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A Model for Green Hydrogen Production.

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Abstract:
Recognized as a cornerstone of the long-term energy market, green hydrogen serves as a versatile energy carrier, storage medium, and fuel across various sectors. Despite substantial progress, challenges persist in scaling up green hydrogen applications due to factors such as production costs and efficiency. The paper examines different green hydrogen technologies, comparing their advantages and limitations, with water electrolysis emerging as the most promising method for large-scale hydrogen generation.
The concept of a "hydrogen economy" envisions hydrogen as a fundamental component of the energy landscape, offering energy security and environmental benefits.
The paper proposes a phased approach for integrating green hydrogen into key sectors such as industry, transportation, buildings, and power generation. It emphasizes the pivotal role of green hydrogen in realizing a renewable energy society and outlines its potential contributions across various domains. However, challenges persist in standardizing the definition of "green hydrogen" complicating international trade and policy formulation. While consensus exists on hydrogen production from renewable sources, harmonizing the definition remains elusive, necessitating concerted efforts in standardization and policy coherence, addressing technical, economic, and policy challenges is imperative to unlock its full potential and accelerate its widespread adoption on a global scale.

Keywords: Green Hydrogen. Hydrogen Policies. Renewable energy, Decarboniztion

Introduction:
-In 2019, worldwide energy-related CO2 outflows come to 33.3 metric gig-tons (G-t) every year, developing at a rate that's anticipated to raise Earth's temperature by a few degrees without mediation [1]. The trouble in diminishing outflows in energy-related divisions is generally due to a worldwide reliance on fossil powers, which contribute to the larger part of CO2 emissions, particularly within the control, buildings and warming, transportation, and industry divisions appeared in Figure 1a. As such, numerous nations have been pushing toward the usage of renewable vitality advances, which seem lead to the jolt of numerous end-use forms with control inferred from clean sources. In any case, due to the differing applications of fossil powers, numerous segments that are troublesome to decarbonize by power alone.

-One elective to fossil fills is 'green' hydrogen, which can be delivered through water electrolysis by utilizing an electric current to part water into hydrogen and oxygen with no nursery gas emissions, provided the power utilized to control the method is totally from renewables. Hydrogen's tall mass vitality thickness, light weight, and effortless electrochemical change allow it to carry vitality over geological locales through pipelines or within the frame of fluid powers like alkali on cargo ships [2]. Over segments because it can be utilized as a chemical feedstock, burned for heat, utilized as a reagent for engineered fuel generation, or changed over back to power through fuel cells. Moreover, hydrogen's long-term vitality capacity in tanks or underground caverns [3] makes it one of the as it were green innovations that can store energy over seasons.

-This drove numerous noticeable researchers and financial specialists to propose a future in which gas will be the most arranged within the fight against climate alter [4,5]. Acceptance of hydrogen will serve as the essential vitality capacity innovation, the central warming fuel, and the driving transportation fuel for cars, trucks, airplanes, and more. The staunchest adversaries to this logic counter that hydrogen will have no down to earth put as a future vitality innovation due to tall generation costs and wasteful aspects in its transformation to and from power [6,7, 8].

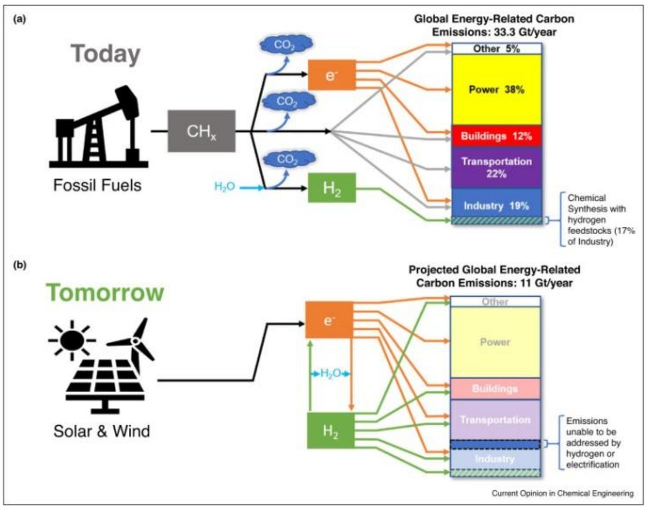
-These researchers argue that imaginative endeavours ought to centre specifically on renewable energy and battery advances, cutting out hydrogen as a go between. We discover the foremost common sense philosophy lies in between these two extremes. The inalienable wasteful aspects of hydrogen generation and transformation show that anything that can be utilize renewable vitality will be. There are a vast number of regions that renewable vitality cannot reach without a bridge. Hydrogen has the potential to fill these holes within the decarbonization exertion since it has a characteristic adaptability as both a chemical and a non-emissive vitality carrier. In our taking after calculations, we extend that the worldwide hydrogen demand could reach over 2.3 (Gt) yearly, compared to the 88 Mt per year utilized nowadays [9].

-The concept of 'hydrogen economy' was initially created by John Bockris within the 1970s. It depicted a vision in which hydrogen is created through water electrolysis and through pipelines to production lines, homes, and fueling stations where it would be changed over back to power in on-site fuel cells. Countries like Japan have put forward plans for a 'hydrogen society', in which hydrogen is the major component of the nation's auxiliary vitality system outlined in their Vital Vitality Arrange [10]. Researchers at the National Renewable Vitality Research facility of the U.S. Office of Vitality have proposed a vision characterized as H2@Scale, in which hydrogen is joined into segments such as lattice control, industry, and transportation but gives additional benefits like vitality security [11].

- In examining the colloquial and proficient utilize of these terms for hydrogen future inside distributions, there's small assentation as to what precisely these terms cruel. Within the vision that takes after, we are going characterize a vitality 'economy' to describe the production, consumption, conveyance, and agreement arrange of a specific vitality carrier and its subordinate segments, counting the resultant trade, financial, and natural impacts. - A vital 'society' is backed upon a few of these economies, where a particularly dominant economy can characterize a society by being profoundly coordinates into its culture and lifestyle. Our examination appears that hydrogen will not be the biggest player within the worldwide vitality framework. Instep, we foresee a green hydrogen economy in which hydrogen will fill a secondary part as the cornerstone that's vital to empower a 100% renewable vitality society.

As appeared in Figure 1b, hydrogen and the hydrogen economy is not a removed concept; or maybe, the current hydrogen economy will scale up to support future request. Underneath is our subjective vision for the integration of green hydrogen into the industry, transportation, buildings and heating, and control segments in a three-phase handle. To begin with, green hydrogen must be executed in sectors such as the chemical amalgamation industry, where there's right now a critical request for hydrogen universally, 96% of which is 'gray' hydrogen created from oil, coal, and steam methane reforming [12].

Before long after, hydrogen could help decarbonize the transportation segment with heavy-duty and long-range fuel cell vehicles, as well as the buildings and heating sector through blending with common gas pipelines for warming. Within the long-term, hydrogen may have an expanded nearness within the transportation division on the off chance that it is used to create electro fuels (e-fuels) for flying applications, and it can be utilized to create high-grade warm for mechanical forms. At this point, it'll enter the control sector, serving as a strategy of regular vitality capacity and lessening the curtailment of renewable vitality to permit for near-total decarbonization of the vitality sector. Electricity will work to benefit all energy-related divisions.



-Figure 1a & 1b: Energy Sectors of Today and Tomorrow.

-Methods of Research and the tools used:

-Experiment: Electrolysis of water to produce green hydrogen gas.

