Gaffney Cline

# Differing Global Paths to Future Hydrogen Market
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## Hydrogen as Contributor to Decarbonisation

As previously mentioned in a number of articles by GaffneyCline, it is widely acknowledged that hydrogen has the ability to contribute to the decarbonisation of the energy and industrial markets and therefore assist with global efforts to meet emissions control requirements.

In the long-term there continues to be debate about the relative contribution of the different ways to produce hydrogen, differentiated by an associated colour palette in reference to environmental credentials relating to their feedstock and production method.

For the short to mid-term, the general consensus appears in favour of investment in Blue Hydrogen (natural gas derived with carbon dioxide emissions abatement), however moving to an ever increasing contribution of Green Hydrogen (water electrolysis from renewable sources of energy). Blue Hydrogen will facilitate the transition of liquid fuels from high carbon intensity (CI) fossil fuels to lower CI hydrogen for hard-to-abate sectors. With hydrogen infrastructure in place, supported primarily by Blue Hydrogen volumes, Green Hydrogen can develop commercially to ultimately supplant Blue Hydrogen production thus moving from abated-low to almost no carbon emissions.

The $CO_2$ emissions performance of Blue Hydrogen production is important to understand for longer term deep decarbonisation. Currently, overall global hydrogen production is responsible for about 830 Million tonnes/year $CO_2$ emissions (Source: IEA). An unabated natural gas SMR produces about 9 tonnes $CO_2$ emissions per 1 tonne $H_2$ produced. Converted to emissions on an energy content basis, this is circa 60 g $CO_2$/MJ, therefore while being a clean burning fuel, it has a carbon footprint higher than natural gas that emits, typically about 50 g $CO_2$/MJ at end combustion, but lower than coal at 90-100 g $CO_2$/MJ. Blue Hydrogen, combining a SMR with abatement technology is therefore significantly “cleaner” and reduces the Carbon Intensity down to anywhere between 35 to 6 g $CO_2$/MJ – depending on which stream and what level of $CO_2$ capture is applied.

Globally, the development of a Hydrogen market is progressing, although the market is still nascent with significant potential technologies still in the R&D stage. Commercial production of Blue or Green Hydrogen is limited to a small number of plants, located near to the end consumer. The largest dedicated hydrogen production units with CCUS, currently are:

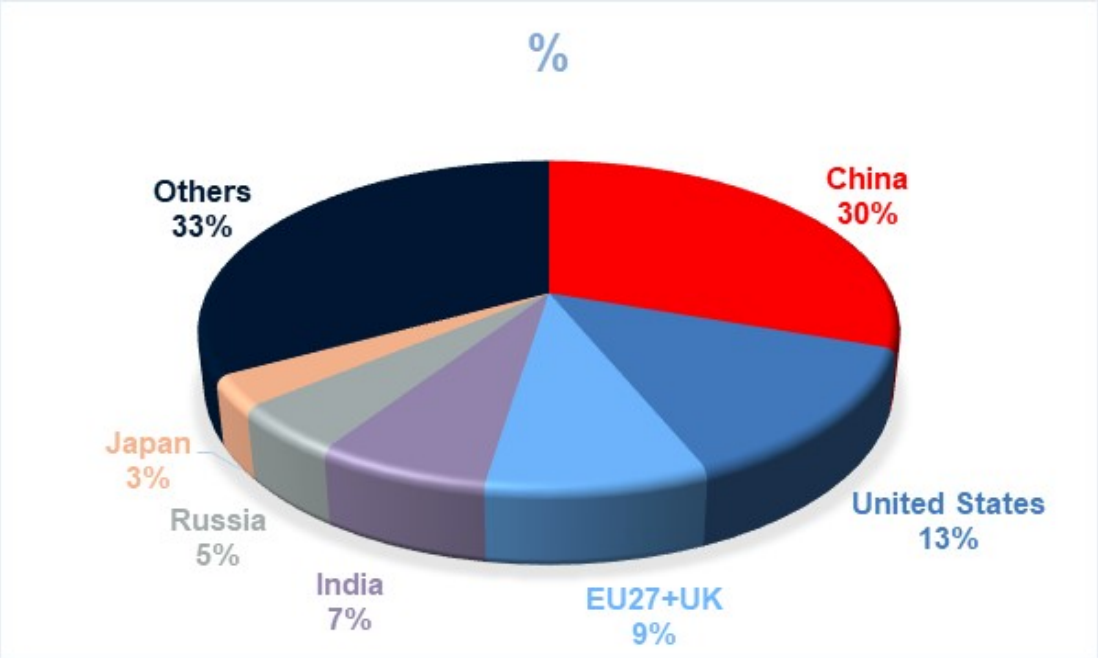
- Air Products’ SMR in Port Arthur, Texas, producing hydrogen for use in the Valero refinery whilst $CO_2$ into transported for oil fields EOR.
- Shell’s Quest project in Alberta, Canada, which produces hydrogen for use in the Scotford bitumen upgrader and injects around 1 Million tonnes $CO_2$/year into long-term geological storage.

