaBH_4$ is released. Half of the hydrogen released comes from sodium boron hydride and the other half comes from water. Therefore, the hydrogen content released from the concentrated sodium borohydride solution is quite high and can easily compete with other known mobile hydrogen storage technologies in terms of energy content per weight. The theoretical hydrogen capacity produced by hydrolysis from sodium boron hydride is 10.8% by weight. The mass-based H-capacity of substances has been used as a measure of storage capacity. $NaBH_4$ has more hydrogen storage qualifications than many hydrogen alloys (Figure 17). Also, studies have shown that sodium borohydride has the ability to hold more hydrogen than the densest compressed air tank (Andersson & Grönkvist, 2019).

## Sodium Boron Hydride Synthesis and Hydrolysis Costs

The Bayer process is the most widely used commercial process for the synthesis of sodium borohydride. In this process, certain amounts of anhydrous borax, sodium metal, and quartz are heated under 3 atm hydrogen pressure at 500°C in a stirrer type autoclave for 2-4 hours. After extraction of the reaction product with ammonia and evaporation of the ammonia, $NaBH_4$ is obtained in a high yield. Sodium metasilicate is formed as a secondary product. The reaction is given below:

$$1/4\ Na_2B4O_7 + 4Na + 2H_2 + 7/4\ SiO_2 \rightarrow NaBH_4 + 7/4\ Na_2SiO_3$$

$$\Delta G^o\ (298) = -411.3\ kJ/mol\text{-}NaBH_4\ ;\ \Delta H^o\ (298) = -541.348\ kJ/mol\ NaBH_4$$

By calculating the enthalpies of the reacting raw materials and reaction products at the reaction temperature, the energy cost required for the reaction was calculated as approximately $2/kg for the production of 1kg of sodium borohydride. However, ideal conditions were assumed and the energy cost required to remove by-products from the system was not taken into account in this calculation. The cost of the raw materials required for the Bayer process is a minimum of $10 for the production of 1 kg of $NaBH_4$.

If the sodium borohydride required for the hydrolysis reaction of sodium boron hydride will be produced by the Bayer process as above, and then used in hydrolysis, the cost of $NaBH_4$ for the synthesis of 1 kg $H_2$ is approximately \$50 under ideal conditions. However, a catalyst such as ruthenium must also be used in this reaction. According to the type of catalyst, the cost of obtaining 1 kg of hydrogen from sodium borohydride reaches \$80/kg, and this cost can be higher depending on the type and amount of catalyst. On the other hand, it should be noted that if $NaBH_4$ is not produced in the system by the Bayer process and is purchased at \$47, the cost reaches \$222, and if the catalyst cost is added to this, the hydrolysis reaction cost will reach approximately to \$260 (Türe, et al., 2006).

It is important for the continuation of the system cycle that the sodium metaborate, which is released next to the hydrogen as a result of hydrolysis, is converted back to sodium borohydride and given to the system. Studies have shown that $NaBH_4$ recycling can occur by using the $MgH_2$ (Amendola et al., 2000) dynamic hydration/dehydration process or using Mg2Si. In this study, the cost of conversion reaction from $NaBO_2$ to $NaBH_4$ using Mg2Si was calculated as approximately \$15/kg $H_2$. As a result, by combining all these costs, in ideal conditions, the total cost of sodium borohydride synthesis, hydrogen synthesis, and recycling of sodium metaborate to sodium boron hydride is determined as approximately US\$ 110/kg $H_2$ without taking into account system losses. However, as mentioned above, if sodium borohydride is not produced in the system and purchased, this cost will be approximately \$290/kg $H_2$ (Türe, et al, 2006).

## Hydrogen Energy Applications

It is of great importance that fuel can be used everywhere, for example in industry, homes, and vehicles. Considering the commonly used fuels today, we see that most of them can only be used for certain applications. It is inappropriate to use coal in automobiles or airplanes in terms of practicality. It is possible to use hydrogen easily almost everywhere. It can be easily used instead of natural gas in heaters, ovens, and geysers for heating purposes in homes. Hydrogen can give energy not only with flaming combustion but also with very different cycles such as catalytic combustion, chemical, and electrochemical conversion, unlike fossil fuels.

It is possible to use hydrogen fuel in all vehicles such as buses, trucks, automobiles, tractors, and agricultural machinery since it provides high-efficiency use in vehicles by generating electricity with fuel cells as well as internal combustion engines.

Since fuel cells used for electricity generation from hydrogen have a very important place today and in the future, this matter is given below in more detail. Hydrogen can be used in fuel cells or vehicles instead of gasoline and in radiators, ovens, and water heaters instead of natural gas in homes. Today, hydrogen is used almost everywhere from

**Figure 18. Usage Areas of Hydrogen**

**Table 4. General Commercial Uses of Fuel Cells**

| Fuel Cell | Fuel Type | Electrolyte | Operating Temperature (°C) | Transfer Molecule | Areas of Usage |
|---|---|---|---|---|---|
| Polymer Electrolyte Membrane (PEM) | $H_2$ | Polymer | 60-100 | $H^+$ | Stationary, Portable and Mobile Systems |
| Direct Methanol (DMFC) | Methanol | Polymer | 50-120 | $H^+$ | Portable Systems |
| Alkaline (AFC) | $H_2$ | Potassium Hydroxide | 50-100 | $OH^-$ | Stationary and Mobile Systems |
| Phosphoric Acid (PAFC) | $H_2$ | Phosphoric acid | 175-200 | $H^+$ | Stationary Systems |
| Molten Carbonate (MCFC) | Natural gas, LPG, Diesel | Lithium – Potassium Carbonate | 600-1000 | $CO_3^-$ | Stationary Systems |
| Solid Oxide (SOFC) | Natural gas, LPG | Zircon | 600-1000 | $O_2^-$ | Stationary Systems |

Source: Xiao, 2021.

cell phones to airplanes. Since high-efficiency electricity can be produced with fuel cells, the usage areas of these batteries are very wide. In Figure 18, some of the vehicles and products that run with fuel cells are shown. It is possible to count among that, the vehicles such as cars, buses, motorcycles, bicycles, golf carts, forklifts, utility vehicles, electrical backup units, aircraft, locomotives, submarines, etc. Hydrogen is widely used in various fields from margarine making to metal processing in the industry.

## Fuel Cells

Fuel cells are described as high-efficiency electrochemical energy conversion devices and basically composed of an electrolyte placed between the anode and the cathode. These devices which produce electricity as a result of the chemical reaction of hydrogen used as fuel with oxygen, are seen as the energy production source of the future. The main advantages of the fuel cell are that it produces pure water as waste, does not cause environmental pollution, and noise and does not contain moving parts. Fuel batteries are generally classified as polymer electrolyte (PEM), alkali, phosphoric acid, molten carbonate, and solid oxide fuel cells, depending on the type of electrolyte used in the cell. PEM fuel cell is especially used in vehicles. Fuel cells are more energy-efficient than conventional internal combustion systems used in automobiles and certainly create less pollution. In addition to this, system size, weight, commissioning time, operating life, and price are key areas required for improving automotive applications.

The fuel cell has an important place in the use of hydrogen. Fuel cell systems can be used in a portable way, as well as in transportation, mobile systems, and stationary applications. As well as fuel cells can generally be used wherever electrical energy is needed, their commercial use, in general, is as in Table 4. While mobile phones, laptops, digital cameras, and camera batteries can be given as examples for portable applications, hospitals, workplaces, homes, and computer networks where generators and uninterruptible power supplies are used can be examples for stationary applications. The world's leading automobile manufacturers in the transportation sector have completed the production of fuel cell-powered automobiles and bus prototypes. A five-year project was started in 2003 for the 1MW locomotive. In addition, fuel cells have been started to be used in mining due to their safety.

### PEM (Proton Exchange Membrane-Polymer) Fuel Cell

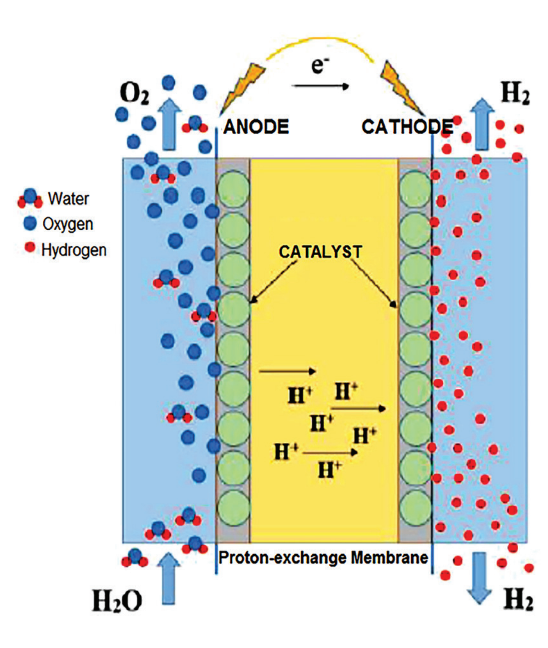
PEM Fuel cells, also known as Proton Exchange Membrane or Polymer Electrolyte Membrane, are a type of fuel cell developed for use in vehicles, especially in the USA, Japan, and Germany. Its first major application is the use of a PEM fuel cell with 1 kW output by GE in the Gemini spacecraft. Pure water produced as a by-product has also been used as drinking water by astronauts. There has been a great increase in studies that will improve both the cost and performance of PEM fuel cells in the last 5 years (Wilkinson & Steck, 1997).

It has been demonstrated that complete fuel cell systems can be used for many transport applications (including city transit buses and coaches). Recent studies have focused on cost reduction and the production of catalysts, membranes, and bipolar plates in large quantities. These studies also coincide with studies on increasing power density, improving water management, operating in ambient conditions, increasing tolerance to converted fuel and increasing module life. A schematic of an example PEMYP cell is shown in Figure 19.

In PEM, as in other fuel cells, the fuel cell module has two electrodes with high gas permeability and in contact with the electrolyte, while the gaseous fuel is continuously fed from the anode, while the oxidizing gas is continuously fed from the cathode. $H_2$ from the fuel is converted to H+ at the anode in PEM electrode reactions. H+ passes through the polymer electrolyte membrane and combines with $O_2$ at the cathode to produce water. The operating temperature is around 80ºC.

As an electrolyte membrane has two functions to provide ionic communication between the anode and cathode, and to separate the two reacting gases. Today, the standard electrolyte material used is Nafion which is a Teflon-based material produced by DuPont in the mid-1960s for space applications. The electrodes used in the PEM cell are typical gas diffusion electrodes and isolate the hydrogen gas into protons and electrons. The layer thickness of the catalyst is 5-50 µm and contains Pt microcrystals with a diameter of 2-4 nm. Pt has been determined as a suitable catalyst for

**Figure 19. PEM Fuel Cell Diagram**




Source: NIST, 2004.

both anode and cathode reactions today. However, it is tried to be used in a minimum amount by using many methods since it is expensive. Carbon/graphite plates for current collection and distribution, gas distribution, and thermal management have using in most PEM cells. The thickness of this layer is ~350 μm and has a catalyst layer attached to one side.

### Direct Methanol Fuel Cell

The first studies on these batteries, which are also admitted as a type of PEM fuel cell, were made by Shell and ESCO-Exon in the 1960s-70s. They obtained low current density due to the negative effect of direct methanol usage on the Pt-Ru catalyst and overvoltage at the anode. Research has been carrying on these batteries, which were ignored because the efficiency obtained in the early 1990s was below 25%. As such in PEM, acidic solid polymer Nafion is used as the electrolyte, and Pt-Pd superimposed carbon is used as the electrode. The most important feature that distinguishes these batteries from PEM is that the fuel methanol/ethanol can be used directly without the need for a fuel converter, and since it does not contain a fuel processing unit, it is less complex, lighter, and cheaper than other types.

### Alkaline Fuel Cell

In an alkaline fuel cell, 35-50% KOH is used as an electrolyte in low temperature (at 120°C) applications. In the high temperature (at 250°C) alkaline fuel cell used in the spacecraft Apollo, 85% KOH was used as the electrolyte. Low-temperature alkaline systems can operate at room temperature and have the highest voltage efficiency among all fuel cell systems. Cells and electrodes can be produced from carbon and plastics at a low cost. It has a long life of 15,000 hours due to adapt well to many materials. In addition, there are many catalyst options available for these fuel cells such as Ni, Ag, and metal oxides.

### Phosphoric Acid Fuel Cell

If the alkaline fuel cell used in space applications is not counted, the closest fuel cell to commercialization is the Phosphoric Acid Fuel Cell today. This fuel cell, in which 100% phosphoric acid is used as the electrolyte, operates at 150-220°C. The phosphoric acid which is acting as the electrolyte has fixed in a porous layer between the electrodes. Both anode and cathode are gas diffusion electrodes. This fuel cell is operated at high temperatures due to phosphoric acid is a poor conductor at low temperatures. In addition to this disadvantage, phosphoric acid provides many advantages as an electrolyte. Among them, it is possible to count its excellent thermal, chemical and electrochemical stability and relatively lower volatility than other inorganic acids above 150°C.

### Molten Carbonate Fuel Cell

The molten carbonate fuel cell operates at very high temperatures such as 600-650 °C and is one of the second-generation fuel cells which has developed recently, i.e., it needs a lot of development in order to be commercialized. A mixture of alkaline carbonates, for example (Na and K), or a mixture of $Li_2CO_3$-$K_2CO_3$ is used as the electrolyte. This electrolyte has attached to a ceramic matrix structure. Those are can be counted as the advantages, that the cell can be produced by printing technique from easily available metal sheets, that Ni catalyst is sufficient instead of expensive precious metal catalysts in cell reactions, that CO is a type of fuel that can be used directly, that the steam released in the cell is at a high enough temperature to be used in turbines or cogeneration applications. However, the Molten Carbonate fuel cell has disadvantages such as operating at high temperatures, causing corrosion, and thus reducing the life of the cell components.

### Solid Oxide Fuel Cell

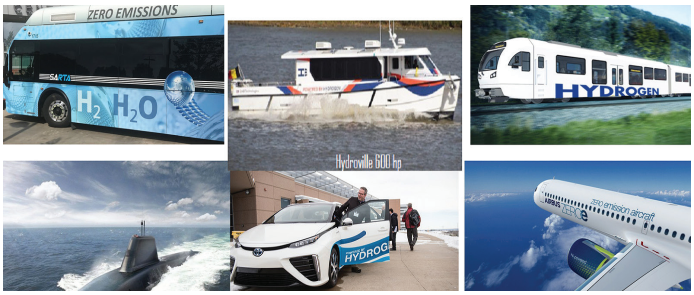
The solid oxide electrolyte is tempting for industrial applications due to some specific benefits. Non-porous metal oxides as a catalyst are used $ZrO_2$ which is containing 8-10% (mol) $Y_2O_3$. Although pure zircon is an insulator, it shows conductivity with the addition of $Y_2O_3$. Using $CeO_2$ instead of $ZrO_2$ can lower the operating temperature. In this fuel cell, porous gas diffusion electrodes are used as in other fuel cells. While porous Pt has been used as anode and cathode, Ni-$ZrO_2$ (containing $Y_2O_3$) or CO-$ZrO_2$ as anode and $LaMnO_3$ with Sr loaded as a cathode are used recently. Since it is possible to reach very high temperatures (1000°C), the fuel can be used directly in the fuel cell without the need for expensive catalysts as in low-temperature applications. Since the gas passage is low and the electronic conductivity of the electrolyte is high, these batteries can give at least 96% of the theoretical voltage in an open circuit. Among the advantages can be counted of solid oxide fuel cells are that it does not cause problems like other electrolytes in the operating conditions of the cell due to the solid electrolyte is very stable, there are no problems such as interface problems, water overflow from the pores, the necessity of wetting the catalyst since there is no liquid phase. For a general comparison, the types and properties of fuel cells are given in Table 5.

**Table 5. Types and Features of Fuel Cells**

| Fuel Cell Type | Electrolyte | Operating temperature, [°C] | Average Yield [%] | Field of Application |
|---|---|---|---|---|
| Alkaline | Potassium hydroxide | 50-100 | 60 | Spaceships, uninterruptible power supply |
| Polimer Electrolyte with membrane | Solid polymer | 50-125 | 70 | Spaceships, Vehicles, Power Supply |
| Phosphoric Acid | Orthophosphoric acid | 180-210 | 55 | Cogeneration constant power, vehicles |
| Molten Carbonate | Lithium-potassium Carbonate | 630-650 | 50 | Cogeneration Constant Power |
| Solid Oxide | | 900-1000 | 65 | Cogeneration Constant Power |
| Direct Methanol | Sulfuric Acid or Polymer | 50-120 | 35 | Low powers, Computer, Mobile Phone, etc. |

Source: Fuel Cell Today Industry Review, 2008.

**Figure 20. Hydrogen-Powered Vehicles**




## Current Uses of Hydrogen Energy

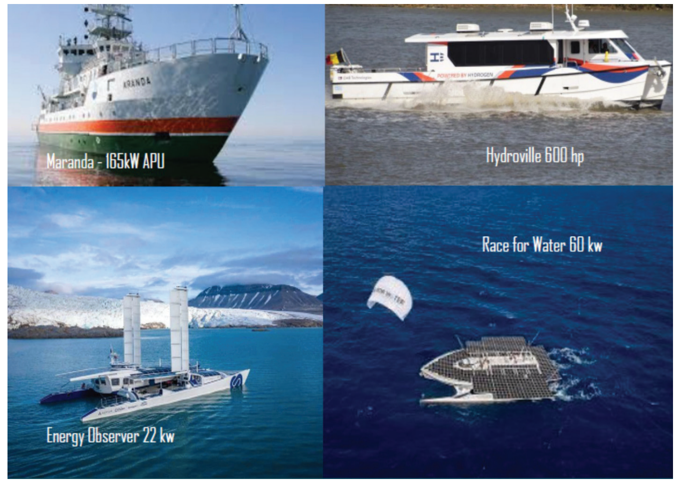
The applications of hydrogen as an energy carrier in almost every field are now well known. It is inevitable that these will increase even more in the near future. Some of the vehicles which utilize hydrogen fuel are shown in Figure 20.

