The Age of Renewable & Hydrogen; "The Present and Future Fuel.

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Abstract

Global perceptions of renewable have shifted considerably over the past decade. Continuing technology advancement and rapid development of many renewable energy technologies have demonstrated their immense potential. However, Energy sources such as Solar and Wind power are inherently variable. For example, Electricity Grid Stability and better efficiency can be realized if part of the capacity of a Wind farm or Solar power could be stored i.e. be available at any time regardless of the weather.

Electrolyzes; provide the means for doing so. Using renewable (Solar/Wind) electricity to drive purified sea water electrolysis and produce hydrogen in large quantities as an energy storage medium, is in fact the most viable options available to humanity. The resultant stored hydrogen can then be used to fuel power plants that run on demand to dispatch electricity to the grid ***and*** *can also be used for other applications.*

Hydrogen; "The Present and Future Fuel"; The manifold benefits of Hydrogen make it the ultimate source of clean energy and the most attractive energy carries, with its ability to connect the energy silos of electricity, heat, transportation and industrial uses in a way no other energy storage solution can if it is thermal or batteries etc. ***Needless to emphasize on the additional tangible environmental benefits***

Hydrogen Fuel Cell Transport Cars, Buses & Trains are picking momentum and penetrating the market. ***Moreover, widespread use of Hydrogen fuel cell for power generation could potentially solve the worlds drinking water problem.***

The technologies involved are simple and are the ones acquired by the advanced countries, Japan, Germany, Korea, China, California …, to produce Hydrogen and use it as fuel. Not only that this technology is simple, but all it requires are Solar, Wind and Sea water as Natural resources which are abandoned. ***Energy, Transport & Industries are already geared for the H2 Era.***

The Hydrogen production cost produced from this process is competitive to the price of LNG (LNG price @ $ 10 per million BTU) and with the recent development,

economy of scale, mass production and large plants, Hydrogen production cost will be competing with Natural Gas.

This paper covers / highlights the technological advancements across the whole Hydrogen value chain with some economic insights. It also concludes that, this is the "Age of Renewable", and "Hydrogen is the Present and Future Fuel".

Renewable Energy Immense Potential *(1)*

Global perceptions of renewable have shifted considerably over the past decade. Continuing technology advanced and rapid development of many renewable energy technology have demonstrated their ***immense potential;***

- *Global winds potential could be in the order of 158,000 TWh in a single year. This would be sufficient to meet the world's electricity requirements 8 times over.*
- *If we consider just solar energy, the US Department of Energy (DOE) states that "enough energy from the sun hits the earth every hour (6 hours) to power the planet for an entire year".*

However, Energy sources such as Solar and Wind power are ***inherently variable.*** *For example, Electricity Grid Stability can be realized if part of the capacity of a Wind farm or Solar power could be stored i.e. be available at any time regardless of the weather.*

Electrolyzes; provide the means for doing so. Using renewable electricity to drive water electrolysis and produce hydrogen in large quantities as an energy storage medium, is in fact the most viable options available. The resultant hydrogen can then be stored at the point of production and used to fuel power plants that run on demand to dispatch electricity to the grid ***or*** *used for other applications.*

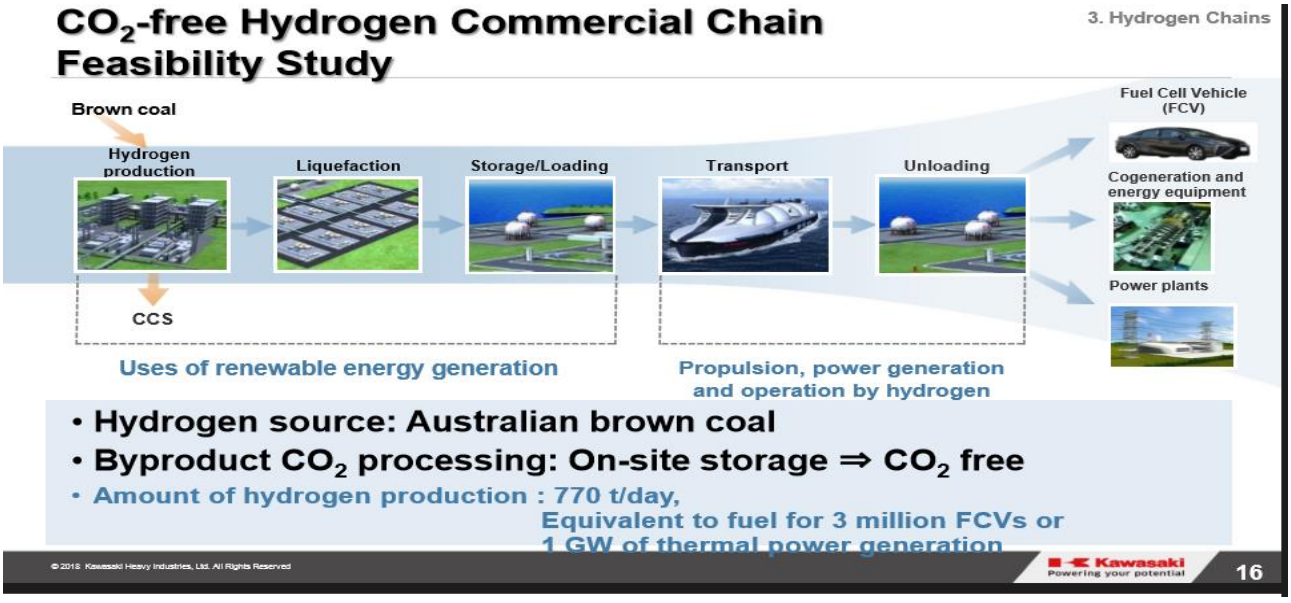
The manifold benefits of Hydrogen make it one of the most attractive energy carries, with its ability to connect the energy silos of electricity, heat, transportation and industrial uses in a way no other energy storage solution can if it is thermal or batteries etc. Hydrogen is the answer, Hydrogen is in fact the most viable options available.