There are also a small number of other projects where hydrogen is produced in a project with CCUS, but where the hydrogen is a component of a mixed syngas stream.

## Global Perspective

Although hydrogen markets will develop across the globe, the initial development of commercialized hydrogen will be defined by national and trading bloc policies in the major economies. The approach and strategy of each country and/or trade bloc differs, very much aligned with localized availability of energy resources, energy demand and Paris commitments. Global hydrogen market development will therefore be heavily dependent on the respective strategies of China, the US and the EU which in turn reflects a response to carbon mitigation in the main global carbon emitters namely China and the US, followed in respective order by the EU, India, Russia and Japan as shown in Figure 1.

**Figure 1: Global $CO_2$ Emissions by Location**




A growing competition between the EU, China and US in terms of technological development is also likely to rapidly drive down costs for hydrogen production, as was the case for solar PV development; high cost solar PV was initially developed in the US and Europe only to move to China for industrial production resulting in significant reductions in global levelised cost of energy for PV solar.

To understand better the global development of a hydrogen market, it is necessary to understand the current focus and drivers in each major economy, as summarised below.

## Regional Strategies Summaries

### China

China is already a significant player in terms of hydrogen, with an estimated 30-40% of current global production. In terms of regulation, a significant number of hydrogen-related policies have progressed in 2020 at national, provincial and municipal levels driven predominantly at the fuel cell vehicle (FCV) market.

Chinese Government interest in Green Hydrogen was considered up to quite recently to be limited with most hydrogen produced by coal gasification, based on domestic resource availability and commerciality. However a recent fuel cell and hydrogen infrastructure subsidy policy announced by the Central Government looks to have provided an incentive to a more rapid Green Hydrogen market development as part of a focus on FCV market.

A number of strategic plans determine strategy in China, with the most recent being the issue in 2015 of the "Made in China 2025" plan which focusses on moving China further into high-tech fields plus new energy and energy-savings vehicles as well as progress in new and renewable energy. An associated "Energy Saving and New Energy Vehicle Technology" roadmap was published in 2016, which focused on FCVs for China's future energy requirements and business competitiveness, providing targets for specific regions.

The draft of the 14th Five Year Plan (2021-2025) to be implemented next year is widely considered to detail a more extensive development of the hydrogen market including support for growth in Green Hydrogen production and technology.

Interestingly many hydrogen-related policies have been driven by the Regional governments with the Central Government still to finalise its overall strategy, although there have been recent specific FCEV-supporting policies announced. Regional or local governments have also announced a number of hydrogen programmes, typically related to hydrogen infrastructure development. The majority of the stimuli plans relate to FCV and hydrogen refueling services, although some provinces are looking to develop hydrogen "valleys" regional industrial hubs.

## United States

The US is at the forefront of hydrogen fuel cell development and is home to a large percentage of global fuel cell vehicles and a large number of small-scale fuel cell power plants whether for remote telecommunications or backup power systems. The US is also the location of a number of commercial hydrogen producing facilities in addition to having extensive hydrogen-related manufacturing and technological capability.

The Federal Government provides a number of tax credits that are applicable for hydrogen-related activities including investment tax credits under Section 48 (fuel cells) and Section 30B/30C (FCVs and refueling services).

An interesting recent House Bill committed "the Secretary of Energy to conduct a study to examine opportunities for research and development in integrating blue hydrogen technology in the industrial power sector and how that could enhance the deployment and adoption of carbon capture and storage," and thereafter to "submit to the Committee on Energy and Natural Resources of the Senate and the Committee on Science, Space, and Technology of the House of Representatives a report that describes the results .."

The Federal Government also continues to invest in R&D through the US Department of Energy's (DOE's) H2@Scale program and the DOE also recently announced, in November, the release of a Hydrogen Program which provides a strategic view of how the DOE manages hydrogen research, development, and demonstration (RD&D) activities. The DOE recently announced around $64 million of funding in 2020 for hydrogen research, development and demonstration projects. Following on from such investment and promotion from the US hydrogen industry, the US Government may well implement a more detailed official strategy to mirror those seen elsewhere in the World.