- Theoretical part:

-Aim: To Demonstrate the Electrolysis of water using renewable energy sources or it's alternatives to produce green hydrogen gas [13].

-Scientific idea: Electrolysis is a technique used by scientists to separate a compound or molecule into its component parts. By adding electricity to water and providing a path for the different particles to follow, water can be separated into hydrogen and oxygen. Electrolysis occurs in a unit called "Electrolyzer"[14].

-At the node:

Oxidation process

$$2H_2O_{(L)} \rightarrow O_2(g) + 4H^+(aq) + 4e^-.$$

-At the cathode:

Reduction process

$$2H_2O(L) + 2e^- \rightarrow H_2(g) + 2OH^-.$$

-Net equation:

$$2H_2O(L) \rightarrow 2H_2(g) + O_2(g).$$

-Aim: To Demonstrate the Electrolysis of water using renewable energy sources or it's alternatives to produce green hydrogen gas [13].

- Practical Part:

-Materials:

1-Power source (Li battery) 5 batteries connected in series.

2- Distilled water
3- Electrolysis chamber (beaker).
4- 4-Acetic acid (vinegar).
5- 5-Two electrodes (typically lead or graphite).
6- Two alligator clips (wires) (black and red).
7- Test tubes or gas collection apparatus. Safety goggles and gloves.
8- Ruler.

-Note:

Instead of solar panels we used li batteries, due to unavailability of solar panels. -
Lithium ion batteries are often touted as a greener alternative to conventional Lead-acid batteries due to Their higher energy Density and prolonged lifespan, which reduce the need for frequent battery replacement and lower overall environmental impact. So, it's a good alternative solution of solar panels.

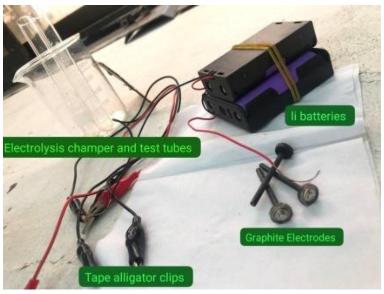


Fig. (2): Materials Used.

-Procedures:

1- Set up the electrolysis apparatus according to the manufacturer's instructions. Ensure all connections are secure.

2- Fill the electrolysis chamber with distilled water.
3- Add 10 mL of acetic acid (vinegar) to make the solution slightly acidic and enable it to conduct electricity. 4- Connect the two electrodes to the power source via alligator clips, where the red one refers to the positive terminal and the black one refers to the negative terminal. Make sure one electrode is connected to the positive terminal (anode) and the other to the negative terminal (cathode).

5- Place the electrodes in the water, ensuring they do not touch each other.

6- Turn on the power source.

7- Observe the electrolysis process. Bubbles should form at each electrode.

8-Collect the gas produced at each electrode separately. One electrode will produce hydrogen gas (at the cathode), while the other will produce oxygen gas (at the anode).

Fig (3): Electrolysis of water to produce green hydrogen gas.

-Safety Precautions:

1- Wear safety goggles and gloves to protect eyes and skin.

Ensure proper ventilation in the experimental area to prevent the accumulation of gases.

3- Handle the electrolysis apparatus and electrical connections with care to avoid electric shock.

4- Do not use tap water or any water with impurities, as it may affect the electrolysis process and damage the equipment.

5- Do not inhale the gases produced during the experiment, as hydrogen and oxygen can be flammable.

-Results :

-Table (1): The volumes of oxygen and hydrogen gases released upon water electrolysis.

Time (min)	Vol. of oxygen (cm^3)	Vol. of Hydrogen (cm^3)
0	0	0
10	0.1	0.2
20	0.5	1
30	0.9	1.8
40	1.8	3

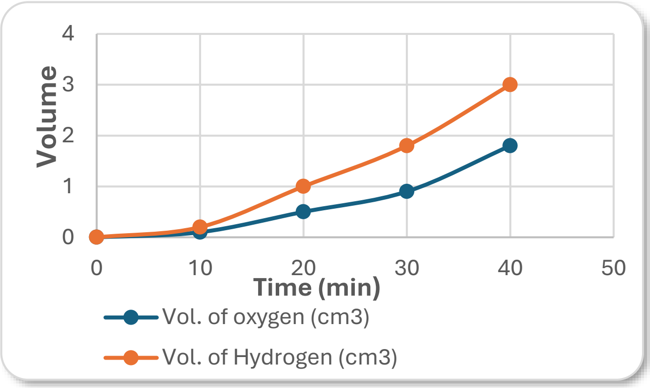


Figure (4): The volumes of oxygen and hydrogen gases released upon water electrolysis.

-Comment: We have successfully demonstrated the electrolysis of water to produce hydrogen gas at the cathode and oxygen gas at the anode. This process highlights the potential of using renewable energy or its alternatives to generate green hydrogen, which has promising applications in sustainable energy systems.

-Scan QR code to watch our experiment

-Experiment: Reaction of sodium hydroxide with aluminum metal in the presence of water.

-Theoretical part:

-Aim*:* to produce green hydrogen in an easy and simple way without emitting any harmful or polluting gases.

-Scientific idea: Hydrogen gas is produced at the surface of aluminum as a result of the reduction of water. This gas often bubbles up vigorously, indicating the reaction's energetic nature. The reaction is exothermic, meaning it releases heat. The production of heat and gas can be quite rapid and intense, sometimes enough to cause the solution to boil. This reaction is not only a classic demonstration in chemistry teaching for redox reactions but also has practical applications in generating hydrogen gas for fuel and in various industrial processes [15].

-Practical Part:

-Materials used:

1-Sodiumhydroxide (**NaOH**).
2- Aluminum metal **(Al)**.
3-Water (**H2O**).

-Tools:

1-Test tube.
2-Forceps.
3-Water
4-Protective glasses.
5-Gloves.
6-ballon.
7-Flaming splinter.

-Procedures:

1-5 gram of sodium hydroxide **(NaOH)** is placed in a test tube.
2- 5 gram of aluminum **(Al)** is placed in the tube using forceps.
3-3 ml of water **(H_2O)** is added to the tube.
4-Detection of gas produced by approaching a burning fragment.

-Equation of this reaction:

$$2Al + 2NaOH + 6H_2O \rightarrow 2NaAl(OH)_4 + 3H_2.$$

-Safety Precautions:

1-Wear safety goggles and gloves to protect eyes and skin.
2-Ensure proper ventilation in the experimental area to prevent the accumulation of gases.
3- Do not inhale the gases produced during the experiment, as hydrogen can be flammable.

-Results:

-When a burning fragment is brought close to the rising gas, it ignites with a crackle, which is evidence of the rising hydrogen gas.
-It is observed that hydrogen gas bubbles are released as a result of the reaction of sodium hydroxide with aluminum metal.
Sodium tetrahydroxidoaluminate is formed as a secondary compound and can be seen as a precipitate in solution.
-Producing green hydrogen without producing any harmful gases that pollute the environment.
The reaction is accompanied by the generation of heat, so observers can feel the temperature rise.

-Comment:

-Aluminum begins to react with the alkaline medium (sodium hydroxide) when a certain amount of water is added, resulting in the release of hydrogen gas produced by the reduction of water on the surface of the aluminium metal, and sodium tetrahydroxoaluminate precipitates. The rising hydrogen gas is considered green as it does not contain harmful gases such as carbon monoxide among its by-products. Thus, we have succeeded in producing green hydrogen in a simple and inexpensive way.