Main Technologies for Hydrogen Production Facility. *(2)*

- ✓ *Brown coal Gasification + CCS.*
- ✓ *Steam Methane Reforming.*
- ✓ *Solar PV + Electrolysis.*
- ✓ *Windmills + Electrolysis*

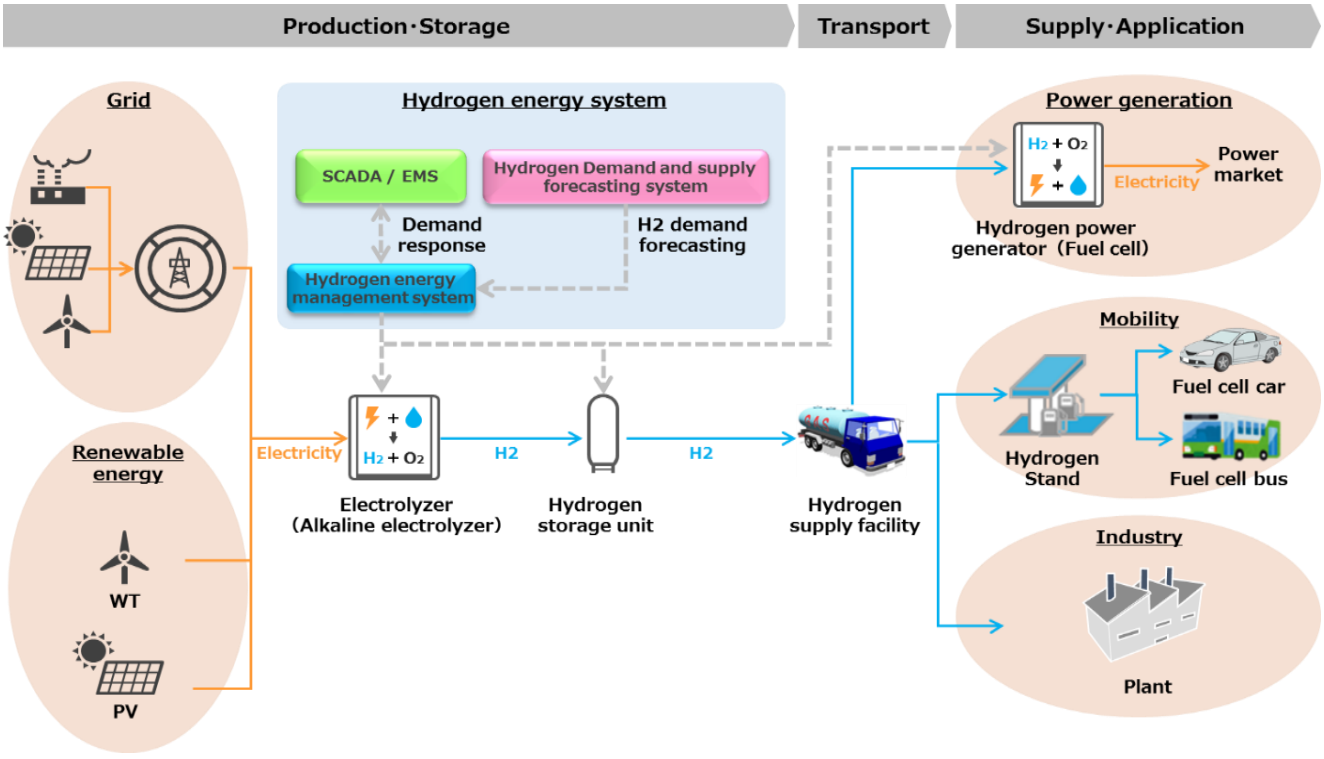
Brown coal Gasification + CCS (3)

This technology simply calls for Gasification of coals then purification and separation of Hydrogen. The CO2 is captured and injected / stored underground while Hydrogen can be stored under pressure or liquified and subsequently exported / transported for use in the different applications. The following diagram shows the first commercialized 770 tons H2 / Day Hydrogen production from Australian brown coal; Gasification, liquefaction, storage, shipping& unloading. This plant is due to be commissioned in 2021.Basiclly, it covers the Hydrogen supply (value) chain.