The $H_2$ City Gold model developed by Toyota can travel 400 km with 5 hydrogen tanks with a total capacity of 37.5 kg placed on the roof of the bus. The bus, whose fuel tanks can be filled in less than 8 minutes, reveals its environmentalist identity by only releasing water vapor.

Today, almost all automobile companies have vehicles working with hydrogen fuel, and it has been announced that they will increase their production rapidly in the coming years. Large oil companies such as Shell and BP are also opening hydrogen filling stations rapidly (Figure 21).

**Figure 21. Hydrogen Filling Stations**


**Figure 22. Hydrogen Watercrafts**




## Applications of Hydrogen in Marine Vehicles

Due to the increasing awareness of climate change and marine pollution in recent years, restrictions have been imposed on ships operating with petroleum-derived fuels, especially in the ports of northern countries such as Sweden and Norway, and the use of clean fuels such as hydrogen on ships has begun to be encouraged. Examples of hydrogen watercraft are shown in Figure 22.

Commercial ship operators and shipyard owners in Turkey have also started work on the use of hydrogen fuel in this context. There are still many ships operating with hydrogen fuel in the world, and their number is increasing. Shown below are hydrogen-fueled ships still in circulation. Hydrogen/oxygen fuel cells (especially low-temperature fuel cells such as PEMFC) have ideal features for powering submarines. They do not need air, can operate under the sea if fuel (hydrogen) and oxide (oxygen) are stored. They produce no absorption or waste material other than water, thus maintaining zero buoyancy. Since they have no moving parts, they operate silently, reducing the sonar (sea radar) signal. They release heat at low temperatures and thus produce very little thermal traces. They are enormously productive. They provide long cruises and little waste of time.

### Hydrogen-Powered Airplanes

Liquid hydrogen has many advantages as a fuel in commercial subsonic and supersonic aircraft. The key advantage of liquid hydrogen is its high energy content (142 MJ/kg), which is 2.8 times the energy content of conventional jet fuels. For this reason, an aircraft powered by liquid hydrogen must carry less fuel, up to one-third the mass of a conventional aircraft. A hydrogen-powered subsonic airliner needs on average 16% less fuel (energy-wise) to complete the same flight compared to a regular airplane. This advantage would be even higher (28%) in supersonic aircraft. Airbus and Boeing are working intensively on hydrogen-fueled aircraft.

Despite popular opinion, hydrogen is a safer fuel for air transport and is currently used as jet fuel. The damage and loss in a liquid $H_2$ fuel aircraft collision will be less than in a standard fuel aircraft collision. In April 1988, one of three liquid hydrogen-powered turbofan engines of a commercial airliner's aircraft (Tupolev 155) was demonstrated in the USSR. On June 19, 1988, American pilot, William H. Conrad, became the first person who operate an airplane (Grumman-American "Cheetah") powered entirely by liquid hydrogen (Maniaci, 2008).

### Hydrogen Applications in Buildings

Hydrogen can be used to heat or cool an area. Likewise, with minor modifications, it is suitable for water heating as natural gas is used today. In addition, hydrogen can be used in catalytic burners by directly heating and humidifying the air instead of flame combustion. Since no further emissions are produced, these burners can also be used safely indoors. The usage of hydrogen will be in the form of hydrogen/hydrogen combination cooling systems in space heating and cooling and, in freezers.

Either flame combustion or catalytic burners can be used for cooking. It is very important to design combustor vessels so that the hydrogen/air velocity is always greater than the flame propagation velocity in hydrogen/air mixtures to prevent backfire propagation.

## Conclusion and Recommendations

Hydrogen is a safe, clean and endless fuel in all respects, and it has no harmful side. The only disadvantage that can be considered as a disadvantage today is that the price is expensive since it is not in widespread commercial use yet, so that is valid for each new technological product. For example, it is well known that the prices of technological products such as mobile phones or calculators when they first hit the market are tens of times their current prices. In addition, it has been calculated that the investment made in this sector since the discovery of oil is estimated to be 160 trillion (160,000 billion) Dollars. Hydrogen pumps must be set up at petrol filling stations and, of course, large amounts of hydrogen must be produced due to widespread usage of hydrogen. Studies in this area have started in many countries. For instance, in April 2004, California Governor Arnold Schwarzenegger started work to increase the number of hydrogen filling stations from 12 to 200 in the next 6 years within the framework of the "Hydrogen Highways" project and gave the good news that there will be filling stations for hydrogen cars every 30 km from now on (Türe, 2020).

Similar to natural gas or air gas, hydrogen gas can be transported anywhere easily and safely through pipelines. It is possible to give that as an example of the transportation of hydrogen by pipe, the 80 km long pipe network used by the petroleum industry in Texas, and the 204 km pipeline that was put into operation in Germany in 1938 in the Ruhr basin and still continue to transport hydrogen under 15 atmospheres pressure.

Sodium boron hydride, which has gained great importance as a hydrogen storage and transport medium today, also has an important potential in special boron chemicals. When the features of sodium borohydride such as being able to store more hydrogen than other compounds with similar purposes, being non-flammable and non-explosive, and releasing hydrogen with an easily controllable reaction, are evaluated together with new and clean energy policies, it will create a widespread and permanent consumption area for the rich boron resources of our country. Turkey, which has to accelerate its technological renewal and industrial production process, should prepare all legal and juridical grounds for the transition to hydrogen energy in the first ten years and establish the primary systems to provide this secondary energy source. In the next stage, it should develop hydride production systems, which are suggested as an alternative, in order to store and transport this fuel more efficiently and prepare the technology to introduce boron fuel solutions to the market. On the other hand, these technologies should be integrated with the fuel cell systems required for the conversion to electrical energy and should be a producing country instead of a technology transfer which is an expensive method, in order to get rid of foreign dependency.

Turkey has been late in catching up with rapidly developing technology and has become a country that constantly imports technology. At least, Turkey has a chance to get out of this position in the energy field. Turkey has an important position in terms of hydrogen energy applications. These technologies, on the other hand, should be integrated with the fuel cell systems required for the conversion to electrical energy, and in order to get rid of foreign dependency, there should be a producing country instead of technology transfer, which is an expensive method.

In order for Turkey to get rid of foreign dependency in the field of energy and to become a developed country, it is necessary to make good use of the hydrogen energy opportunity. Informing the Turkish society about hydrogen starting from primary school, directing the studies of scientists in Turkey to hydrogen, especially hydrogen production using renewable energy sources are crucial issues. In order for Turkey to get rid of foreign dependency in the field of energy and to become a developed country, it is necessary to make good use of the hydrogen energy opportunity.

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# Bolstering Confidence and Jointly Overcoming Difficulties to Build a Better World*

**Xi Jinping**

President of the People's Republic of China

**The United Nations (UN) should hold high the banner of true multilateralism and serve as the central platform for countries to jointly safeguard universal security, share development achievements and chart the course for the future of the world. The UN should stay committed to ensuring a stable international order, increasing the representation and say of developing countries in international affairs, and taking the lead in advancing democracy and rule of law in international relations. The UN should advance, in a balanced manner, work in all the three areas of security, development and human rights.**

*Xi Jinping's speech at the 76th General Assembly of the United Nations General Assembly on September 21, 2021.*

Mr. President,

The year 2021 is a truly remarkable one for the Chinese people. This year marks the centenary of the Communist Party of China. It is also the 50th anniversary of the restoration of the lawful seat of the People's Republic of China in the United Nations, a historic event which will be solemnly commemorated by China. We will continue our active efforts to take China's cooperation with the United Nations to a new level and make new and greater contributions to advancing the noble cause of the UN.

Mr. President,

A year ago, global leaders attended the high-level meetings marking the 75th anniversary of the UN and issued a declaration pledging to fight COVID-19 in solidarity, tackle challenges together, uphold multilateralism, strengthen the role of the UN, and work for the common future of present and coming generations.

One year on, our world is facing the combined impacts of changes unseen in a century and the COVID-19 pandemic. In all countries, people long for peace and development more than ever before, their call for equity and justice is growing stronger, and they are more determined in pursuing win-win

* *The text is retrieved from Ministry of Foreign Affairs of the People's Republic of China Website, https://www.fmprc.gov.cn/mfa_eng/wjdt_665385/zyjh_665391/202109/t20210922_9580293.html*

How to cite: Xi, J. (2022). Bolstering confidence and jointly overcoming difficulties to build a better World. *Belt & Road Initiative Quarterly (BRIQ)*, 3(3), 50-53.

cooperation.

Right now, COVID-19 is still raging in the world, and profound changes are taking place in human society. The world has entered a period of new turbulence and transformation. It falls on each and every responsible statesman to answer the questions of our times and make a historical choice with confidence, courage and a sense of mission.

**Staying committed to development as a priority. We need to put development high on the global macro policy agenda, strengthen policy coordination among major economies, and ensure policy continuity, consistency and sustainability.**

**First, we must beat COVID-19 and win this decisive fight crucial to the future of humanity.** The history of world civilization is also one of fighting pandemics. Rising to challenges, humanity has always emerged in triumph and achieved greater development and advancement. The current pandemic may appear overwhelming, but we humanity will surely overcome it and prevail.

We should always put people and their lives first, and care about the life, value and dignity of every individual. We need to respect science, take a science-based approach, and follow the laws of science. We need to both follow routine, targeted COVID-19 protocols and take emergency response measures, and both carry out epidemic control and promote economic and social development. We need to enhance coordinated global COVID-19 response and minimize the risk of cross-border virus transmission.

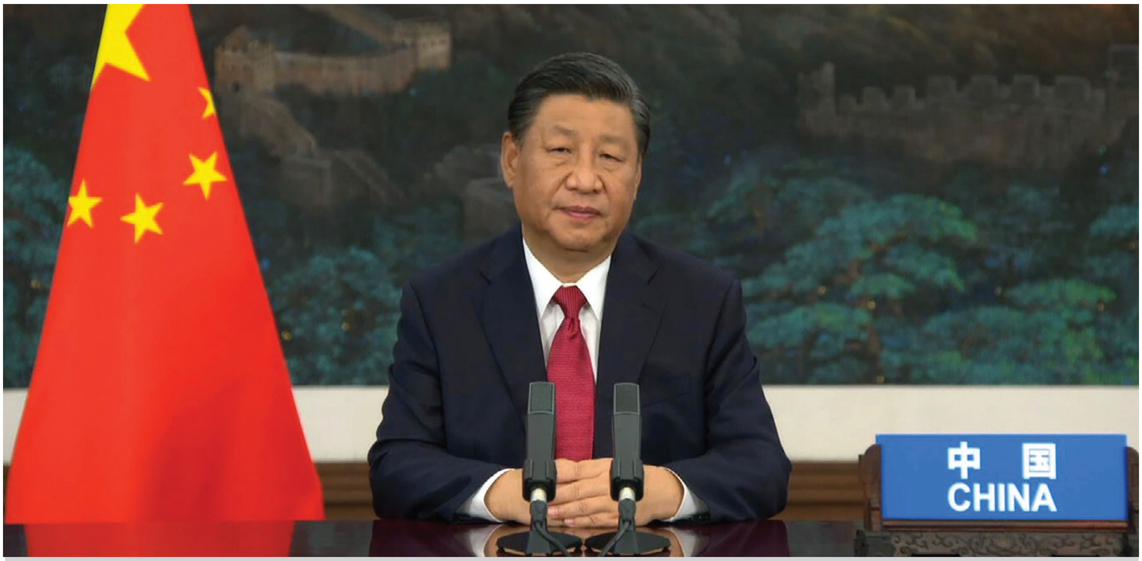
Vaccination is our powerful weapon against COVID-19. I have stressed on many occasions the need to make vaccines a global public good and ensure vaccine accessibility and affordability in developing countries. Of pressing priority is to ensure the fair and equitable distribution of vaccines globally. China will strive to provide a total of two billion doses of vaccines to the world by the end of this year. In addition to donating 100 million US dollars to COVAX, China will donate 100 million doses of vaccines to other developing countries in the course of this year. China will continue to support and engage in global science-based origins tracing, and stands firmly opposed to political maneuvering in whatever form.

**Second, we must revitalize the economy and pursue more robust, greener and more balanced global development.** Development holds the key to people's well-being. Facing the severe shocks of COVID-19, we need to work together to steer global development toward a new stage of balanced, coordinated and inclusive growth. To this end, I would like to propose a Global Development Initiative.

**Staying committed to development as a priority.** We need to put development high on the global macro policy agenda, strengthen policy coordination among major economies, and ensure policy continuity, consistency and sustainability. We need to foster global development partnerships that are more equal and balanced, forge greater synergy among multilateral development cooperation processes, and speed up the implementation of the UN 2030 Agenda for Sustainable Development.

**Staying committed to a people-centered approach.** We should safeguard and improve people's livelihoods and protect and promote human rights through development, and make sure that development is for the people and by the people, and that its fruits are shared among the people. We should continue our work so that the people will have a greater sense of happiness, benefit and security, and achieve well-rounded development.

**Staying committed to benefits for all.** We should care about the special needs of developing



President Xi Jinping addresses the general debate of the 76th session of the United Nations General Assembly, Sept 21, 2021. (Xinhua, 2021)

countries. We may employ such means as debt suspension and development aid to help developing countries, particularly vulnerable ones facing exceptional difficulties, with emphasis on addressing unbalanced and inadequate development among and within countries.

**Staying committed to innovation-driven development.** We need to seize the historic opportunities created by the latest round of technological revolution and industrial transformation, redouble efforts to harness technological achievements to boost productivity, and foster an open, fair, equitable and non-discriminatory environment for the development of science and technology. We should foster new growth drivers in the post-COVID era and jointly achieve leapfrog development.

**Staying committed to harmony between man and nature.** We need to improve global environmental governance, actively respond to climate change and create a community of life for man and nature. We need to accelerate transition to a green and low-carbon economy and achieve green recovery and development. China will strive to peak carbon dioxide emissions before 2030 and achieve carbon neutrality before 2060. This requires tremendous hard work, and we will make every effort to meet these goals. China will step up support for other developing countries in developing green and low-carbon energy, and will not build new coal-fired power projects abroad.

**Staying committed to results-oriented actions.** We need to increase input in development, advance on a priority basis cooperation on poverty alleviation, food security, COVID-19 response and vaccines, development financing, climate change and green development, industrialization, digital economy and connectivity, among other areas, and accelerate implementation of the UN 2030 Agenda for Sustainable Development, so as to build a global community of development with a shared future. China has pledged an additional three billion US dollars of international assistance in the next three years to support developing countries in responding to COVID-19 and promoting economic and social recovery.

**Third, we must strengthen solidarity and promote mutual respect and win-win cooperation in conducting international relations.** A world of peace and development should embrace civilizations of various forms, and must accommodate diverse paths to modernization. Democracy is not a special right reserved to an individual country, but a right for the people of all countries to enjoy. Recent developments in the global situation show once again that military intervention from the outside and so-called democratic transformation entail nothing but harm. We need to advocate peace, development, equity, justice, democracy and freedom, which are the common values of humanity, and reject the practice of forming small circles or zero-sum games.

**The world is once again at a historical crossroads. I am convinced that the trend of peace, development and advancement for humanity is irresistible. Let us bolster confidence and jointly address global threats and challenges.**

Differences and problems among countries, hardly avoidable, need to be handled through dialogue and cooperation on the basis of equality and mutual respect. One country's success does not have to mean another country's failure, and the world is big enough to accommodate common development and progress of all countries. We need to pursue dialogue and inclusiveness over confrontation and exclusion. We need to build a new type of international relations based on mutual respect, equity, justice and win-win cooperation, and do the best we can to expand the convergence of our interests and achieve the biggest synergy possible.

The Chinese people have always celebrated and striven to pursue the vision of peace, amity and harmony. China has never and will never invade or bully others, or seek hegemony. China is always a builder of world peace, contributor to global development, defender of the international order and provider of public goods. China will continue to bring the world new opportunities through its new development.

**Fourth, we must improve global governance and practice true multilateralism.** In the world, there is only one international system, i.e. the international system with the United Nations at its core. There is only one international order, i.e. the international order underpinned by international law. And there is only one set of rules, i.e. the basic norms governing international relations underpinned by the purposes and principles of the UN Charter.

The UN should hold high the banner of true multilateralism and serve as the central platform for countries to jointly safeguard universal security, share development achievements and chart the course for the future of the world. The UN should stay committed to ensuring a stable international order, increasing the representation and say of developing countries in international affairs, and taking the lead in advancing democracy and rule of law in international relations. The UN should advance, in a balanced manner, work in all the three areas of security, development and human rights. It should set common agenda, highlight pressing issues and focus on real actions, and see to it that commitments made by all parties to multilateralism are truly delivered.

Mr. President,

The world is once again at a historical crossroads. I am convinced that the trend of peace, development and advancement for humanity is irresistible. Let us bolster confidence and jointly address global threats and challenges, and work together to build a community with a shared future for mankind and a better world for all.

# The Energy of the Ecological Civilization: Hydrogen


## SALİH ERTAN

Electrical Engineer


*Salih Ertan is a METU graduate electrical engineer who is actively involved in the fields of energy and biofuel production from biomass. He published many papers on energy and environmental-related issues. His research interests lie in active topics include agriculture and field forestry, carbon sinks through agroforestry applications, and the establishment of energy farms as part of "negative carbon emission" strategy. In the past, as a researcher, he took part in many projects carried out on the seas surrounding Turkey. Projects include the investigation of hydrocarbon resources in the sea, inspection studies of submarine natural gas pipelines, shallow and deep seismic studies carried out (particularly in the Black Sea), and MEDPOL (Pollution Measurement and Control Project in the Mediterranean) carried out on behalf of UN-UNEP in the Aegean and Mediterranean Seas. He also worked on determining physical losses caused by various damages in drinking water networks by remote and undamaged inspection methods and was involved in energy working groups operating with NGOs at home and abroad. He was among the founders of the Energy Industrialists and Businessmen Association. He continues to work within NGOs.*


*E-mail: salih.ertan@gmail.com*



**Received:** 14.12.2021

**Accepted:** 05.05.2022

How to cite: Ertan, S. (2022). The energy of the ecological civilization: Hydrogen. Belt & Road Initiative Quarterly (BRIQ), 3(3), 54-71.