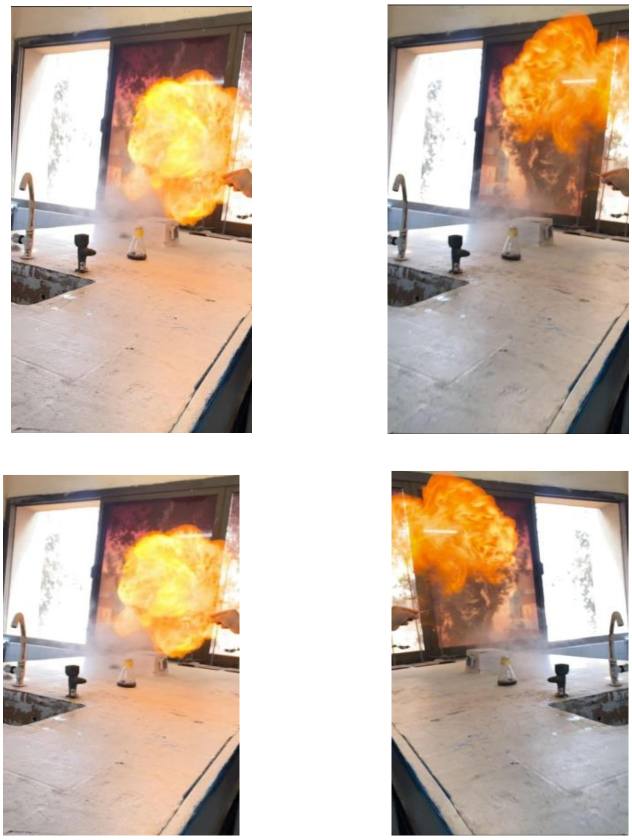


Fig. (5): Detection of green hydrogen.

-Scan QR code to watch our experiment

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-Discussion:

-GREEN HYDROGEN DEFINITIONS

The first reference we have found to the term green or renewable hydrogen was mentioned by NREL (1995), [16] who used the term renewable hydrogen **(hydrogen produced from renewables)** as a synonym for green.[17] The State of California (2006) defined green hydrogen as being produced cleanly and sustainably, using a renewable source such as solar or wind. The first mention of green hydrogen in EU policy documents is the declaration for establishing a green hydrogen economy in Europe (European Parliament, 2007). [18]

- Definitions of green hydrogen in the literature can be split into the **seven categories** listed in **Table 2.** There is not a harmonised definition, which in turn makes international trade and the inclusion of hydrogen in energy policies, more difficult. **In contrast,** the definition for **"black/brown"** hydrogen is more homogeneous and it is typically understood as hydrogen produced from fossil fuels feedstocks definition, with some sources also including nuclear power sources in this group [19]. Yet others categorise hydrogen from fossil, nuclear, and industrial residual gases as green, or **'clean'**, or 'blue' (World Energy Council, 2019), when their GHG emissions are sufficiently low [20].

-Aarnes et al. (2018) exclude **blue hydrogen** when CO_2 is used for enhancing oil recovery. Just 2 out of 7 of the categories in **Table 2** focus on GHG emissions reductions (with or without supplementary environmental targets), and are truly technology-neutral (include any production pathway) [21]. The remaining categories state that green hydrogen requires the use of **renewable pathways,** with or without caveats [22].

-The definition of renewable hydrogen is somewhat **more universal**, as it constraints the eligibility of pathways to renewables sources. Existing definitions can be used to define renewable sources, for example the EU Directive 2018/2001/EC (also known as RED2)
(European Commission, 2018).

However, additional eligibility criteria **(such as a carbon intensity threshold)** can also differentiate **(from a legal standpoint)** the different interpretations adopted by governments and standardisation bodies [23].

Definition
Any renewable sources
Any renewable energy sources with an

explicit mention to air pollution, an energy security and global-climate a problems
Any renewable energy sources with an explicit mention to low emission GHG intensity factors
Any renewable sources or any other net zero carbon energy through CCS and/or emissions offsets
Any renewable and nuclear sources
Any source (renewable or not) with an unspecified low immersion intensity.
Any low carbon energy sources with low environmental impact

Table 2.Green hydrogen definitions in the literature.

-Hydrogen generation:

Hydrogen can be created from different sources of crude materials counting **renewable** and **non-renewable** sources which are around 87 million tons/year.[24] Be that as it may, as of 2020, most of the hydrogen (95%) was delivered from non-renewable fossil powers particularly steam re-shaping of normal gas, transmitting 830 million tons/year of $CO_2$and the rest of the hydrogen was delivered from renewable assets counting water electrolysis [25].

-The major hydrogen generation strategies and their applications are as appeared in Fig 6. 1.Hydrogen is classified into diverse colour shades i.e., **blue, gray, brown, dark,** and **green** individually based on their hydrogen generation innovation, vitality source, and natural affect, as appeared in **Table 3** [26].

-The blue hydrogen is created from the steam changing of common gas. Amid this prepare, common gas is part into hydrogen **(H_2)** and carbon dioxide **(CO_2),** the created $CO_2$is captured **(85%–95%)** and put away underground utilizing mechanical carbon capture and capacity procedures and a few of the produced CO_2cannot be captured. In expansion, long-term impacts of capacity are dubious, and spillage can still adversely influence the environment and climate [27, 28, 29].

-The gray hydrogen is delivered from non-renewable fossil fills such as characteristic gas or coal by steam reforming/auto-thermal changing prepare, this prepare is comparative to the blue hydrogen handle, but the created CO_2 isn't being captured, it is straightforwardly discharged into the climate [30].

-Brown hydrogen is most copious in utilize nowadays, which is professionally-induced from hydrocarbon-rich feedstock **(brown coal or methane)** by means of the gasification prepare. But as a result, each tone of brown hydrogen discharges **10–12 tons** of CO_2into the climate. The dark hydrogen is created from coal gasification, amid this coal gasification handle syngas are delivered from the gasifier and the hydrogen can be isolated from the other gasses utilizing safeguards or extraordinary films and the remaining gasses can be discharged into the climate [31].

-Green hydrogen is created from renewable water and power by electrolysis prepare, in this prepare water is part into hydrogen **(H_2)** and oxygen **(O_2)** beneath the impact of power with zero carbon outflows.

Within the move towards worldwide decarbonization, these days renewable-powered green hydrogen generation is one way that's progressively being considered as a implies of diminishing nursery gas outflows and natural contamination.

Hence, there is an expanding intrigued to create the generation and utilization of this green hydrogen more versatile and flexible prepare. Water electrolysis may be a key innovation for splitting water into hydrogen and oxygen by utilizing renewable energy **(sun based, wind)** [32].

Sun based and wind energies are arranged and well **reasonable renewable** control sources for hydrogen generation through water electrolysis due to their far-reaching control dissemination.

The combination of renewable energy with water electrolysis is standard-titularly more profitable since excess electrical vitality can be put away chemically within the shape of hydrogen to adjust the disparity between vitality request and generation [33].

-Assist, the created hydrogen and oxygen can be straightforwardly utilized for the transportation and mechanical segment as essential vitality sources.

Hydrogen isn't as it were an essential energy source it is a vitality carrier that can be straight forwardly utilized in fuel cell vehicles and the mechanical division [34] .

Additionally, hydrogen can moreover be utilized as a feedstock in chemical and petrochemical businesses to deliver smelling salts and manufactured fills [35].

Separated from that, another advantage of hydrogen as an energy carrier is the expanded proficiency of hydrogen capacity frameworks when compared to batteries [36].