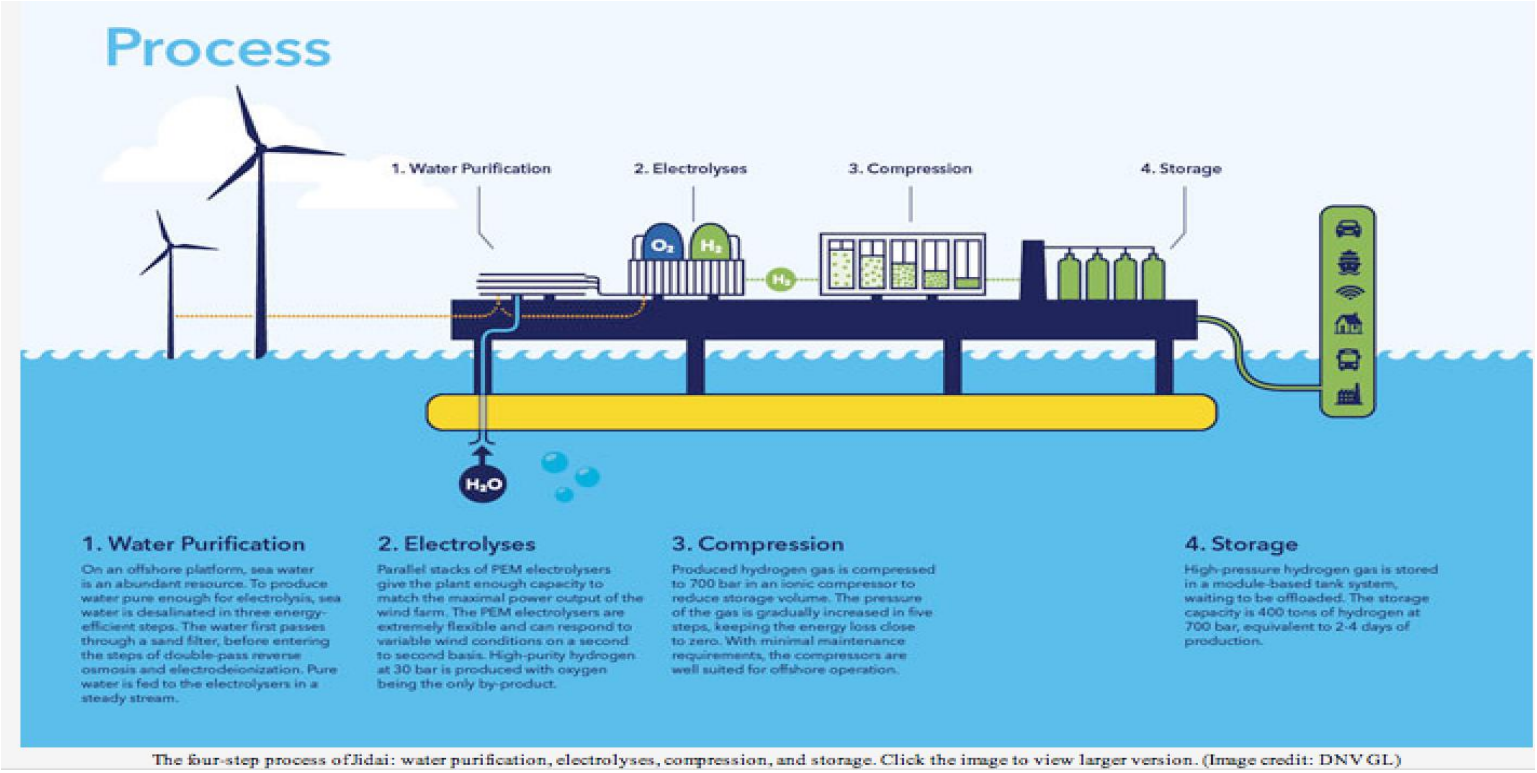


Solar PV/ Windmills + Electrolysis. (4)

This technology calls for the use of Renewable Energy (Solar PV- Windmills) electricity produced in electrolyzes units to split the purified water into H2 and O2, then the hydrogen can be stored and transported to be used for the different applications if it is Transport and/or Electricity generation and/ or Industry. Simplified diagram for 10 MW Large Hydrogen Energy System in Japan is shown below.