## ABSTRACT

It is widely accepted that the primary reason for the phenomenon of Climate Change due to Global Warming is energy production based on traditional fossil fuels. In this context, strategies and energy policies based on Renewable Energy Resources (RES) should be immediately planned and implemented as soon as possible. Today, when life in our world is under an existential threat, the "Sixth Mass Extinction" can be prevented with the transition to RES, which is both clean and inexhaustible. We observe that hydrogen energy classified as RES is coming to the fore. Besides its distinctive advantages, such as being transportable and storable, hydrogen also has the potential to replace fossil fuels. The critical question is: can RES completely replace traditional fossil fuels? The RES, in which Hydrogen Energy will have a significant share of the total energy production capacity, has a remarkable potential to replace nuclear energy and the entire range of fossil fuels combined. In this study, the view that "hydrogen-carbon" technologies will characterize the "New World Order", also called Ecological Civilization, is examined and discussed.

**Keywords:** carbon-hydrogen era, DC grid, energy from hydrogen, hydrogen fuel cell, hydrogen sulphur

TODAY, WE SEE THAT THE NECESSITY OF transitioning from Conventional Fossil Fuels (CFF: coal-oil-natural gas) to Renewable Energy Sources (RES) is at the top of the global agenda.

It has become clear that the transition is not a choice and stems from a deep concern for collective ecological destruction caused by Climate Change. Today's civilization is essentially a coal-oil-natural gas civilization. Since the First Industrial Revolution, which began about 250 years ago, the world has constantly been warming, particularly due to energy production and consumption. In other words, the ongoing lifestyle associated with the prevailing "system" across the globe has caused Global Warming leading to Climate Change and the destruction of the world's ecosystem.

We consider that the phenomenon of Climate Change caused by Global Warming has turned into an existential threat for human beings over the past 250 years and has brought the entire global ecosystem to the brink of the "Sixth Mass Extinction" (Robinson, 2021).

In this context, today's obvious and simple fact is that even one more gram of coal and oil, and even one more cubic meter of natural gas, should no longer be used for energy production. In this context, REC has become an absolute necessity.

A question has always been at the center of the discussions on RES: can it completely replace CFF today and in the future?

I seek the answer to this question in this study. We can say with confidence that RES has the potential to replace CFF and Nuclear Energy combined with the prominence of Hydrogen Energy, which is among the RES varieties. RES is thought to have the capacity and potential to protect life on our planet from the threat of mass extinction.

RES types are divided into two groups in terms of their key characteristics. While wind, solar (PV), concentrated solar (CSP), and wave (including tides) are all classified as intermittent types, geothermal, biomass and hydrogen-based energy production methods are identified and differentiated as RES types with "base load" character. Among RES varieties, only biomass and hydrogen have the advantage of being transportable and storable.

It is worthwhile to note that although hydrogen and biomass-based energy production systems can be in operation for 7,500 to 8,000 hours a year (hence their base load character), the time that wind and solar energy-based systems can be available during the year is only 2,000 to 3,000 hours in sometimes unpredictable periods. On the other hand, it should be noted that unlike CFF and other RES types, which are defined as "primary energy sources", hydrogen must be primarily produced from other sources to be used in energy production, and in this sense, it is not a "primary" energy source. Hydrogen is defined as an "energy carrier" in the literature (IEA, n.d.).

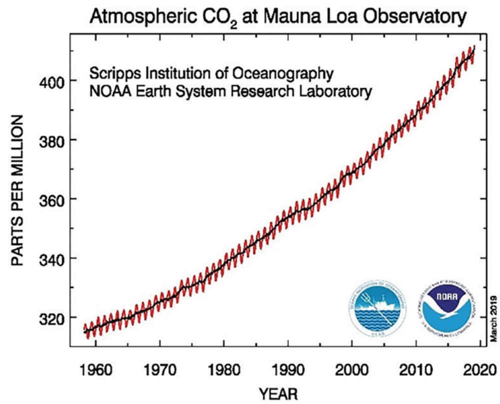
## Climate Change and the Necessity of Transition to RES

Since the First Industrial Revolution, the earth's ecosystem has been brought to the brink of a total collapse due to our lifestyle and the uncontrolled consumption of natural resources. One factor leading to this result is the use of CFF in energy production. Energy production from CFF, as the major cause of Global Warming by human beings, has led to Climate Change, which has turned into an existential problem today. It would be beneficial in terms of the integrity of the subject to include the findings and indicators regarding the reasons behind said obligation.

In the NOAA-sourced graphs below, the results obtained from the $CO_2$ concentration measurements started in the 1950s at the Mauna Loa observatory in the Hawaiian Islands (Figure 1a and Figure 1b) are shown. Depicted in the graphs are changes over a wider time interval starting around 1750, marking the beginning of the first industrial revolution and extending until the present day. Along with the continuous increase in the $CO_2$ concentration, the amount of $CO_2$ released into the atmosphere is also shown (Figure 2).

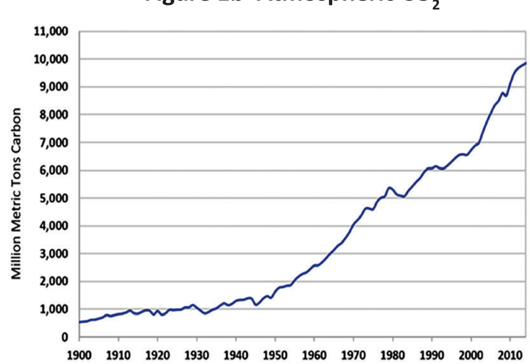
According to measurements and calculations, the current $CO_2$ gas in the atmosphere is approximately 3.2 trillion tons. Considering that the $CO_2$ concentration, which was 280 ppm in the pre-industrial period, has reached 420 ppm today, it can be concluded that approximately 1.1 trilli-

**Figure 1a. Atmospheric $CO_2$**




Source: NOAA Global Monitoring Laboratory, 2022.

**Figure 1b. Atmospheric $CO_2$**




Source: NOAA Global Monitoring Laboratory, 2022.

on $CO_2$ gas, which corresponds to one-third of the said quantity, has been emitted in the last 250 years (Lindsey, 2020). However, it should be emphasized that there is no common agreement in the calculations based on different assumptions.

Figure 3 shows the change in concentrations of $CO_2$ and other important greenhouse gases, like methane and nitrous oxide, over the 2000-year time series. It is clear that the increase due to human actions has skyrocketed since the 1700s.

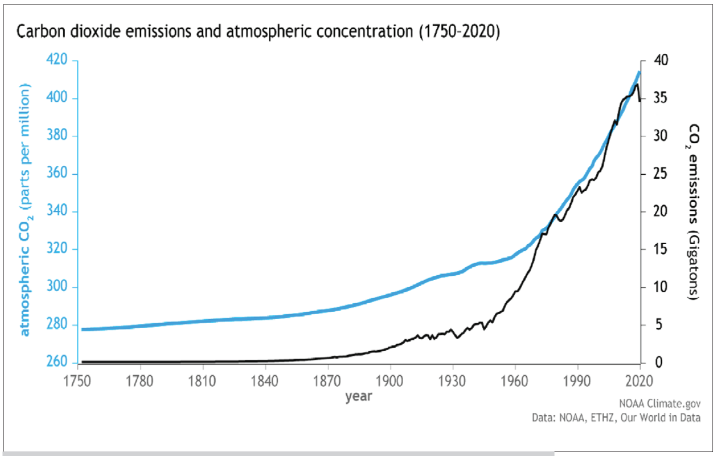
Figure 4 shows the average increase in the earth's temperature between 1880 and 2020. The y-axis on the left of the graph represents the temperature change in Celsius units. Regular measurements reveal that the earth's temperature has increased by an average of 1.18°C between 1880 and 2020 (World of Change: Global Temperatures, n.d.).

Meanwhile, only $CO_2$ concentration measurements are included in the Mauna Loa observatory results. When other greenhouse gases such as methane, nitrous oxide, and HFCs are taken into account, it is remarkable to see that the total greenhouse gas concentration reached 457.0 ppm in 2018 (European Environment Agency, 2022).

Promises and wishes listed under the headings of "Zero Carbon Emission" and "Transition to a Low Carbon Economy" were frequently repeated in the 26th UN Climate Change Conference (COP26) held in 2021. In addition, there are claims that a "Carbon Neutral" period will be started in 2050. However, the answer to the question is still open: suppose, for example, if the concentration of $CO_2$ in the atmosphere reaches 500ppm by 2040, how can we ever know that the "Point of No Return" has not been passed?

The looming danger is that Permafrost (permanently frozen lands, mostly surrounding the Arctic Ocean and exceeding 20.0 million square

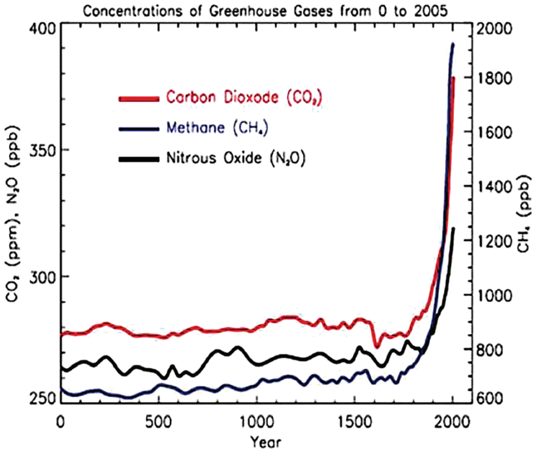
**Figure 2. Carbon Dioxide Emissions and Atmospheric Concentration (1750-2020)**




Source: NOAA Climate.gov, 2022.

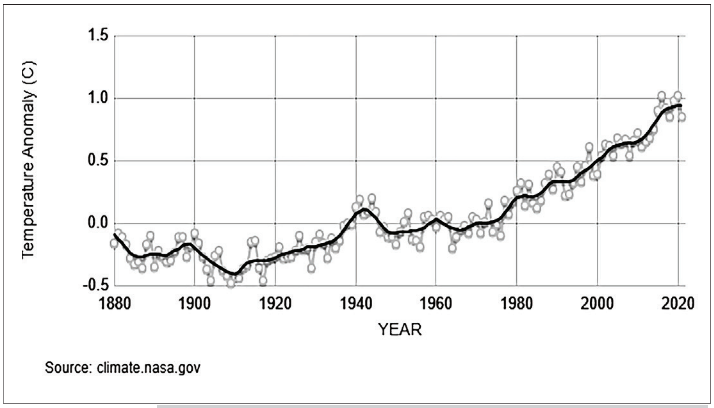
kilometers) is rapidly thawing. With the accelerating thaw process, tens of billions of tons of methane gas captive within the frozen soil layers will be released into the atmosphere, along with viruses and bacteria that have been hibernating for thousands of years. Nor are we immune to these disease vectors, some of which are perhaps more dangerous than COVID-19. A scenario as such is exactly what "the Point of No Return" means.

**Figure 3. The Change in Concentrations of $CO_2$**




Source: Environment and Natural Resources, n.d.

**Figure 4. The Average İncrease in the Earth's Temperature Between 1880 and 2020**




Source: Earth Science Communications Team, 2021.

Such consequences of Climate Change, which are likely to emerge in the short term, show that instead of ineffective strategies such as Zero Emissions-based formulations that fall short against the current existential threat and vague promises that are of no use, the methods and applications aiming at "Negative Carbon Emission/ Carbon Negative" targets must be implemented with no delay at the global scale. It is mandatory to capture and permanently store more greenhouse gases from the atmosphere than those we emit. So how can this goal be achieved? The answer is a subject of study in itself and should be dealt with separately.

## Why Hydrogen Energy?

After giving place to the picture revealed by global warming and the related Climate Change threat in the above section, it should be underlined that the transition to RES is an urgent and overwhelming necessity.

Among the RES types, hydrogen energy has prominent importance and privilege. Backed up by hydrogen-based solutions, RES will be able to replace not only CFF but also nuclear energy completely. However, it is useful to underline the following point: no type of RES is a "silver bullet" (final solution) on its own. In other words, we cannot claim that hydrogen alone or, for example, solar energy (PV or condensed solar) alone can be sufficient to solve the world's energy problem.

However, it would be useful to point out the unique advantages of hydrogen energy compared to other RES types.

The common feature of RES types, including hydrogen, and the major advantage in terms of environmental impact is that they have a "Clean and Inexhaustible" character. Unlike others, hydrogen must be produced indirectly from other sources. Therefore, as mentioned above, hydrogen is classified as an "energy carrier" (IEA, n.d.).

Compared to hydrogen, which has the feature of "Base Load" (7,000+ hours of operation/availability per year), solar (PV) and wind energies (WES) are intermittent because of the limited availability of wind and sunlight. In much the same way as hydrogen, it is worth noting that biomass and geothermal are of base-load character, too. It is obvious that limited and indeterminate (in the case of wind) features are a significant disadvantage.

Establishing an energy transmission network comprising only PV and WES, albeit popular on a global scale, is not possible due to technical constraints, although the established power capacity of both PV and WES is steadily rising. Wind and solar sources are available for use for only about 3,000 hours throughout the year. While the availability of the resource can be predicted to some extent for the PV, it is not possible to make such an estimate for the WES. Local climatic anomalies make the WES estimates uncertain.

Transforming WES and PV into relatively safe sources in terms of energy supply necessitates energy storage. If the energy (electricity) produced in

WES and PV facilities is not stored, it must be consumed as soon as it is generated.

With storage, for example, to double the total period of availability to about 6,000 hours of operation in a year, one needs to increase the established capacity by two. A "battery farm" facility should also be established where the electricity generated will be stored.

**When it comes to considering biomass, it stands out as a type of RES that is clean, inexhaustible, portable, storable, and can be found in every area except deserts.**

In this study, we do not mention the increase in the establishment cost of WES and PV energy plants equipped with battery farms aiming to transform WES and PV plants into base load power generation units. This is because we do not consider cost to be the main determining parameter and its minimization in the background is another issue. We give some definitions of metrics regarding the cost factor in the following section.

Another popular type that should be mentioned when energy storage is discussed is Li-Ion batteries.

At this point, the following determination should be underlined: energy storage tools and technologies are still in their infancy. We are still far from the stage of developing these into mature and competent solutions.

Moreover, although wind and sun are plentiful and free, the same is not true for Lithium. Here, special emphasis is placed on Lithium, as it is the main element on which the most frequently cited solutions for energy storage are based. Although proven and probable lithium reserves are far above the current production level and global demand, there is no expectation of a shortage in supply and a jump in prices accordingly in the near and medium-term. It is believed that dependence on a limited number of suppliers may be a potential source of problems (National Minerals Information Center, n.d; Garside, 2022).

However, it should be noted that there are intensive studies on many solutions (Sodium-Sulfur, Aluminum-Ion, etc.) as an alternative to the Li-Ion battery type. One of the disadvantages of wind and sun is that the energy production based on them is limited to certain areas with favorable conditions for wind and sunlight. For example, establishing wind and PV energy generation facilities in areas where the wind blows 3,000+ hours per year or where the exposure time to daylight is at this minimum will be appropriate for "process efficiency".

## Brief Review of Geothermal and Biomass Compared to Hydrogen

Although Geothermal-based power generation facilities also have a base load function, it should be noted that the areas where the required geothermal resources are available are limited to areas with tectonic risks, where the earth's crust is broken by faults and magma is close to the earth's surface. Although the resource is practically unlimited, the limited geothermal fields are their own disadvantage.

In contrast, when it comes to considering biomass, it stands out as a type of RES that is clean, inexhaustible, portable, storable, and can be found in every area except deserts.

Biomass power plants (BES) can be established to form a distributed system topology as a network of facilities featuring different capacities with base load function over a geographical area. An important and distinctive advantage of BES is that it has the potential to play an integrative role in the solutions of energy and environmental problems as an effective tool in the disposal of organic wastes generated in urban areas. There is also the possibility of producing biofuels from biomass to replace fossil fuels. In terms of the main theme of our study, it should be noted that biomass can also be used as a hydrogen source. We discuss this function of biomass below.

## The Importance and Privilege of Hydrogen Energy

Hydrogen is a type of RES with all the advantages and privileges of biomass mentioned above. Using hydrogen as an energy and fuel source, RES will be able to replace CFF completely. This possibility can only be realized with the prominence of hydrogen and biomass.

> **It can be foreseen that the "ecological civilization", which will replace the "Old World Order", will be a hydrogen-carbon age.**

The target set for RES to replace CFF can also be expressed as "Carbon Zero"/"Net Zero Carbon Emission". However, the "Carbon Zero" stage is far from the final stage in the fight against Climate Change. The primary target is to rapidly implement "Negative Carbon Emission"/"Negative Carbon" practices so they become widespread globally.

Unlike biomass, since hydrogen is not a direct (primary) energy source, it must be produced from various sources. One of the sources of hydrogen production is biomass. When hydrogen is used for heat and electricity generation or as a fuel in vehicles, only water vapor is released into the atmosphere with absolutely no adverse effect on the natural environment.

There is a "braking distance"; a sort of resistance in the transition from CFF to RES. The transition will not be overnight, from evening to morning. There is inertia working against the changes that need to be realized in a short time frame. Although the players and decision-makers in the energy sector are not against RES, they intend to continue using fossil fuels as long as possible. A common view is to give the use of natural gas (recognized as a lesser evil) a weightier place in the current energy equation. At this point, we can suggest two propositions:

1. As emphasized in the Introduction, even 1.0 cubic meter of $CO_2$ or any other greenhouse gas should not be released into the atmosphere from now on.

2. It is essential and imperative to develop methods and practices to have natural gas turned into a RES variety and add it to the spectrum of RES. As a concrete recommendation, we may well use natural gas as a source of hydrogen and pure carbon.

It can be foreseen that the "ecological civilization", which will replace the "Old World Order", will be a hydrogen-carbon age. Namely:

Natural gas is mostly methane. Decomposition of methane through the pyrolysis process (introduced in a subsequent part of this study) yields carbon and hydrogen, basic components of methane. As a carbon-zero fuel, Hydrogen can be used to generate electricity and heat, while pure carbon can be used to produce advanced materials. In this way, the carbon component of natural gas, which would otherwise be released into the atmosphere when natural gas is directly combusted, will be permanently stored in carbon-made materials while still indirectly making use of natural gas as a source of energy (Meier et al., 2013).