Hydrogen color shades and their Technology, cost, and CO_2 emissions.

Hydrogen Color	Technology	Source	Products	Cost ($ kg/H_2)	CO_2 emissions
Brown Hydrogen	Gasification	Brown coal (Lignite)	$H_2 + CO_2$	1.2–2.1	High
Black Hydrogen	Gasification	Black coal (Bituminous)	$H_2 + CO_2$	1.2–2.1	High
Grey Hydrogen	Reforming	Natural gas	$H_2 + CO_2$ (Released)	1–2.1	Medium
Blue Hydrogen	Reforming + carbon capture	Natural gas	$H_2 + CO_2$ (Captured 85-95%)	1.5–2.9	Low
Green Hydrogen	Electrolysis	Water	$H_2 + O_2$	3.6–5.8	Minimal

Table3:Hydrogen color shades and their Technology , cost ,and CO_2emission.

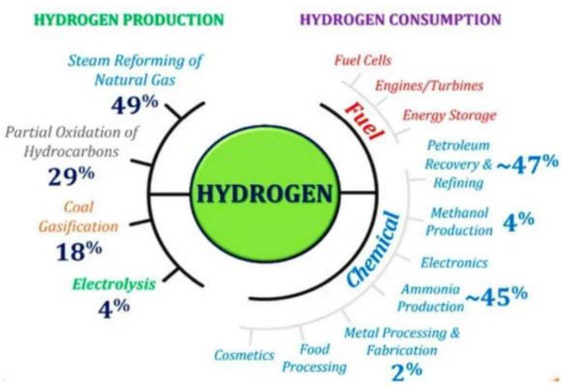

Fig (6): Hydrogen Production &Consumption.

-What is Green Hydrogen Utilized For?

Green hydrogen is getting to be a key component in bringing approximately vitality move and guaranteeing a feasible future. The diminished fetched of creating green hydrogen utilizing renewable energies, along with a drive towards diminishing nursery gas emanations, have given clean hydrogen an exceptional boost. [37]

This component will play a key part within the decarbonisation of different divisions such as industry, versatility, vitality storage.

We certainly have reasons to anticipate extraordinary things from green hydrogen. In a previous article on Supportability we as of now clarified what green hydrogen is, so here we'll go on to clarify a few of its benefits and employments.

-Benefits of green hydrogen

Within the age-old wrangle about between fossil powers and renewable energies, there is less and less contention against the last mentioned. In spite of the fact that there are a few misguided judgments encompassing renewable energies, one of their primary downsides is their dependence on natural elements. Sometime recently, in the event that there was no wind, there was no wind control [38]. In the event that it was night-time, there was no sun oriented control.

Within the nonappearance of being able to compel the sun to sparkle at night or summon winds that impel the edges of windmills at our will, endeavours are centred on finding an appropriate apparatus that permits overabundance vitality produced by great climate conditions to be put away so that it can be used for when conditions are less positive.

-The contender? Green

As we as of now clarified in this article, green hydrogen is gotten from renewable sources through electrolysis. Well, ready to store this clean hydrogen compressed in particular tanks. And afterward, when we require vitality, this component is channelled into a fuel cell, where we combine hydrogen with oxygen from the to deliver power and the as it were by-product delivered is water [39].

-Green hydrogen as fuel:

Much appreciated to innovations just like the fuel cell, green hydrogen is being utilized in transport, giving a feasible portability elective. Cars that run on this clean vitality have a hydrogen tank that interfaces to the fuel cell, where the power that powers the motor is created. Fuel cell electric vehicles **(FCEVs)** imply a transformation within the vitality and transport division towards utilizing fuel with a carbon-neutral impression. They as of now as it were account for 0.5 % of unused low-emission vehicle deals. In any case, as expressed by the Worldwide Vitality Office, the advertise for FCEVs is beginning to prosper. Hyundai has reported that it'll be fabricating 500,000 hydrogen vehicles by 2030, Paris has started creating a armada of taxis that run on this fuel and in a few European cities squander collection vehicles are as of now fuelled by this innovation .

Green hydrogen will moreover be key for mining vehicles, trains, aircrafts, Lorries, buses and indeed oceanic transport. [40]

-Green hydrogen in industry:

In expansion to the above-mentioned utilize as a vitality store, hydrogen is right now basically utilized in two divisions. One utilize is in the chemical industry for fabricating alkali and composts. While its second primary utilize is within the petrochemical industry to deliver petroleum items .Moreover, it is starting to be utilized within the steel industry, a segment which is beneath impressive weight in Europe since of its contaminating impact. Much appreciated to this gas, there's an opportunity to alter a few of the industry's forms to form them less forceful to the environment.

-Green hydrogen in household utilize:

With respect to household utilize, there are as of now a few economical ventures underway that point to supplant the common gas organize with a green hydrogen arrange that gives power and warm to families without creating toxin emanations .

-Green hydrogen is without a doubt taking a driving part within the decarbonisation of the economy. Undoubtedly, renewable energies will control the **post-COVID-19** world In any case, there are still challenges ahead with respect to its rollout diminishing generation costs, enhancing its capacity and sending negligible framework. There are some obstacles that we are going oversee overcome in order to cement green hydrogen as the vitality that's not of the long, run but of a more economical show. [41]

Sources: IRENA, Hydrogen Council

Fig. (7)

Expansion to hydrogen's utilization within the chemical and oil and gas segments, it can moreover be utilized in transportation applications such as Inner Combustion Motors (Frosts) and fuel cells.[42] Hydrogen fuel cells have colossal potential within the transportation segment to move forward the vitality effectiveness, essentially decrease nursery gas emanations, and eventually kill the utilization of fossil powers.[43] Not as it were can fuel cells be utilized in trucks, buses, and cars, but they can too be utilized to control electric ships and supplant diesel electric generators in trains .[44] Hydrogen fuel cells are seen as the foremost promising control source for next-generation automobiles within the hydrogen economy and the as it were innovation that encompasses a chance of equalling inner combustion motors **(Frosts).** Hydrogen's essential offering point as a fuel is its inherent appropriateness for utilization in fuel cells. A fuel cell vehicle fuelled by immaculate hydrogen is considered an emission-free vehicle since the as it were by-product is water. Whereas keeping up comparable characteristics in terms of top speed, extend, and speeding up, fuel cell vehicles are considered way more effective than ordinary vehicles .[45] Among the various classes of fuel cells, the Proton Trade Film Fuel Cells **(PEMFCs)** are considered the foremost reasonable for versatile applications due to their speedy reaction to stack changes, quick start-up, and exceptionally tall control by thickness.[46]

-PEMFC-powered vehicle inquire about is being carried out by car producers all over the world, with tests being conducted on both buses and cars to decide the mechanical and financial reasonability of this innovation. **In any case,** there are financial and specialized obstacles to overcome some time recently hydrogen fuel cell vehicles will be globally accessible. Headways within the hydrogen-powered vehicle innovation are market-driven and must compete with the routine vehicles by and by. [47] The lack of refuelling framework, the moo taken a toll of gasoline, and the rise in vehicle costs are all impeding the progression of hydrogen fuel cell technology vehicles. [48] Another major concern is how to supply hydrogen to fuel cells. The choices accessible are to either utilize the vehicle's fuel processor to create hydrogen or store hydrogen on board of the vehicles. Hydrogen can too be considered as one of numerous complementary low-carbon advances, beside on-site renewables, jolt, warm systems, and request decrease as an elective to warming with common gas or oil (Connell et al., 2022) .[49]

-Whereas the hydrogen showcase is ruled by oil refining and compost generation, there are still numerous other employments for hydrogen. We anticipate that over time the number of productive utilize cases for hydrogen will increment as development inside the industry drives down costs. [50]

-Hydrogen fuel cell innovation is one utilize case that incorporates a developing backing and takes after this drift. These fuel cells create power by combining hydrogen iotas and oxygen iotas. Hydrogen fuel cells can control vehicles as an elective to inner combustion motors.