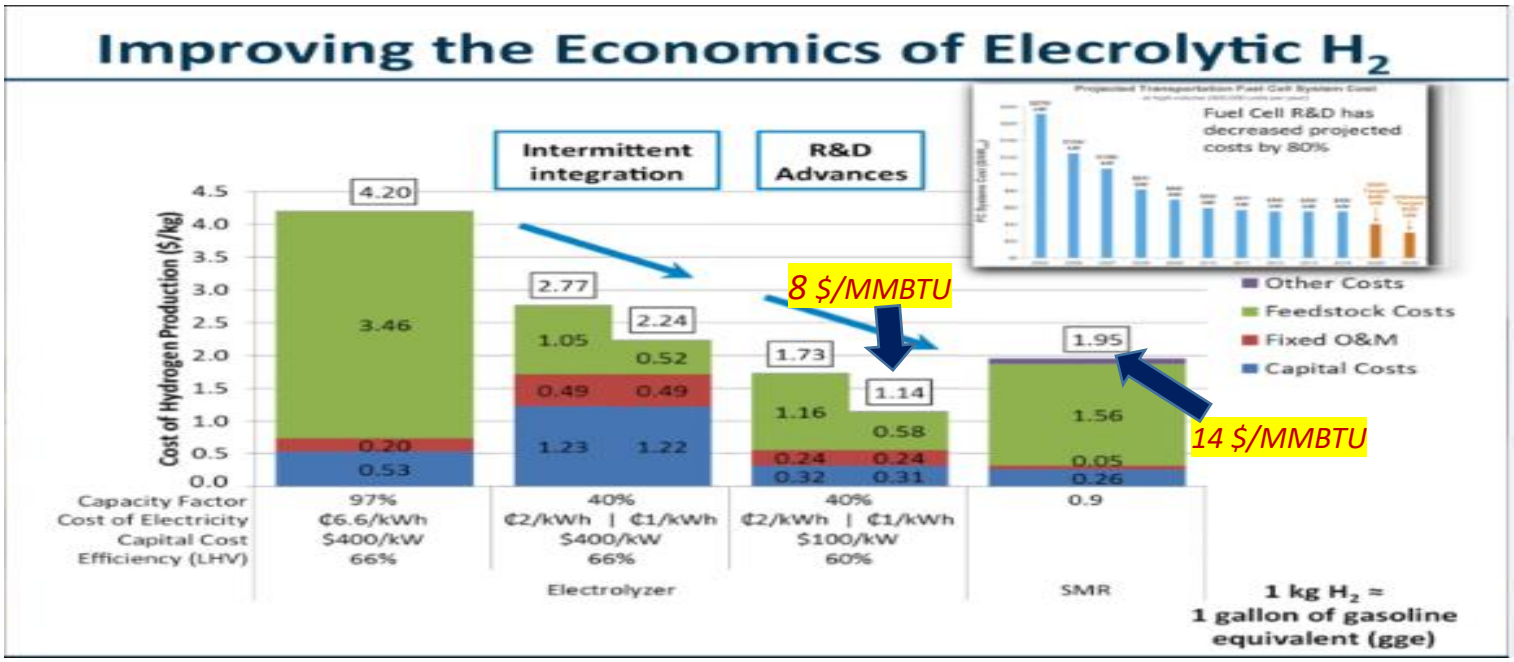
Another futuristic Renewable Energy, Hydrogen production plant in JAPAN called New Era (JIDAI) Project for production of hydrogen from Ocean wind & sea water. The below schematic diagram gives brief description of the same



The four-step process of Jidai: water purification, electrolyses, compression, and storage. Click the image to view larger version. (Image credit: DNV GL)

Steam Methane Reforming. *(5)*

The following diagram provide comparative analysis between H2 production by electrolysis against Methane Steam Reforming Technology represented by the fourth column on the right which gives H2 production cost at $ 1.95/ Kg H2 with Methane feedstock at a price of $ 2.5 to 3 / MMBTU. First column the right gives the cost of $ 4.2 / Kg H2 from electrolysis at electricity cost of Cent $ 6/ KWh. The second column from the right gives the cost of H2 of $ 2.77 to 2,24/kg H2 by doubling the size of the plant i.e., doubling the capital investment and operate the model with only Renewable electricity at price Cent $ 2 to 1 / KWh. The third column assume cost reduction in the Electrolysis units like the H2 fuel cell trend due to R&D which have gone long way since 2009. Basic conclusion, the cost of H2 production from electrolysis using Renewable Energy is becoming very competitive to the Old Methane Steam Reforming, no it is competitive.



