The Black Sea: A Sea of Energy, Prosperity, and Peace

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ABSTRACT

This paper discusses the potential role of the Black Sea in establishing a wider, more sustainable, environment-friendly, and interdisciplinary platform for innovative solutions with international cooperation among the Belt and Road Nations. Although this platform concept is based on two hydrogen research centers, one in China and the other in Turkey, with satellite centers along the entire Belt and Road, the benefits are discussed to fall out to a very wide spectrum of technological developments focusing on renewable energy, transportation, and welfare. The paper also argues the local benefit of cleaning the sea from harmful and dangerous concentrations of H_2S gas by the close collaboration of the six countries around the Black Sea.

Keywords: Black Sea, BRI, exergy, hydrogen economy, renewable energy

WITH THE EVER-INCREASING CLIMATE warming urgency and depletion of known fossil fuel reserves, decision-makers and energy strategists are concentrating on new alternative fuels such as abundant renewable and waste energy sources, which used to be ignored due to their low quality (exergy). Exergy is the useful work potential of a quantity of energy. These alternatives are becoming the most important assets of our future. However, industry, transport, and agricultural sectors require high-quality sources of energy, which rely on fossil fuels. This conflicts with the necessity of using alternative energy sources as widely as possible. One of the emerging technologies that can resolve this conflict is the renewables-based hydrogen economy.

By using lower-quality renewables like solar energy to generate hydrogen from water provides a zero-carbon fuel, which has higher quality than natural gas. Black Sea countries are very fortunate in this respect because the seawater is exceptionally rich in H_2S gas that may be split into hydrogen and sulfur using abundantly available off-shore renewable energy sources like wind, wave, and solar. The Black Sea has alarmingly high levels of H_2S awaiting useful applications to reduce simultaneously environmental and human risks.

This article focuses on the production of hydrogen gas and its transport to land on a ship powered by wave, sun, wind and also by hydrogen. Additionally, it will be discussed the hydrogen city project which uses coal and geothermal energy resources in the region based on Sinop city sample as well as its economic, environmental and political advantages.

The Black Sea: A Potential Hub for Energy and Peace

The Black Sea is one of the world's largest inner seas with an area of 432,000 km^2, a maximum water depth of 2,200 meters, and a water volume of approximately 534,000 km^3. (Ertan, 2020; Kılkış, 2020). *The Commission on the Protection of the Black Sea Against Pollution* depicts the Black Sea quite soundly by describing it as the most isolated sea from the rest of the World's Oceans, with a catchment ratio[1] of over six. Such a high catchment ratio makes it very critical for landside activities, non-coastal countries, and sea pollution. Its characteristic geomorphology with exceptionally high H_2S concentrations

1 Catchment ratio is the amount of land area with respect to the sea surface area, which contributes water to that sea by rivers flowing to that sea.

has resulted in a very thin upper layer of about 150 meters to support marine life (Ertan, 2020; Kılkış, 2020). The situation is worsened by other ecological mistakes, like partly discharging the municipal wastewater of the city of Istanbul using the bottom current of the Bosporus to the Black Sea.

The Black Sea, H_2S Reserves, and Special Advantages

The Black Sea Region has a four-pronged advantage, namely:

1- Wind and Wave Energy Abundance

2- Abundant H_2S reserves for H_2 and S, which are equally important for the environment and industry

3- Low Salinity for Sea Water Electrolysis

4- Relatively Stable Politics.

There are well-defined and well-agreed upon continental shelves of the six countries around the Black Sea. This makes the area much more stable and free of military skirmishes as long as the 1936 Montreux Convention about the natural straits of Bosporus and Dardanelles holds and the man-made Canal Istanbul project is suspended, which may be vulnerable to foreign military aggression for free passage of warships and submarines, especially to unnecessary but planned NATO interventions that possibly will make the region much less stable. The energy potentials of the Black Sea are not limited to natural gas and hydrogen but also offer gas hydrides in large amounts (Ertan, 2020). Moreover, it is clear that interests will be towards the Black Sea due to reducing hydrocarbon energy in the Middle East which does not have another energy resource. In all these respects, the Black Sea with such a diversity of abundant resources is the second Middle East, which only has fossil fuel reserves and keeps adding international conflicts in the region each day. The only way to prevent these kind of threats is to share this abundant resources with coastal countries by conducting joint projects.

H_2S Potential

The Black Sea is one of the world's largest H_2S reservoirs. The total reserves are estimated at between 28-63 billion tons (between $41x10^{12}$ and $92x10^{12}$ m^3) (Ertan, 2020; Kılkış, 2020). Assuming a retrieval ratio of just 50% and considering that there are six countries with continental shelves, the Turkish share is estimated between 7 and $15x10^{12}$ m^3 of hydrogen. (Ertan, 2020; Kılkış, 2020). Hydrogen has an exergy-based calorific value of almost three times more than natural gas (Kılkış, 2020). Therefore, on a natural gas equivalence comparison, the natural gas-equivalent net reserve for Turkey will be about 21 to $45x10^{12}$ m^3 of equivalent natural gas. This is almost 65 times more than the recently discovered Tuna-1 (Sakarya) natural gas reserve (Kılkış, 2020).

