HYDROGEN

THE NEXT EPOCH

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Introduction

Hydrogen is being lauded as the future's most viable fuel alternative to revolutionize today's energy economy. It is also in that favor that the European Union has set decarbonization and sustainability as the two key trends of its 2050 long-term strategy. Since the EU reports significant delays in their schedule for its 2030 goals, realistic alternatives to fossil-fuels need to be identified in a rather rapid fashion. As a matter of consequence, Hydrogen, the first element on the periodic table, has been qualified as the key candidate to quickly align the EU with the decarbonization strategy, set for 2050.

Hydrogen Types and Characteristics

As the most abundant element on earth, Hydrogen as a fuel comes along with remarkable potential benefits. To classify the role of hydrogen as a potential decarbonization agent, its types (i.e., color coding according to raw material source and production method) must be considered in a differentiated manner.

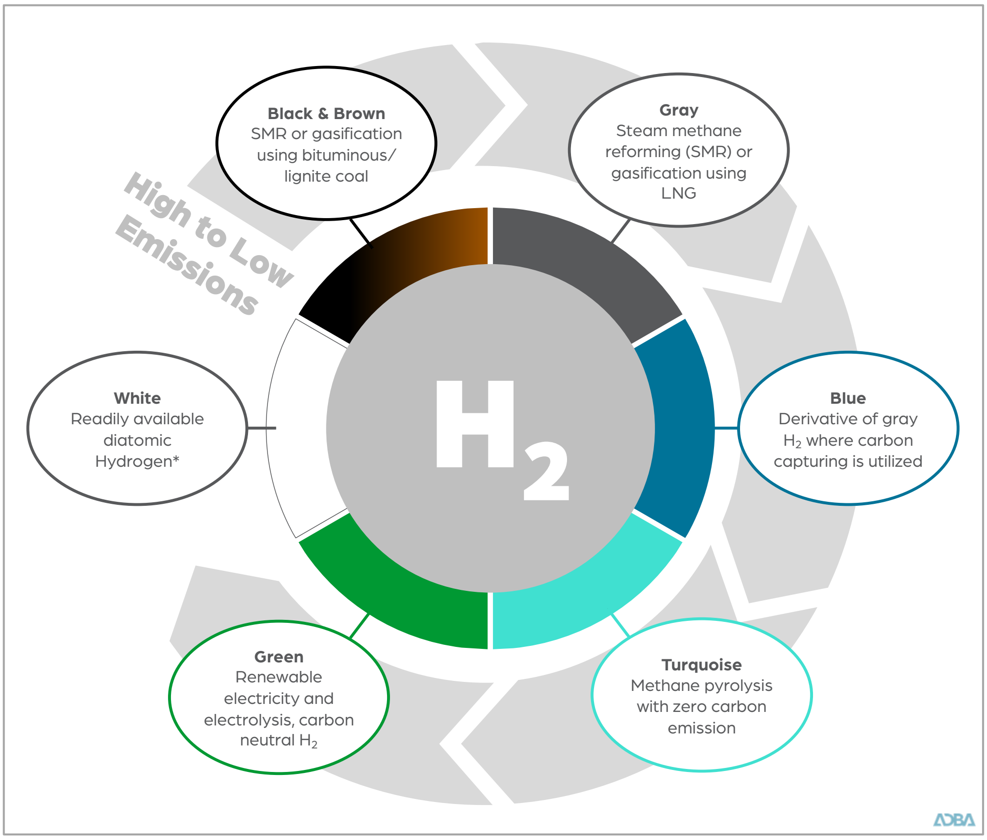

Figure 1 – Types of Hydrogen

The emission relief of the respective hydrogen species improves with increasing brightness of the assigned color scheme. To date, approximately 95% of world's hydrogen demand is covered by gray Hydrogen, while less than 1% is green. The benefits and drawbacks of Hydrogen should be assessed to comprehend its viability potential as a fuel or a decarbonizing agent for the future. Currently, hydrogen produced with nuclear energy is also being discussed as a part of the net zero scenarios, though due to its immaturity, its ecological impacts cannot be evaluated thoroughly.