H2 Comparative Unit Prices;*(6)*

The next Figure is an extract from National Renewable Energy Laboratory of the U.S. Department of Energy "Current (2009) State-of-the-Art Hydrogen Production Cost Estimate Using Water Electrolysis". It simple indicate by extrapolation that at electricity cost of Cent $ 2.5 /KWh, the production cost of Hydrogen from Water Electrolysis is estimated below $ 1.5 for each 1 Kilo gram Hydrogen with 21% adjustment for Capital and other costs. Based on the estimated cost of Hydrogen production from water electrolysis, it is calculated that the cost of one million BTU Hydrogen will be less than $ 10 and this price is very competitive to the current LNG price of $10 per million BTU.

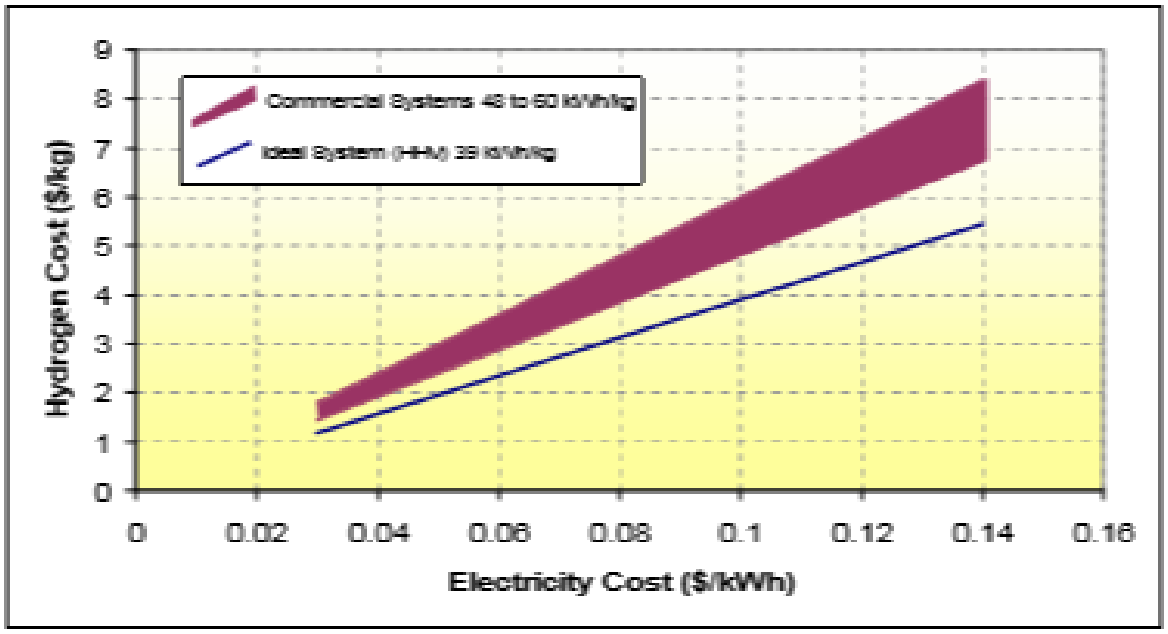


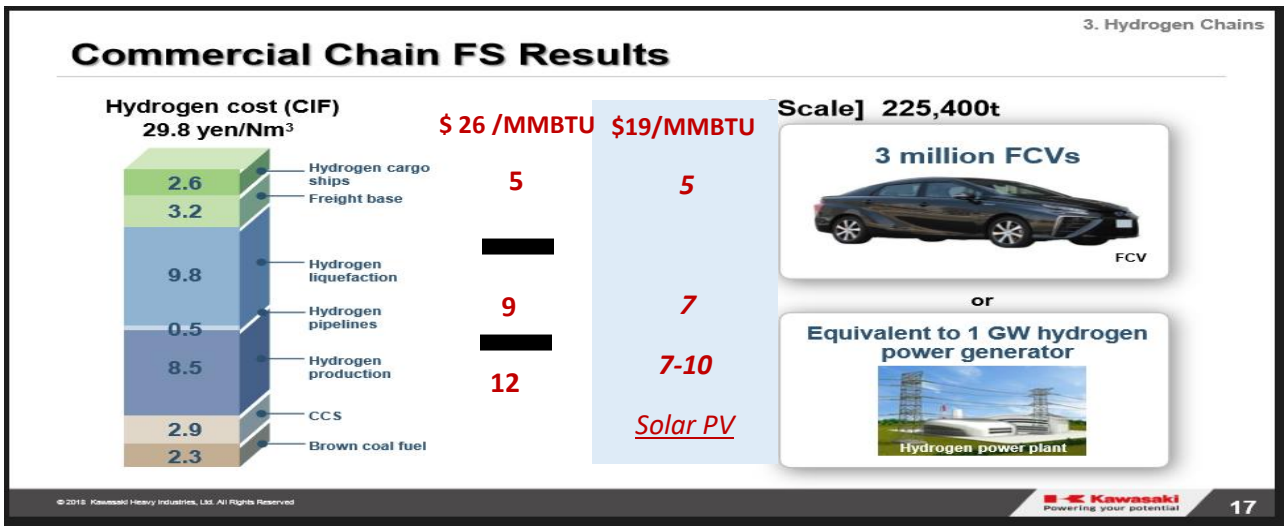
Figure 3. Influence of electricity cost alone on hydrogen cost (without capital, operating, or maintenance costs)