Thanks to the natural gas being "tamed" and transitioned to RES, economic concerns that existing natural gas and "Gas Hydrate" reserves will be wasted are also eliminated.

## Hydrogen Production Methods

Methane (hence natural gas, gas hydrates, shale gas), biomass, and water are the sources from which hydrogen can be produced.

Hydrogen and carbon can be obtained from natural gas through several methods. One of the methods in widespread use is the “methane reformation".

### Steam-Methane Reformation

As a proven method, which dates to 80 years ago, it is the most common hydrogen production technology today. For example, 95 % of the current hydrogen production in the USA is provided through this method from natural gas (Hydrogen and Fuel Cell Technologies Office, n.d.). The method is as follows:

The methane is processed with hot steam in the temperature range of 700-1000 °C. Carbon monoxide (CO) and hydrogen ($H_2$) are released at the end of the process, during which some catalysts are also used under a pressure of 3.0 to 25.0 bar.

The process expressed with a simple chemical equation is as follows:

$CH_4 + H_2O + heat \rightarrow CO + 3H_2$ (Since energy is consumed to evaporate water, the reaction absorbs heat - “endothermic reaction”)

The chemical reaction in the second stage of the process is called “water - gas exchange”:

$CO + H_2O \rightarrow CO_2 + H_2$ + a small amount of heat

While more hydrogen is produced in the second stage, some $CO_2$ is also released. The output includes some heat released during the reaction (exothermic reaction). The method can also be applied to methanol and other short-chain hydrocarbons. The key point is that CO and $CO_2$ formation continue to be a problem in the context of global warming in connection with this method.

Although it is an old and proven method, methane reformation is still being developed today, and research is continuing to find more suitable catalysts to be used in reactions (Chen et al. 2020). With this method, $CO_2$ is released as a by-product. In today's world, although it is the conventional and widely used method, steam reform is a method that can no longer be considered favorable under the conditions of Climate Change and "Carbon Negative" methods and applications.

### Partial Combustion-Gasification

Another method for hydrogen production from methane is Partial Combustion Gasification. Besides methane, heavy oil, different petroleum derivatives, and biomass can also be used as raw materials (Zhang & Ruan, 2019). Gasification is the partial combustion of carbon-containing organic material (in this specific case, methane) under conditions where controlled amounts of water vapor and oxygen are supplied to the reactor where the process occurs. The products released at the end of the process are $H_2$, CO, and $CO_2$. Hydrogen sulfide ($H_2S$) in minor amounts can also be an output product depending on the chemical composition of the input material. In the case of methane, the chemical reactions involved are:

$CH_4 + O_2 \rightarrow CO + 2H_2$

$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$

$CH_4 + H_2O$ (in the form of hot vapor) $\rightarrow CO + 3H_2$

The gasification process is endothermic (absorbing heat). In this process, the final products are CO, $CO_2$ and $H_2$. The volumetric ratio of $H_2$ and CO products released in the steam-methane reformation process is 3:1, while this ratio is 1:1 in gasification (Syed, 2021).

**It is necessary to apply "Carbon Negative/Negative Carbon Emission" methods on a global scale to reduce the $CO_2$ and other greenhouse gases already stored in the atmosphere to protect the ecosystem and life on our planet.**

There are also gasification methods in which catalysts reduce the process temperature between 1300 and 1500 °C. As a result, the release of CO and $CO_2$ gases as by-products does not make these methods positive regarding Global Warming. However, when these methods were used to produce $H_2$ in the distant past, the phenomenon of Climate Change was not a decisive criterion, as it is today.

### Hydrogen From Biomass

Biomass and $H_2$ have remarkably comparable properties in terms of their advantages and flexibility. Both types of RES have the advantage of being portable and storable. Both are independent of the location constraint applicable to WES and PV plants. Biomass is a source of $H_2$ and carbon and a primary energy source due to its organic origin and its high content of $H_2$ and carbon.

A wide range of products, from organic-based urban solid wastes, sewage sludge, and scrap vehicle tires to "energy crops" and agricultural and forestry product wastes, are included in the definition of biomass.

Gasification provides the decomposition of biomass into its two components, CO and $H_2$ (SynGas), through a thermo-chemical process. The process occurs in a gasifier/gasification reactor in a high-pressure environment with an ambient temperature of 800-1000°C. SynGas (mainly CO + $H_2$) obtained here can also be used, in the next step, via the Fischer-Tropsch process, to produce biofuels (biodiesel, bio-gasoline, etc.) and many other materials currently produced in a typical petrochemical plant. Meanwhile, it is known that the plasma gasification method, which is an innovative and newly emerging technology, can also be used in $H_2$ production (Favas et al., 2017).

### The Relationship Between Hydrogen Production and Climate Change

Hydrogen is a basic ingredient used for various purposes in many industries. In this study, however, the feature of hydrogen as an energy source, as a type of RES that will eventually replace CFF, is taken as the basis (Kalamaras & Efstathiou, 2013).

In the days when the CFF-based energy paradigm was not questioned and the Climate Change phenomenon did not pose a vital threat at today's level, it was seen that hydrogen production through the methods described in the previous section was not critical regarding the by-products such as CO and $CO_2$ released into the atmosphere at the end of the process.

However, today, Climate Change has become the main criterion and the dominant parameter in all investment and business plans in all fields of activity, especially in the energy sector.

## Decarbonized/Clean Hydrogen Production

What should be the means of achieving hydrogen production in such a way as to enable the transition to a "hydrogen economy"?

The decomposition of natural gas into carbon and hydrogen components by subjecting it to pyrolysis seems to be a valid method for clean hydrogen production. Pyrolysis decomposes organic materials such as biomass into simpler components by heat treatment in an oxygen-free environment. Products of the pyrolysis process include volatile short-chain gases and pyrolysis oil and coke (Basu, 2018).

Depending on the intended end product, the raw material can be pyrolyzed at high temperatures (800 °C and above) for a relatively short time (for pyrolysis oil production) or a relatively low temperature (500 °C and for a long time for charcoal production). When it comes to methane/natural gas, the final products are hydrogen and carbon.

In Figure 5, the “decarbonization” of natural gas is expressed visually. The stages of the pyrolysis process in Figure 6 are a simplified process flow chart in which biomass is generally taken as raw material.

The conversion of natural gas into carbon and hydrogen through the pyrolysis process can also be described as rendering natural gas environmentally friendly through “decarbonization”. Thus, natural gas passes through the ranks of RES indirectly from the ranks of CFF, where it is currently present.

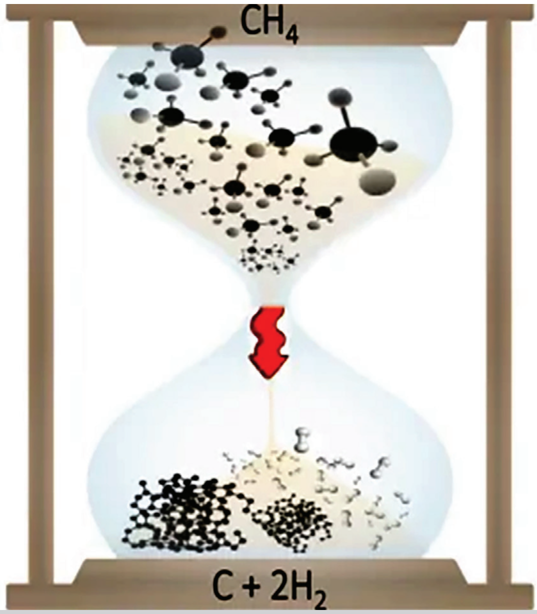
While the hydrogen obtained from the “clean” natural gas through heat treatment (pyrolysis) will be used as raw material and fuel in electricity production, carbon will be used to produce hundreds of advanced materials. As the simplest and most common use, using "black carbon/coke" as a soil improver is possible. Graphene, new generation PV panels, carbon-based semiconductors, and carbon-based building materials are a few of the many uses. In this way, the carbon contained within the chemical structure of natural gas will be permanently captured and stored.

Is that much just explained above enough to avert the "Sixth Mass Extinction"? The short and definitive answer: no. It is also imperative to reduce $CO_2$ and other greenhouse gases, which have been accumulated in the atmosphere continuously and in increasing amounts over time since the First Industrial Revolution.

It is necessary to apply "Carbon Negative/Negative Carbon Emission" methods on a global scale to reduce the $CO_2$ and other greenhouse gases already stored in the atmosphere to protect the ecosystem and life on our planet.

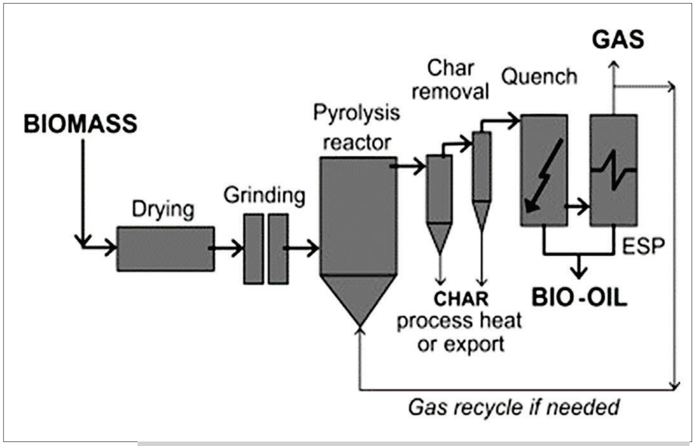
It is worthwhile putting a special emphasis on natural gas-related issues. A common view is that natural gas may still be considered a part of future energy strategies, as its carbon footprint is smaller

**Figure 5. Decarbonization**




Source:Ozin, G., (2018).

**Figure 6. Prolysis Process**




Source: Meier vd., 2013.

(half or even less) than coal. Due to natural gas as fuel in energy conversion power plants, capturing and storing the existing $CO_2$ in the flue gas (Carbon Capture and Storage - CCS) is a method frequently mentioned and advocated by many experts. However, it is possible to evaluate the two options together when this is achieved.

The storage of $CO_2$ gas captured in a natural gas-based power plant in the deep layers of the earth's crust/lithosphere has been the most frequently discussed solution. If the natural gas cycle power plant were located in the Scandinavian Peninsula, a tectonically stable part of the lithosphere, it could be considered a storage solution.

However, this solution (CCS), for example, for a power plant placed in the Aegean Region of Turkey, which is the western gate of the New Silk Road, such a CCS is definitely out of the question. The Anatolian Peninsula, especially Western Anatolia, is faulty and poses high tectonic risks. In a land fragmented with faults, it is impossible to store $CO_2$ in the stagnant ground layers. As a controversial and very questionable solution: a special pipeline between Aegean Region and the Black Sea Coast can be used to transport the captured $CO_2$ to deploy in the bottom layers of the Black Sea. This option is fraught with unforeseen risks. So, this is not an option at all, either.

If the $CO_2$ pipeline heads south towards the Mediterranean, the 4,700-meter-deep Rhodes Trench may also be a site for deployment. However, such a proposal would be a null and void idea. We can conclude that any region where tectonic risks exist cannot be considered a solution.

We point out that the "pyrolysis" method (Schneider et al., 2020). has special and primary importance in producing hydrogen from natural gas. In the transition period from CFF to RES, coal seems to be the most easily dispensable type of CFF in the relatively short term. On the other hand, the most resilient CFF type seems to be natural gas. Russia will be the country that will suffer the most from this transformation in the transition from natural gas to alternative fuels. However, it is remarkable that Russia has plans to transition to hydrogen energy (Sharma, 2021).

A striking example marking the tendency to transition to hydrogen is the policy recently adopted by the Russian Government and energy giants of Russia. Having made accurate determinations about the future role of hydrogen energy, Rosatom and Gazprom decided to act jointly to build an energy facility based on hydrogen on Sakhalin Island to the north of Japan (Communications Department of ROSATOM, 2021).

A significant development concerning Turkey is that Rosatom, which is building a nuclear power plant in Mersin Akkuyu, and Gazprom, which supplies a large amount of natural gas to Turkey, have formed a solution based on hydrogen energy. This occasion should be sufficient to give an adequate and convincing idea of the direction of current trends in the global energy sector.

Without a doubt, hydrogen is a candidate to be the primary energy source of the future. The main argument in the focus of this study is that by implementing energy policies based on RES, which emphasizes hydrogen (an endless energy source in practice), there will be no need for CFF or even nuclear energy. The importance of hydrogen stems from the fact that it can be used as a fuel and be a source of electricity and heat.

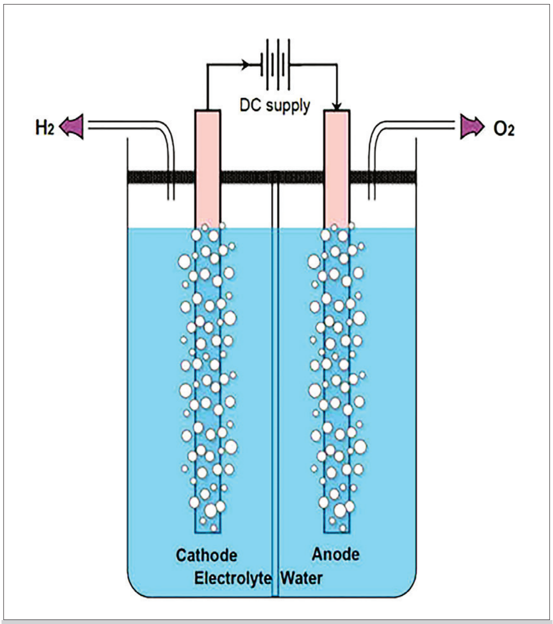
## Hydrogen Production Through Electrolysis Method

Thanks to hydrogen production from pure water or seawater, hydrogen can become an inexhaustible resource. Many studies are underway to eliminate technical problems such as the cost barrier. It is predicted that using an electrolysis method for hydrogen production will become extremely common (FuelCellWorks, 2022).

Electrolysis is the process of decomposing water into its components comprising hydrogen and oxygen by applying a certain direct current (DC) voltage in an electrolysis cell containing water. The oxygen (anion) is ionized under direct current voltage and is collected in the positively charged anode conductor. The positive hydrogen ions (cation) pass into the gas phase around the negatively charged cathode conductor.

A very simplified electrolysis scheme is shown in Figure 7.

**Figure 7. A Simplified Scheme of the Electrolysis Process**




Source: MDPI, n.d.

Using intermittent type RES such as wind (WES) and solar (PV) energies as an energy source in the electrolysis process stands before us as a frequently mentioned and discussed issue. The hydrogen produced in this way is called “Green Hydrogen” in the literature. While electricity is already produced in WES and PV facilities, why should we use the energy for hydrogen production by adding an extra step to the supply chain?

Answers that immediately come to mind: using hydrogen, an energy source that can be stored, transported, and used as fuel, will be obtained. Hydrogen is an energy carrier that can easily replace natural gas, which is almost described as “clean”, as many energy experts argue. For example, hydrogen can be transported over existing natural gas transmission lines.

However, wouldn't Green Hydrogen production add another link to the supply chain, possibly bringing additional technical problems and increasing costs? Although this question may seem appropriate at first glance, it is useful to look at the issue of costs from a different perspective. However, before this topic, it is worth mentioning two issues that are Turkey's only advantage.

## A Source of Hydrogen: Hydrogen Sulfide ($H_2S$) in The Black Sea

The Black Sea, which has the longest coastline and the largest Exclusive Economic Area in Turkey, is a major source of $H_2S$ within seawater because of its formation's unique factors and processes. Due to this feature, the Black Sea has an unmatched advantage and privilege as a hydrogen source compared to other world seas (Demirbas, 2009; Yüksel et al., 2021b).

**Turkey has more than 70% of the proven boron reserves globally.**

In the deep-water layers of the Black Sea, which has an isolated inland sea feature, the $H_2S$ formation process has been continuing for approximately 7,500 years in the Black Sea, which was formed 9,000 years ago due to the decomposition of organic materials in an oxygen-free environment. We want to point out that the production of $H_2$ from $H_2S$ can be accomplished more easily and with a lower energy budget than water, which is an almost unlimited resource. Therefore, the Black Sea is a hydrogen source due to the formation of $H_2S$ (Haklidir & Kapkin, 2005; Baykara et al. 2007).

As a result of various field studies and measurements, it is calculated that there are 4.6 billion tons of $H_2S$ at the bottom of the Black Sea (Volkov & Neretin, 2007; Demirbas, 2009). The water mass in the Black Sea is 90% oxygen-free and contains $H_2S$. Scientists state that around ten thousand tons of $H_2S$ are formed in the Black Sea every day (Baykara et al. 2007).

In the meantime, we would like to draw attention to the fact that $H_2S$, which is highly toxic, poses an increasing environmental threat in the Black Sea. $H_2S$. The amount, which is increasing day by day, is rapidly turning the Black Sea into a dead sea area. The water body suitable for life in the Black Sea (the upper layer at a depth of 90 to 200 meters from the surface) decreased by 40% between 1955 and 2015 is alarming (University of Liège. 2016). Hydrogen production from a toxic pollutant, $H_2S$, will provide a valuable energy source and have a positive environmental impact.

In the production of $H_2$ from $H_2S$, "thermal decomposition/pyrolysis" is performed at a processing temperature of 800-1000°C (Demirbas, 2009).

In the Black Sea, an environmental disaster, which is inevitable in case of inaction, is prevented, while at the same time, hydrogen production, which is the energy source of the future, creates an area of cooperation among the countries surrounding the Black Sea.

## Novel Hydrogen—Sodium Boron Hydride ($NaBH_4$) Based Technologies

Like every country, Turkey has to use its unique advantages for a competitive advantage. Turkey has more than 70% of the proven boron reserves globally. $NaBH_4$ is a material that enables brand new hydrogen fuel cell designs and can be a hydrogen carrier. Developing $H_2$—$NaBH_4$ based fuel cells is a challenge for Turkey.

The development of fuel cells based on $NaBH_4$ is a candidate to play an important role, especially in increasing the adoption rate of vehicles based on $H_2$ energy across the world (Wee et al., 2006). So, there is an important area of cooperation in the Belt and Road Initiative context in this regard.

## Transporting Hydrogen

Naturally, the first thing that comes to mind to transport hydrogen is the use of existing natural gas pipelines. It is focused on hydrogen and natural gas transportation, which will gradually be blended at a certain rate via natural gas transmission lines. Of course, this scenario can be valid, assuming that the hydrogen will be converted into energy at the point of use, far distant from the source from which it is produced.

