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2030 Ambitions for Hydrogen, Clean Hydrogen, and Green Hydrogen †

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Abstract: Hydrogen production has been dominated by gray hydrogen (hydrogen produced from fossil fuels without carbon capture). Historical data for 2019–2021 show nearly steady global production and demand of hydrogen, with an average annual of 92 Mt (million tonnes) for either production or demand. Each of the global hydrogen production or demand should grow to 180 Mt in 2030 for compliance with the Net Zero Emissions by 2050 scenario (NZE) of the International Energy Agency (IEA), to bring CO_2 emissions to net zero by 2050. Recently, green hydrogen (hydrogen produced by water electrolysis using electricity from renewables) received attention, with 11 countries (Australia, United States, Spain, Canada, Chile, Egypt, Germany, India, Brazil, Oman, and Morocco) identified as expected top producers may produce together 15.9534 Mt in 2030. All of these countries except Spain, Canada, and Germany, were classified by the global Hydrogen Council as having optimal production potential of green hydrogen. Blue hydrogen (hydrogen produced from fossil fuels with carbon capture) and green hydrogen together form clean hydrogen. The share of clean hydrogen in the global total final energy consumption (TFEC) was less than 0.1% in 2020. In alignment with the 1.5 °C pathway of the International Renewable Energy Agency (IRENA) to limit the global average temperature rise to 1.5 °C above pre-industrial levels, this share should grow to 3% in 2030 and 12% in 2050, with 154 Mt of clean hydrogen and its derivatives produced in 2030 (and 614 Mt in 2050), compared to only 0.8 Mt in 2020.

Keywords: hydrogen; clean hydrogen; green hydrogen; blue hydrogen; gray hydrogen

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1. Introduction

Hydrogen as an energy carrier or a feedstock can be used in several applications, such as direct electricity generation (through fuel cells which in turn can be used for stationary applications or for powering electric vehicles, ships, or drones), gas turbines (powered hydrogen as a pure fuel or as a blending fuel to be mixed with natural gas), heating, ammonia production, methanol production, e-fuels production, and iron production (through direct reduced iron, DRI) [1].

Being free from carbon atoms, hydrogen has the environmental advantage of not emitting carbon dioxide (CO_2), which helps in reaching carbon neutrality (CO_2-neutrality) and mitigating climate change [2]. Moreover, producing green hydrogen and its derivatives (green ammonia, green methanol, or green e-fuels) from electricity produced by renewable energy sources provides a way of storing surplus electricity from variable sources as chemical energy that is readily available and can be transported and traded conveniently [3]. Synthetic non-fossil fuels derived from green hydrogen allow sectors or parts of a sector that are difficult to be electrified to remain operational without major changes but with reduced harmful emissions through PtX decarbonization [4].

Green hydrogen represents an emerging market, and it is not clear how successful it can reach, which depends on its economic feasibility and its ability to be competitive with traditional energy sources, with or without governmental incentives or subsidies. The growth in demand, the ease of global trade, and the presence of a nation-level support are also important factors in promoting a green hydrogen market [5].

The current study presents historical data about hydrogen production and demand, as well as future estimations of the necessary role of clean hydrogen in different sectors as a contributing component in global carbon neutrality by 2050. The current study also lists 11 countries with highest expected production capacity of green hydrogen in 2030.

2. Materials and Methods

The current study is based on analysis of data from several sources, as described in the respective references. These data can be in the form of tabulated values, part of a published study, or part of a press release. The next section presents graphical, statistical, and qualitative results obtained after the source data were processed.

3. Results

3.1. Global Hydrogen Production

Figure 1 is a visual representation of numerical data collected from the International Energy Agency (IEA), regarding the global hydrogen in general (not just green hydrogen or clean hydrogen) in 3 consecutive years. The latest data year was 2021 when the data was accessed on 26 June 2023 (it was last updated on 8 September 2022) [6]. The production is categorized by the technology into 5 sources. These historical data are compared with future estimation in 2030 as part of IEA NZE. It is noticeable that there was practically zero green hydrogen production up to 2021. Also, the produced hydrogen by each technology did not change largely between 2019 and 2021. The majority (81.52%) of global hydrogen production during 2019–2021 was gray hydrogen, which involves a lot of harmful emissions. This fraction should decline to only 39.84% in 2030 in the IEA NZE.