In conclusion, If the forecasted reduction of 50 to 60% in the price of Solar PV electricity & electrolyzes are realized due to the expected technology advancement and the large scale plants - economy of scale – mass production of the different

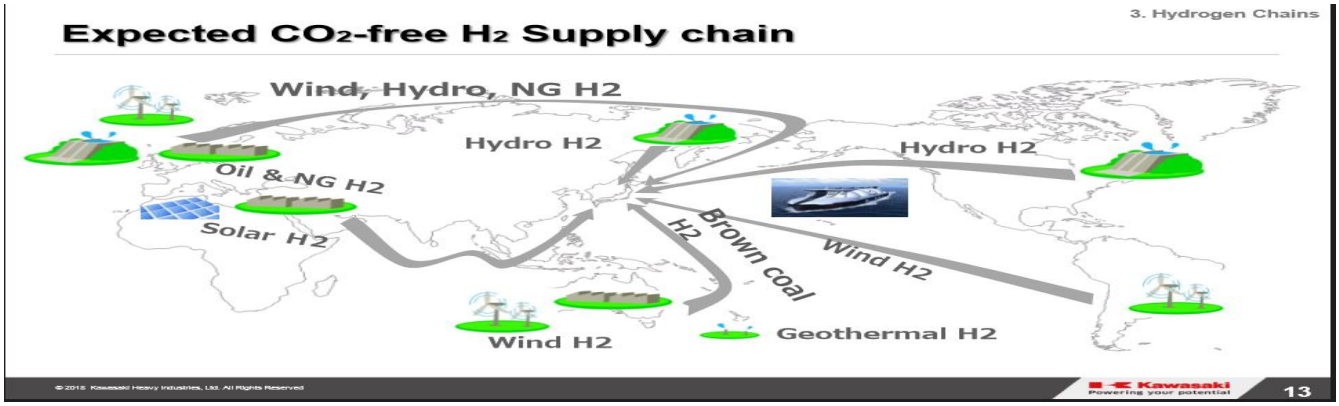
*equipment's, then the price of hydrogen produced from water electrolysis will be - **if not already** - competitive to Natural Gas($ 4 -7per. million BTU).*

Comparative H2 production cost "Australian brown coal Against RE / Elect".

Kawasaki Heavy Industries (KHI) estimates that hydrogen from Australia costs about ¥29.8/nm3 (about 26 $/MMBTU) and the company plans to establish a global LH2 supply chain like that for liquefied natural gas. Norway aims to deliver liquefied hydrogen to Japan for ¥24 per normal cubic meter (about 21 $/MMBTU). A study on the plan is due to be completed in 2019. Egypt have every chance to beat both prices.

