Hydrogen Power, Our Future Energy?

The 21st century, or people usually named as the era of technologies, technology has become the blockbuster innovation which is essential in daily lives. With the help of technologies, people and businesses are able to improve the efficiency of many important sectors such as energy, agriculture, infrastructure and supply chain. They are able to scale quickly which also help the global Gross Domestic Product (GDP) to escalate. O'Neill (2021)[1] recorded the global GDP reached USD 84,537 billion in 2020 which is also around 2.5 times increased since 2000 (USD 33,985 billion). This figure represents significant improvement in numbers of factory, manufacture and production rate which all yield in global economic rise. Yet, without knowing, these activities also produce pollutions or dangerous gases namely Greenhouse gases (GHGs). Since the GHGs are trapped in the atmosphere, it will result in further earth's warming and change in global climate pattern. This phenomenon we called as global warming and climate change respectively (NASA, 2021)[2]. Cook et al. (2016)[3] claimed that all these results are human-induced, which means human activity as the main contributor to the earth's mean temperature increase.

Among all sectors, energy sector is the main contributor of global GHGs. Since, it covers most of the fossil fuel consumption in sub-sector like transportation, manufacturing, electricity generation, and building (WRI, 2021)[4]. Another similar finding from WRI (2021)[5] that in 2018, the energy sector has accounted for 76.1% of total global GHGs, which shows how serious is needed to be tackled. Many mitigations have been proposed, especially to tackle the excessive use of fossil fuels. For instance, promote the use of renewable and clean energy, also comprehend it with the Carbon, Capture, Utilization and Storage (CCUS) technology which is able to yield future negative carbon emission. There are actually still many mitigation schemes that proposed by the federal official or government, yet these two are the most prominent schemes.

Hydrogen power which might utilize both schemes to produce electricity and heat, has become one of the foremost alternatives to achieve future carbon neutrality. As the simplest and most abundant element in the universe, hydrogen can be produced from diverse resources, including fossil fuels, nuclear energy, biomass, and other renewable energy sources (Energy Gov, 2019)[6]. This has caused some dilemma on hydrogen entity as the clean energy. Despite it is come from water as the main resource, but the process to produce hydrogen might produce certain emission.

As the result, the hydrogen power is split into 4 different colour categories (IRENA, 2020)[7]. They are grouped based on the different production method, whether it is clean or not. Below is the explanation for the **Figure 1**.

- **Grey Hydrogen**: The most common method and is generated from fossil fuels such as, natural gas through gasification process and methane through Steam Methane Reforming (SMR) process. The use of grey hydrogen entails substantial CO_2 emissions, which unsuitable for a route toward net-zero emissions.

- **Blue Hydrogen**: The source and process are pretty similar to Grey Hydrogen; however, the process is equipped with the additional Carbon, Capture Storage (CCS) technology. With CCS, it is expected to mitigate 85-95% of production emission at best, which yield in 5-15% of the CO_2 will still be emitted. Despite that, this alternative is much better than the raw Grey Hydrogen.

- **Turquoise Hydrogen**: Using methane as the main source of electricity and through pyrolysis process. The remaining carbon in the methane becomes solid carbon black. The solid carbon black can be easily buried and stored underground (with no technology) which yield to zero carbon. At the moment, turquoise hydrogen is still at the pilot stage or still in the experimental phase.

- **Green Hydrogen**: Also refer as "Clean Hydrogen", which is produced from renewable energy, such as solar or wind power. The process is called electrolysis which splits the water into hydrogen atoms and one oxygen atom (Clean). Since, renewables cannot generate consistent power all day long, therefore sometimes the power generated from the excess grid is required. This makes the Green Hydrogen become more attainable, especially with increasing renewables power grid nowadays. This is the most suitable one for a fully sustainable energy transition and achieve the net-zero carbon route.