Given the nature of US regulation, each State will also likely progress a range of policies and strategies for future hydrogen market development, in parallel with the Federal Government. To date there are a number of different enacted energy policies that establish tax exemptions, credits, rebates, loans, grants and corporate income tax credits promoting infrastructure development for hydrogen utilization.

California (amongst other West Coast states) is at the vanguard of policy development in support of low carbon activities including hydrogen. Over the last 10 years, there has been the Low-Carbon Fuel Standard, the Alternative Renewable Fuels and Vehicle Technology Program leading into the successor Clean Transportation Program. The California Air Resources Board also provides mandates and funding to zero emissions vehicles and supporting infrastructure.

## EU

The EU is targeting carbon neutrality by 2050 and Hydrogen is a key part of its European Green Deal strategy and action plan, as a potential solution for the many hard-to-decarbonise industrial and heavy transportation sectors. The European Green Deal is a package of strategies intended to reduce emissions through implementation of a Climate Law to formalize climate strategy in addition to revision and review of a number of directives including strengthening the EU ETS, revisions to guidelines on state aid and plans including energy taxation.

The EU Commission recently issued a specific Hydrogen Strategy that prescribes a 3 phase plan for hydrogen market development. The first phase of the hydrogen strategy (covering the years 2020-24) plans for 6 GW of electrolyzer capacity to produce up to 1 million tonnes of Green Hydrogen. Planning for hydrogen infrastructure will also commence as well as laying down the regulatory framework for a fungible and functioning hydrogen market, support being provided through appropriate State aid rules.

A second phase (covering the years 2025 to 2030), calls for 40 GW of operational electrolyzer capacity, producing some 10 million tonnes of Green Hydrogen (currently, the EU has the capacity to build a little under 1 GW of electrolyzer capacity). In this phase, the EU plans to support and stimulate investments for a fully developed hydrogen ecosystem. A third phase is also planned, from 2030 to 2050, but details are provisional at present.

The EU acknowledges the role of Blue Hydrogen in the forward plans as a transition technology for development of an extensive Green Hydrogen market. The EU quotes a strategic vision where the share of hydrogen in Europe's energy mix is projected to grow from the current less than 2% to 13-14% by 2050 (the majority produced by Blue Hydrogen), promoting growth and employment as well as an intent for global leadership in renewables technology.

In support of the EU plans, funding instruments, such as the Innovation Fund and InvestEU programme have been developed, which will allow for enhanced investment in hydrogen related projects, plus the EU has initiated a European Clean Hydrogen Alliance, comprising both public and private organisations, to facilitate and implement EU strategy.

## India

The Government of India operates its renewables strategy through the Ministry of New and Renewable Energy (MNRE). A National Hydrogen Energy roadmap was developed in the mid-2000's but the vision presented is distant from what has been achieved by 2020 - a major target was 1 million vehicles on the road using hydrogen by 2020, plus a plethora of infrastructure and power generation plans, none of which have come to fruition.

The MNRE is reported to be supporting extensive R&D programmes for hydrogen development, and references two hydrogen refuelling stations, at IOL's site in Faridabad and one at the National Institute of Solar Energy's Gurugram site.

The GOI in 2015 issued a plan for the development of 175 GW of renewable power by 2022, with significant strides being made in renewable power generation, although hydrogen has not been included in the plans to date. There is however much discussion in India with both state and private companies investing in hydrogen technologies including Indian Oil Company and Reliance Industries and Adani. Related ministry officials regularly mention the intent to have a Hydrogen Roadmap at conferences and to the media and no doubt policy is being formulated.

## Russia

In April 2020, the Russian government adopted a planning document called the "Energy Strategy 2035" plan. Russian ambitions focus on development of the energy sector for domestic economic growth by prioritising development of internal infrastructure and increases in exports dominated by the hydrocarbon sector.

The Energy Strategy 2035 plan does however reference hydrogen as being important to the Russian energy market, although with limited detail. The plan references Russia as becoming one of the world leaders in hydrogen production and export. Commentary is included on diversification of natural gas use, increased hydrogen production from a range of sources, the implementation of CCUS combined with reforming or methane pyrolysis. There is also other commentary relating to increasing the domestic fuel cell market, regulation development and legislation as well as developing export markets. There is also a statement confirming a plan to export 2 million tonnes/year by 2035.