Furthermore, the yearly increase of H_2S gas reserve in the Black Sea is annually increasing by a rate between 4-9 million tons/annum (Ertan, 2020). Again, taking the lower estimate, this annual H_2S gas increase in the Black Sea is about nine times more than the Tuna-1 reserve. In other words, if H_2S gas is not used by renewables to produce hydrogen, Turkey will be missing nine natural gas reserve-equivalent energy reserves every year, which is a much cheaper-to-produce zero-carbon fuel. Furthermore, if H_2S gas with a self-ignition temperature of 505 K (232°C), highly volatile and combustible, is not removed from the sea stock, its great and irreversible

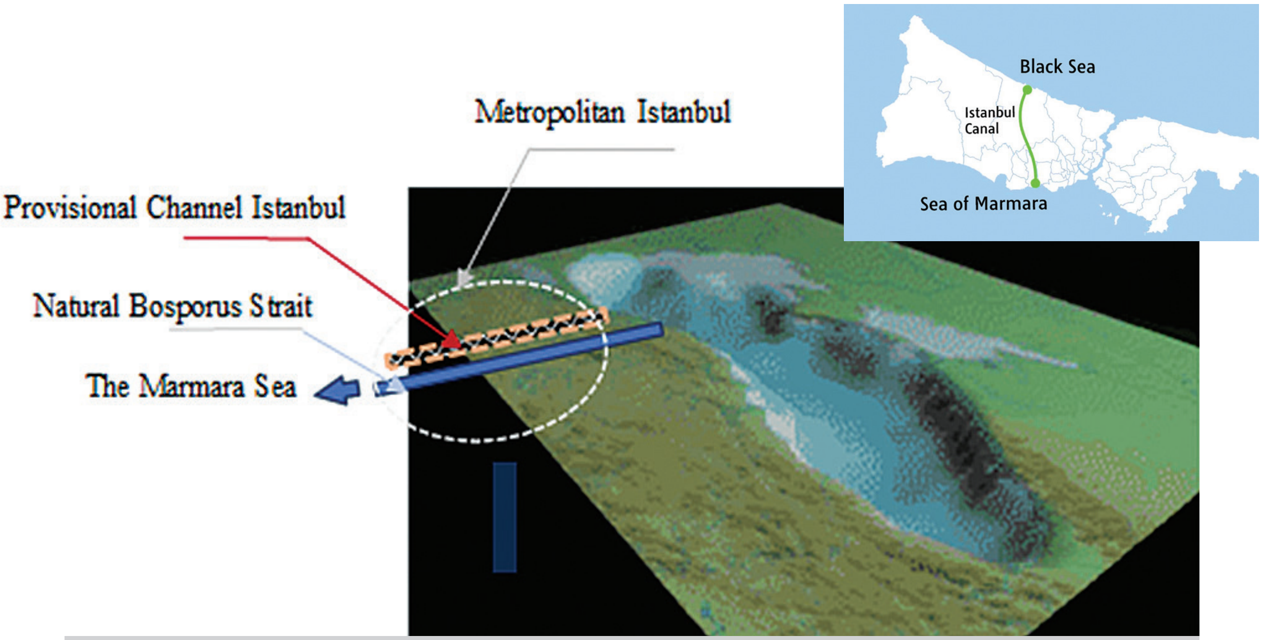

Figure 1: The Black Sea Bathymetry

threat to the population and the environment, marine life, and humanity will keep increasing. In a NATO ASI Book, edited by Veziroğlu and Tsitskishvili, several authors present the Black Sea as an important and potentially carbon-free energy reserve due to its high H_2S concentration in the seawater (Veziroğlu & Tsitskishvili, 2013). H_2S may be claimed onshore, off-shore, or below the seabed systems, even by using a deep-sea platform that utilizes a decommissioned submarine (Petrov et al., 2011). The Black Sea Hydrogen Sulfide Workshop (BSHSW) concluded that a common platform for concerted research including environment, energy, economy, and the overall feasibility, must be established by the surrounding countries, with a pilot system (Petrov et al., 2011; Yazıcı, 2013). A complete survey about the potential H_2S to hydrogen production in the Black Sea was also carried out (Yazıcı, 2013; Haklıdır & Kapkın, 2005).

Potential Threats of the H_2S Concentrations in the Black Sea

Figure 1 shows the unique sea bed bathymetry. The shelf depth is between 0 to 160 meters. In terms of concentration, Black Sea contains a very large amount H_2S gas that any ocean or sea has not and this concentration increases every year.

The Current Situation

The connection from the Black Sea to the Marmara Sea is a narrow, natural waterway, named the Bosporus, which plays a vital role in the entire ecosystem. There are two counter flows, one above the other which do not mix in the Bosporus, namely an upper flow towards the Marmara Sea and a bottom flow from the Marmara Sea to the Black Sea. The cooler upper flow transports fresh and less salty water (average is 19‰), mainly from rivers like the Danube river to the Marmara, then to the Aegean Sea, and the Mediterranean Sea.