As in the transportation of natural gas, hydrogen transportation by liquefaction is also not a suitable choice from a technical point of view due to unnecessarily high costs and the necessity of keeping it in very thick-walled tubes/pressure vessels. This is because the hydrogen molecule can pass through almost any material used as the wall of the container. The most suitable method would be to deliver the hydrogen compressed under high pressure and still in gaseous form via existing transmission pipes.

Besides $NaBH_4$, experts state in the literature that ammonia ($NH_3$) is a hydrogen carrier substance. Saudi ARAMCO and ENEOS of Japan agreed to establish a hydrogen and ammonia-based supply chain (Sampson, 2021). Before this agreement, ARAMCO exported the first batch of 40 tons of ammonia to Japan (Saudi Arabian Oil Co., 2020). It is remarkable that Saudi Arabia, rich in oil and gas, aims to establish a facility to produce and store hydrogen with an investment of 5.0 billion dollars in the city of Neom, which it plans to establish on the Red Sea coast. They also aim to operate this facility with RES (The Japan Times, 2020).

In addition to using existing pipelines or chemicals for hydrogen transport, there is another valid option: transporting electricity to be produced from hydrogen instead of hydrogen itself.

## Electrification of Hydrogen

With the transition to RES, the current structure of the energy transmission and distribution network and how it should evolve into a topological structure (network) in the future should also be emphasized. It is known that the existing national networks are not particularly suitable for the connection of WES and PV, which are intermittent-featured RES types.

As a solution, networks to accommodate WPPs and SPPs should comprise micro-grids locally with DC or HVDC (High Voltage Direct Current) arteries connecting them on a wider geographical scale. In the next stage, establishing a transcontinental and even transoceanic network (a global-scale Super-Grid), where long-distance HVDC lines interconnect national networks, may be the subject of discussion. It is necessary to mention a current trend closely related to the DC Grid issue, which is emerging today and will form the upper floor of national interconnected systems: electrification.

At a conference in New Delhi in July 2019, IEA executive committee director Dr. Fatih Birol stated that electrification will shape the future (CEEW, 2019).

Instead of transferring the hydrogen to be obtained from natural gas or water electrolysis by the pyrolysis method long distances via existing or newly constructed pipelines, it seems to be a reasonable solution to transform the energy in the form of electricity into electrical energy in the cycle plants established at the location where they are produced and deliver the energy in the form of electricity to the end consumer via DC/HVDC lines.

The electricity to be produced in hydrogen power plants, for example, can provide the energy required for heat pump systems to be installed for district heating-cooling in urban areas. It is in this context that the electrification of hydrogen finds its place. A DC/HVDC Grid compatible with RES types will create a suitable infrastructure for transporting electrical energy produced from hydrogen long distances. It would be useful to mention the DESERTEC project, which was designed as a regional Grid, to make the subject under consideration here clear.

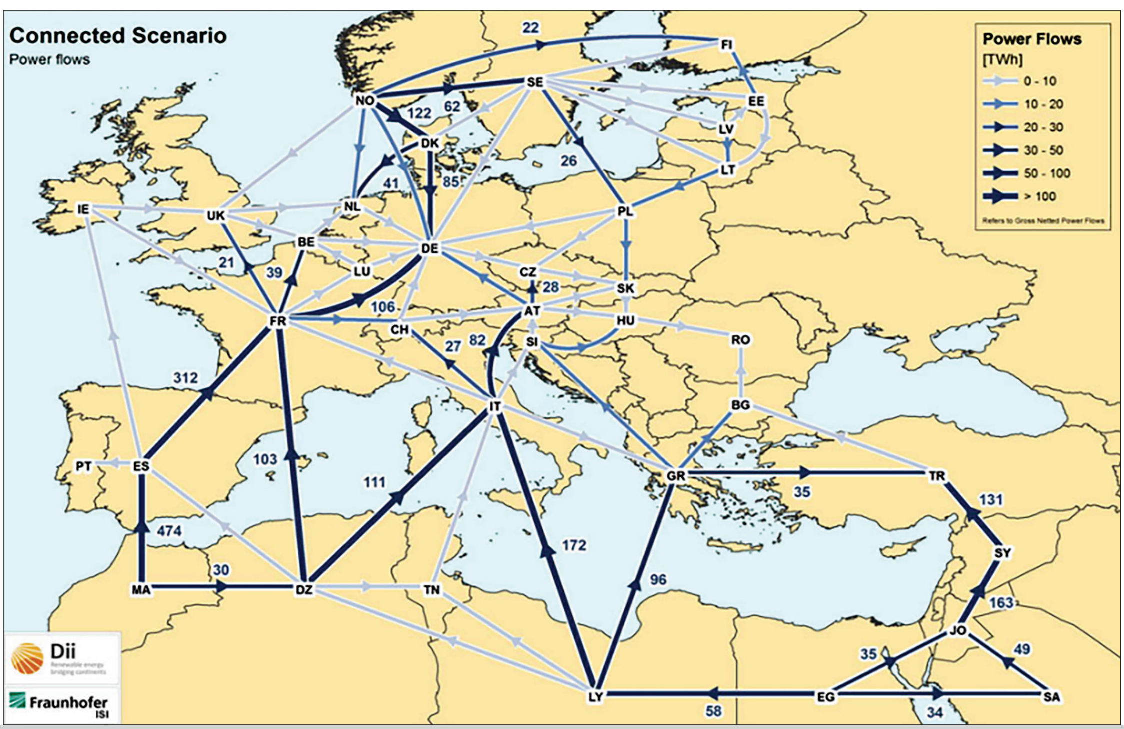
DESERTEC, whose concept plan originated in the early 2000s, was formulated as a DC GRID project aiming to integrate Middle East and North Africa (MENA) and EU countries through High Voltage DC (HVDC) lines.

While Figure 8 shows the geographical area that the project is envisaged to cover, Figure 9 symbolically depicts the electricity to be produced in MENA, mainly to be produced in the PV as well as in the WES power plants, transmitted to the European Union (EU) via Southern European countries over HVDC transmission network.

DESERTEC is based on the idea that deserts have a huge energy potential. Considering that this region is located at the same longitudes as Europe when bordered by the Sahara Desert, it does indeed have a huge PV potential, but it does not seem to gain a significant advantage in terms of utilization time (availability).

However, when the Middle East countries, including Iran, are taken into account, it is noteworthy that the solar energy utilization time will increase significantly during the day (day and night) utilizing the PV (and WES) facilities to be connected to DESERTEC DC GRID. In Iran's geographical area (60 east longitude in the east of Iran), it is possible to benefit from solar energy within a 6-hour period. An important conclusion regarding this situation is that a DC GRID/SUPER GRID spanning in an East-West direction will also function as a backup tool for RES types with intermittent and indeterministic

**Figure 8. Power Flows in the Connected Scenario**




Source: Zickfeld, F. & Wieland, A., 2012.

**Figure 9. EU-MENA (Middle East & North Africa combined) HVDC Super Grid**


Source: Zickfeld, F. & Wieland, A., 2012.

features such as sun and wind.

In the first years of the DESERTEC project, the main emphasis was PV, with little attention on RES. At that time, the issue of transmitting hydrogen or hydrogen energy to the EU by connecting to GRID was seldom on the agenda. Implementing the original DESERTEC and subsequent renewed idea plans was not possible. Recently, a new version called DESERTEC 3.0 has been introduced. DII (Desert Industrial Initiative) consortium was established in 2009 by the DESERTEC foundation, which was established in the early 2000s to gather companies active in the energy sector and accelerate the transition to RES with an effective and strong structure (DESERTEC Foundation, n.d.).

In the approach adopted by DII and the current definition, DESERTEC version 3.0 highlights the hydrogen energy. Accordingly, "Green Hydrogen", which will be produced mainly by PV and WES, will be delivered to EU countries via natural gas pipelines laid on the Mediterranean floor (for example, Algeria - France connection).

## Costs Related to RES and Hydrogen Energy

A very common issue in discussions on RES is the establishment and operating costs of RES types. Keeping the cost criterion in the foreground stems from a 20th-century thinking habit. For a long time, cost has ceased to be a determining parameter when comparing RES - CFF. First, RES is getting cheaper day by day. Moreover, we are at a crossroads where the prevailing political and social system and the traditional energy paradigm based on CFF have brought our world to the edge of catastrophe.

We have to make a definitive and final decision between death and life. If death is cheap and life is expensive, which one are we supposed to choose? If CFF is cheap and RES is expensive, which way should we choose? For one thing, CFF is not cheap. On the brink of the "Sixth Mass Extinction", there are no more choices. Necessities impose themselves for the sake of preserving life on our planet.

If there is an increased cost due to RES for industrial and commercial organizations, public places and households, not reflecting this should be among the principal duties of the states. Moreover, isn't the main task of governments to increase the income and welfare of households while growing their country's economies? If the incomes remain at a level to cover the increasing energy costs by regulating the distribution, this will not burden individuals and organizations.

It is also necessary to look at the othr side of the coin regarding the cost of fossil fuels (CFF). According to a report published by the IMF in September 2021 (Parry et al., 2021), subsidies applied to fossil fuels amounted to $5.9 trillion, corresponding to 6.8% of global GNP, as of 2020, when external (indirect) costs are also taken into account. It is estimated that this rate will increase to 7.4% in 2025

Apart from the indirect (external) costs such as diseases caused by environmental pollution, labor losses, and health expenses, we observe that between 2017 and 2019, fifty-two developed and developing countries supported fossil fuels directly with subsidies of approximately 600 billion dollars annually (Timperley, 2021; Geddes et al., 2020). This amount temporarily decreased in 2020 due to the Coronavirus pandemic.

According to the IMF report, there is also a cost of life that human beings are paying due to the phenomenon of Climate Change, for which it is impossible to assign a cost in monetary terms. Every year, approximately 900 thousand people lose their lives indirectly due to adverse environmental conditions caused by Climate Change.

Based on the data above, the conclusion and the first thought that comes to mind is as follows: we may well use the aforementioned subsidies for the necessary financial incentives during the transition to RES. In a UNDP-sourced study, it was noted that the subsidies for fossil fuels exceed the resources used to fight poverty on a global scale (UNDP, 2021).

## Conclusion

Today, when the transition from fossil fuels to RES completely and as soon as possible has gained existential importance and urgency, the transformation towards Hydrogen, or as stated in more general terms, a hydrogen-carbon society, and a radical paradigm shift in this direction have emerged as a necessity. We also observe that Hydrogen becomes increasingly prominent in energy strategies based on RES. As a clean and inexhaustible energy source, Hydrogen combined with other RES types is a candidate to replace both CFF and nuclear energy. Hydrogen, which is portable and storable for electricity generation, will also have widespread use in transportation thanks to Hydrogen Fuel Cells, which are poised to revolutionize transport technology.

With a transformation of energy paradigm and policies in a radical way that will leave its mark on Ecological Civilization, we consider that a new era, "A New World Order," is ahead of us. Ecological Civilization, a synonym of the New World Order, will be characterized and identified with RES, featuring hydrogen as the main actor.

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# Highlights from China's Medium and Long-Term Plan for the Development of the Hydrogen Energy Industry

BRIQ EDITORIAL TEAM

TODAY'S WORLD IS EXPERIENCING GREAT changes that have not been seen in a century. A new stage of technological and industrial reform is on the horizon. One of the most important branches of this reform is sustainable energy. Hydrogen energy is gradually becoming one of the most important carriers of global energy transformation and sustainable development. This summary reflects China's medium and long term plan for developing the energy industry.

## Guiding Ideology and Principles

### "Four Revolutions, One Cooperation"

"Four Revolutions, One Cooperation" is a term of strategy for energy security. It is based on instructions from General Secretary Xi Jinping at the 18th National Congress of the Communist Party of China in 2012.

The four revolutions are as follows:

To improve energy consumption structure by containing unnecessary consumption; to build a more diversified energy supply structure; to improve energy technologies to upgrade the industry; to optimize energy systems for the benefit of the energy sector.

"One cooperation" refers to comprehensive cooperation with other countries to realize energy security in an open environment. (The State Council Information Office of the People's Republic of China, 2020)

### "Carbon peak, Carbon neutrality"

"Carbon peak, Carbon neutrality" refers to the transformation goals from carbon-based, unsustainable development models to an ecological civilization. By 2025, China aims to gradually increase the clean energy consumption rate to 20 percent. This rate is planned to be increased to 25 percent by 2030. By 2060, the country's non-fossil energy consumption is expected to reach 80 percent.

China's carbon dioxide emission is expected to stabilize and decline by 2030. By 2060, China plans to establish a green, low-carbon, circular economy and eventually become carbon



How to cite: Highlights from China's medium and long-term plan for the development of the hydrogen energy industry. (2022). *Belt & Road Initiative Quarterly (BRIQ)*, 3(3), 72-74.


April 8, 2022, China Center for International Economic Exchanges – UNDP (United Nations Development Programme) Hydrogen Energy Industry Summit Forum. (China Daily, 2022)

neutral. (The Communist Party of China Central Committee and the State Council, 2021)

### "1+N" Policy"

China's "1+N" climate policy concisely describes its "carbon peak and carbon neutrality" goals and necessary measures. The description's "1" refers to "2030, the declivity of carbon emission" and "2060, carbon neutrality" goals, where "N" stands for the measures that will be taken before 2030.

With the policy (1+N), the aim is to lead reforms in the following ten areas:

- To optimize the energy production system and establish a clean, safe, and efficient energy system based on new energy sources;
- To optimize production, curbing reckless development of high energy-consuming and high-emission industries;
- To promote the construction of energy-saving and low-carbon buildings and infrastructure;
- To establish a low-carbon transportation system;
- To develop a circular economy to increase the efficiency of resource use;
- To promote green and low-carbon technological innovation;
- To develop green finance and expand the capital support;
- To publicize relevant economic policies and reforms;
- To establish a formal carbon trading market;
- To implement nature-based solutions.

(Zhenhua, 2020)

### Strategic View of the Hydrogen Energy

"The hydrogen energy industry is emerging with strategic importance. It is one of the key development directions of the industry." (National Development and Reform Commission, 2022)

China sees hydrogen energy as an important part of the future national energy system and a necessity to achieve "carbon peak, carbon neutrality" goals, aiming to utilize clean energy in major fields of energy consumption and reduce the overall carbon emission to close to zero. By 2025, hydrogen production from renewable energy is estimated to reach 100,000-200,000 tons per year, which will reduce carbon dioxide emissions by 1-2 million tons per year. It is also predicted that the number of fuel cell vehicles will reach 50,000 by 2025. (National Development and Reform Commission, 2022)

### Some of the Exemplary Application Plans

In mining areas, ports, industrial parks, and other areas with high operation intensity, the aim is to carry out demonstration operations of hydrogen fuel cell trucks. Fuel cells will be used in public service fields, including urban buses, logistics distribution vehicles, and sanitation vehicles.

Areas with rich renewable energy resources and areas with high demand for hydrogen energy will be centralized as renewable energy and hydrogen production stations. These centers will be supported and take an exemplary role for other similar enterprises.

The application of fuel cell systems for communication base stations will be encouraged. There will be new communication base stations constructed with standby fuel cell systems. Some of the existing base stations will use fuel cell power generators. Gradually the application of hydrogen fuel cells will be expanded. The application scope of hydrogen fuel cells is expected to cover hospitals, schools, commercial centers, industrial zones, mining enterprises and more (National Development and Reform Commission, 2022).

### About the Current Situation

China is the largest hydrogen producer globally, with an annual hydrogen production of about 33 million tons, of which about 12 million tons meet the industrial hydrogen quality standard. There are more than 300 Industrial enterprises within the whole industrial chain, concentrated in the Yangtze River Delta, Guangdong, Hong Kong and Macao Bay Area, Beijing, Tianjin, and Hebei. However, China's hydrogen energy industry is generally still in the early stages of development. (National Development and Reform Commission, 2022)

To further analyze the development structure, we have chosen Shanghai as an example of the practice and development of the hydrogen energy industry. We present the report titled **"Practice and development of hydrogen energy industry in Shanghai"**, published by the Expert Committee of the Shanghai Energy Conservation Commission.

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# Practice and Development of the Hydrogen Energy Industry in Shanghai*

EXPERT COMMITTEE OF SHANGHAI ENERGY CONSERVATION COMMISSION

## ABSTRACT

With the deepening of China's energy revolution, the goal of "carbon peak and carbon neutrality" is pushed forward, and the new energy and industrial system with the core values of building green, low-carbon, clean, environmental protection, safety and efficiency are advancing steadily. In combination with national policy guidance and support for developing the hydrogen energy industry, relying on its science and technology, good manufacturing technology, and resources, Shanghai has intervened in the hydrogen energy industry. Fuel cell development in the hydrogen energy industry is at the leading level in Shanghai. This paper introduces the basis, technology, development practice characteristics, and experience of the Shanghai hydrogen energy industry and puts forward suggestions and specific measures for its continued development.

**Keywords:** Eco-civilization, green development, hydrogen energy, industry, revolution

## Introduction

With the deepening of China's energy revolution, the goal of "carbon peak and carbon neutrality" is pushed forward, and the new energy system and industrial system with the core values of building green, low-carbon, clean, environmental protection, safety and efficiency are advancing steadily. Hydrogen energy, as a secondary energy source with rich reserves, is of great significance in reducing the proportion of traditional fossil sources, improving the application level of clean energy, optimizing the industrial energy structure, and constructing a safe and reliable energy supply. The development of the hydrogen energy industry aims to promote the strategic transformation of China's energy development and energy utilization models. It is not only the change and transformation of energy in the traditional sense but also the reconstruction of the whole energy structure, energy consumption structure, and industrial structure, alongside socio-economic development and the development of a green, low-carbon society.

Combined with national support and guidance for developing the hydrogen energy industry, Shanghai has intervened in the field of the hydrogen energy industry and fuel cell development. This has creatively promoted the coordinated development of the whole hydrogen energy industry chain, especially in fuel cell development and vehicle

* The text retrieved from Qikan website (http://qikan.cqvip.com/Qikan/Article/Detail?id=7105396768), translated from Chinese to English by Onurcan Balcı.