Tragically, the need of fuel station framework and tall costs still make usage for traveller vehicles challenging. **In any case,** a few car companies and nations are setting targets for hydrogen vehicle advancement and generation. [51]

- Past fuel cells, the employments for hydrogen are shockingly flexible. These incorporate:
-Excitement and discuss transportation.
-as a lifting specialist.
-Nourishment industry
-for corrosive and base generation.
-Handling of plastics.
-Preparing of paints and varnishes.
-Welding-particularly of steel, with oxyhydrogen welding.
-Metal extraction from mineral.
-Therapeutic utilize-for hydrogen peroxide generation.
-Glass generation.
-Hydrogen Fuel Cells for cars.
-Fluid hydrogen as Rocket fuel. [52]
-Excitement and discuss transportation-as a lifting specialist.
-Nourishment industry-for corrosive and base generation.

Fig. (8)

- Nowadays, the essential employments of hydrogen are in petroleum refining and smelling salts generation for composts. Also, inquire about appears that the transportation and utility businesses are two fundamental markets that will see hydrogen vitality selection increment within the another a few decades. [53]

- What is green ammonia? Alkali may be a sharp gas that's broadly utilized to form agrarian composts. **Green alkali generation** is where the method of making alkali is **100% renewable** and **carbon-free.** One way of making green smelling salts is by utilizing hydrogen from **water electrolysis** and **nitrogen isolated** from the discuss. [54]

- One way of making green smelling salts is by utilizing hydrogen from **water electrolysis** and **nitrogen isolated** from the discuss. These are at that point nourished into the **Haber handle (moreover known as Haber-Bosch),** all fueled by maintainable electricity. Within the Haber prepare, hydrogen and nitrogen are responded together at tall temperatures and weights to create alkali, NH3. [55-56]

- In any case, the method of making smelling salts is right now not a **"green"** handle. It is most commonly made from **methane,** water and discuss, utilizing steam methane changing ***(SMR)*** **(to deliver the hydrogen)** and the Haber prepare. Roughly **90%** of the carbon dioxide delivered is from the SMR handle. This prepare devours a parcel of vitality and produces around **1.8%** of worldwide carbon dioxide emanations. [57]

-What's the long-standing time for green ammonia?

-The generation of green smelling salts might offer encourage choices within the transition to **net-zero carbon dioxide** emanations. These incorporate:

Vitality storage- smelling salts is effectively put away in bulk as a fluid at modest pressures **(10-15 bar)** or refrigerated to **-33°C.** This makes it a perfect chemical store for **renewable vitality.** There's an existing dissemination organize, **in which** smelling salts is put away in huge refrigerated tanks and transported around the world by channels, street tankers and ships.[58]

-Zero-carbon fuel :alkali can be burnt in an motor or utilized in a fuel cell to deliver power. When utilized, ammonia's as it were **by-products** are **water** and **nitrogen.** The maritime industry is likely to be an early adopter, supplanting the utilize of fuel oil in marine motors. [59]

-Hydrogen carrier :there are applications where hydrogen gas is utilized **(e.g. in PEM fuel cells),** in any case hydrogen is troublesome and costly to store in bulk **(requiring cryogenic tanks or high-pressure barrels).** Smelling salts is simpler and cheaper to store, and transport and it can be promptly **"cracked"** and filtered to deliver hydrogen gas when required. [60]

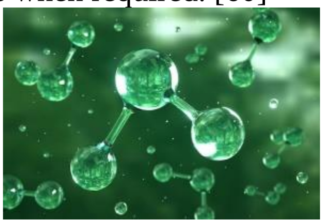

Fig (9)

-Storage Method:

-High-Pressure Hydrogen Capacity(Vaporous):

Hydrogen is compressed to tall weights for capacity in extraordinarily planned tanks. This strategy is ordinarily utilized for brief capacity and short-range transportation.[61]

-Fluid Hydrogen Capacity (Fluid): Hydrogen is cooled to exceptionally to temperatures **(-253 degrees Celsius)** to change over it into a fluid shape that can be put away at higher densities. Fluid hydrogen capacity is utilized when volume is **basic,** such as in transportation applications. [62]

-Chemical Compound Capacity (Chemical Capacity): Green hydrogen can be put away in chemical compounds known as hydrogen capacity materials. These materials incorporate metal hydrides and natural compounds. This strategy requires particular innovation to extricate hydrogen when required. [63]

-Hydrogen Capacity in Permeable Materials (Adsorbent Capacity): Green hydrogen can be put away in certain fluids that have retentive properties for hydrogen at particular weights and temperatures. [64]

-Hydrogen Capacity in Metal Hydrides (Hydride Capacity): Hydrogen can be put away in metal hydrides through the method of retention and desorption inside the structure of the hydrides. [65]

-Underground Salt Caverns: Hydrogen can be put away in huge underground salt caverns, comparable to the capacity of normal gas. Salt caverns offer tall capacity and are generally cheap to develop. [66]

-Hydrogen Capacity in Carbon Nanotubes: Carbon nanotubes can adsorb hydrogen atoms on their surfaces, giving a potential strategy for compact and proficient hydrogen capacity. Investigate in this region points to improve the capacity and energy of hydrogen take-up and discharge. [67]

-Hydrogen Capacity in Metal-Organic Systems (MOFs): MOFs are profoundly permeable materials with huge surface zones, making them reasonable for hydrogen capacity. Hydrogen atoms can be adsorbed inside the pores of MOFs, advertising potential for tall capacity. [68]

-Hydrogen Capacity in Fluid Natural Hydrogen Carriers (LOHCs): LOHCs are natural compounds that can reversibly tie and discharge hydrogen, permitting for secure and effective hydrogen capacity and transportation. Hydrogen is chemically reinforced to the carrier atom, empowering storage at encompassing conditions. [69]

-Hydrogen Capacity in Smelling salts (NH3): Smelling salts can be created utilizing green hydrogen and put away as a fluid at direct weights and temperatures. It offers tall vitality thickness and set up foundation for dealing with and conveyance, making it a promising hydrogen carrier. [70]

-These extra strategies give encouragement choices for putting away green hydrogen, each with its interesting characteristics and potential applications. Analysts proceed to investigate and create imaginative capacity advances **to address the developing request for renewable vitality capacity arrangements**

- The legitimacy of green hydrogen as a vitality source after capacity depends on the capacity strategy, conditions, and expecting utilize. Here are a few focuses that influence the legitimacy of green hydrogen after capacity.[71]

-Hydrogen Misfortune: Hydrogen can be misplaced amid capacity due to spillage from capacity frameworks or interaction with materials utilized in channels or tanks. Capacity frameworks ought to be carefully outlined to play down misfortune rates. [72]

-Fabric Security: Materials utilized in hydrogen storage must comply with security necessities and natural compatibility. Interaction between hydrogen and capacity materials can lead to framework disintegration and destructive impacts. [73]

-Vitality Misfortune: Put away hydrogen may be utilized in vitality transformations, such as creating power in fuel cells or combustion in inner combustion motors. In each transformation handle, vitality misfortune can happen due to wasteful operation. [74]

-Hydrogen Compound Debasement: In a few cases, hydrogen compounds may corrupt over time or beneath natural conditions, lessening their proficiency as a vitality source.