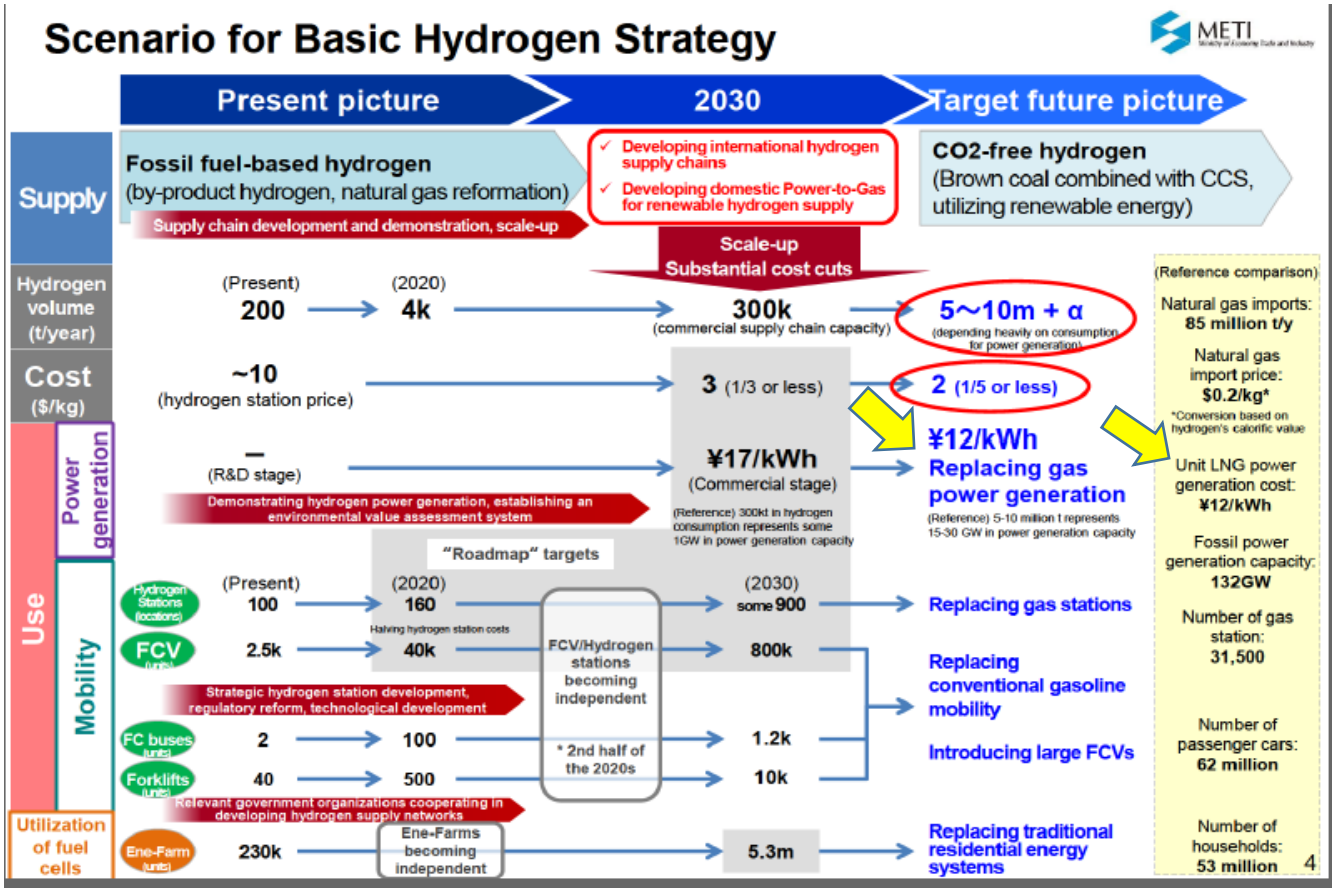


The envisaged Japan Hydrogen supply chain is shown in the next diagram where Hydrogen is envisaged to be produced using RE. (3)



<u>Japan Basic Hydrogen Strategy</u>;*(7)*

In the next diagram, Japan Hydrogen Strategy is shown, one indicative figure is the cost of electric power generation projected at Cent $ 10 / KWh from H2 which is competitive to LNG.

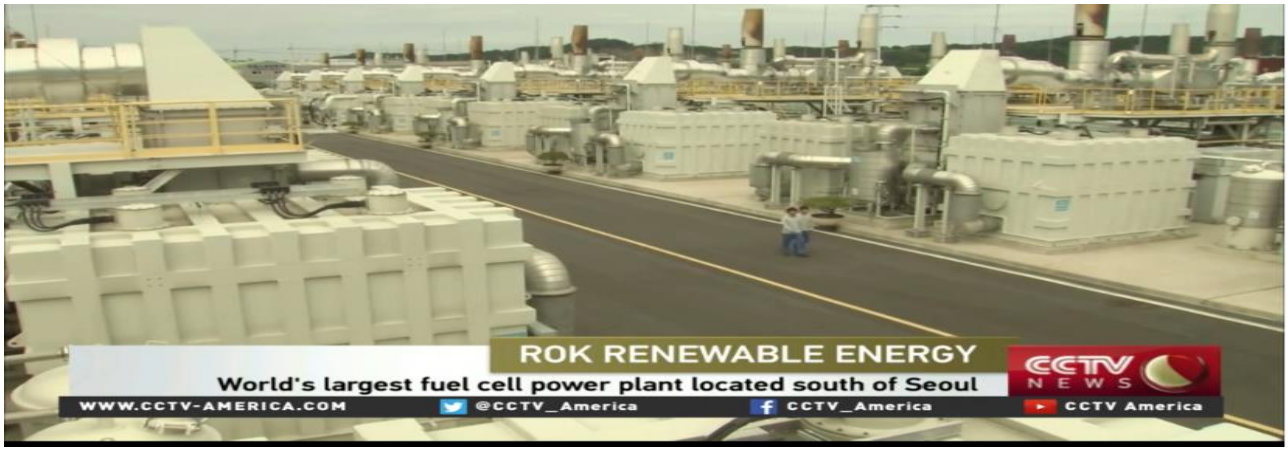


Hydrogen Applications – End use value chain;