How to cite: Expert Committee of Shanghai Energy Conversation Comission (2022). Practice and development of the hydrogen energy industry in Shanghai, *Belt & Road Initiative Quarterly (BRIQ),* 3(3), 75-87.

applications. According to the "Competitiveness ranking of China's hydrogen energy cities" recently released by relevant authorities, Shanghai ranks first in the competitiveness ranking of China's hydrogen energy cities with high competition and development potential. From the perspective of overall development, Shanghai's hydrogen energy industry has the advantages of hydrogen energy resources, first-mover advantage, manufacturing technology, and a combination of university and research activities.

**Hydrogen energy, a clean and efficient secondary energy with a wide range of reserves and rich application scenarios, can lead an energy reform and cope with climate change.**

## Significance of the development of the hydrogen energy industry in Shanghai

### The practice and development of the hydrogen energy industry is an important measure to practice ecological civilization

As a clean energy source, hydrogen energy can effectively reduce environmental pollution caused by fossil fuels. The development of the hydrogen energy industry is an important step toward energy conservation, emission reduction, and cross-border ecological civilization. Through the practice and development of the hydrogen energy industry, we can build a diversified energy supply system dominated by clean energy in Shanghai and guide the transportation industry. Deep decarbonization of industry, buildings, and other energy consumption terminals and achieving the goal of "Carbon peak and Carbon neutrality" are important measures to practice President Xi's goal of ecological civilization.

### The practice and development of the hydrogen energy industry is an important way to realize energy revolution

Hydrogen energy, a clean, flexible, and efficient secondary energy with a wide range of reserves and rich application scenarios, can lead an energy reform, cope with climate change, and promote the large-scale development of renewable energy in Shanghai. It is the best choice to realize large-scale deep decarbonization in other areas such as transportation and the construction industry. It is also an important way to realize the next energy revolution.

### The practice and development of the hydrogen energy industry is an important means to enhance future competitiveness

As the main production base of China's automobile manufacturing, Shanghai is also the pioneer of China's fuel cell vehicle technology research and development industry. The importance of the hydrogen energy industry is comparable to that of today's large aircraft, high-speed rail, and artificial intelligence industries. We should plan for its usage combined with the requirements of Shanghai's transformation and development and take advantage of the opportunity of hydrogen energy development to continuously improve Shanghai's core competitiveness.

### The practice and development of the hydrogen energy industry is an important driving force for strengthening green industry

Developing hydrogen energy and fuel cells can expand Shanghai's green and low-carbon industry. Hydrogen has a wide range of applications. It can be used in daily energy consumption, transportation, construction, and many other fields. It can be directly used in production, such as refining and metallurgy, to reduce carbon emissions. Fuel cell technology can also be applied to automobiles, rail, and ships to reduce the dependence of long-distance and high load transportation on oil and natural gas. It can also be applied to distributed power generation to supply energy for settlements and commercial properties.

As an emerging industry, from production, storage, and transportation to the downstream application of the energy industry chain, hydrogen spans many fields such as energy, materials, and equipment manufacturing, and high-end manufacturing industries involving important materials and key parts. It can effectively drive the transformation and upgrading of traditional industries to create a new green, low-carbon industrial chain.

### The practice and development of the hydrogen energy industry is an important direction of international energy cooperation

It has become a trend for the international community to strengthen cooperation and promote the development of the hydrogen energy industry. Shanghai has rich hydrogen energy resources and the first-mover advantage in the hydrogen energy industry. Facing the rapid development momentum of the global hydrogen energy industry and the huge opportunities contained in international cooperation, Shanghai committees should actively participate in the cooperation and management mechanisms of the global hydrogen energy industry. By taking advantage of the favorable opportunity to develop the hydrogen energy industry, Shanghai can establish and strengthen international cooperation mechanisms and grasp the new direction of international energy industry cooperation.

## Foundation of the Shanghai hydrogen energy industry

The practice and development of the hydrogen energy industry in Shanghai has a good foundation and conditions, mainly reflected in the following three aspects.

Exterior view of The New SHPT (Shanghai Hydrogen Propulsion Technology) Park. (Zhang Yang / Shanghai)

### Hydrogen energy resources are abundant, and the foundation is available

Shanghai is a major refining and chemical production base in China, with rich industrial by-product hydrogen and rich resources for hydrogen production. According to recent statistics, the $H_2$ capacity of 5 gas companies in Shanghai and 2 by-product enterprises can reach 130 thousand tons per year. Considering that 2kg of hydrogen energy is enough to cover the average daily usage of vehicles (100km), current production can theoretically support 180 thousand fuel cell vehicles for their daily operations.

### The first-mover advantage and leading technology

As early as the Tenth Five Year Plan period, Shanghai began to participate in the research and development of national fuel cell vehicles and key equipment and was listed in the "863" project of the Ministry of Science and Technology. With the support of the project, Anting Hydrogenation Station, China's first hydrogen energy station, was built in 2006. At the same time, the independent research and development capacity was enlarged. Breakthroughs were made in such fields as membrane electrode assembly (MEA) technology, integration of hydrogen energy vehicles, fuel cell technology, high-pressure hydrogen dispensers, hydrogen power units, and the localization rate of hydrogen refueling stations.

### Excellent manufacturing capability and rich experience

Shanghai is an innovator in developing and utilizing new energy and a leader in the new energy automobile industry. As a pioneer, the sales volume of fuel cell vehicles in 2020 has reached 1050, ranking first in China. From the "Surpass No. 1" fuel cell vehicle started in 2003 to the large-scale mass production of SAIC Maxus FCV80, Shanghai's fuel cell vehicle technology has always been the leader and highest level of fuel cell vehicle technology in China.

**Shanghai has formed a relatively complete hydrogen energy industry chain through the practice of the hydrogen energy industry for many years.**

Shanghai also has rich experience in demonstration operations. Since 2003, with the support of GEF/UNDP (Global Environment Facility, The United Nations Development Program), Shanghai has successively participated in phase II and III demonstration projects of "Promoting the commercial development of fuel cell vehicles in China". Additionally, the cumulative demonstration mileage of various fuel cell vehicles has exceeded 20 million km.

## The practice of the hydrogen energy industry in Shanghai

At present, Shanghai has formed a relatively complete hydrogen energy industry chain through the promotion and practice of the hydrogen energy industry for many years. The conditions for promotion and application are mature and have gradually radiated to the Yangtze River Delta, driving the regional development of the hydrogen energy industry.

### Industrial policy lead development

#### *Guidance of Planning*

Shanghai has been paying attention to the development and utilization of the hydrogen energy industry for a long time. As early as the Tenth Five Year Plan period, Shanghai participated in the national "863" plan and focused on the scientific and technological development of hydrogen energy fuel cells.

1) In September 2017, Shanghai took the lead in releasing “Shanghai's fuel cell vehicle development plan” (hereafter referred to as "the plan"). The plan specifies that Shanghai will take the development of fuel cell vehicles as the core in the development and utilization of hydrogen energy to drive the development of the hydrogen energy industry.

The plan puts forward the overall goal of "Establishing a domestic leading and international first-class fuel cell vehicle industrial chain, and building a fuel cell vehicle technology innovation center and industrial base".

The plan also defines the six tasks of building an application-driven development model, planning the construction of hydrogen refueling stations, creating industrial parks, building public service platforms, and implementing major special projects to establish industrial funds for the development of the Shanghai hydrogen energy industry.

2) In May 2019, the “Yangtze River Delta hydrogen corridor construction and development plan” (hereafter referred to as the "development plan") was released. The development plan is based on the development conditions of the hydrogen energy industry in the Yangtze River Delta. The plan will build the Yangtze River Delta hydrogen corridor into a hydrogen infrastructure network internationally to realize the coordinated and balanced development of hydrogen

infrastructure and fuel cell vehicles.

3) In November 2020, the Sixth Committee of the Shanghai Economic and Information Technology Commission jointly issued the implementation plan for the Shanghai fuel cell vehicle industry (the implementation period is 2020-2023). By 2023, the aim is to develop Shanghai's fuel cell vehicle industry to reach "100 stations and 100 billion vehicles". More than 30 hydrogenation stations have been completed and are operating.

In Shanghai, the hydrogenation network is the largest in the country, with an output scale of about 100 billion yuan. There are more than 10000 fuel cell vehicles in Shanghai, and the application scale of hydrogen energy is the greatest in the country. The overall development level of the fuel cell vehicle industry has reached an international level. Key technologies have been mastered independently, innovative products have been introduced to the global market, the hydrogen energy infrastructure has been improved, and the promotion and application scale has expanded significantly.

4) July 2021, the General Office of Shanghai Municipal People's Government has announced the 14th five-year plan for developing the advanced manufacturing industry in Shanghai. The plan aimed:

To focus on the application of hydrogen energy and fuel cells

To realize batch production of key parts such as power electronic stacks, membrane electrodes, and bipolar plates

To achieve an international leading industrial chain

To promote the efficient storage and transportation of hydrogen

To promote the technology research and development of rapid hydrogen filling and multiple safety protection

To accelerate planning of the layout of hydrogen infrastructure.

### *Improving management and service*

Hydrogen energy is an emerging industry that


Fifteen buses equipped with hydrogen fuel cell systems developed by the Jiading district-based Shanghai Hydrogen Propulsion Technology Co (SHPT) are delivered to three Shanghai bus companies.
(Shanghai Jiading WeChat account, 2022)

has been developed in recent years, involving many management departments. In recent years, Shanghai has actively explored the construction and improvement of the hydrogen energy industry management system.

The formulation of the layout plan of the Shanghai vehicle hydrogenation station has been made. The construction and operation management measures of fuel cell vehicle hydrogenation stations have been taken. Before the relevant management measures are released, the Shanghai Municipal Commission of Housing and Urban Development and relevant management departments will approve the project to manage hydrogen infrastructure construction on a case by case basis.

To further promote the development of the hydrogen energy industry in Shanghai, relevant administrative departments will further accelerate the construction and layout of hydrogen refueling stations in Shanghai, expand the demonstration operations of fuel cell vehicles, and study a series of supporting policies for the development of fuel cell vehicle industry.

Shanghai Energy Conservation Association cooperated with Shanghai Petrochemical Shenneng group, Xinao Gas, Pujiang Gas, and other 32 enterprises in the Yangtze River Delta. It also initiated the establishment of the Yangtze River Delta Hydrogen Energy Infrastructure Industry Alliance. The alliance is committed to bringing comprehensive solutions to hydrogen energy infrastructure in the Yangtze River Delta and actively promoting the development of the hydrogen energy industry in the Yangtze River Delta. The alliance's motivation is to establish mutually beneficial resource-sharing relationships in the hydrogen energy industry chain.

**In the Tenth Five Year Plan period, a scientific research-driven model was formed, and several national projects were undertaken.**

In March 2021, the Shanghai hydrogen energy industry development professional committee, which aims to combine resources from all sectors of society to promote technological progress, commercialization, and large-scale development of the hydrogen energy industry, was officially established. The committee focuses on the goal of "100 stations, 100 billion yuan (in production scale), 10000 vehicles" to develop the fuel cell vehicle industry in Shanghai and promotes a scientific and rational approach. The committee actively participates in the formulation of standards, promotes the commercialization of various technical products, and actively guides the development strategy of the hydrogen energy industry. The committee covers the fields and enterprises related to the hydrogen energy industry's production, storage, and transportation, fuel cell vehicles, and system supporting applications. The first initiative had 66 enterprises as member units.

## Development of the Industry

After nearly 20 years of effort, a relatively complete hydrogen energy industry chain has been formed, and the agglomeration effect of the hydrogen energy industry in Shanghai has appeared. The development characteristics of the Shanghai hydrogen energy industry mainly include the following five aspects.

### *The development of hydrogen energy is qualified, and the technology is advanced*

As early as the Tenth Five Year Plan period, a scientific research-driven model was formed, and several national projects were undertaken. The model has shown the advantages of technology accumulation and R & D foundations. During the Eleventh Five Year Plan period, Shanghai formed a demonstrative application model, built infrastructure such as hydrogen refueling stations, and accumulated rich experience in the demonstration operation of hydrogen fuel cell vehicles. During the 13th five year plan, Shanghai's hydrogen energy development route was clearer, and the fuel cell vehicle industry was focused.

Within the efficient production process, the "Surpass No. 1" hydrogen fuel cell vehicle and "SAIC Roewe 950" hydrogen fuel cell passenger vehicle were manufactured in 2003 and 2015, respectively. SAIC started the mass production of the FCV80 in 2017, which is the first fuel cell light passenger vehicle in the world, representing the cutting-edge technology of China's automobile industry, with a total sales volume of 400 vehicles. In 2018, six fuel cell buses manufactured by SAIC Shenwo had been in operation for 100000 km and initially achieved commercialization. The Roewe 950FCV fuel cell car is the first fuel cell passenger car with sales and licensing in China.

### *Initially forming three industrial clusters and completing the industrial chain*

After years of operation, the development of hydrogen fuel cell vehicles in Shanghai formed three industrial clusters: the R & D of hydrogen fuel cell vehicles with Jiading at the center, the manufacturing of hydrogen fuel cell vehicles with Lingang at the center, and the hydrogen energy supply with Jinshan Chemical Zone at the center. These clusters form a relatively complete enterprise covering the whole industrial chain of hydrogen fuel cell vehicles. At present: 9 hydrogen refueling stations have been built in Shanghai; 23 hydrogen fuel cell industry chains have been formed; 21 hydrogen production industrial centers have been built; 18 hydrogen refueling station industrial centers have been made; 11 hydrogen fuel cell system industrial centers have been established.

### *Effects of the exemplary initiative*

With the support of the international organization GFF/UNDP, the Ministry of Finance, and the Ministry of Science and Technology, Beijing and Shanghai jointly implemented the project "Promoting the commercial development of hydrogen fuel cell vehicles in China". As one of the main exemplary cities, Shanghai used the international demonstration platforms of electric vehicles to carry out the demonstration operations of 86 fuel cell buses, fuel cell passenger vehicles, and fuel cell commuter vehicles, including 6 fuel cell city buses purchased with GEF funds. So far, many sales in Shanghai have occurred. A total of 1500 hydrogen fuel cell vehicles have been demonstrated and operated, including 1445 fuel cell vehicles connected to the Shanghai New Energy Vehicle Data Acquisition, Monitoring and Research Center platform. Fuel cell buses and passenger vehicles have started to operate in succession. The demonstration operation of postal vehicles and van logistics vehicles has nearly 20 million km of total operating mileage.

### *Speeding up the construction of hydrogen refueling stations*

Shanghai Anting hydrogen refueling station began operation in July 2009. It is the first hydrogen refueling station in Shanghai. Shanghai has built 9 hydrogenation stations, 5 in Jiading District, 3 in Fengxian District, and 1 in Baoshan District. In 2020, stations served fuel cell vehicles 55000 times, with 300,000 kg of hydrogen. By 2025, 78 hydrogen refueling stations are planned. In addition to the completed stations, 69 more will be built.

aoshan Iron & Steel Co, a core enterprise of Shanghai-based China Baowu Steel Group Corp, has made great efforts to turn its Baoshan base into a model of low-carbon development. (Liu Ming / China Daily)

### *Promoting the construction of a "hydrogen high-speed network" in the Yangtze River Delta*

In 2017, Shanghai established an investment, construction, and operation platform for hydrogen energy infrastructure to build a "Hydrogenation station corridor around Shanghai" within three to five years. This platform was established by the investments of Shanghai Shunhua New Energy System Co. Ltd., Linde Gas (Hong Kong) Co. Ltd., Shanghai Yidong Automobile Service Co. Ltd., and Shanghai Jianwan Investment Co. Ltd. In April 2018, the "Yangtze River Delta hydrogen corridor construction and development plan" was officially launched in Jiading, Shanghai, and the construction of a "hydrogen high-speed network" with Shanghai, Suzhou, Nantong, Rugao and Yancheng as the centers was put on the agenda.

## The practice of the industry

### *Using the industrial advantages*

Thanks to the existing initiative advantages of the Shanghai hydrogen fuel cell industry in enterprise projects and R & D, the commercial promotions of the industry are improving. Shanghai has preliminarily possessed relatively complete industrial elements such as hydrogen energy, hydrogen fuel cell, fuel cell vehicles, and infrastructure.

1) Enterprise advantages

Many powerful enterprises related to the hydrogen energy fuel cell industry chain have emerged in Shanghai, providing important resources and good conditions for developing the hydrogen energy and fuel cell industry.

**Shanghai also pays great attention to exploring other application fields of hydrogen energy.**

2) Project advantages

On February 12, 2018, Shanghai's first hydrogen energy and fuel cell industrial park was unveiled in the "Huantongji Chuangzhi City" located in Anting, Jiading. According to the plan, the output value of the industrial park will strive to exceed 10 billion yuan by 2025. Shanghai Hydrogen Fuel Cell Vehicle Powertrain Co., Ltd. and other energy research institutions and related enterprises have signed contracts to settle in the park. 12 enterprises have signed strategic cooperation agreements as well.

3) R&D advantages

We're taking advantage of the scientific research technology and professional talents of Shanghai universities to carry out the combination of production, learning, and research to form a joint force to promote the development of the hydrogen energy industry and accelerate technological progress. The new energy vehicle engineering center of Tongji University (hereafter referred to as the center), which is the national fuel cell and power system engineering technology research center of the Ministry of Science and Technology, undertakes the work of the Liaison Office on the international hydrogen energy economy and fuel cell partnership programs. The fuel cell research institute of Shanghai Jiaotong University is the first professional fuel cell research institution established by colleges and universities in China. It has successfully carried out research with enterprises in molten carbonate fuel cells, proton-exchange membrane fuel cells, and solid oxide fuel cell systems.

### *Improving the supporting policies*

The recent focus is on introduction projects, enterprise cultivation, and scientific and technological innovation of the hydrogen energy industry. It is planned to further improve various supporting policies in terms of financial support and industrial support and introduce relevant support measures, including the whole link from enterprise registration to project implementation and later development to cover the whole industrial chain of fuel cell vehicles.

1) Enlarging the agglomeration of the industry

New large-scale domestic and foreign-funded projects will be rewarded.

2) Optimal financial support

The optimal financial support policies are very important to developing the hydrogen energy industry and guiding the development foundation for hydrogen fuel cell vehicles.