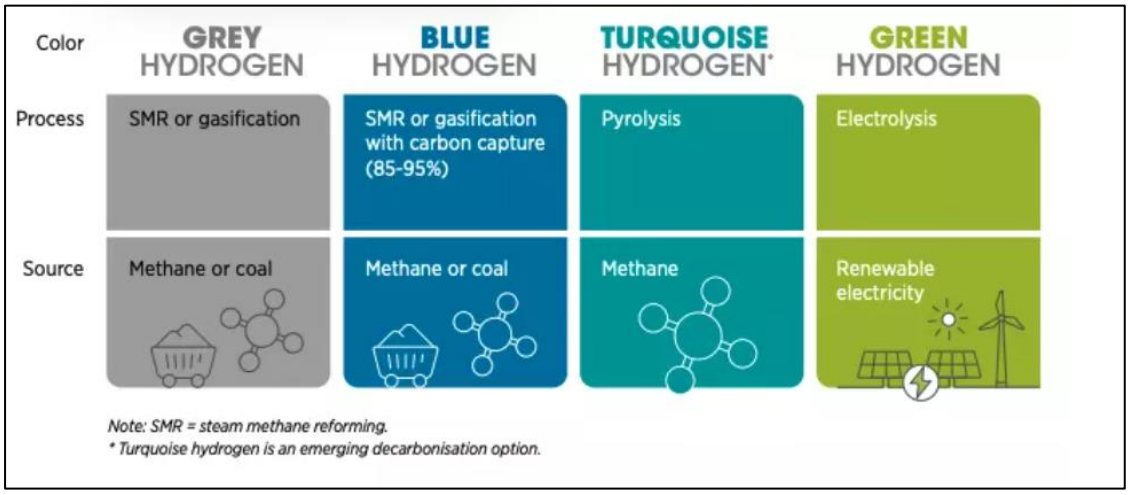

Figure 1. *Grey, Blue, Turquoise and Green Hydrogen.* (Source: IRENA, 2020)[7]

It is obvious to achieve the 2050 carbon neutrality, the Green Hydrogen and Turquoise Hydrogen are the perfect candidates. First, they yield in zero carbon emission. Second, they are fossil fuel free which means similar route towards the future net zero target. IPCC (2018)[8] stated to achieve carbon neutrality by 2050, the fossil fuel powered engine needs to be removed and replaced with clean & renewable energy immediately. Despite that, Turquoise Hydrogen is still in experimental phase which is not fully mature as a solid alternative, and it is difficult to be applied immediately, as we cannot wait no more. This set the Green Hydrogen as the priority among all the different hydrogen powered methods.

To get better understanding in the Green Hydrogen, we are going to learn how it is generated from the start production, process and final use for different industries. Below is the process step by step:

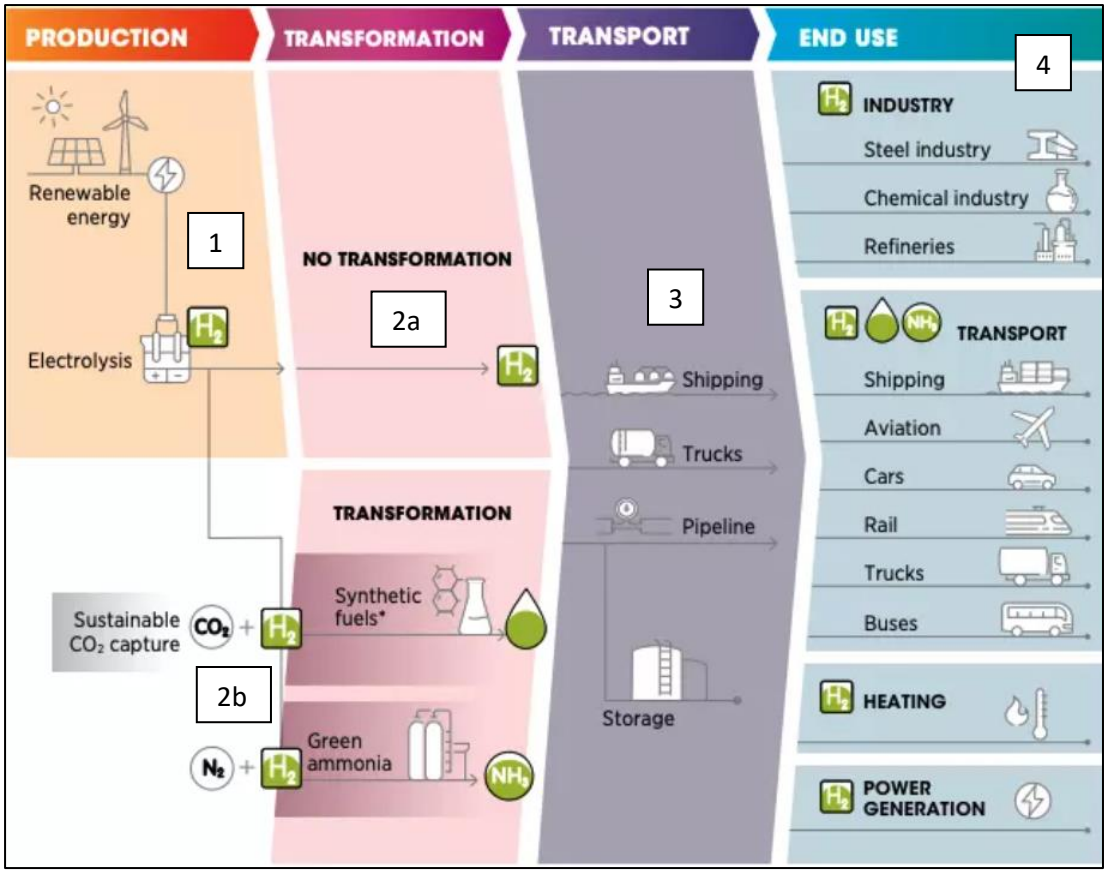

Figure 2. *Green Hydrogen full power generation process.* (Source: IRENA, 2020)[7]

1. **Production**: This step relies on water as the main input. Like the name of the Green Hydrogen, the power generation comes from the renewable energy source. This electrical output will be used to activate electrolysis process, which splits the water into hydrogen atoms and one oxygen atom.

2a. **No Transformation**: The raw hydrogen production can be used directly without any transformation.

2b. **Transformation**: The hydrogen also can be combined with another chemical substances such as Carbon dioxide (CO_2) and Dinitrogen (N_2). Synthetic fuel is the product by combining hydrogen with CO_2. The CO_2 is captured by the CCUS technology, which is clean. Green Ammonia is the other product by combining hydrogen with N_2. The Green Ammonia is fairly use in agriculture sector and might also replace transportation fuels. Both synthetic fuels and green ammonia are carbon-free, which are the perfect scenario to reach future carbon neutrality.

3. **Transport**: The logistic or carrier of the hydrogen as well as synthetic fuels and green ammonia, to the industry or factory site.

4. **End Use**: The green hydrogen is readily use in many sectors such as industry, heating, electricity generation and transportation use. Specifically, for transportation use, beside the green hydrogen, they might use the synthetic fuels and green ammonia to power the transportation. It is recommended since both are net-zero carbon as well as hydrogen-based product.

Green hydrogen is an energy carrier that can be used in many different applications. However, its actual use is still very limited. In 2019, IEA recorded less than 0.1% of hydrogen production came from the green hydrogen production (IEA, 2019)[9]. However, with declining costs for renewable electricity and government incentives, they expected the proportion of green hydrogen production will increase in upcoming years. In mid-year of 2019, NDRC issued Feed-in-Tariff (FiT) policy which subsidies both the PV and wind energy project in China until 2021 (Sino-German Energy Partnership, 2019)[10]. This incentive boosted both the solar and wind energy markets in China by 2020, which within a year, they accounted for around 61% and 175% increased respectively (NEA)[11]. China 2020 wind power installation also has broken the world record for most wind power capacity installed in a single year (GWEC, 2021)[12]. As the result, in 2020 the green hydrogen production is increased to 5% of global hydrogen production (IRENA, 2020)[7]. With more innovation of high efficiency and cost-saving technologies, hopefully the green hydrogen might be more attainable and replace at least half of the global hydrogen production in future.