Benefits and Drawbacks
Hydrogen comes along with undoubtable benefits but also bears drawbacks. In the present stage of available technology, achieving a high rate of maturity quickly is the key challenge associated with hydrogen's value chain.

Benefits	Drawbacks
Most abundant element on earth, practically endless stock due to output to input cyclicality	Rare in diatomic form (H_2) and no technology to mine diatomic H_2 from natural sources
High energy density ($1kg\ H_2 = 2.8kg$ gasoline)	Natural state (gaseous) volume is comparatively large
Combustion output is eco-friendly (water only)	Highly flammable
Can be carbon neutral if green (i.e., produced with renewable energy)	Production of hydrogen globally contributes a major portion of carbon emissions
Scores of application opportunities and storage forms	Corrosive
Hydrogen based synthetic fuels are drop-in replacements of traditional fossil-based fuels	Low efficiency through high energy losses in conversion process
Supports overall decarbonization goals by its usefulness in sectors where carbon abatement is only possible through H_2	Conversion and transportation requires new specialized equipment and infrastructure

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Figure 2 – Excerpt of Benefits and Drawbacks (Excerpt)

It is certain that new challenges will emerge as technology standards continue to evolve. However, it can be assumed that with an increasing focus on hydrogen-related technologies, newly discovered disadvantages will also be overcome. Therefore, selected co-operations with research and science are to be classified as an enabler on the journey of making green hydrogen mass-compatible and applicable.

As of 2022, the production of green hydrogen sustainably is not at the desired efficiency level. However, towards a greener and more sustainable future, the shift to green hydrogen has to happen sooner rather than later, also bearing in mind the commitments of policymakers of relevant industry nations.

Hydrogen Value Stream

Green hydrogen's relevance as a fuel for the future correlates to its production and logistics efficiency, backed-up by relevant and scalable application areas. Market demand as the key trigger for the supply of green hydrogen has been at a low-level to none – up to now.

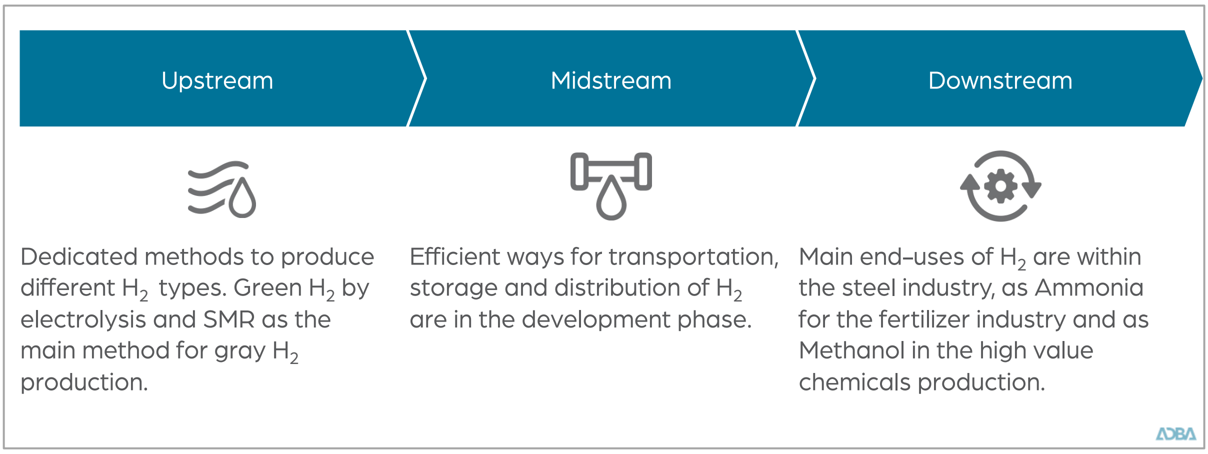

Figure 3 – Hydrogen Value Stream (high-level illustration)

Methods to produce blue/gray/brown/black hydrogen, are on an acceptable industrial efficiency level, whereas green hydrogen production relies on emerging immature technologies. Not only technology immaturity, but lack of stable streams for green energy supply and their consequently high price, are decisive reasons, as to why green hydrogen is priced at almost two times blue or gray hydrogen.