3) Expanding the scope of the support

In developing the hydrogen energy industry, we should further expand the scope of support. For example, subsidies can be obtained to construct hydrogen refueling stations to speed up the construction of hydrogen energy infrastructure.

4) Covering the industrial fields

The first batch of advanced oil and hydrogen joint construction station plans and other projects in the Yangtze River Delta have been signed, covering six fields, including the vehicle and parts industry, an industry-university research platform, demonstration operations, and data acquisition.

### *Expansion of application field*

In addition to focusing on hydrogen fuel cell vehicles, Shanghai also pays great attention to exploring other application fields of hydrogen energy.

1) Popularization of standby power supply with hydrogen fuel cell

According to statistics, among about 12000 base stations in Shanghai, more than 100 base stations have adopted hydrogen fuel cells as backup power supply.

2) Hydrogen fuel cell distributed generation

Besides their studies and exploration, relevant enterprises and institutions have also carried out demonstration projects. For example, Shanghai Shunhua New Energy System Co., Ltd. and Tongji University have built a hydrogen fuel cell to provide part of the power and heat (cooling) capacity for the building of the Automotive Faculty of Tongji University.

Relevant enterprises and scientific research institutes in Shanghai are actively doing research. There are studies about applying portable fuel cells in ocean freight shipping, urban rail transportation, mobile phones, and laptops. As for the development of hydrogen energy storage methods, relevant scientific research institutes are carrying out feasibility exploration considering the characteristics of Shanghai's energy supply development.

## Practical characteristics of the hydrogen energy industry in Shanghai

### Market development enters the industrial period

After more than ten years of effort, Shanghai has mastered fuel cell stack technology and its key components, core technologies (such as power generating systems), and vehicle integration. Various demonstration projects of hydrogen energy development and utilization have also gained preliminary experience and have formed a relatively complete market industrial system, including evaluation and certification institutions, demonstration operators, and hydrogen energy infrastructure construction enterprises. The whole market development of hydrogen energy development and utilization has entered the industrial period.


A hydrogen racing car displayed at the 4th China International Import Expo (CIIE) in Shanghai. (Meng Tao / Xinhua, 2021)

### Application of technology enters a new period

Shanghai attaches great importance to the leading role of scientific, technological innovation in developing the hydrogen energy industry. Shanghai actively promotes the construction of new R & D institutions, strengthens public relations in key areas, introduces high-level innovative talents and teams in hydrogen energy, and cooperates with universities and enterprises. These efforts have injected vitality into the industrialization of hydrogen energy development and utilization.

At present, the fuel cell lifetime of passenger cars has exceeded 5000 hours, and the lifetime of commercial vehicles has exceeded 10000 hours, which meets standard vehicle operating conditions. The engine power density of hydrogen fuel cell vehicles has reached the level of the traditional internal combustion engine, the power of electric stacks has reached 3.0 kW/l (kilowatt per litre), and the power covers 30 ~ 150 kW. Many performance indexes are close to the international advanced level. Based on 70 MPa hydrogen storage and hydrogenation technology, the driving range of hydrogen fuel cell vehicles has reached 750 km. The starting temperature of hydrogen fuel cells has reached - 30 C. The overall application range of vehicles has reached the level of traditional vehicles, and the key technology has entered the upgrading period.

### Diversity period in investments methods

Energy enterprises, automobile enterprises, and scientific research institutions have entered the field of hydrogen energy development and utilization to create competitiveness in the hydrogen energy industry. They each rely on their capabilities such as traditional business investment, design, innovation, and construction capabilities to carry out business extensions and innovation. They cooperate with strategic partners and projects through diversified investment, obtain the strategic resources required for development, accelerate the transformation and development of enterprises, and realize the integration and optimization of funds, resources and business required to develop the hydrogen energy industry.

**By 2025, Shanghai will build several comprehensive hydrogen energy industrial parks to carry out hydrogen energy operations.**

The active participation of private enterprises and social funds, especially the state-owned comprehensive energy group companies, has stabilized the development expectation of the hydrogen energy industry, enhanced the confidence in its development, and strengthened consensus.

### The business models have entered a period of innovation

During the market introduction period of hydrogen energy development, Shanghai has vigorously guided the construction of hydrogen energy infrastructure and hydrogen energy vehicles to create a good environment for the market-oriented and commercial development of the whole industrial chain of hydrogen energy. Hydrogen energy commercial operations have entered a period of innovation.

The methods include; using the "UNDP" project to promote the commercial development of hydrogen fuel cell vehicles; using "Leasing + TCO + TC" to enlarge the service scale and reduce costs; providing complete services for users, promoting commercial operations; exploring diversified application methods.

Qingpu Industrial Park will demonstrate the operation of hydrogen energy vehicles. By expanding into diversified application fields, we are exploring new business models, providing a large-scale market for the hydrogen energy industry.

## Suggestions for the development of the hydrogen energy industry in Shanghai

### Development requirements

Considering the overall requirements of Shanghai's development and the objective of "carbon peak and carbon neutrality", we will adhere to an innovative, green, open, and shared development concept, establish a scientific outlook on energy development, and progress towards the goal of building a green, low-carbon energy supply system. We should make full use of the existing hydrogen energy resources and the industrial foundation in Shanghai. We will arrange the development of different links in the hydrogen energy industry scientifically, strive to build a whole industrial chain cluster, build a high-quality hydrogen energy industry ecosystem in the Yangtze River Delta, and make Shanghai a capital of the hydrogen energy industry with global influence.

### Development principles

1) Adhering to market orientation and government guidance

Considering the decisive role of the market, we will clarify the positioning and development direction, issue corresponding support policies, and gradually cultivate the hydrogen energy development and utilization market. In this process, we will give roles to the enterprises in all links of the hydrogen energy industry and form a hydrogen energy market dominated by market development and guided by government policies.

2) Adhering to overall planning and orderly development

We should coordinate the resources of the hydrogen energy industry, clarify the main areas of hydrogen energy industry development, optimize the planning and layout of industrial clusters, and manage the development holistically.

3) Adhering to innovation-driven cooperation and opening-up

While establishing and improving the innovation system of the hydrogen energy industry, we will promote collaborative research platforms, strengthen cooperation and exchange, and stimulate the innovation vitality of different fields within the industry.

4) Adhering to the law and adjusting measures to local conditions

We should attach importance to the objective law of the development of the hydrogen energy industry, formulate development goals at different stages, consider both the development phase and the basic conditions of development, and guide the continuous healthy industrial development.

## Development goals

The development of the hydrogen energy industry in Shanghai implements the "two-step" strategy. The first step is to complete the layout of the hydrogen energy industry chain by 2025. This step includes forming a regional industrial cluster covering the hydrogen energy industry chain, making breakthroughs in key core technologies, reaching an international standard, building a reliable hydrogen energy industry infrastructure and application network in key development areas, and forming an output value of 100 billion yuan. The second step is to develop the hydrogen energy industry into a major energy industry in Shanghai by 2030. The industrial chain cluster will influence all industrial chain links and the key core technologies. We plan to establish a complete infrastructure network for the hydrogen energy industry in the whole city, expand the scope of application, and radiate the Yangtze River Delta hydrogen energy development model.

A technician works at the fuel cell test area at the hydrogen energy technology center of Great Wall Motor (GWM).

1) Breakthrough in hydrogen energy industry technology

By 2025, many national innovative R & D platforms for the hydrogen energy industry will be formed. The technical level of all links in the hydrogen energy industry, especially fuel cell vehicles, will reach international standards. By 2030, some gaps in cutting-edge technologies in the hydrogen energy industry are planned to be filled. The hydrogen energy technology application, power generation, energy storage, and energy supply distribution in aerospace and other fields will be expanded.

2) Forming the development foundation of the hydrogen energy industry

By 2025, several hydrogen energy industrial policies, industrial norms, and standards will be formulated. The industrial policy system will be formed and improved, and the industrial supervision methods will be established. The standard system for all links of the hydrogen energy industry will be constitutively enhanced and covered. By 2030, Shanghai will improve the hydrogen energy industry policies, industry standards, and regulatory system and complete the development system of the hydrogen energy industry.

3) Remarkable achievements have been made in the cultivation of hydrogen energy enterprises

By 2025, Shanghai will build several comprehensive hydrogen energy industrial parks to carry out hydrogen energy operations, introduce and establish enterprises, and provide sources for storage, transportation, and manufacturing of key equipment such as fuel cells and other industrial chain applications. By 2030, many influential hydrogen energy industry enterprises in China and abroad will be cultivated in all hydrogen energy industry chain links.

**By 2025, a complete network of hydrogen refueling stations and supporting facilities will be established in Shanghai.**

4) The market of the hydrogen energy industry continues to expand

By 2025, a complete network of hydrogen refueling stations and supporting facilities will be established in Shanghai. There will be mass launches of regional public transport vehicles, official vehicles, commercial logistics, and other fields, contributing to the exploration, industrialization, and commercialization of hydrogen energy, hydrogen standby power supply systems, and hydrogen power generation. By 2030, Shanghai will become a fuel cell vehicle application city with international influence. Its overall technology will be synchronized with international standards, and some technologies will be ahead of the international standards. The field of hydrogen energy will be expanded to the civil consumption market, and the hydrogenation distributed energy system will be popularized and applied. It is planned to diversify the application of the national hydrogen energy industry, radiate the Yangtze River Delta model to the whole country, and guide the transformation of energy in the future.

## Specific measures for the development of the hydrogen energy industry

### Institutions

At present, industrial by-product hydrogen is the main resource for developing the hydrogen energy industry in Shanghai. However, with the development of the hydrogen energy industry, hydrogen demand has increased greatly. Therefore, it is necessary to promote construction of hydrogen production market systems and hydrogen energy systems. In the near future, hydrogen, the main industrial by-product, will be used as the main resource of hydrogen energy production. Carbon-free production will be realized in later development by relying on clean and renewable energies. We can first pilot the manufacturing of green hydrogen from renewable resources such as waste heat (cooling) and wind in the demonstration projects and pilot the comprehensive utilization of Yangshan LNG cold energy in Lingang to expand the manufacturing capacity of green hydrogen in Shanghai. This can form green and clean development in the whole life cycle, from "ash and hydrogen" to "blue hydrogen", and finally to "green hydrogen".

### Storage and transportation

It is necessary to increase the research on liquid hydrogen materials and improve the localization level of gas storage and cylinders, liquid hydrogen cones, and other equipment. We should continuously improve the efficiency and safety of hydrogen storage and transportation and promote a formation of a complete hydrogen storage and transportation standard. We should encourage research on solid hydrogen storage and hydrogen gas pipeline transportation. In the near future, the container and long tube trailer will still be the main method of storage and transportation. In later development, a transportation network based on liquid stations, solid-state storage/transportation, and pipeline hydrogen transportation will be gradually formed to reduce costs, expand applications, and improve efficiency.

### Hydrogenation stations

We will clarify the competent departments of hydrogen refueling stations and related infrastructure,


The commissioning ceremony of the New Hydrogen Technology Park (SHPT). (Information Office of Jiading District, 2021)

and strengthen planning management. We will take demand as a guide, integrate resources, allocate reasonably, pay attention to the market-oriented expansion of the hydrogen infrastructure network, and improve the strength and accuracy of financial support. We should accelerate the construction and popularization of hydrogen refueling stations and reduce their construction and operation costs. In the forthcoming period, we should accelerate the construction of hydrogenation infrastructure, take the formation of a hydrogenation network in the Yangtze River Delta as a goal, and apply it to the needs of the development of the hydrogen energy industry in Shanghai.

### Hydrogen fuel cell

The power density of domestic key components, such as membranes and fuel cells, is continuously improving. In later development, we will integrate the production and R & D forces of fuel cells, cultivate enterprises that integrate production, and accelerate technological progress. We will consolidate the foundation of Shanghai's independent core technology of fuel cells, support development, and maintain Shanghai's leading position in the fuel cell industry.

### Hydrogen fuel cell vehicles

We will focus on developing hydrogen passenger cars, logistic trucks, official vehicles, urban sanitation vehicles, and other specific vehicles. Later, we will focus on the development of ordinary passenger vehicles and the utilization of hydrogen fuel cells in rail transits, shipping vehicles, aerospace, and other fields. We will support the fuel cell vehicles in terms of policies such as right of way and reduced license costs to popularize the usage of fuel cell vehicles.

### Expanding the field of hydrogen energy development and utilization

The emerging industrial changes that can respond to Shanghai's development are as follows: scientific development of the energy industry, efficient energy utilization, the transformation of energy structure, adjustments in industrial structure, energy conservation and emission reduction, and improvement of modern energy supply systems. In later development, Shanghai will make full use of the advantages and characteristics of hydrogen energy and continuously expand the application fields of hydrogen energy. We will enhance the peak shaving capacity of urban energy supplies, improve the quality and safety of urban energy supplies, and integrate them into the energy supply system of the whole city.

# 1st International Belt and Road Initiative and Turkey Symposium: Turkey Carries the Potential to Become the Vanguard of the Digital Silk Road


THE 1ST INTERNATIONAL BELT AND ROAD Initiative and Turkey Symposium was held on May 30-31, 2022 in cooperation with the Turkish-Chinese Business Development and Friendship Association and the Istinye University Center for Belt and Road Studies (CBRS). The main theme of this symposium was the "Importance of the Digital Silk Road for Developing Countries and Contribution of Turkey to the Digital BRI", which was discussed by distinguished business people, academics, and diplomats from different countries.

The opening session included Mustafa Varank (the Minister of Industry and Technology of the Republic of Turkey), Lin Songtian (President of the Chinese People's Association for Friendship with Foreign Countries), Liu Shaobin (Ambassador of the People's Republic of China to Ankara), Prof. Dr. Erkan İbiş (Rector of Istinye University), Lin Songtian (Chairman of the China Association of Friendship with Foreign Countries), Prof. Dr. Guo Changgang (Shanghai University Center for Turkish Studies), and Assoc. Prof. Efe Can Gürcan, Director of the CBRS. A total of 11 sessions were held over two days, where many topics were discussed, ranging from agriculture, education, transportation and logistics to finance, tourism, and development.

## Organizers

Turkish-Chinese Business Development and Friendship Association, Istinye University Center for Belt and Road Studies (CBRS), China Economic Cooperation Center (CECC), Shanghai University Center for Turkish Studies.

## Supporters

National Strategy Center (USMER), Belt and Road Initiative Quarterly (BRIQ), Institute of Communication and Business Sciences, Journal of Theory, Journal of Science and Utopia, Turkish Student Union in China.

## "The world of the oppressed will humanize digitalization"

In his opening speech, Adnan Akfırat, President of the Turkish-Chinese Business Development and Friendship Association, said that "digitalization in the 20th century was developed and exploited by global capitalism to eliminate national borders, but in the 21st century, the initiative in digitalization has passed to developing countries". Pointing out that the World of the Oppressed in the Asian Century has made digitalization one of the tools to get rid of the hegemony of US imperialism, Akfırat emphasized the involvement of the People's Republic of China for digitalization as a leading state in this area. Akfırat observed that advanced capitalist



How to cite: Turkey carries the potential to become the vanguard of the Digital Silk Road. (2022). *Belt & Road Initiative (BRIQ)*. 3(3), 88-89.

countries have transformed digitalization into an enemy of humanity that propagates individualism and intensifies exploitation. According to him, the main purpose of this symposium is to encourage Turkey to become a vanguard in the construction of the Digital Silk Road based on its young, dynamic, and qualified labor force as well as its talented and bold entrepreneurs. Akfirat also asserted that the BRI is driven by the principle of shared development and Turkey is one of the countries that benefit most from this collective initiative.


## **The Ukrainian crisis and the BRI:** Challenges and opportunities

BRIQ was the main organizer of "The Ukrainian crisis and the BRI: Challenges and opportunities", a hybrid forum that discussed the implications of NATO's Eastward expansion and the challenges and opportunities brought by the Ukraine operation to the BRI.

The co-organizers of this forum, held on May 21, 2022, included the Russian Centre of Science and Culture, Friends of Socialist China Platform, Turkish Student Union in China, and Istanbul Kent University. Distinguished speakers from 4 continents and 10 different countries took part in the forum. Adnan Akfırat, President of the Turkish-Chinese Business Development and Friendship Association and Chairman of the BRIQ, made the opening speech and moderated the forum discussions.

In his speech, Akfirat said that the unipolar world, led by the United States and institutionalized by hegemonic tools such as the NATO and the EU, has collapsed, and now the initiative has passed to developing countries. He noted that a new international order is rapidly emerging, which is more egalitarian, fairer, more people-centered, and environmentally friendly. Stating that 87 percent of the world's population do not agree with the USA and the EU regarding the sanctions against Russia, Akfırat concluded his speech by saying, "every step taken by NATO on the way to expand Eastward brings itself closer to its grave". In this environment, Turkey should develop its relations with Asia, Africa, and Latin America within the framework of the Belt and Road Initiative in order to resist the pressures of Western countries.

Professor Ma Xiaolin, from Zhejiang University International Studies University, said in his speech that over the past 8 years, the Belt and Road Initiative has expanded the foreign trade volume of participating countries by 3 to 10 percent, while 7.6 million people have been lifted out of extreme poverty and 32 million people have been lifted out of poverty. He mentioned that the BRI greatly contributes to the construction of infrastructures such as railways and highways. Prof. Ma pointed out that after the Ukraine crisis, the West's unilateral sanctions has negatively affected the global financial system. He went on to add that the United States has been conducting a demonization campaign to break the influence of the Belt and Road Initiative, which offers a better alternative to the whole world.

Other participants included Mushahid Hussain, Pakistan Senator and Chairman of the Defense Committee, Dr. Darya Platonova from Moscow University, Dr. Rajiv Ranjan from Shanghai University, Dr. Governor Kaleji from Tehran University, Keith Bennett, Editor of the Friends of Socialist China Platform, and Dr. Ahmed Shahidov, President of Azerbaijan Democracy and Human Rights Institute. The speakers concurred that the unipolar order has come to an end and unilateral sanctions by Western countries have only served to intensify the global problems.

# Domestic Reasons for the Belt and Road Initiative


## Zhao, L. (2021).

The Belt and Road Initiative and the Development of Western China.