-Framework Accessibility: Satisfactory framework must be accessible for transporting, putting away, and utilizing hydrogen after era. This infrastructure incorporates coordination systems, pipelines, and offices to guarantee the accessibility of hydrogen as a vitality source.

-In rundown, the legitimacy of green hydrogen as an vitality source after capacity depends on a few components, and it is critical to require vital measures to preserve its quality and safety during capacity and utilization. [75]

-Ways of Transportation:

-Hydrogen can be transported using a variety of ways. Some of the most common modes include **transportation** using pipelines, tube trailers, ships/barges, and railways. We shall begin this article by first discussing gaseous Hydrogen transportation through tube trailers. [76, 77]

-Hydrogen can be transported as a gas **by using** tube trailers. As gaseous Hydrogen is produced at a **low pressure,** it must be compressed for **storage** into these **tubular vessels** for transport. The hydrogen in this process is compressed to around **180 bars (around 2600 psig (Pounds per square inch gauge))** or higher and then transported to the desired location through a trailer, hence the name **tube trailer!** The most common types of trailers are steel tube trailers, but recently composite tubes have been designed and constructed that have much higher capacities **(560-900kgs of H_2).** The ideal materials for these tubes have high tensile strength, low density and rarely interact with the hydrogen **(minimum H_2 evaporation).**
Some examples include austenitic stainless steel, copper, or Aluminium alloys [78,79,80] .

-Trailer based **transportation** is normally used to transport Hydrogen **over shorter distances (<1000kms)** between the production plants and the end usage site. This is because as discussed in our earlier article, gaseous hydrogen shows the lowest density of storage, and thus **cannot efficiently** store hydrogen **over long distances.** [81]

Fig (10)

-The **second method** of transporting Hydrogen is **using pipelines.** Pipelines can transport Hydrogen through much **farther distances than** tube trailers. The USA has almost **1600 miles** of Hydrogen pipelines, most of which are owned by merchant hydrogen producers. These pipelines are mainly concentrated where **large petroleum** and **chemical plants** are situated e.g., the Gulf Coast region. Hydrogen transport through pipelines is a **low-cost possibility** which could transport **large volumes** of the **gas over long distances.** This has made it a lucrative possibility amongst many countries, and thus has been used often for a **variety of applications** [82,83] .

Fig (11)

-Method of transporting Hydrogen is through **the process of liquefaction.** Hydrogen is stored as a **liquid in tanks,** and then transported to the destination through **liquid tankers.** The Hydrogen in this method is first liquified by cooling it to below -235 degree Celsius **(-423 degrees F),** and then sent to delivery trucks for transportation to various locations. At the end point, Hydrogen is then vaporized to a high-pressure gaseous product for use in applications such as **dispensing.** Trucking liquid Hydrogen over long distances is also **more economical** than transporting gaseous Hydrogen due to liquid H_2being capable of holding a larger quantity of hydrogen per unit volume. **The main drawback with liquid based transportation** of Hydrogen includes potential for the **"boil-off"** of Hydrogen from the container [84,85].

Fig (12)

-Advantages and disadvantages of green - hydrogen:

-This energy source has pros and cons that we must be aware of. Let's go over some of its most important good points:

-100% sustainable: green hydrogen does not emit polluting gases either during combustion or during production.

-Storable: hydrogen is easy to store, which allows it to be used subsequently for other purposes and at times other than immediately after its production [86].

-Versatile: green hydrogen can be transformed into electricity or synthetic gas and used for commercial, industrial or mobility purposes **However,** green hydrogen also has **negative aspects** that should be borne in mind:

-High cost: energy from renewable sources, which are key to generating green hydrogen through electrolysis, is more expensive to generate, which in turn makes hydrogen more expensive to obtain.

-High energy consumption: the production of hydrogen in general and green hydrogen in particular requires more energy than other fuels [87].

-Safety issues: hydrogen is a highly volatile and flammable element and extensive safety measures are therefore required to prevent leakage and explosions.

-Impact of green hydrogen:

Hydrogen as a fuel is a reality in countries like the United States, Russia, China, France and Germany. Others like Japan are going even further and aspire to become a hydrogen economy. ***Below we explain what the impact will be in the future:***

-Electricity and drinking water generator: These two elements are obtained by reacting hydrogen and oxygen together in a fuel cell. This process has proved very useful on space missions, for example, by providing crews with water and electricity in a sustainable manner.

- Energy storage compressed hydrogen tanks: are capable of storing energy for long periods of time and are also easier to handle than **lithium-ion batteries** because they are lighter.

- Transport and mobility: Hydrogen's great versatility allows it to be used in those consumption niches that are very difficult to decarbonise, such as heavy transport, aviation and maritime transport. There are already several projects under way in this area, such as **Hycarus**

and **Cryoplane**, which are promoted by the European Union **(EU)** and aim to introduce it in passenger aircraft.
[88,89]

-Renewable vitality and hydrogen arrangements in Egypt

-The extension of the RE segment is vital for the decarbonization of a nation and for creating green hydrogen. The taking after presents advancement measures of REs. After that, political activities for building up a hydrogen showcase in Egypt will be presented.

-Egypt's renewable vitality arrangements:

In 2014, the Egyptian government issued the primary Renewable Vitality Law (No. 203), administering four measures to empower private speculation into RE. One of the law's essential destinations is to empower a continuous move from state-administered ventures to secretly financed ventures. The measures incorporate competitive offers, feed in duties, and free control generation through third-party get to (IRENA, 2018). [90]

- Competitive offering conspire for private companies: Ventures run by the EETC and open for private speculation on a build-own-operate premise where created power will be sold at an arranged cost between EETC and the plant proprietor.

-Feed-in tax bolster framework: Ventures administered by a feed-in-tariff bolster framework where private financial specialists offer power to EETC agreeing to the introduced capacity and sort of renewable.

-Autonomous control generation through third-party get to: Private makers are permitted coordinate offering to shoppers conditioned by EETC endorsement and accessibility of lattice arrange and subject to a framework get to charge.

Also, the Egyptian government focused on the overall **phase-out of fossil fuel** appropriations in2018/2019 but later amplified it to 2021/2022 and after that to 2024/2025. [91]

-Egypt's renewable vitality targets:

In February 2008, the Egyptian Preeminent Committee of Vitality affirmed the primary renewable vitality target for 2020. This included power era from 20 % RE, comprising of 12 % wind, 6 D44 hydro, and 2 % PV (IRENA, 2018). [92]

This target, **in any case,** was amplified to 2022. -In **January 2013,** the Government of Egypt started a 20-year procedure, the Coordinates Feasible Vitality Technique **(ISES)** 2015 to 2035, through a extend financed by the European Union and built up in participation with all important national accomplices. The ISES points to guarantee vitality security, soundness, and supportability through the broad extension of renewable vitality innovations. With the ISES to 2035, Egypt is expanding its RE target, pointing to reach **over 40** D44 of introduced RE capacity by 2035. [93]