Nowadays, hydrogen utilization is popular around the world, especially after 196 countries pledges to aim 2050-2060 carbon neutrality (Gutteres, 2020)[13]. Since, hydrogen powered electricity do not emit pollution and more importantly if it is produced with clean energy, it will yield in zero carbon emission, which is very vital for global route of future net zero emission. One recent example, in the 2020 Tokyo Olympic or namely "Hydrogen Olympic", Japan was able to promote hydrogen power as reliable source towards sustainable future. For the first time in the history, both the Olympic torch and Cauldron were fuelled by hydrogen (Euronews, 2021)[14]. Not only that, the official cars, buses and power supplies at the Olympic Village are all powered by hydrogen-based electricity. Moreover, there also available dozens of hydrogens refuelling stations across the city, which shows how strong their commitment in hydrogen powered (Nature Research, 2021)[15]. As the world largest green hydrogen production plant, Fukushima Hydrogen Energy Research Base has provided the hydrogen for the Olympic Games. The electricity used to create the hydrogen comes from a solar array (PV technologies), which means it is 100% clean (green hydrogen). The plant uses up to 10,000 kilowatts of solar power to produce 900 tonnes of hydrogen each year (Euronews, 2021)[14].

Figure 3. *Tokyo 2020 Version ePalette vehicles that support athlete mobility at the Olympic and Paralympic Games Tokyo 2020.* (Source: IOC)

The utilization of hydrogen is broad, yet transportation has been the hydrogen most focus sector. Nowadays, many new application and invention of hydrogen batteries, cars, buses and train have been made. Beside the direct use, the hydrogen can also be mixed with another substance such as CO_2 and N_2 to produce both synthetic fuels and green ammonia respectively. But these hydrogen transformations are alternative way, since they still rely on the standard combustion vehicles to operate, which we want to omit by 2050. Therefore, the direct use of hydrogen fuel in transportation is priority to reach the 2050 carbon neutrality. In order to see the future of hydrogen-powered transportation, we are going to see the comparison with the fossil fuel cars and electric vehicle (EV).

Hydrogen vs Fossil Fuel Vehicles

The reasons people are still driving fossil fuelled power cars instead of the hydrogen powered cars are due to accessibility, convenience and cost. Compare to fossil fuel, hydrogen powered fuel is considered to be more expensive, especially the green hydrogen which could price twice as much as blue or conventional hydrogen (DiChristopher, 2021)[16]. Another factor is, the hydrogens refuelling stations are still lacking in some countries, which also lead to lower hydrogen transportation productions on the respective country.

However, this does not mean that hydrogen powered cars are on disadvantage, yet they are known for the high efficiency, zero-emission electric vehicles production. The fuel cell is two to three times more efficient than an internal combustion engine running on gasoline (EIA, 2021)[17]. Carey (2021)[18] also claimed fuel cells have the characteristics of high energy density and better heat tolerance which lead to cooler engine despite long distance travel. The most important is the green hydrogen powered vehicles will not emit single pollution, which are technologies we are looking for in future.

Figure 4. *Green Hydrogen Transportation.* (Source: AA+W - Adobe Stock)

Hydrogen vs Electric Vehicles (EVs)

Recently, the EVs market start to grow rapidly, especially since the Tesla and General Motors reign the international market (IEA, 2021)[19]. Federal incentives and more technology innovation such as autopilot mode and battery swapping are the reasons EVs become such popular nowadays. Similar to hydrogen powered cars, EVs are carbon free which also help the global to achieve zero emission target. Despite that, there are issues for EVs, such as charging time problem, accessibility and cost. With the incentive given by the federal, both clean energy vehicles able to get their price be more affordable, yet for certain models and brand,