This flow refreshes the Mediterranean Sea, which is saltier (38‰). The warmer bottom flow transports the saltier water coming from the southern seas to the Black Sea. This is a perfect hydrodynamic balance, which has existed for thousands of years and keeps the Black Sea about 30 cm to 60 cm (mainly depending upon the season) above the Marmara Sea. The thin upper layer of marine water (about 200 meters) supports the unique biological life in the Black Sea ecosystem. The deeper and more dense water layers are saturated with hydrogen sulfide, that over thousands of years, accumulated from decaying organic matter in the Black Sea.

Provisional Canal Istanbul

The most potentially dangerous human activity is the recently planned Canal Istanbul, which is to be artificially opened almost parallel to the existing natural waterway, the Bosporus. Figure 2 is an estimate of the predicted early events after Canal Istanbul. The H_2S-rich layer might be hydrodynamically sucked in towards the Canal Istanbul and will jet flow through the small nozzle under the pressure of the potential energy from the Black Sea due to the difference in height of the surface levels of the two seas. Surface velocities in the Canal initially may exceed 14 knots (29 km/h). This flow will move high H_2S concentrations up to the surface level, thereby exposing all the flammability, explosive, and toxic dangers to the environment and the nearby settlements. The total potential energy that currently exists is about 0.8x103 terajoule (TJ). This potential energy did not find a route through the Bosporus, because of the well-balanced surface and bottom currents. If Canal Istanbul is going to be opened, this potential energy is estimated to be gradually released through the Canal.

Therefore, it is an urgent issue to dilute the H_2S gas concentration in the Black Sea itself without expanding the threat to the city of Istanbul and its surroundings and further down towards southern countries and seas.

H_2S gas -if decomposed to H_2 and S- is a great energy source, much better than natural gas and other fossil fuels if handled and utilized properly by using collocated renewable energy sources readily available in the Black Sea, namely wind, solar, and wave energy. In this case, all the activities must be in the Black Sea with minimal or no disturbance to the H_2S layer. This requires no hydrocarbon explorations with drilling activities and no hydrocarbon exploitation with off-shore gas platforms, all of which involve electromechanical actions penetrating through the H_2S layer. This limitation also includes off-shore wind

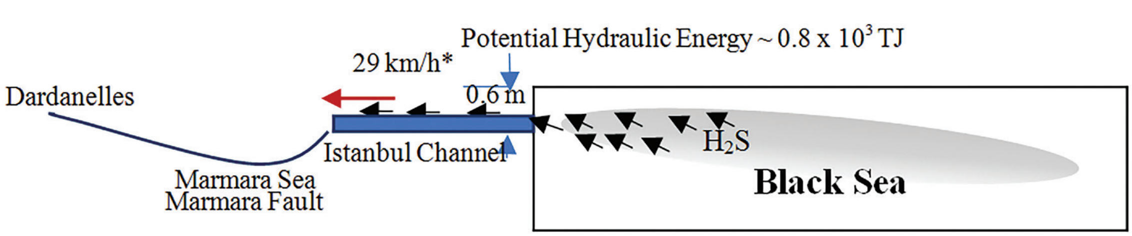

*Figure 2: H_2S Overflow Risk to Istanbul and the Marmara Sea through the Provisional Canal Istanbul The figure is not to scale) ©B. Kilkis *At the Initial Stages of the Canal Operation.*

turbines with rigid foundations to the seabed, which may disturb the natural water flows below the surface. In this respect, the most recent decision of hydrocarbon explorations in the Black Sea needs to be reconsidered until the H_2S problem is solved below a safer level. After all, natural gas or oil has CO_2 content and release net additional moisture to the atmosphere, both of which speed up global warming. Hydrogen is a clean-burning, very high calorific value gas with minimal global warming footprint compared to fossil fuels, and water is the only output. It may be argued that hydrogen combustion also emits moisture, but this water release results from the closed water loop, which uses the original quantity of water consumed for decomposing it to hydrogen. So, the net moisture release, with twice the greenhouse effect, compared to CO_2 emissions, is nearly zero, provided that it is generated from natural reserves and renewable energy sources.

Hydrocarbon Economy versus Hydrogen Economy

-Natural Gas Explorations. Recently, natural gas explorations, both in the Mediterranean Sea and the Black Sea, are increasing. Ship engines having much longer piston strokes, generally use marine diesel oil (MDO). Onboard the exploration ships, as with all other ships in the stock, this type of fuel is used with limitations on NO_x and particulate emissions both for steering the ship, for its domestic uses, drilling for pilot and natural gas wells.

The drilling process, as well as all domestic demands, mainly consumes electricity by using the same type of marine diesel oil in electric generators and only a few ships use combined heat and power (CHP), or trigeneration units for domestic cooling purposes. When the natural gas reserves are found, another off-shore gas platform extracts the natural gas and prepares for shipment by ships, by fixed or semi-floating pipelines to the shore using pumps, all of which consume part of the exploited natural gas. On the other hand, caution must be taken for handling hydrogen to prevent leakages during storage, transport, and use.