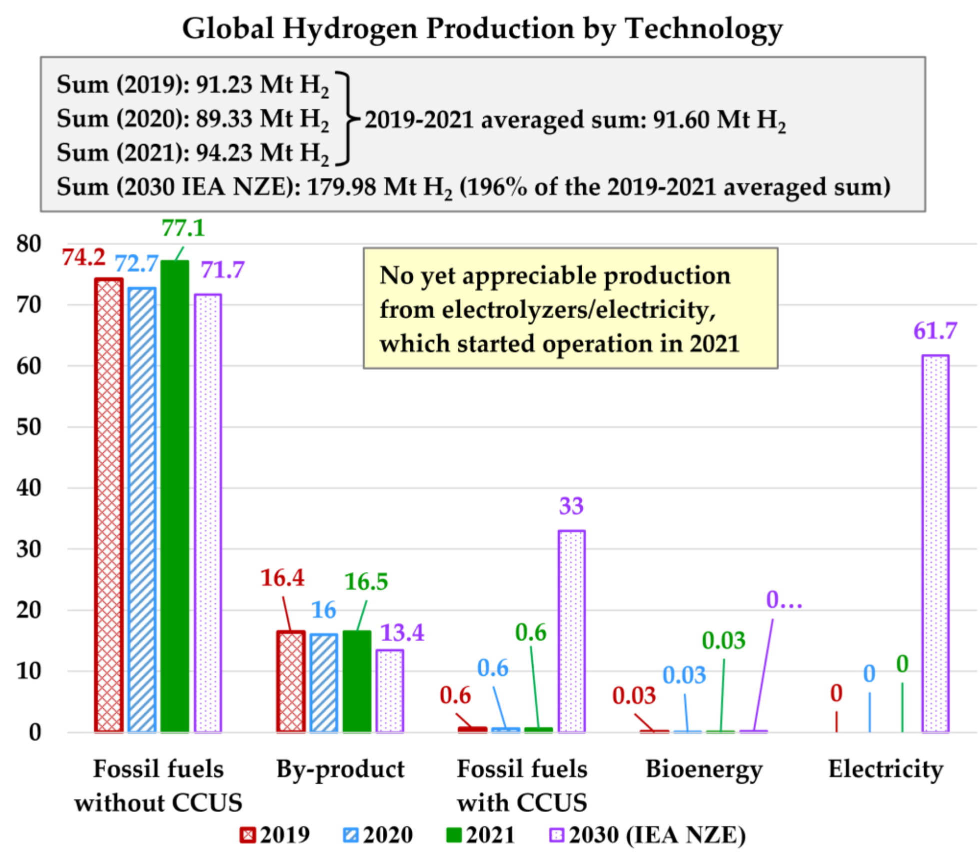

Figure 1. Global hydrogen production by source technology, in 2019, 2020, 2021; and the corresponding 2030 expected production according to the NZE of the International Energy Agency (IEA).

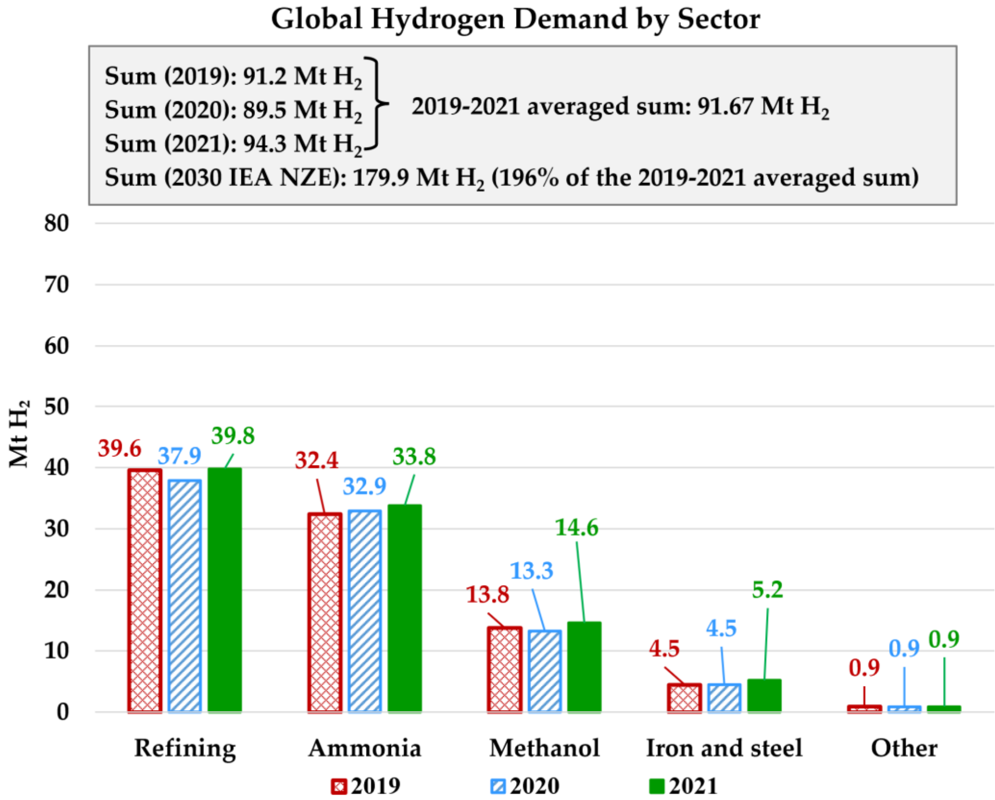

Figure 2. Global hydrogen demand by consuming sector, in 2019, 2020, 2021.