the cost still pretty high. For refuelling cost, EVs have the edge over the hydrogen powered cars, a full charge of an electric car costs around £8 from a home charger, a full tank on a Toyota Mirai (Hydrogen powered) is roughly £75 (Naylor, 2021)[20]. Actually, with more mature market system, the hydrogen powered could overcome the pricing problem by time, as more and more people buy hydrogen cars, the costs will go down and there will be more fuel stations to use. This also given the fact that hydrogen powered cars have better accessibility compare to EVs. Beside by market reason they have access to more fuel station, it is also portable and quick refuelling, as it is in liquid form. On the other hand, EVs only can rely on charging station, which charging also believe is time costly. Nowadays, EVs companies have invented a fast-charging system and battery swapping, which put the EVs on advantage over the hydrogen cars (Baxter, 2020)[21]. Yet, these technologies are still on early stage which costing so much funds. This has put another consideration as the pathways towards zero carbon is getting close and we cannot wait no more.

Despite technical difference between EVs and hydrogen cars, both technologies actually have the similar concept and objectives. Instead of competing and comparing, it is better that we embrace both technologies and encourage them to take over the fossil fuels vehicles in future. Support from the federal government and official are also required, as incentives and infrastructure subsidies will increase the production, popularity and market growth.

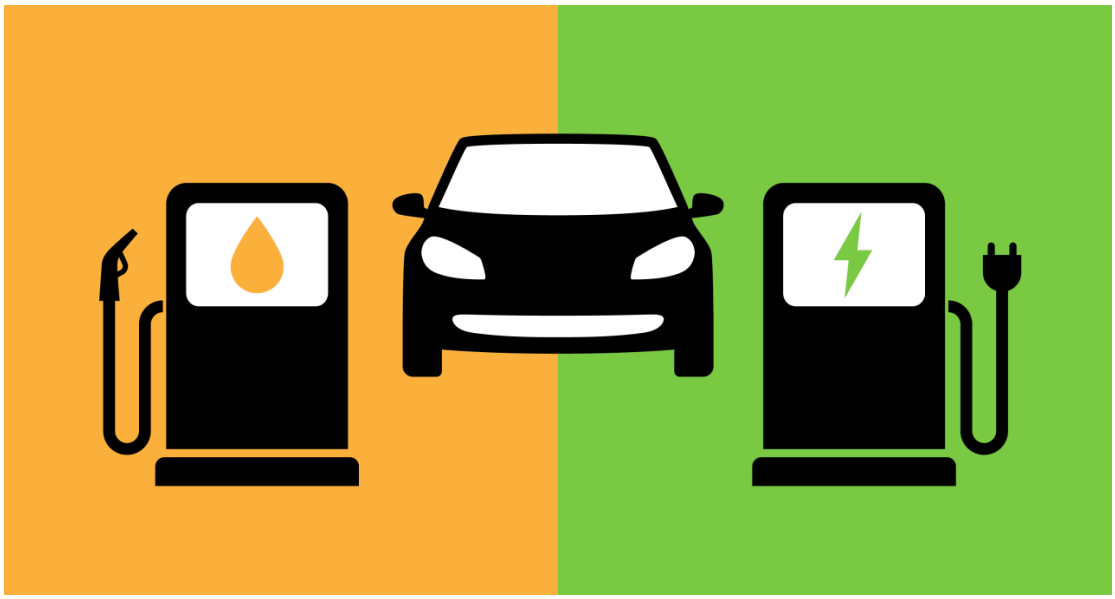

Figure 5. *Fuel Cells or Electric Charging.* (Source: Durbin)

The Future of Hydrogen Powered Electricity

The future of hydrogen powered system seems promising. Beside clean transportation, they also might help industries, power supplies and even agriculture sector to achieve zero emission. IEA (2019)[9] also stated that hydrogen could play an important role in our clean energy future. By the note that, they could make real contribution towards sectors where clean energy almost absent like transport, buildings and power generation. With increase of wind and solar power, it might also enhance the market and popularity of the green hydrogen. There is no doubt, we will prioritize the green hydrogen over grey hydrogen production in the future. Especially with the federal official bans and pledge to reduce fossil fuels production in future, which are on the pathways towards future 1.5 and 2 degree (IPCC, 2018)[8].