Hydrogen economy in the Black Sea has no drilling costs because no drilling is necessary to reach the H_2S concentrations at the sea.

As a result, both natural gas or any other hydrocarbon fuel exploration ships and off-shore gas platforms will be responsible for global warming in terms of CO_2, SO_x, NO_x, particulate emissions, as well as moisture. On the contrary, H_2S exploration and rational utilization of hydrogen after generating from on-board renewables in a complete hydrogen economy (both on the seaside and the landside) will be almost a zero-hydrocarbon application.

-Business as Usual Scenario: Hydrocarbon Economy. Hydrocarbon exploitation activities like natural gas exploration, drilling, exploiting, transferring, and consuming the fuel in the built environment have average rational use of the quality of energy sources value of 0.2 (world average) (Kılkış, 2020). Considering both direct and avoidable CO_2 emissions, due to quality destructions in such applications, the off-shore CO_2 emissions responsibility higher than the hydrocarbon reserves will be about 1 kg CO_2 for each kW-h.

-Hydrogen Economy Scenario. The hydrogen economy on-board a conceptual hydrogen mother ship will be self-sustaining with nearly zero environmental footprints, excluding the embodiments of the system and equipment. Hydrogen economy in the Black Sea has no drilling costs because no drilling is necessary to reach the H_2S concentrations at the sea, except

small-radius cruises of the mother ship to follow the maximum concentration and optimum depth within the sea shelf of every nation bordering the Black Sea.

Costs and Environmental Impact of Natural Gas Exploration Compared to H_2S: Cost of Hydrogen Ships

The only major cost is the specially designed and constructed hydrogen ship. There is no need for deep-sea electromagnetic and sonic exploration shipbuilding costs, no pilot drilling and production well drilling costs. The operation costs of the hydrogen platform are comparably low. The only CO_2 responsibility is minor exergy destructions related to onboard activities.

Black Sea Wave Energy and the Black Sea Composite Map

For renewable energy, H_2S, Water, and Hydrogen Nexus, it must be noted that the Exergy-Maximum H_2S Exploration Field lies within the Turkish continental shelf. Marine Renewable Energies and the Black Sea topic has been also of interest to the EU. For wave energy east of the Turkish Black Sea, lignite and geothermal reservoirs on the land close to the shore are also in the same area on the land side (Sinop and Zonguldak Provinces). For wind energy though, along the middle region of the Turkish coastline, the Black Sea has the highest potential. The potentially optimal region is shown by the square box in Figure 3. This box is within the Turkish continental shelf. Solar energy insolation level, In, which is around 500 W/m_2, is not too feasible in the Black Sea.

Hydrogen Ship with 100% Renewables for the Black Sea

General Concept and Layout

Figure 4 shows a not-to-scale plan view of the hydrogen ship, which has a semi-catamaran hull.

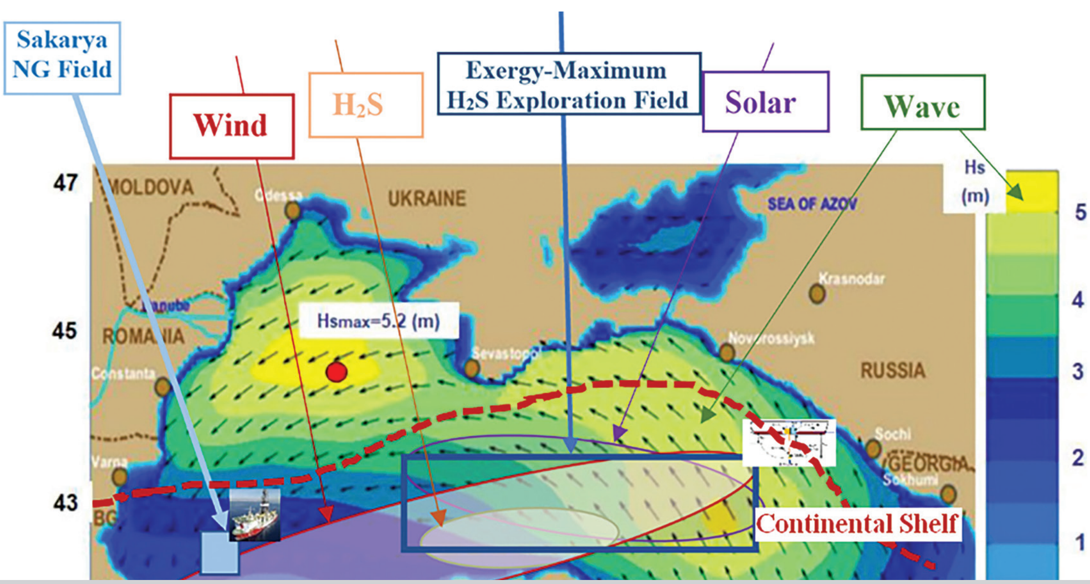

Figure 3: Composite map of renewables overlaid with wave energy for exergy-maximum H_2S exploration field. The Figure also shows the most recently discovered natural gas field by TPAO with 320x109 m^3 reserve. (Announced on August 21, 2020)