-Based on the ISES to **2035**, Egypt targets power era from **55 %** warm control plants, **42 %** RE, and **3** % atomic vitality by 2035 (**see Figure** 1**3**). The breakdown for renewable power era targets is as taken after: **22 %** from PV sources, **14 %** from wind, **4 %** from concentrated sun based control **(CSP),** and **2 %** from hydroelectric control. In specific, the target for PV expanded essentially, showing a move within the technique compared to 2008. Reports recommend that the changed timeline expanding to **2040** will consolidate components such as hydrogen generation and a key arrange for advancing a green economy in Egypt. [94]

- In **2020/21,** Egypt had **88 %** of its power era from warm control plants and **12 %** from REs, composed of **7** % hydroelectric control, **2 % PV,** and **3 %** wind control (**see Figure 13**). By accomplishing a **2 %** power era from PV in **2020/21,** the PV era would successfully fulfill the target for **2022.** Hydroelectric control would outperform its objective for 2022 by an edge of **1 %** focuses**. In any case,** wind vitality would drop underneath the target for **2022,** with as it were a 2 D44contribution to power era in **2020/21,** anticipated to fall flat its focused on **12 %** share by **2022** .[95]

Fig (13): Egypt's electricity mix and targets

-Egypt's hydrogen approaches:

-There have been plans for Egypt to distribute its to begin with hydrogen technique at the Climate Alter Conference in 2022 **(COP27) (Hydrogen Europe, 2022).** By the by, as of Eminent 2023, Egypt has not however discharged any national hydrogen methodology in spite of the expecting arrange. **Meanwhile,** a few assentions with universal accomplices and companies for green hydrogen generation, particularly within the Suez Canal Financial Zone **(SCZONE),** have been marked.

- A few hydrogen ventures have been discharged amid **COP27** in **2022**; their generation offices will be put at SCZONE: East Harbour Said and Sokhna. Each of these ventures centers on producing a certain sum of hydrogen at that point expanding it every year, depending on the given offices included to the strategies utilized in each extend. The Egyptian specialists venture their speculations in green hydrogen activities to reach roughly USD **41.5 billion** by **2030**, with plans to increment this figure to USD **81.6 billion** after that.

Thus, the government's commitment is expected to include **20 %** to **25 %** of the by and large speculation within the introductory stage of these ventures **(Day by day News, 2022).** [96]

-Egypt has **a few** partnerships with international organizations to set up a territorial center for green hydrogen generation. For occurrence, Egypt Green consortium counting the Norwegian RE company Scatec, plans to create a green hydrogen generation extend in **Ain Sokhna.**

-The office will become Africa's to begin with coordinates green hydrogen plant upon completion. It'll include a**100 MW** electrolyze capacity, fueled by **260 MW** of sun based and wind vitality (Vitality & Utilities, 2022).

-Egypt also announced in **2022** the setup of the Brilliant Licenses Unit, which could be a **legitimate system** to encourage the permitting prepare for companies that contribute to the accomplishment of maintainable improvement. Green hydrogen ventures **(counting generation, transportation, capacity, dispersion, and send out)** to qualify for the permit (GAFI Interpretation Division, 2022).
[97]

- Hydrogen foundation:

With the expanded force into green hydrogen generation in Egypt, a proficient hydrogen foundation should be created. As nowadays hydrogen generation is found where hydrogen is devoured, hence huge infrastructures are not set up however. Within the brief term it is anticipated that green hydrogen will be delivered in clusters to supply mechanical offices or refineries.

Over time, be that as it may, to be fundamentally competitive with unabated fossil fills the generation of hydrogen moves encourage absent from request centers to regions with tall wind and sun powered assets.[98]

-When the potential in Egypt for producing **renewable vitality** carriers from wind and sun powered is abused, and a hydrogen industry is inclining up, a hydrogen framework will be fundamental for long transport separations **For this,** repurposed unused common gas as well as unused pipelines can be utilized.

The degree of repurposing, and hence the require for unused development, **depends on** the amounts of hydrogen to be transported within the future, long-standing time localization of generation and request of hydrogen and long-haul request for common gas **(for household utilize and for send out).**

A comprehensive hydrogen framework extend incorporates the offices required to deliver, store, and transport hydrogen to conclusion clients either broadly or universally. The separate between generation locales, hydrogen offices, and conclusion clients altogether affects the plan and degree of a foundation venture. [99]

- One potential approach to facilitate a cost-efficient establishment of hydrogen infrastructure **involves** repurposing existing natural gas pipelines. In a decarbonized economy, the demand for natural gas will be reduced drastically, which leads to lower utilization of natural gas pipelines in the medium to long term. For creating a viable hydrogen infrastructure, it is crucial to use precise data on the natural gas network, the natural gas demand, and the temporal patterns of these factors, alongside a dependable forecast of hydrogen supply and demand. Such comprehensive information is indispensable for developing a suitable hydrogen distribution system (EWI, 2022a).[100]

-Egypt's existing gas pipeline network, with **3,545 km** in total, is illustrated in **Figure14**. **Additionally,** Egypt has **290 km** of pipelines under construction and **622 km** of pipelines proposed (Global Energy Monitor, 2022). These New pipeline projects are expected to transform Egypt into a regional hub for the natural gas industry. [101]

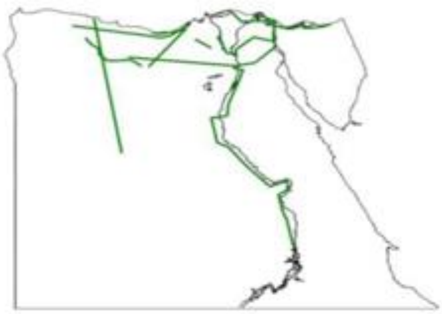

Fig (14): Existing natural gas pipelines in Egypt as of December 2022.

-Hydrogen request:

After analyzing hydrogen generation and foundation in Egypt, this chapter sheds light on the country's request for hydrogen. Hence, the pertinent hydrogen requesting businesses are surveyed. This incorporates the fertilizer industry, the steel industry, and the petroleum- related businesses. A few suspicions are made to decide the current request for hydrogen in Egypt, which is completely met by dim hydrogen. As the whole hydrogen generation in Egypt is devoured locally, we accept that generation volumes can be generally likened with the major utilization volumes. [102]

- Hydrogen within the alkali industry:

The fertilizer industry employments hydrogen to create smelling salts, which is utilized to deliver nitrogenous fertilizers. Egypt positions among the best alkali makers universally and is recognized as the biggest smelling salts maker in Africa.

In **2019,** Egypt created **4.2 million tons** of alkali (USGS, 2023). Until presently, this request has been met by carbon-intensive hydrogen. Subsequently, the costs of characteristic gas are the ruling costs of smelling salts generation, bookkeeping for up to **90 %** (Marketplace Industry & Marketplace Vitality Move, 2023). Figure15 appears the chronicled hydrogen utilization within the fertilizer industry from **2011** to **2019**. [103]

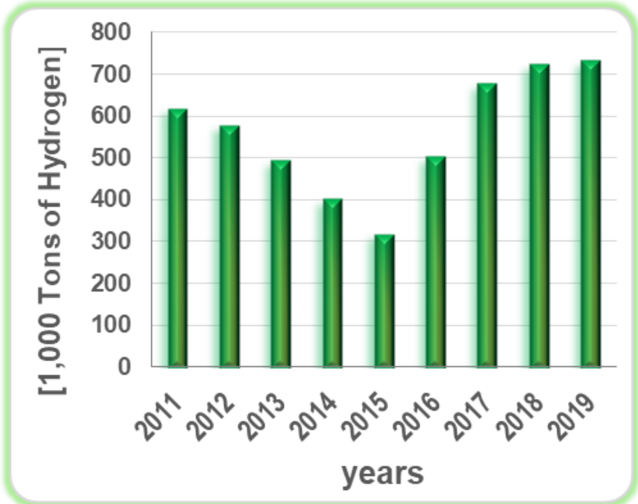

Fig.(15):Estimated hydrogen consumption in the ammonia industry

-Beginning in **1960**, green hydrogen for alkali generation was created in Egypt utilizing power from hydropower provided by the Aswan dam. **In any case,** the plant was decommissioned in 2019.

