DOE Hydrogen and Fuel Cells Program Record	
Record #: 19002	**Date:** October 1, 2019
Title: Current Hydrogen Market Size: Domestic and Global	
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Item

The U.S. produces approximately 10 MMT per year of "on-purpose" hydrogen [1–4]. Relative to worldwide production, the U.S. constitutes 12%–16%[5] of the approximately 70 MMT per year of "on-purpose" hydrogen [1–3]. This record discusses the variability of production estimates based on which segments of hydrogen production are included in the market size calculation, particularly related to the treatment of by-product hydrogen [5]. The range for global hydrogen production (65–100 MMT per year) is consistent with 2018 estimates of global hydrogen demand, approximately 70 MMT for pure hydrogen[6] and approximately 40 MMT for hydrogen in mixed gases [6].

Background

Hydrogen Production

Hydrogen production can be divided into three segments [1]:

1. "Merchant" hydrogen—hydrogen generated on site or in a central production facility and sold to a consumer by pipeline, bulk tank, or cylinder truck delivery;
2. "Captive" hydrogen—hydrogen produced by the consumer for internal use;
3. "By-product" hydrogen—hydrogen that is recovered from by-product process streams and can be consumed by the same company (as with captive) or sold to another company (as with merchant).

Both merchant and captive hydrogen production can be considered "on-purpose," while by-product hydrogen is the result of processes that are not for the purpose of producing hydrogen.[7] For example, merchant hydrogen can include hydrogen produced from steam methane reforming, water electrolysis, or even purchased by-product hydrogen (e.g., from an ethylene plant). Examples of captive hydrogen production include steam reforming of hydrocarbons and ammonia dissociation (which is common in the

[1] U.S. Department of Energy Fuel Cell Technologies Office
[2] International Energy Agency (IEA)
[3] Shell
[4] Praxair
[5] The percentage of world production is calculated for each of the three references.
[6] The IEA accounts for hydrogen demand for applications that use pure hydrogen as well as hydrogen as part of a mixture of gases, such as synthesis gas, for fuel or feedstock.
[7] In some cases, by-product, or unintentionally produced, hydrogen is sold to merchant hydrogen suppliers.

metals industry) [1]. Hydrogen is produced as the by-product of many processes, one example of which is brine electrolysis for chlorine and sodium hydroxide production [1]. By-product hydrogen can be vented, sold as merchant hydrogen, or captured and used on site.

Based on which segments are included in accounting for hydrogen production, estimates can vary by up to a factor of ten [5]. For example, some sources do not include by-product hydrogen because hydrogen production is not "on-purpose."

Table 1 compares the U.S. and global production estimates, by segment, from two sources published in 2016 with the more recent estimates from IHS Markit on production capacity.[8] These estimates vary from 9 to 15 MMT per year for U.S. production and from 65 to 100 MMT per year globally.[9] The variability in the three estimates is mostly attributable to the accounting for by-product hydrogen; estimates of "on-purpose" hydrogen production are within ±10% of 9 MMT and 65 MMT per year in the U.S. and globally, respectively. The U.S. produces approximately 4 MMT per year of merchant hydrogen, 40%–60% of global merchant hydrogen production.

Table 1. Comparison of U.S. and Global Hydrogen Production and Production Capacity from Various Sources, by Segment

	Markets & Markets [3] *Production*	*Brown [2]* *Production*	*IHS Markit [1]* *Capacity*
U.S. Hydrogen Production (MMT)			
Merchant	3.78	3.83	4.30
Captive	5.27	5.86	4.08
"On-Purpose" Subtotal	***9.04***	***9.69***	***8.38***
By-Product	-	5.68	0.43
Total	**9.04**	**15.37**	**8.81**
Global Hydrogen Production (MMT)			
Merchant	9.02	6.16	7.92
Captive	55.44	55.39	61.25
"On-Purpose" Subtotal	***64.46***	***61.55***	***69.17***
By-Product	-	40.93	3.15
Total	**64.46**	**102.48**	**72.32**

[8] The Markets & Markets [3] and the Brown [2] estimates are based on 2014 production, while the IHS [1] estimates are based on 2017 production capacity.

[9] The IEA [6] estimate on global hydrogen demand in 2018 is approximately 70 MMT of relatively pure hydrogen and an additional 45 MMT of hydrogen that is part of a mixture of gases, for example as synthetic gas without hydrogen separated. These values are consistent with the ranges described in Table 1, considering market growth in recent years.