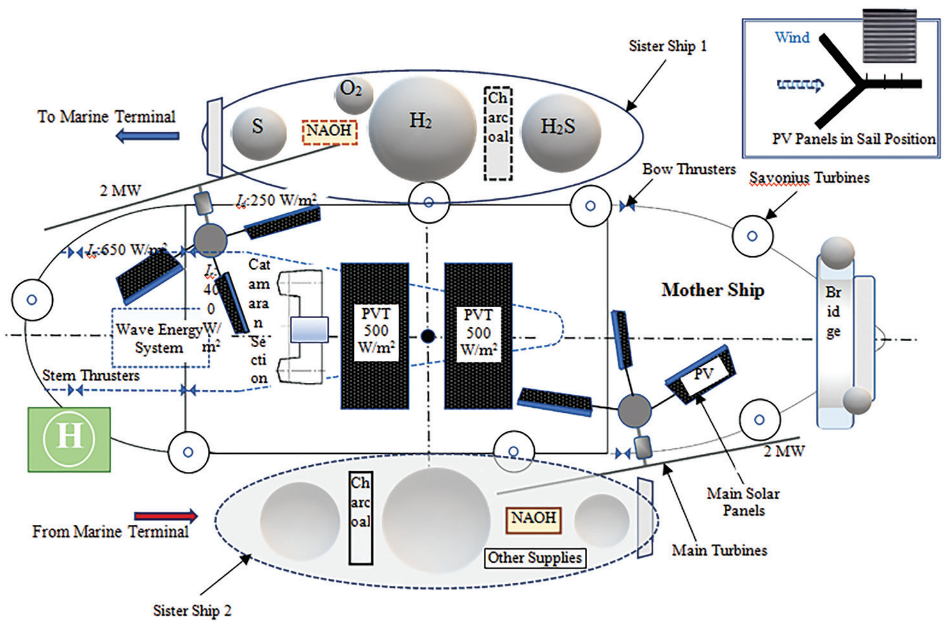

Figure 4: On-board, all hydrogen, all renewable semi-catamaran energy ships for hydrogen and sulfur production in the Black Sea [Patent Pending]. The figure is not to scale ©Birol Kilkis

For each mother ship, there are two sister hydrogen ships for transporting hydrogen, sulfur, oxygen, and H_2S to the landside through their marine terminals. The set of these sister shuttle ships has separate H_2, H_2S, O_2, and S tanks and supply material chambers. They shuttle between the mother ship and the marine terminals alternatively as hydrogen-sulfur transfer ship and logistics ship on their return to the mother ship. One ship stays with the main ship while it is charged with hydrogen and sulfur. When the second shuttle ship arrives back with supply material like charcoal and other chemicals, it departs and the cycle continues (Kılkış, 2020).

All ships can navigate and operate independently on their hydrogen power. Each mother ship of comparable size to the Fatih exploration ship has two main twin-blade wind turbines with fixed axes. They are mounted on the ship such that their moments are canceled at the center of gravity of the mother ship. Twin-blade wind turbines are noisier on the land and they have not been preferred. However,on the seaside noise is not a problem for the coastal regions. Savonious type of turbines on the starboard and port side of the deck complement the wind energy system. There are embedded pressurized-air tanks inside the hollow, tubular main wind towers to store pressurized air derived from the wave energy system, by which an air turbine is driven for generating electricity. Thus, the hybrid 100% renewable energy system has also a fourth dimension, namely mechanical energy storage. The wave energy system is located in a vertical position on the catamaran section of the hull. It is a vertical, piston-crank mechanism type of air pumping system and operates only when the mother ship is at a stop or at a dead-slow motion. Otherwise, it is retracted up to eliminate drag during normal cruising. Main solar panels track the sun, rotating around the towers. On each tower of the wind turbines, there are three main PV panels mounted symmetrically at 120° between them. They can rotate together around the tower and they can independently adjust their azimuth angles, controlled by a central control system. As an emergency case during cruising, these PV panels may be positioned such that two of them act as a wedged sail (See the inset in Figure 4). During the nighttime when solar energy is not available, panels are brought to a vertical position for cruising by sailing. During daytime, solar panels are adjusted to their optimum inclinations, considering the mechanical wind-sailing effect versus maximum DC (direct current) power generation from the sun, if wind energy is available and cruising is required. They may also be rotated for steering the ship. Under normal operations, one PV panel tracks the sun in azimuth, the second one tracks the reflected sunshine from the sea, and the third one tracks the ambient solar light. Two additional horizontal PVT panels are laid on the deck. These also provide low-temperature heat for domestic uses (Kılkış, 2020).

Another option is to lay additional PV cells on the inner roof of the catamaran end facing the sea surface to absorb reflected sunlight. As a precaution to helicopter pilots, their approach line versus sun glare from solar PV panels alongside standard wind turbine lighting must be applied according to international aviation regulations. All ships operate on DC mains (Kılkış, 2020).