Next to mass production of hydrogen, various operational challenges need to be dealt with for the midstream. Conversion, transportation, storage, and distribution of hydrogen needs to be at an industrial maturity and efficiency level, to elevate hydrogen to an industry and market relevant energy form. Since the volume of hydrogen depends on the conversion method (and therefore its physical state), conversion or liquefaction of hydrogen is integral to reduce storage and logistics burden. Logistics are no easy feat either, as these processes require both specialized equipment and tailor-made infrastructural elements to support the transportation network of hydrogen from its place of production to its end users.

With its vast number of potential end-uses in various sectors, hydrogen can be utilized either as a feedstock, as a gas, or to generate electricity. Industrial uses make up most of the demand as the chemicals sector, along with oil and gas, consumes ¾ of the world's hydrogen. As hydrogen technology is continuously advancing, it is expected to become a viable solution in the mobility sector as well. E.g., in the shipping and aviation sector, where carbon abatement can only be done by switching to hydrogen fuels or fuels that are made with hydrogen as the main input; Such as e-kerosene for aviation or ammonia fuels for maritime fuel. Moreover, as hydrogen based synthetic fuels are drop-in by nature, they do not require conversion or specialized networks to be distributed within the readily available refueling ecosystems.

Having the ability to activate R&D efforts for primary production technologies, assuring sufficient green energy supply and creating the market activation strategy for profitable uses are the key critical drivers in orchestrating the hydrogen ecosystem. This will decide whether one dominates selected areas in the developing green hydrogen market or not.

Hydrogen Today

Global hydrogen production in 2018 amounted to 60 Mt, nearly doubling already in 2019. Production from dedicated sources, made up around 2/3rd of the total production. Currently, annual hydrogen production from dedicated sources is approximately 94 Mt, while forecasted to increase in the near- and long-term future. Today, hydrogen consumed by sectors, mainly differentiated to chemicals, oil & gas, steel industry and other consumers.

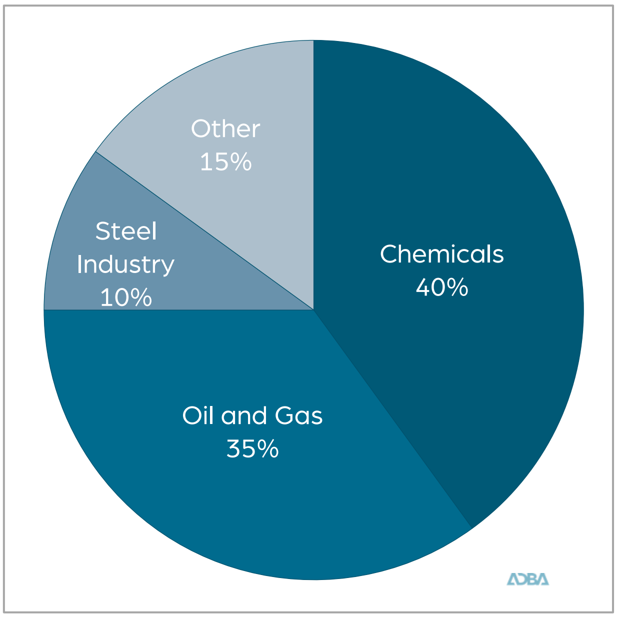

Figure 4 - Hydrogen Demand by Sector

The chemicals sector uses hydrogen to create ammonia, which is then used to produce fertilizers, cleaning products, for refrigeration and many more industrial applications. Moreover, hydrogen is used to create high-value chemicals, such as methanol (by being combined with CO and CO_2) to be used as a chemical precursor in areas, such as the polymer production, or to create fuels and additives.