-An unused plant commissioned supplanted green hydrogen with dark hydrogen utilizing SMR. [104]

-Hydrogen within the steel industry:

Nowadays, the steel industry is the moment greatest buyer of hydrogen in Egypt. Hydrogen is utilized in steel generation within the Direct Lessening Press (DRI) prepare (Habib, 2021). Within the DRI prepare, oxygen is evacuated from press within the strong state utilizing hydrogen and carbon monoxide as operators. Egypt has a surmised add up to yearly generation capacity of **8.95 million tons** of DRI.

-Table 4 gives an outline of steel plants in Egypt. As of now, eight plants are in operation, and an extra one is beneath development. Other than the DRI course, the Electric Circular segment Heater

(EAF) handle too plays a part in Egyptian steelmaking, whereby no hydrogen is utilized .[105]

Steel Plant	Company Name	Crude steel capacity [in thousand tons per annum]	Iron capacity [in thousand tons per annum]	Primary steelmaking process	Status
Egyptian Steel Beni Suef plant	Egyptian Steel	600	N/A	Electric	Operating
Al-Ezz Dekheila Steel Alexandria plant	Al Ezz Dekheila Steel Company Alexandria SAE	3,200	3,100	Integrated (DRI), EAF	Operating
Ezz Steel Rebar Sadat City plant	Ezz Steel Co SAE	1,000	N/A	Electric	Operating
Egyptian American Steel Rolling Company Sadat City plant	Egyptian American Steel Rolling C	1,200	N/A	Electric	Operating
Egyptian Sponge Iron and Steel Company Sadat City plant	Egyptian Sponge Iron & Steel Co	3,000	2,000	Integrated (DRI)	Operating
Suez Steel Solb Misr Attaka plant	Suez Steel Company SAE	2,100	2,100	Integrated (DRI)	Operating
Egyptian Steel Ain Sokhna plant	Egyptian Steel	600	N/A	Electric	Operating
Ezz Flat Steel Ain Sokhna plant EAF expansion	Al Ezz for Flat Steel Industries Company SAE	1,600	N/A	Electric	Construction
Ezz Flat Steel Ain Sokhna plant	Al Ezz for Flat Steel Industries Company SAE	2,300	1,900	Integrated (DRI)	Operating

Table 4: Steel plants in Egypt

-**Figure 16** appears an expanding request for hydrogen by the DRI industry after 2016 (USGS, 2019; USGS, 2023). The expanded request for rough steel from the DRI handle, and subsequently expanded hydrogen utilization, is due to the expanding intrigued of the nation in megaprojects that require tremendous sums of steel, e.g., wind station extend, Jabal Al-Zeit, within the Center East with 580MW [106].

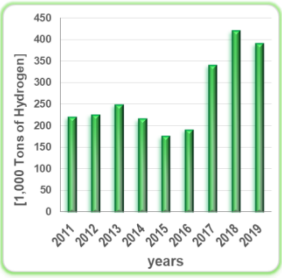

Fig. (16): Estimated hydrogen consumption in the steel industry

- Hydrogen in refining processes:

Refineries utilize hydrogen to diminish the sulfur substance in petroleum items, such as **diesel Fuel, kerosene** , etc..

-The refining industry is one of the most punctual businesses.

To be built up in Egypt to supply the advertise with its needs for gasoline and diesel fuel and Other items that formed the center of the mechanical change in Egypt, **Figure 17** appears the hydrogen request for unrefined oil generation for the a long time **2011** to **2019.**

After the **2011** insurgency in Egypt, the request for oil items expanded somewhat, in this way expanding the hydrogen utilization. Be that as it may,when considering the long-term improvement of unrefined oil Generation since **1993**, it becomes apparent that it has been reliably declining.

-One noteworthy Reason for this is often the diminishing yield from more seasoned inland areas. In parallel, oil utilization has Expanded, driving Egypt to move from a net exporter to a net merchant since 2010 [107] .

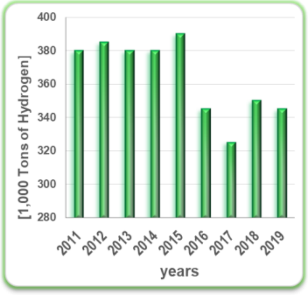

Fig. (17): Estimated hydrogen consumption in refining processes

-Hydrogen within the methanol generationindustry:

The methanol generation is considered as one of the major hydrogen customers. Nowadays, methanol is basically created as a item from common gas utilizing SMR [108].Within the decade of the 21st century, methanol generation through hydrogenation of carbon dioxide was exceptionally restricted. In Egypt, the solitary methanol generation plant within the country was established in 2011 [109].Arranged in Damietta, this office has a generation capability of up to 1.3 million metric tons of methanol every year, fundamentally catering to residential and European markets [110] **Figure 18** appears the hydrogen utilization in methanol generation in Egypt in 2018.

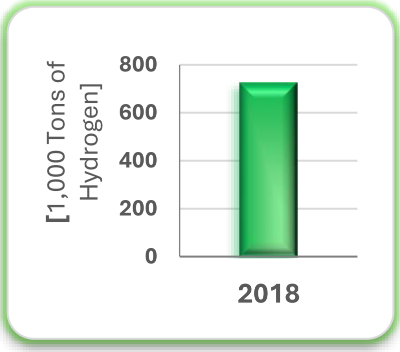

Fig. (18): Estimated hydrogen consumption in the methanol production

-Conclusion:

-Green hydrogen has great potential as a key component of a sustainable energy future. As explained in this paper.

The production and use of green hydrogen can significantly contribute to reducing greenhouse gas emissions, improving energy security, promoting economic growth and decarbonizing various sectors. **Here,** we have outlined viable pathways for hydrogen penetration into four sectors: industry, transportation, building and heating, and energy to reduce CO_2 emissions in hard-to-decarbonize applications.

-Green hydrogen should first be introduced into industrial chemical synthesis applications, and there is currently a market where it can reduce CO_2 emissions by almost **1.1 Gt** per year. In the medium-term energy transition, hydrogen will reduce CO_2 emissions by **95 Mt** or **3.1** Gt per year in the transport, building and heating sectors due to its physical similarity to current fossil fuel infrastructure. **Finally,** hydrogen is one of the few green technologies that can meet the energy sector's **15%** seasonal storage needs needed to achieve a **100**% renewable energy society.

In total, the total hydrogen demand is 2.3 Gt per year, providing scope for a large, scalable and complex future green hydrogen economy that can decarbonize around 18% of energy-related sectors. Hydrogen will not become the largest energy industry.

Energy losses are inevitable when converting electricity to hydrogen, so it is most productive to use electricity directly whenever possible. **However**, hydrogen is ideal for decarbonization applications that are not possible with renewable electricity.

Academic and industry efforts should therefore target green hydrogen as the linchpin of the economy, working with electrification and other technologies, rather than as the only solution to decarbonization or an unfeasible idea that should be abandoned.

We should aim to realize one society fully supported by renewable energy.

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