The electrical exergy demand of the circulation pump for waste heat retrieval at the bottom of the wind turbine tower must be less than the exergy of the waste heat retrieved. A computer-controlled adjustment of pumping flow rate is necessary for this kind of application.

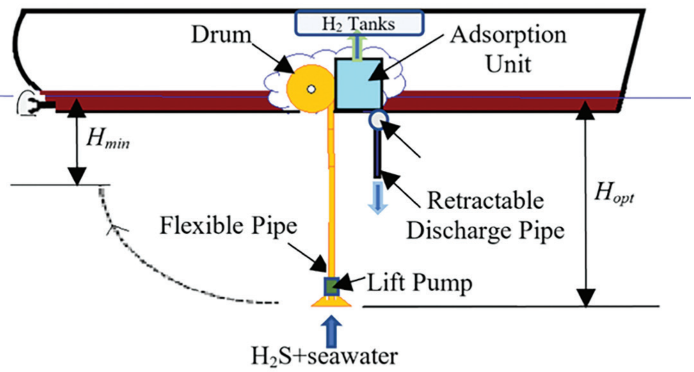

Figure 5: Flexible and retractable H_2S claim system of the mother ship. The figure is not to scale ©Birol Kilkis

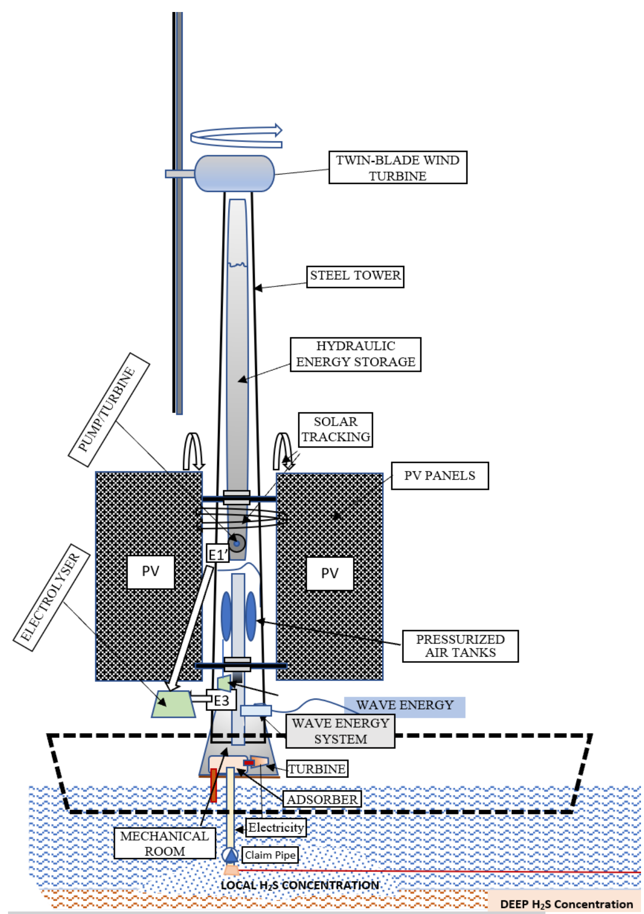

Figure 6: Hydrogen city integrated, off-shore renewable energy system for Black Sea H_2S reserves (Artist`s conception, Patent Pending): 100% renewable energy system principles. The Figure is not to scale ©Birol Kilkis