In the United States, the oil refining industry is responsible for the majority of both hydrogen production and consumption [2]. Industrial gas companies have been increasingly building hydrogen production plants on site or adjacent to refineries as merchant demand has grown in this industry [1]. Merchant hydrogen, supplied by industrial gas companies, now constitutes the majority of hydrogen consumption at refineries, estimated at 2.4 MMT in 2014 [7].

As shown in Table 1, Markets & Markets [3] does not account for by-product hydrogen at all, because it is not considered "on-purpose." The IHS Markit Report [1] excludes hydrogen that is burned as a fuel or vented.[10] As most by-product hydrogen from industrial processes is combusted on site for process heat rather than being sold externally as a commodity, the IHS analysis accounts for less by-product hydrogen than described in Brown [2]. The IHS estimates only include hydrogen produced as a by-product of chlorine-sodium hydroxide and sodium chlorate production, which is a small fraction of what is in included in Brown's analysis of by-product hydrogen. For example, Brown includes hydrogen that is the by-product of ethylene production, even though it is typically burned on site to generate heat for the crackers.

The potential for producing hydrogen as a by-product from ethylene crackers is estimated at 3.3 MMT in Lee and Elgowainy (2018) [5], over double the amount reported by Brown as being produced in 2014. The difference is likely due to the recent increase in natural gas liquid cracking and, to a lesser degree, differences in accounting methodologies. Given appropriate market incentives, much of the current by-product hydrogen could be separated via pressure swing adsorption and exported to the merchant market to meet near- and mid-term hydrogen demand [5]. As a result, it is estimated that by-product hydrogen from various processes could potentially supply more than 7 MMT per year to the current U.S. market in addition to the approximately 9 MMT per year of "on-purpose" hydrogen.

Figure 2 characterizes a range of estimates for total domestic and global hydrogen production. Variations in estimates from different sources are likely due to differences in accounting methodology, several of which have been outlined above. In all sources used, U.S. hydrogen production constitutes 12%–15% of global hydrogen production. Regional analyses indicate that Asia is responsible for the greatest hydrogen production and consumption, followed by Europe and the United States [1, 3].

[10] In addition, the IHS Markit Report does not include: hydrogen produced by dissociation of ammonia, hydrogen that is both produced and consumed in manufacturing ammonia or methanol, or hydrogen produced in refineries for captive use. Only by-product hydrogen that is recovered for sale is counted in the IHS estimates [1].

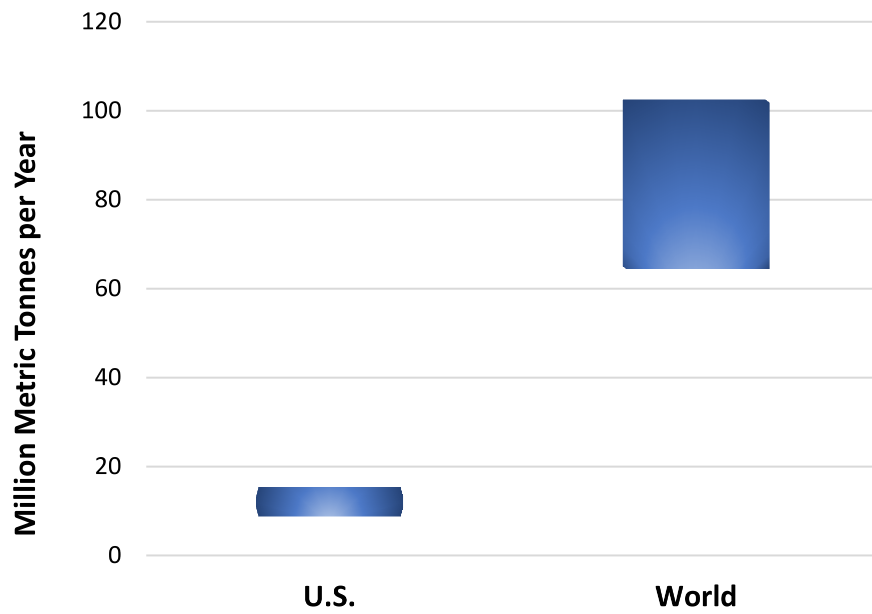

Figure 2. Range of estimates for total domestic (9–15 MMT/year) and global (65–102 MMT/year) hydrogen production [1, 2, 3]

Hydrogen Consumption

Hydrogen is currently used in a number of industries, including [8]:

- Petroleum refining
- Ammonia production and fertilizers
- Metals production
- Methanol production
- Food processing
- Electronics.