3.2. Global Hydrogen Demand

Figure 2 presents historical (2019–2021) data for the hydrogen demand worldwide. The latest historical data was for 2021 when the data was accessed on 26 June 2023 (the data was last updated on 16 September 2022) [7]. The variations between 2019 and 2021 are weak. The refining activities were the largest consumer of hydrogen, with the average portion out of the total demand during 2019–2021 being 42.65%. According to the NZE forecasting, the total global demand should nearly double in 2030 compared to its value during 2019–2021, reaching 179.9 Mt H_2 instead of 91.67 Mt H_2.

3.3. Clean Hydrogen Performance

The 1.5 °C pathway of IRENA is similar to the NZE scenario of IEA, although the former may have more focus on renewable and clean energies. IRENA identified 6 key performance indicators (KPIs) that correspond to 6 areas of technological transitions, and these KPIs are aligned with meeting the IRENA 1.5 °C targets by 2050. The 5th IRENA KPI corresponds to hydrogen, and it is stated as "KPI. 05: The production of clean hydrogen and its derivative fuels must ramp up from negligible levels in 2020 to 154 Mt by 2030" [8].

In addition to this specific hydrogen KPI for 2030, other IRENA performance measures for the growth in producing or utilizing clean hydrogen are listed in Table 1.

Table 1. Some targets for clean hydrogen as an environmentally better substitute for fossil fuels, as projected by the International Renewable Energy Agency (IRENA) in its 1.5 °C pathway.

Hydrogen Target	2020 (Historical)	2030 (IRENA 1.5 °C)	2050 (IRENA 1.5 °C)
Annually produced clean hydrogen and its derivatives (Mt/year)	0.8	154	614
Annual energy as clean hydrogen and its derivatives (EJ/year)	>0 (negligible)	19	74
Share of clean hydrogen in TFEC	<0.1%	3	12%
Share of clean hydrogen in transport TFEC	<0.1%	0.7%	12%
Share of (ammonia, methanol, and e-fuels) in transport TFEC	<0.1%	0.4%	8%
Total world energy use as clean hydrogen in industry (EJ)	>0 (negligible)	16	38
Total world energy use as clean hydrogen in buildings (EJ)	0 (negligible)	2	3.2
Annual investments in hydrogen and its derivatives, including electrolyzers, feedstocks, and infrastructure (USD billion/year)	0 (negligible)	133	176

3.4. Expected Top 11 Countries by Green Hydrogen Production Capacity in 2030

According to Rystad Energy (an Oslo-based company that conducts independent energy research), 10 countries were identified as projected to have the largest green hydrogen production capacity [9]. Although Oman (the Sultanate of Oman) was not in this top 10 list, it is added here given its officially announced target of producing 1 Mt H_2 annually by 2023 [10], which enables it to be within the list (before the last 11th rank). The list of these 11 countries with the estimated 2030 production capacity are in Figure 3.