The Ministry of Energy organized a working group in late 2019 to assess hydrogen development comprising the Ministry with representatives of energy-related companies including Gazprom, Sberbank and Rosatom, as well as a number of academic institutions. A subsequent roadmap relating to development of hydrogen energy in Russia for 2021-2024 was presented in July 2020 to the Russian government, and was approved in mid-October. The roadmap included establishing a regulatory framework for hydrogen comprising state support for R&D, assessment of mixed fuels for power generation and transportation plus hydrogen

infrastructure development including new technical and safety regulations, possibly supported by fiscal incentives.

It is clear from the roadmap that Gazprom and Rosatom with academic support will be the main conduits for hydrogen development and that nascent Russian hydrogen policies will likely mature rapidly.

Hydrogen is currently produced in Russia for use in refining and petrochemical industries, typically at site. Hydrogen technological development to date has been limited and focused on R&D activities, however some new activity has progressed with Rosatom and Japan's Natural Resources and Energy Agency signing an agreement to develop a pilot project to export hydrogen from Russia to Japan, sourced from electrolysis. Gazprom and Rosatom have been recently mentioned as planning to commence hydrogen production in 2024 with support from the government, plus there have been articles relating to development of hydrogen-capable turbines, potential hydrogen use in transportation infrastructure and a project has been signed between RusHydro and Kawasaki for hydropower-based generation of hydrogen for export to Japan. The potential to sell hydrogen to the European market either directly or combined with natural gas exports is also being considered by Gazprom.

## Japan

Japan Government strategy on hydrogen is driven by the Ministry of Economy, Trade and Industry (METI) as well as the Ministry of the Environment, with significant investment planned in developing a hydrogen-based energy. Japan currently imports about 90% of its energy supplies with renewables only providing about 10% of electricity supply and is focused on developing a more robust and environmentally friendly future energy mix; Japan is considered as being at the forefront of state support for hydrogen market development.

Japan announced its fourth Strategic Energy Plan in 2014 to initiate its move towards developing a hydrogen-based energy sector. Japan, mostly through METI, commenced heavy investment in R&D at that time for low-cost hydrogen production, developing of a logistics infrastructure in addition to transportation and power generation sectors. METI also provides subsidies for fuel cell roll-out as well as FCVs. Japan has also reviewed and revised a number of standards and codes for infrastructure which has facilitated easier roll-out of hydrogen in certain areas. Local governments are also supporting the hydrogen market development with some subsidies and the private sector is also involved with Toyota having commenced commercial production of the first FCV, the Mirai.

The 2014 Energy Plan was followed in 2017 by a hydrogen-specific roadmap, the Basic Hydrogen Strategy, which developed plans, setting specific targets to be met by 2030 and proposes a 3 phased approach. The main components of the roadmap are:

- Cost reduction of hydrogen, including pricing targets for electrolysers and domestic fuel cell systems
- Increases in FCV over a 10 year period as well as hydrogen fueling stations
- Development of supply chain for hydrogen and transportation focused hydrides.

A further roadmap update on Hydrogen and Fuels Cells was issued in 2019, again providing more specific details on targets and plans. A few key items in the roadmap include:

- FCVs increasing in stages from about 3,000 currently to 800,000 vehicles in 2030
- Increase to 320 hydrogen fueling stations by 2025
- Over 5 million domestic fuel cells systems by 2030.

Japan's efforts are reflected in a number of hydrogen projects. The Fukushima Hydrogen Energy Research Field (FH2R), completed in March 2020, is a PV solar system producing up to 1,200 $Nm^3$/ hr and in May 2020, Japan's AHEAD (association) supported by both governments commenced pilot transport of hydrogen as an organic chemical hydride from Brunei to Tokyo. More recently importing liquid hydrogen from Australia has been mooted with the development of the Hydrogen Energy Supply Chain pilot project using hydrogen produced from lignite in Australia, with an intent for carbon capture to be included in the project; the project is scheduled for deliveries in a 2022/2023 window.

## Summary

The global roadmap to a low-carbon future supported by a hydrogen market to help mitigate hard-to-abate sectors is at the very early days of development. The hydrogen policies and focus of the major economies will be the determining factors of the rate of growth of the hydrogen market. Currently the policies are varied and in differing levels of maturity, however the intent to progress a hydrogen market development is a strong common element of all major economies' strategy which should permit for increased opportunity in the sector whilst limiting the risks.