The oil and gas industry already heavily relies on hydrogen as a key ingredient in hydrocracking and desulphurization processes. For this reason, most refineries have their own hydrogen production facilities to cover up to 80% of their own hydrogen demand.[1]

As the steel industry is one of the most process-heat intensive sectors, its hydrogen demand ranks third in the sectoral perspective. This sector uses hydrogen as an energy source, converting hydrogen into electricity, thus powering highly energy intensive electrical arcs needed in the process of turning iron ore to steel.

"Other" uses cover mobility and general wide-scale power generation. Thanks to its convertibility, in the fields of power generation, hydrogen mostly is used as an energy storage vector. Although in the mobility sector H-fuel-cells have not been widely adopted yet, while hydrogen is being used (and will in future even more) to decarbonize shipping and aviation sectors through the synthetic fuels such as e-kerosene and ammonia fuels. Moreover, and increasingly, uses in the heavy trucking sector[2], to power lorries for extended ranges become more relevant, for which electrification with battery systems is inefficient. As a fuel, 1 kg of hydrogen is equivalent to 3 kg of diesel fuel and is able to power a standard vehicle for up to 100 km. Current production-ready fuel cell trucks have ranges of 400 km, while prototypes that can travel further than 1000 km have also been presented.

[1] 1 Mt of hydrogen is used to refine 285 million barrels of oil, while it is 21 MBOE if used as a fuel, which amounts to a quarter of global daily oil consumption.
[2] To date, mainly in China

Trends and Predictions

In the following years, hydrogen demand is expected to rise exponentially. By 2030, with the improvements in hydrogen production technology and given the projects that have already started and are to be completed in the upcoming years, global hydrogen demand is expected to almost double from 2022 demand and reach 115 Mt at the current project implementation pace and policymaking structures of the governments. By 2050, the demand must reach 545 Mt to be aligned with the Net Zero Emissions goals. Comparatively, demand composition will change immensely by 2050, as mobility (with increasing mature technologies in use) is expected to become a major sector that uses hydrogen.

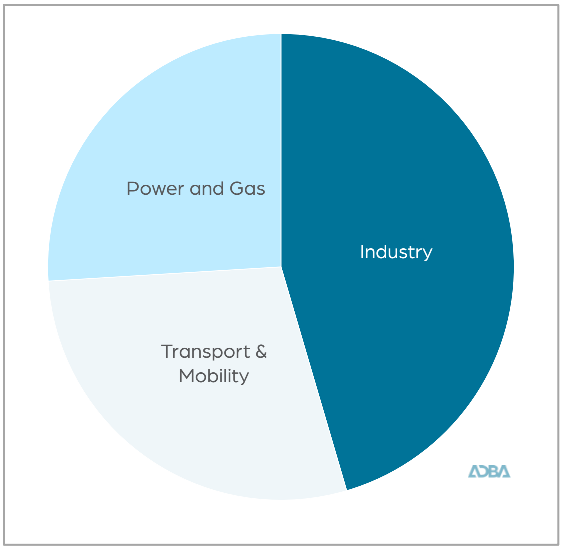

Figure 5 – Hydrogen Demand Composition, 2050

As demand changes, production efforts are destined to change as well, in-line with the European Union's decarbonization goals. 2021's hydrogen demand was met mainly from fossil fuels *without* carbon capturing, utilization, and storage (CCUS). By 2030, it is expected that fossil fuels will be used to produce ±70 Mt of hydrogen per year, while electricity powered hydrogen production (i.e., green hydrogen) will take the second spot with ±60 Mt. Moreover, with the improvements in the CCUS technology, 33 Mt of hydrogen will be provided with fossil fuels but with CCUS measures in place. For the 2030 Net Zero Scenario, 700 GW installed capacity of electrolyzers is necessary, so that 120 Mt of hydrogen can be produced with zero emissions.