Hydrogen technology is already deployed,

- ⇨ *Power Generation.*
- ⇨ *Transportation.*
- ⇨ *Industrial feedstock.*

⇨ *Building heating and power.*



World's Largest Fuel Cell Power Plant Located South of Seoul (21 Units each 2.8 MIGA Watt. h) -(8)

Basically, Hydrogen enables large- scale renewable integration through cost – effective long storage. It is targeted / projected that 1500 TWA would be produced from Hydrogen by 2050. (9)

Hydrogen powered vehicles are commercialized in cars, buses, trucks, trains, etc. It is envisaged that, by 2030, 1 in 12 cars sold in California, Germany, Japan and South Korea would be powered by Hydrogen. Globally 10 to 15 million cars and 500,000/- trucks would be powered by Hydrogen. It is targeted / projected that up to 400 million passenger vehicles (about 25% of worlds total), 5million trucks (about 30% of world totals), and more than 15 million buses (about 25% of world total) would be running by Hydrogen by 2050.
In the Fertilizer and Refining, Hydrogen could replace Natural Gas feed stocks on environmental and cost competitiveness i.e. Hydrogen from Renewable Energy is more feasible. Other industries can follow.

2015 Toyota Miraa is one of the first H2 fuel cell vehicles to be sold commercially

Network of pipelines have been built to transport Hydrogen. As an example, Air Products has more than 950 km of pipeline in the southern US States of Texas and Louisiana connecting 22 hydrogen plants and with a capacity of 1.3 million Nm cube /hr. In Europe, more than 1,500 km of hydrogen pipelines are in operation by the major global gas manufactures. Gas transmission pipelines offer a significantly more effective means of moving large quantities of energy over distances than power lines do and are subject to lower losses, as are distribution pipelines.

Challenges: Egypt Fossil Fuel (Oil, Gas, Coal) Proved Reserves;*(10)*

Egypt Fossil /Conventional Fuels - Oil, Gas & Coal– proved reserves are challenging;

- ✓ *Oil proved reserves continue to decline.*
- ✓ *No commercial scale coal proved reserves.*
- ✓ *Natural Gas proved reserves are balanced for short / medium terms at current level of consumption (about 7 – 8 BSCFD) after AL ZOHR discovery and about 30 GWH power production. However, with the fast growing demand / consumption, Egypt will needs to import fuel plus the fact that proved reserves would be depleted at faster rate in the medium (somewhere within the next 10 t0 20 years).*

In addition to the above, Egypt is also facing water shortage challenge.

The answer to the above challenges lays in Renewable Energy combined with sea water electrolysis to produce Hydrogen - the Future Fuel - to solve the many energy, water shortage and environmental challenges Egypt is facing. Needless to say, that. the developed Nations had already taken major Strategic steps in this Direction.

Conclusions;

- ✓ *Natural Resources: Sun, Wind, Sea water, which are abandoned.*
- ✓ *Technologies: Solar PV / Windmills, Electrolyzes and H2 Fuel Cells* ***– Simple Technologies,*** *plus H2 Storage & Handling.*
- ✓ *Based on the above, the estimated cost of Hydrogen production from water electrolysis using Renewable Energy, is very competitive to the current LNG price of $10 per million BTU.*
- ✓ *Hydrogen is the Universal Solution and is the way to solve the many energy and environmental challenges the world is facing plus the fact that it can produce water.*
- ✓ *Energy, Transport & Industries are geared for the H2 Era.*

Benefits / Conclusions;

- ✓ *Building 100 Giga Watt commercial scale plant(s) based on solar PV/ electrotyper / hydrogen and power generation by Fuel Cell – over the next 17 to 20 years - will save about $ 70 Billion yearly fuel importing bill (about 19 BSCFD Natural Gas).*
- ✓ *Additional benefits will be the production of about 3 Billion Cubic Meters of the most need water.*
- ✓ *Exporting Hydrogen commercially based on Solar PV / Electrolyzes / hydrogen storage & export, present a great business opportunity.*
- ✓ *Domestic economy grows, money stays in and increase the wealth of the Nation.*
- ✓ *Huge opportunity in establishing Industrial Base, Engineering & Contracting and applied R& D in the Renewable Energy fields and beyond.*
- ✓ *Create jobs. Achieving targeted world hydrogen economy by 2050 where Hydrogen would be 20% of the Global Energy, would create/ provide sustainable employment for more than 30 million people.*
- ✓ *It is estimated that the value of 100 GWh electric power generation would be about 832 Bil. EGP (assuming one KWh price is 0.95 EGP). This is five times more than the revenue from 7 Mil. Fudan assuming that yearly revenue from one Fudan is about 20,000/ - EGP / Annually.*

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