Beijing: CITIC Press Group

LIN SHITING*
Department of History, College of Liberal Arts, Shanghai University, China

SINCE THE BELT AND ROAD INITIATIVE (BRI) was put forward in 2013, 172 countries and international organizations have signed cooperation agreements with China, and the cumulative trade volume of goods has reached 9.2 trillion US dollars. At the same time, the study of the BRI has gradually become a "promising research field", which has aroused the warm attention of scholars in China and around the world. However, while foreign scholars focus more on the international factors and global impact of the BRI, Chinese scholars prefer to analyze the domestic background of the BRI and its great contribution to China's development. Among them, *The Belt and Road Initiative and the Development of Western China*, written by Professor Zhao Lei, is a representative work in Chinese academia. Zhao Lei is a well-known Chinese political scientist whose research focuses on Chinese diplomacy and international relations. He currently works at the Party School of the CPC Central Committee and is the author of The Belt and Road Initiative: China's Civilizational Rise and many other books and articles.

*The Belt and Road Initiative and the Development of Western China* consists of eight chapters, which can be divided into three parts. The first part consists of chapters 1, 2, and 3, introducing how Western China has greatly improved its opening up to the outside world by actively participating in the BRI. The second part includes chapters 4, 5, and 6. It mainly introduces that the western region has made remarkable progress in economic development by strengthening economic and trade cooperation, cultural tourism cooperation and Green Silk Road construction with Central Asia countries un-

* Lin Shiting, Master Student from the Department of History, College of Liberal Arts, Shanghai University.
Email: lindsay2020@foxmail.com
Recieved: 08.02.2022 Accepted: 01.05.2022


How to cite: Lin, S. (2022). Domestic Reasons for the Belt and Road Initiative. [Review of the book *The Belt and Road Initiative and the Development of Western China* by Zhao, L.] *Belt & Road Initiative Quarterly (BRIQ)*, 3(3), 90-92.

der the framework of the BRI. The third part includes chapters 7 and 8, taking the case of the China-Europe Railway Express to introduce the great impetus brought by the BRI for the development of the western region, western countries' cognition of the BRI, and China's response.

**In general, how to make use of the BRI to promote the formation of a high-level opening-up pattern in western China is the target theme of Zhao's book, and how to rely on the BRI to realize the grand blueprint of a community with a shared future for mankind is its purpose and philosophy.**

In general, how to make use of the BRI to promote the formation of a high-level opening-up pattern in western China is the target theme of Zhao's book, and how to rely on the BRI to realize the grand blueprint of a community with a shared future for mankind is its purpose and philosophy.

**First, the internal reason for China to propose the BRI is to achieve a high-quality opening-up in Western China.** Narrowing the development gap between the eastern and western regions has long been one of the priorities of the Chinese government. As early as 2000, the Chinese government has put forward the "Great Western Development" plan and carried out key projects such as the Qinghai-Tibet Railway, the south-to-north water diversion project, and the west-to-east gas transmission project. These projects have greatly promoted energy industry development in western China, but the problem of unbalanced development between the east and the west is still quite prominent.

Therefore, the BRI was put forward in this context, and western provinces have carried out a series of practices under the initiative. Xinjiang Uygur Autonomous Region has continuously strengthened its aviation construction and has achieved a magnificent transformation from a single airport in Urumqi to 21 airports (p. 81). Shaanxi Province has established several international production capacity cooperation centers, such as Aiju Grain and Oil Industrial Park in Kazakhstan and Zhongda Industrial Park in Kyrgyzstan. Guangxi Zhuang Autonomous Region continues to promote the construction of the China-Indochina Peninsula International Economic Corridor, strengthen cooperation with Association of Southeast Asian Nations (ASEAN) countries to build a "Digital Silk Road", and build a Beidou navigation service base facing ASEAN. Yunnan Province, which faces South Asia and Southeast Asia, trives to build a regional international economic and trade center. In 2019, its foreign trade volume exceeded 200 billion yuan for the first time, accounting for more than 70% of the total trade share with countries along the BRI.

**Second, international cooperation promoted by the BRI, especially cooperation between China and Central Asia countries, has reaped rich fruits.** Neighborhood diplomacy is an important part of China's major-country diplomacy with Chinese characteristics. As a neighboring region, Central Asia is not only at the forefront of the Westward push of the BRI but also a demonstration area for promoting China's international cooperation. As soon as the BRI was put forward, it received positive responses from the five Central Asian countries.

In terms of infrastructure construction, Chinese companies have assisted and undertaken several infrastructure projects in Central Asia, including but not limited to Almaty Solar Power Station, Almaty Wind Power Station, Turgusun Hydropower Station, Capital Ring Road (Kazakhstan), and the Kamchik tunnel of the Anglian Pappu railway (Uzbekistan), have solved the long-standing problems of power supply, heating, transportation, and other livelihood issues for the local people.

At the economic and trade cooperation level, high-quality Chinese enterprises have entered Central Asian countries with capital investment and industrial technology and built industrial parks such as the China-Kazakhstan Border Cooperation Center, China-Tajikistan Industrial Park, and Djizzak Industrial Park. These investments promote the economic transformation of this region and achieve win-win cooperation. Take the Caspian Sea Asphalt Plant as an example. It is an important project for the joint construction of the BRI between China and Kazakhstan. After the plant began operation, it quickly met the demand for asphalt in Kazakhstan, and at the same time, it showed good social benefits in terms of employment and personnel training.

**The Chinese have an old saying when facing a crisis, "A chopstick is easily broken, but ten pairs of chopsticks hold together into a ball". This ancient historical wisdom is still quite suitable for today's current situation.**

At the level of people-to-people and cultural exchanges, labor dispatch has deepened the exchanges between workers on both sides in terms of infrastructure technology, overseas tourism has spawned a wave of Chinese citizens traveling to Central Asia, and cultural exchanges have expanded the scale of international students from both sides and improved cultural understanding. So far, 13 Confucius Institutes have been set up in Central Asia.

**Third, the BRI is a global public product that China, as a responsible country, provides to the world.** Taking the China-Europe Railway Express as an example, China hopes to deeply participate in the economic integration of the Eurasian continent. The Eurasian continent's population accounts for 75% of the world's population, and its trade volume accounts for more than 60% of the world's total, with huge potential for economic development. However, many countries in the Eurasian continent are restricted by many factors and fail to share the fruits of economic development.

The cross-border flow of products, personnel, and services brought by the China-Europe Railway Express will give these countries unprecedented development opportunities. The China-Europe Railway Express launched a single line (Chongqing, China - Duisburg, Germany) in 2011. With the advantages of price, speed, and service, it has formed three major west, middle, and east channels. Raw materials such as textiles, electronic products, and rubber can be exported from Southeast Asia to Central Asia and Europe, and products such as fast-moving goods, machinery, and non-ferrous metals can be exported from Europe to Southeast Asia, Japan, and South Korea (p. 248).

**This book also expounds on the influence of Confucianism on the BRI.** Prof. Zhao proposed two concepts to explain the philosophical meaning of the BRI. One is "Confucius' Improvement", and another one is "Mencius's Optimal" (p. 177). "Confucius' Improvement" emphasizes that the realization of self-interest and the interests of others are closely related, and only when the related interests of others are realized can self-interest be realized. "Mencius's Optimal" emphasizes that individual interests and group interests are coexisting and co-promoting. Only in groups with sufficient cooperation and harmonious member relationships can the individual interests of group members be optimally realized.

In the BRI, any country can be self-interested and other-interested, reflecting the idea of "Confucius' Improvement". Respecting the diversity and complementarity of cooperating subjects is the practical concept of the Belt and Road Initiative, which embodies the idea of "Mencius's Optimal".

Since the Great Discovery in the 1500s, our world has become a whole. The economy and war have deepened the world's connection, and the global spread of COVID-19 has cemented it. The Chinese have an old saying when facing a crisis, "A chopstick is easily broken, but ten pairs of chopsticks hold together into a ball". This ancient historical wisdom is still quite suitable for today's current situation. History can testify that adhering to the principle of the inclusiveness of Chinese culture and building a community with a shared future for mankind through the BRI is not a rigid slogan but a deliberate and vivid practice of China for the whole world.

# CARL GUSTAV MANNERHEIM

The yard of the pottery workshop in Yangishar *

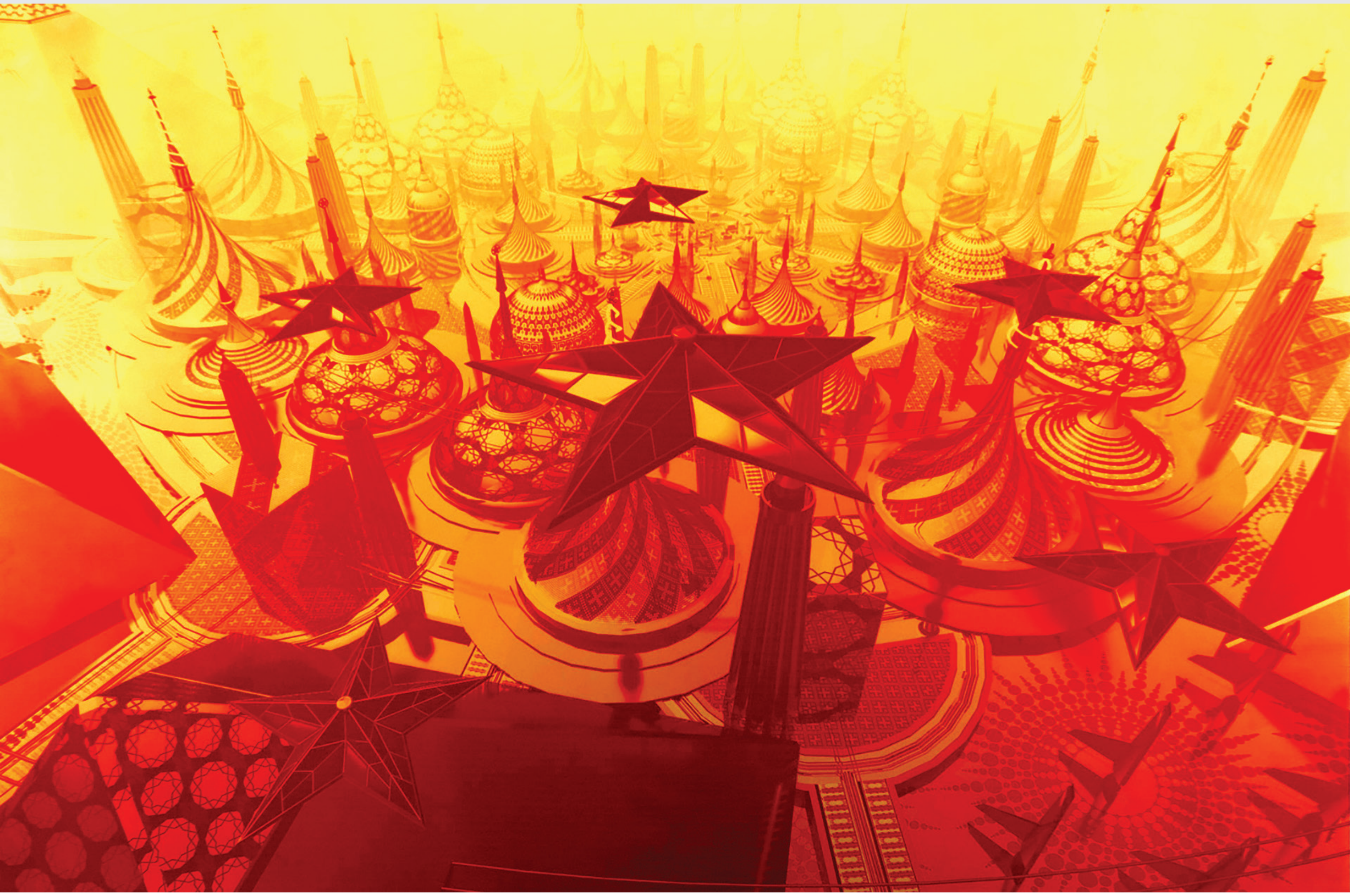
*The Mannerheim Asian Expedition is a reconnaissance expedition to the north and west of the Qing Empire, organized by the Russian General Staff and carried out by Colonel of the Russian Army Baron Gustav Mannerheim, from March 1906 to December 1908. At the end of June 1906, Gustav Mannerheim, with 490 kg of luggage, including a Kodak camera and two thousand glass photographic plates with chemical reagents for their processing, left St. Petersburg by train. Carl Gustav Mannerheim visited the territory on his way to China and took a number of unique pictures.*

*Retrieved from https://humus.livejournal.com



How to cite: : [Painting by Carl Gustav Mannerheim]. (2022). The yard of the pottery workshop in Yangishar. *Belt & Road Initiative Quarterly (BRIQ),* 3(3), 93.

# ALEKSEY BELIAYEV GUINTOVT



Supernova Moscow*

*Aleksey Beliayev Guintovt was born in Moscow in 1965. In 1985 graduated from the Moscow Architectural-Construction Technical College. Between 1985-88 studied in MAI (in the department of Urban Planning). Guintovt, one of the important figures of Russian contemporary painting, stands out with his bold and unique works. His powerful lines combine the traditions with trends of the Russian Avant-garde and Constructivism, and also the imposing Soviet style. His paintings are currently in the collections of the Tretyakov Gallery, the Russian Museum, Moscow Museum of Modern Art, as well as dozens of other museums and many private collections. The artist who was also awarded the Kandinsky award in 2008, promotes a grand style in Russian contemporary art and his paintings create bizarre utopias made up of Orthodox churches, the Soviet Empire, and Apollonian heroes.*

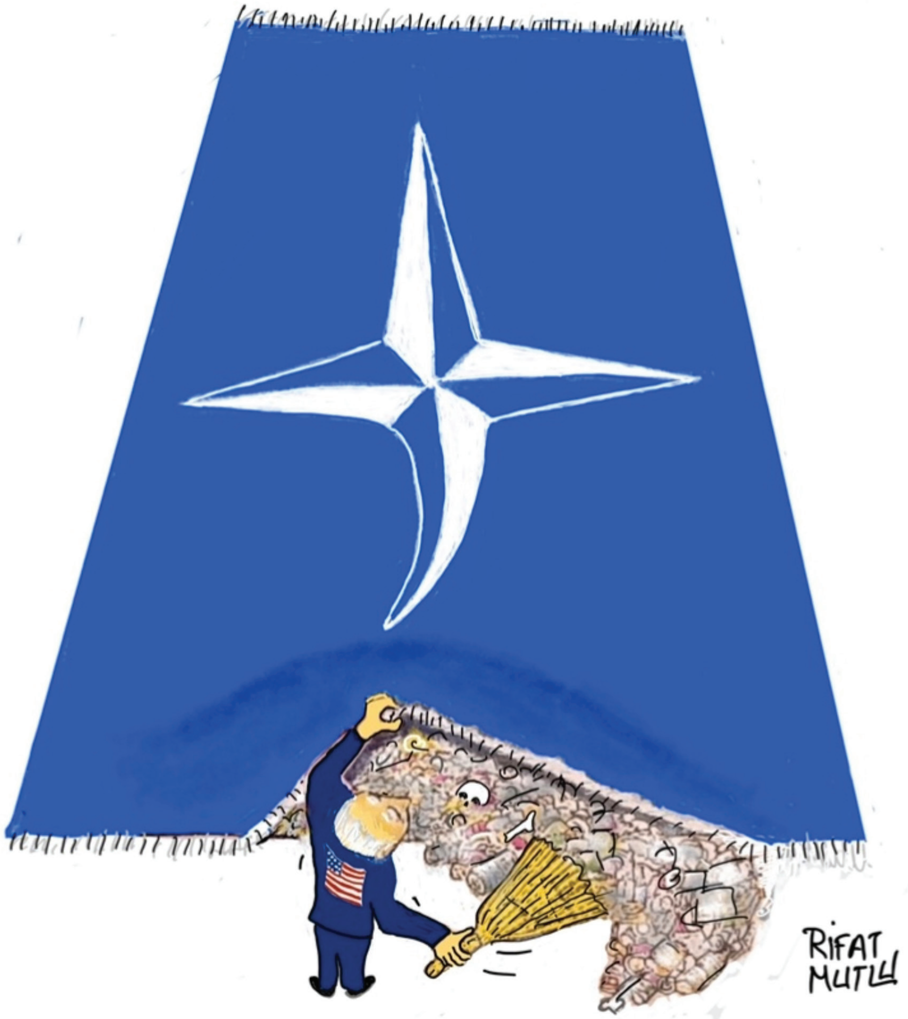
* Aleksey Beliayev Guintovt. "Supernova Moscow" 2012. MDF board, inkjet print, palm print of the author. 150/100 cm.



How to cite: [Painting by Aleksey Beliayev Guintovt]. (2022). Supernova Moscow. *Belt & Road Initiative Quarterly (BRIQ)*, 3(3), 94.

CARTOON

# RİFAT MUTLU




*Rifat Mutlu is a medical doctor specializing in neurosurgery. During serving as a doctor, he served as an Executive Committee member of the Izmir Medical Chamber in Turkey. He worked at the Umea University and the Uppsala University in Sweden, which conducted research and studies on the surgery of people with disabilities. After returning to Turkey, Mutlu, who worked as a neurosurgeon in public hospitals, served as the Provincial Director of the Agency for Social Services and Children Protection in Izmir. Mutlu, who started to work as the Deputy Secretary General of Izmir Metropolitan Municipality in 1999, established the first Emergency Rescue Health Project in Turkey, "AKS-110". He created the "Council of Disabled People" and the "Center for Youth with Disabilities". Rifat Mutlu, a member of the Cartoonists Society in Turkey, served as the İzmir representative of the Cartoonists Society between 2012 and 2014. His comic strip, "Birileri", was regularly published in the local and national press between 2004 and 2011. He has two cartoon albums named "İki Gözüm İki Çeşme" and "Birileri", and a cartoon book, "Anatolian Anecdotes with Cartoons". Having 11 personal cartoon exhibitions, Mutlu still draws political cartoons for Aydınlık Newspaper. Rifat Mutlu is currently a member of the Central Executive Board of the Patriotic Party.*

How to cite: [Cartoon by Rifat Mutlu]. (2022). *Belt & Road Initiative Quarterly (BRIQ)*. 3(3), 95.