Furthermore, as hydrogen continues to be adopted in more and more areas, 60 Gt of CO2 emissions will be mitigated by 2050. Although major, the emission abatement done with hydrogen adoption only makes up 6% of the total emission reductions. In the greater picture, the portion of emission reductions of hydrogen will mostly be in the areas of shipping, aviation, and trucking as conventional electrification or use of other alternatives is not possible due to fueling duration constraints and low range-to-consumption ratios.

Following the increasing demand trend, relevant countries prepare for the hydrogen ecosystem through infrastructural investments. For example, Spain is preparing to become the biggest green hydrogen producer in Europe with a targeted installed electrolyzer capacity of 70 GW; One of the busiest ports in Europe, the Port of Rotterdam has started transforming its facilities to load and unload different hydrogen carriers such as ammonia, methanol, or LOHC; Pipelines networks are being prepared to handle their transport, to stay relevant in the hydrogen supply chain by becoming Europe's biggest hydrogen import hub. Another example of a key European player in the circular hydrogen economy is Germany. The German government has called to produce 80% of its power through renewables by 2030 and likely will make up one third of Europe's hydrogen demand. Another 20% of the EU's total demand will be coming from France and the Netherlands.

Green Hydrogen and the Opportunities of the Future in Europe

New projects suggest that hydrogen production will increase rapidly. By 2030, with projects currently in development, production of green hydrogen will be around 10 Mt, requiring electrolyzers with an installed capacity of 138 GW. Most of the new productions will focus on carbon-neutral methods, as decarbonization horizons are getting closer with each year. With more new projects, the installed capacity is expected to scale up rather quickly, depending on the project sizes. In 2021, the 2030 installed capacity estimates were only 1/3rd of today's 2030 estimates, while the size of the average project is expected to enlarge as well. In 2021, the average project size was 5 MW, while by 2025, this value will increase geometrically. Within the current roadmap, only 5% of projects are GW scale, but by 2030, average project size is expected to easily be at least a GW. By the end of year 2022, above 1 GW of total installed capacity will be achieved. By 2040, the EU aims to have 40 GW installed capacity and the government pledges to date cover 34 GW. However, this is far from the net-zero goals to produce enough hydrogen needed for the NZS[3].

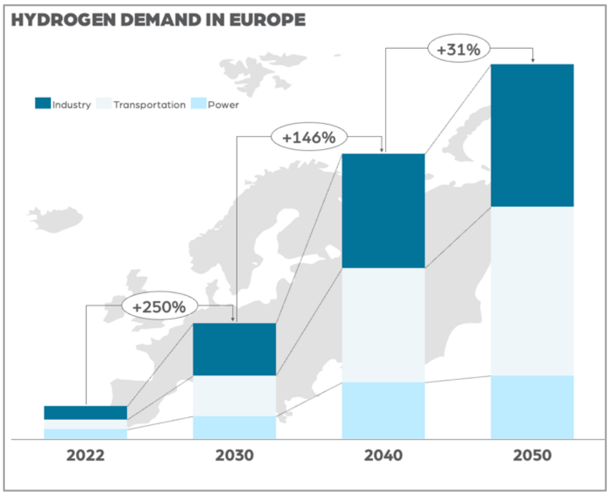

Figure 6 – Hydrogen Demand Growth in Europe

With its sights set on decarbonization and becoming independent of imported oil and gas, European nations are displaying exponentially increasing hydrogen demand trends, and will likely source hydrogen through politically amicable or neutral countries.

Conclusion

Given persistent demand for hydrogen that keeps increasing daily, countries must be prepared to take their relevant spots in the circular hydrogen economy, as being a laggard in this adoption rush will have irreparable impacts on the countries' energy policies and decarbonization efforts. Along with increased adoption, it is definite that supply of green hydrogen will increase parallel to the decarbonization efforts of the countries, and inversely proportionally to the green energy prices.

[3] Net Zero Scenario

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