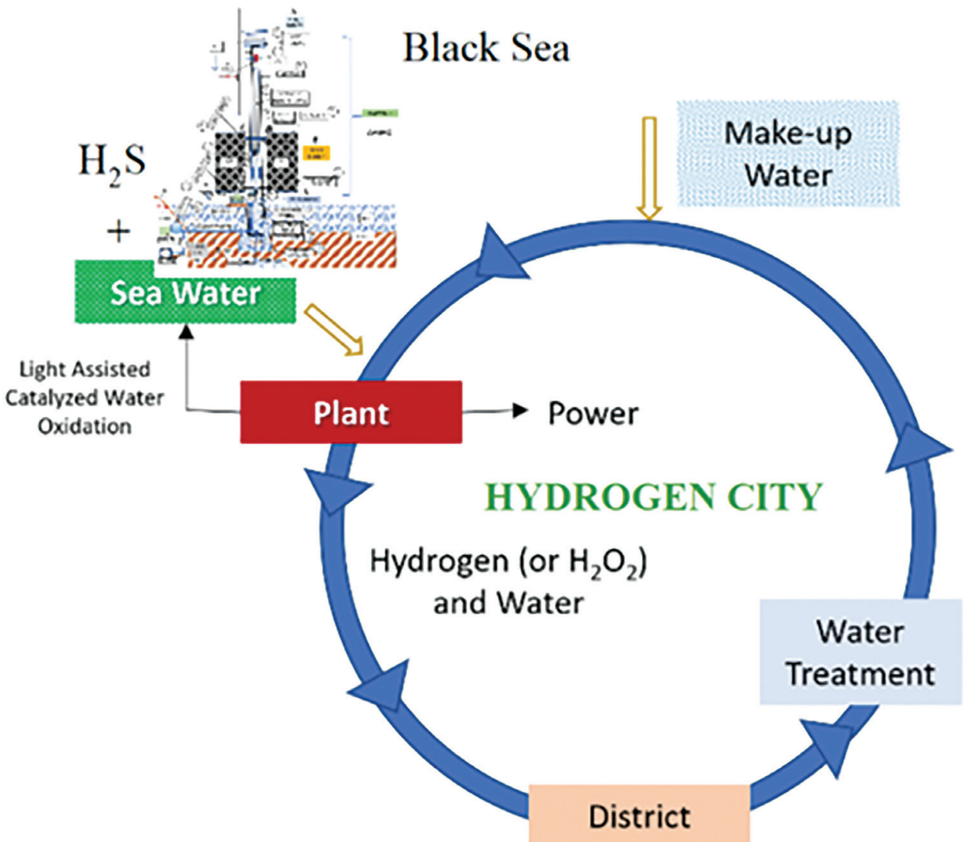

Figure 7: Land and sea cooperation for complete water nexus ©B. Kilkis

In wintertime, the heat generated in the nacelle may be used to warm the electromechanical system only. Fuel cells generate electricity from hydrogen, while the waste heat can be utilized for onboard domestic uses. The specially designed or retrofitted hydrocarbon exploration vessel is driven by electric power, which is supplied collectively from fuel cells, renewable energy systems, and CHP units, which are also driven by hydrogen energy. Hydrogen-fueled CHP is a backup for power and domestic heat demands in the ship.

Hydrogen energy is generated in two steps, namely by electrolysis of seawater and absorption of H_2S+seawater. This system with H_2 storage tanks makes the solar, wave, and wind energy collocation on the mother ship, which is shown in Figure 4. A flexible piping system with a lift pump(s) rises H_2S+seawater mixture from the optimum claim depth for maximum concentration. Optimum depth is adjusted by both winding the flexible tube around a drum and also bending it with an adjustable pull rope as shown in Figure 5. The optimum claim depth, Hopt is adjusted by a combination of winding or unwinding the flexible pipe and at the same time swiveling it backward or forward. The discharge is made by a deployable discharge pipe with its dedicated pump. Figure 6 shows the wind turbine tower with four functions. Depending upon year-round climatic conditions, exergy-based techno-economic feasibility, size of the ship, etc. additional DC power may be obtained by thermoelectric generator (TEG) elements and/or organic rankine cycle (ORC) turbines by utilizing the heat generated in the nacelle of the wind turbines by electro-mechanical drives.

Land Side

Coupled with biogas, wind turbines, PVT panels, geothermal, and lignite for hydrogen, the hydrogen city completes the hydrogen economy circle with almost-zero carbon emissions responsibility.

The Black Sea and Belt and Road Connection

The Black Sea has an important role in the Belt and Road Initiative in several aspects. First of all, the Black Sea -not only in terms of hydrogen technology but in terms of all energy types and forms- will act as a scientific and innovative crucible, and a role model for the world, for strengthening the economies of the countries along the Belt and Road by centralizing the focus on coordinating and strengthening research and