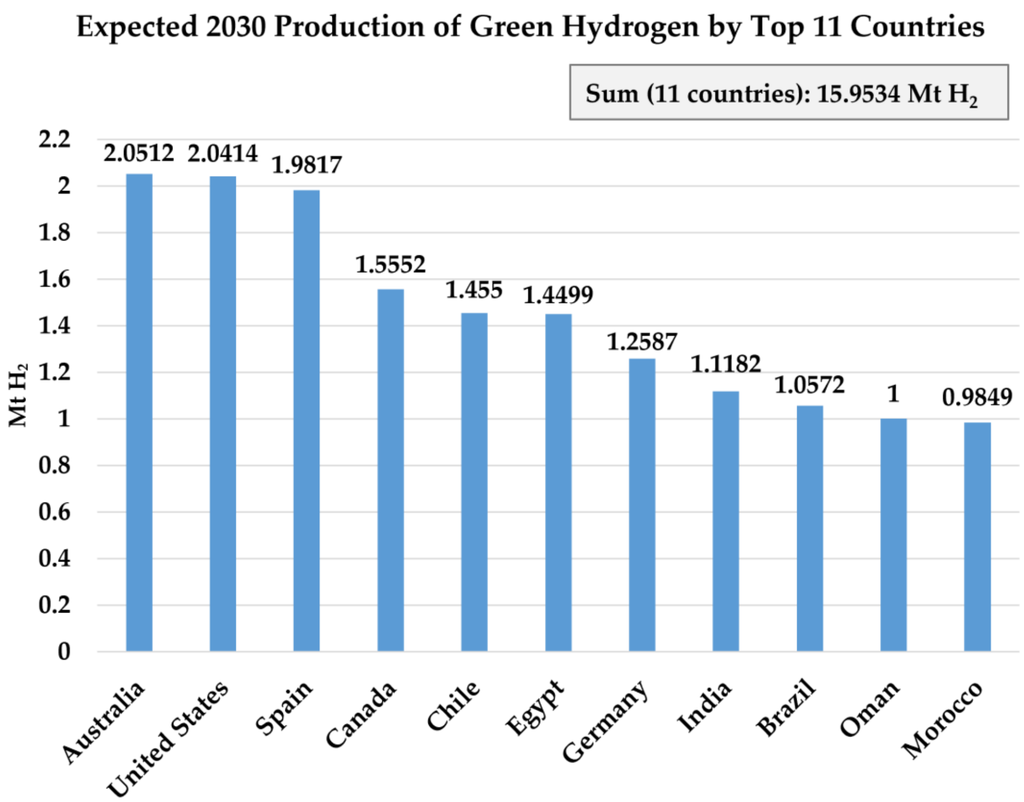

Figure 3. Expected annual production capacity of green hydrogen by top 11 producers in 2030, based on projections of Rystad Energy for the cumulative production capacity from 2023 to 2030 for 10 countries (all the listed except Oman), and a governmental announced target for Oman.

According to the global Brussels-based Hydrogen Council [11], the production potential of clean hydrogen for the above 11 countries is given in Table 2, along with the recommended (best) type of hydrogen to be produced. It is found that 8 of the 11 countries (all except Spain, Canada, and Germany), are considered to have optimal production potential of green hydrogen.

Table 2. Classification of the expected top 11 producers of green hydrogen in 2030 based on the production potential and the favorable type of clean hydrogen (according to a 2020 report by the internationally-recognized Hydrogen Council).

Rank (Green Hydrogen)	Country	Production Potential	Hydrogen type
1	Australia	Optimal	green
2	United States	Optimal	green and blue
3	Spain	Average	green
4	Canada	Optimal	blue
5	Chile	Optimal	green
6	Egypt	Optimal	green
7	Germany	Average	green
8	India	Optimal	green
	Brazil (east)	Optimal	green
9	Brazil (west)	Average	blue
	Brazil (remaining)	Average	green
10	Oman	Optimal	green
11	Morocco	Optimal	green

5. Discussion

A Germany-led global initiative (scheme) called H2Global was launched to encourage producing 3 products derived from green hydrogen outside the European Union (EU). These are ammonia, methanol, and e-kerosene (PtX liquid fuel can be used in aviation). This initiative motivates the production through long-term (10 year) agreements, with the first agreement having a period from 1 January 2024 to 31 December 2033. The H2Global initiative also motivates the selling of the imported products to EU or German consumers through utilizing a governmental (Germany) subsidy of 900 million euros (approved by the German Federal Ministry for Economic Affairs and Climate Action, BMWK, in December 2021) to bring the prices to an attractive level. The H2Global Foundation was established in June 2021. The first procurement lot is specifically for ammonia [12].

6. Conclusions

The hydrogen market (production side and consumption side) may show quantitative and qualitative changes through more utilization of hydrogen and its derivative, and through replacing gray hydrogen with clean hydrogen, especially green hydrogen. This study presented miscellaneous but brief details related to this subject.

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Conflicts of Interest: The author declares no conflict of interest.

Nomenclature (Alphabetical Order)

blue hydrogen	hydrogen produced from fossil fuels with carbon capture (thus, trapping most or all of the released carbon dioxide, CO_2)
CCUS	carbon capture, storage and utilization
clean hydrogen	a term that combines blue hydrogen and green hydrogen. It may also be called (low-emission hydrogen).
e-fuel	electrofuel or synthetic fuel (fuel produced by PtX)
EJ	exajoule (10^{18} joules), a large unit of energy
gray (grey) hydrogen	hydrogen produced from fossil fuels without carbon capture
green hydrogen	hydrogen produced by water electrolysis using electricity generated from renewable energy without harmful emissions
IEA NZE	Net Zero Emissions by 2050 Scenario (NZE) of the International Energy Agency (IEA), to bring CO_2 emissions to net zero by 2050
IRENA 1.5 °C	1.5 °C pathway (scenario) of the International Renewable Energy Agency (IRENA) to limit the global temperature rise to 1.5 °C and bring CO_2 emissions to net zero by 2050
KPI	key performance indicator
Mt	million tonnes (10^9 kg)
Mt H_2	million tonnes of hydrogen
PtX	power-to-X (electricity conversion and energy storage concept that uses surplus electricity to produce something, referred to by the generic letter ‘X’, such as hydrogen or a liquid fuel)
TFEC	total final energy consumption (sum of useful energy that can be directly used by the final consumers without further processing)

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