Most merchant hydrogen in the U.S. (>80%) is sold to refineries [1] for purposes such as: hydrocracking, ultra-low-sulfur diesel hydrotreating, fluid catalytic cracking (FCC) feed (gas oil) hydrotreating, and naphtha hydrotreating [9]. From 2012 to 2017, U.S. hydrogen consumption increased by over 3% per year, mainly due to the increase in volume of crude refining, the processing of heavier crude, and the more stringent regulations on sulfur and aromatic contents [1].

In June 2019, the International Energy Agency (IEA) published its Future of Hydrogen report [6], released at the G20 Summit. The report encompasses comprehensive analyses and references on the current status of hydrogen technologies, including hydrogen demand. The coordinated analysis was peer reviewed by a number of international stakeholders, including the U.S. Department of Energy's Fuel Cell Technologies Office and national laboratory analysts.

Figure 3 shows global hydrogen demand in 2018 to be above 70 MMT for pure hydrogen and above 40 MMT for hydrogen in mixed gases. Demand for pure hydrogen includes for purposes such as refining, ammonia production, transportation, and power-to-gas applications [6]. Hydrogen that is part of a mixture of gases can be used as fuel or feedstock for applications such as methanol production and iron reduction

[6]. Note the estimated demand for pure hydrogen is consistent with the production range described in the previous section; it is likely that hydrogen production estimates do not account for all, if any, of the hydrogen produced as a part of a mixture of gases.

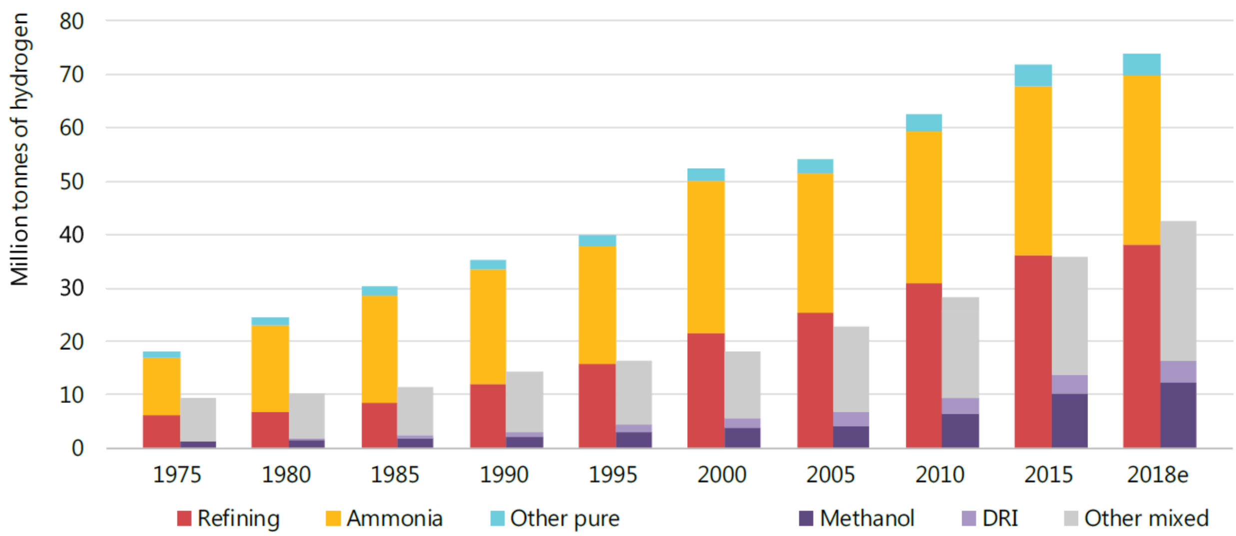

Figure 3. Global annual demand for hydrogen (pure or as part of mixed gases) by application. Source: IEA (2019), *The Future of Hydrogen*, all rights reserved.

Notes: DRI = direct reduced iron steel production. Refining, ammonia and "other pure" represent demand for specific applications that require hydrogen with only small levels of additives or contaminants tolerated. Methanol, DRI, and "other mixed" represent demand for applications that use hydrogen as part of a mixture of gases, such as synthesis gas, for fuel or feedstock.

References

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