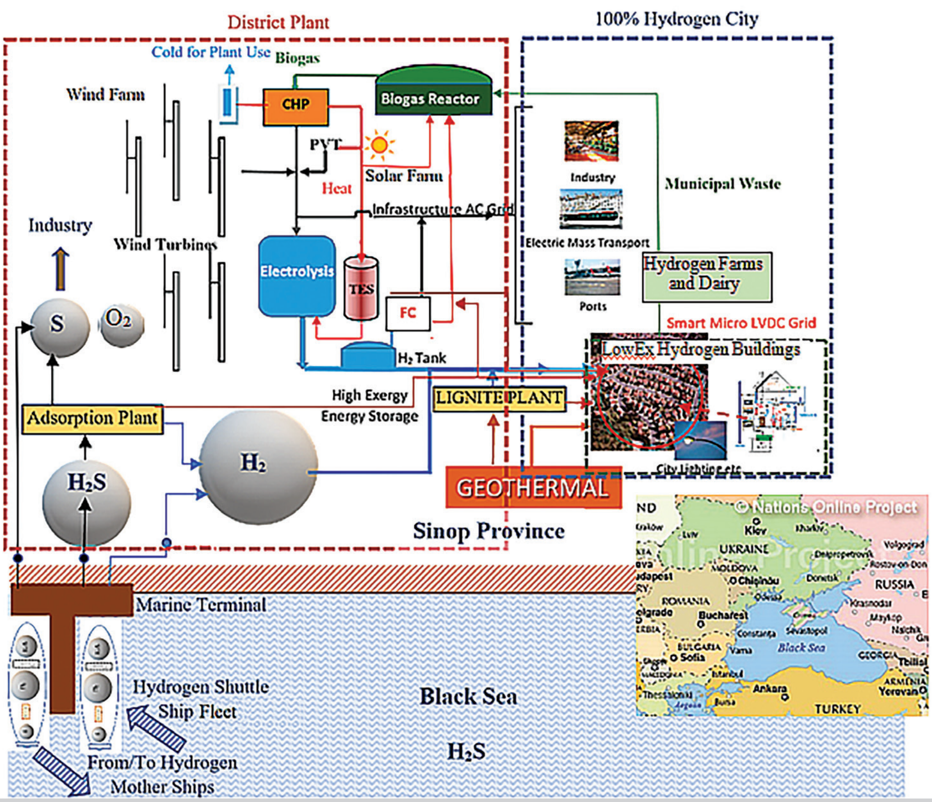

Figure 8: Land and sea cooperation for hydrogen economy ©2020B. Kilkis

innovation regarding renewable energy systems in an orchestrated manner while global warming agents are reduced. Such a monumentally productive task will be facilitated by the new Hydrogen Energy Center to be open in China in the near future. This center will be paired with the Sinop Hydrogen Research Center. These centers, in good coordination will accelerate the decarbonization efforts in all forms of energy. For example, China is considering replacing coal, wood, and lignite use in homes of Northern Climates with wind energy-driven electric heating. This idea was critically reviewed earlier because the direct electricity-to-heat conversion is not rational among other integrated solutions of better ways of utilizing wind power. As in this example, these new centers will lay the foundations of teaching and discussion grounds in such a manner that hydrogen storage may be more feasible to utilize wind power, including heating at the end of the energy utilization chain, including farming, and light industry.

On the other hand, China and all other Central Asian countries are rich in geothermal energy. These centers may develop innovative solutions by combining and linking all the Belt and Road countries with their renewable assets and expertise about geothermal, solar, and wind power. By doing so, they can share the wealth, and develop clean cities as exemplified above in this paper regarding the Hydrogen City of Sinop. As already shown in Figure 8, this city concept is not all about hydrogen but all about an optimum and rational combination of local renewables and fossil fuel resources like geothermal, solar, wind, biogas, wave energy (if available), and local industry, all facilitated by cogeneration, fuel cells, heat pumps, and circular hydrogen economy.

Hydrogen in the Black Sea is not just hydrogen but is an important eye-opener and catalyst for the Belt and Road Collaborative actions to be taken for its sustainable and continuing future. (Source: Pexels website)

China and all other Central Asian countries are rich in geothermal energy. These centers may develop innovative solutions by combining and linking all the Belt and Road countries with their renewable assets and expertise about geothermal, solar, and wind power. (CGTN, 2018)

In the future, the new Center in China may also get involved in the hydrogen-nuclear relationship and boron as a safety and energy storage medium. Turkey for example is already exporting boron by using the railroad link to China over the Belt and Road Initiative. Geothermal energy may also provide lithium more cleanly in deep wells for electric mobility, including electrical mechanization of farms in all Central Asian countries as well as Turkey, and beyond. Freight trains, transport trucks from one end to the other may be electrified with renewable energy. Even ordinary jet fuel may be produced by a combination of hydrogen and certain local industrial wastes (Ertan, 2020). This is also important for future regional and international airports linking all countries in the Belt and Road region from far east to west using their existing air transport fleet without any need for modification of the planes. At the same time, the Black Sea will open an exemplary Belt-Road as an innovative web of land, rail, sea (Black Sea and Caspian Sea), air (with strategically located new airports), and rivers (the Danube for example) spanning across the two continents, namely Asia and Europe, and even beyond. The Black Sea will be the last but the most important link of this web of economics, environment, clean cities, health, and wealth. At the same time, six Black Sea countries may find this web useful for furthering more peaceful share of resources, technology, and research. The Black Sea link concept may also be combined with the Five Seas Strategy, which may further expand the Belt and Road Initiative to Southern Latitudes by sea.

To the understanding of the Author, hydrogen in the Black Sea is not just hydrogen but is an important eye-opener and catalyst for the Belt and Road collaborative actions to be taken for its sustainable and continuing future.

Conclusions

• If hydrogen and hydrocarbon economies are simultaneously mobilized at an optimum mix, much more power and national pride without international conflicts may be achieved.

• Hydrogen economy in the Black Sea will also reduce the potential risks of this combustible and flammable H_2S gas at no cost as a bonus for the hydrogen economy.

• No oil platform costs and operating expenses, no drilling and seismic exploration expenses.

• Much cleaner cities with nearly-zero-carbon emissions.

• Hydrogen infrastructure will use the existing natural gas infrastructure with about one-third of the natural gas capacity, leading to less maintenance and repair costs. A 20% mix of hydrogen by volume to the existing natural gas lines will save about 60% natural gas and proportionate savings of operating and maintenance costs, while the same exergy demand compared to natural gas is satisfied without any energy compromise.

• If money continues to be the first in the agenda of politicians and economists, then the following argument holds:

The hydrogen economy is the most sustainable, cheap, and environmentally safe solution, especially for the Black Sea countries.

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