Similar to 2020 Tokyo Olympic. In February 2022, China will promote the green power hydrogen system through the next Winter Olympic events. The event will be held at Beijing city and expect to build 5 hydrogen refuelling station as well as provide 212 hydrogen powered buses by the event time (CNPC, 2021)[22]. They predicted this could mitigate approximately 30 tons of carbon emission. Currently, Beijing-Futian hydrogen refuelling station has been on operation since August 2021, which is the first hydrogen refuelling station for Winter Olympic. To success the Green Winter Olympic, government and federal official presence are required to encourage and promote this event. PetroChina as one of the state-owned petroleum enterprises also empowered the "Green Winter Olympic". They have involved in construction of the green hydrogen station in Beijing. Chinese Governments through pledges and commitment in dual carbon target such as 2030 carbon peak and 2060 carbon neutrality, certainly will help the country to be in transition (Chinese Government, 2021)[23]. More importantly, government incentives in the clean and renewable energy.

Figure 6. T*he Beijing 2022 Olympic and Paralympic Winter Games* (Source: CGTN)

In the future, many transportation sector enterprises are also racing towards clean energy source, either EVs or hydrogen powered. One of them is Jaguar Land Rover (JLR), they committed before 2025, their products will be fully electrified through hydrogen fuel cell prototype. JLR claimed that hydrogen fuel cells have the characteristics of high energy density, fast fuel replenishment, and cooler engine, which favours their vehicles to travel long distances and drive under extreme temperature conditions (Carey, 2021)[18].

Similarly, in power supplies sectors, GCL as a clean energy company from China officially released green hydrogen strategy in July 2020. It plans to build 100 integrated energy stations by 2025, with an annual production capacity of 400,000 tons of green hydrogen (Sina, 2021)[24].

Personal Opinion towards Hydrogen Powered Source

Hydrogen power surely is versatile, which has broad utilization, like it could be mixed with other substance to create others zero carbon products. Nevertheless, more efforts still need to be put, in order to make hydrogen as main global energy source. One reason is, hydrogen

especially green hydrogen, still costs much higher than some other energy source. Another is, to produce hydrogen it requires technologies, which pretty complex and increase production cost. In transportation sector, EVs might potentially take over the hydrogen powered vehicles for future clean transportation alternative, due to battery swap and fast charging technologies. Moreover, federal incentives are also the reason that global EVs market soared in recent years. Despite that, hydrogen power is still used widely at global level, which can be seen from the Tokyo Olympic and upcoming Beijing Winter Olympic. China for instance, also very keen into the hydrogen transition. This year, hydrogen energy has been included in the national "14th Five-Year Plan"[25] and the outline of long-term goals for 2035. More than 20 provinces have issued strategic plans for the hydrogen industry, includes Shanxi province as a pilot province in hydrogen production. According to the Vice Governor of Shanxi Province, the province's annual hydrogen production exceeds 3 million tons (Sina, 2021)[24]. Another good news came from "China Hydrogen Energy and Fuel Cell Industry White Paper 2020", which they estimate the annual output value of China hydrogen will worth 1 trillion Yuan by 2025. And possibly by 2050, hydrogen power could be accounted for more than 10% of China's energy systems, with annual output value worth 12 trillion Yuan (China Economic Net, 2021)[26].

The future is now, accelerate hydrogen energy utilization and promotion is a must. More research and innovation in green hydrogen efficiency, technologies and products are required. Together with governments and industries smart policies, this transition should be done by 2030. This first checkpoint is important, as this will determine on the possibility of the global to reach carbon neutrality by 2050. By taking full advantage of these near-term opportunities could position green hydrogen to play a critical role in the long-term global effort to achieve a clean, secure, resilient and cost-effective global energy system. By the note, both synthetic fuels and green ammonia could help to achieve this goal as well.

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