

## HYDROGEN AND FUEL CELLS



# THE U.S. MARKET REPORT



a report by the national hydrogen association

*[This page intentionally left blank for 2-sided printing]*

# **Hydrogen and Fuel Cells: The U.S. Market Report**

A Report by the National Hydrogen Association on 2008 Data  
G. Bromaghim, K. Gibeault, J. Serfass, P. Serfass, E. Wagner

March 22, 2010

This report was developed by Technology Transition Corporation for the National Hydrogen Association with the guidance of an ad hoc committee. It does not necessarily represent the views of all NHA member organizations.

National Hydrogen Association  
1211 Connecticut Avenue NW  
Suite 600  
Washington, DC 20036  
USA

+1 202-223-5547  
[info@hydrogenassociation.org](mailto:info@hydrogenassociation.org)  
[www.hydrogenassociation.org](http://www.hydrogenassociation.org)

*[This page intentionally left blank for 2-sided printing]*

# Table of Contents

List of Figures	vi
List of Tables	vii
Definitions & Acronyms	viii
Acknowledgements	x
Executive Summary	xii
1. INTRODUCTION & BACKGROUND	1
1.1 Overview	1
1.2 Methodology	1
2. HYDROGEN PRODUCTION & DELIVERY	3
2.1 Overview	3
2.2 Delivery	5
2.2.1 <i>Methodology</i>	5
2.2.2 <i>Cylinder and Truck Delivery</i>	5
2.2.3 <i>Pipeline Delivery</i>	6
2.2.4 <i>Onsite Production (No Delivery)</i>	7
2.3 Centralized Hydrogen Production	8
2.3.1 <i>Overview</i>	8
2.3.2 <i>Methodology</i>	8
2.3.3 <i>U.S. Hydrogen Prices and Common Sales Volumes</i>	9
2.3.4 <i>Byproduct Hydrogen</i>	12
2.3.5 <i>Employees</i>	13
2.4 Distributed Production	13
2.4.1 <i>Overview</i>	13
2.4.2 <i>Methodology</i>	14
2.4.3 <i>Electrolyzers</i>	15
2.4.4 <i>Reformers</i>	16
2.4.5 <i>Employees</i>	17
2.4.6 <i>Electrolyzer and Reformer Comparisons</i>	17
2.5 Renewable Hydrogen Production	19
2.5.1 <i>Overview</i>	19
2.5.2 <i>Methodology</i>	20
2.5.3 <i>Projects</i>	20
3. HYDROGEN USE	23
3.1 Overview	23
3.2 Industrial Use	24
3.3 Energy Use	25
3.3.1 <i>Vehicles</i>	25
3.3.1.1 <i>Methodology</i>	25
3.3.1.2 <i>Light-duty Vehicles</i>	25
3.3.1.3 <i>Heavy-duty Vehicles</i>	27

3.3.1.4	Hydrogen Fueling Stations	31
3.3.2	<i>Material Handling Vehicles</i>	32
3.3.2.1	Overview	32
3.3.2.2	Methodology	32
3.3.2.3	Findings	33
3.3.3	<i>Stationary Power</i>	35
3.3.3.1	Overview	35
3.3.3.2	Methodology	35
3.3.3.3	Findings	35
4.	EDUCATION & JOBS	36
4.1	Education	36
4.1.1	<i>Overview</i>	36
4.1.2	<i>Methodology</i>	36
4.1.3	<i>Findings</i>	37
4.2	Jobs	39
4.2.1	<i>Overview</i>	39
4.2.2	<i>Methodology</i>	39
4.2.3	<i>Findings</i>	39
5.	LOOKING AHEAD	40
5.1	Overview	41
5.2	Distributed Hydrogen	41
5.3	Renewable Hydrogen Projects	41
5.4	Hydrogen Fueling Stations	41
5.5	Heavy-Duty Vehicles	42
5.6	Material Handling Vehicles	42
5.7	Stationary Power	42

## List of Figures

<i>Figure 1. U.S. daily hydrogen production .....</i>	<i>4</i>
<i>Figure 2. Night-time satellite photographs of the United States and Europe overlayed with the locations of major hydrogen production plants and a 100 kilometer (60 mile) radius circle around it. Bright white spots (light) represent cities.....</i>	<i>10</i>
<i>Figure 3. Electrolyzers: hydrogen production capacity installed in 2008 .....</i>	<i>15</i>
<i>Figure 4. Electrolyzers: total installed hydrogen production capacity by application (2002-2008).....</i>	<i>16</i>
<i>Figure 6. Reformers: Total installed hydrogen production capacity by application (2002-2008) .....</i>	<i>17</i>
<i>Figure 7. Electrolyzers and Reformers: installed production capacity, 2002-2008 .....</i>	<i>18</i>
<i>Figure 8. Electrolyzers and Reformers: number of installed units by application, 2002-2008.....</i>	<i>18</i>
<i>Figure 9. Electrolyzers and Reformers: installations from 2002-2008.....</i>	<i>19</i>
<i>Figure 10. Renewable energy projects active in 2008.....</i>	<i>23</i>
<i>Figure 11. Renewable energy projects active in 2008 in the Greater Los Angeles area .</i>	<i>23</i>
<i>Figure 12. U.S. merchant hydrogen consumption by industry .....</i>	<i>24</i>
<i>Figure 13. Light-duty hydrogen vehicles and buses on U.S. roads .....</i>	<i>29</i>
<i>Figure 14. 2008 Hydrogen vehicle miles traveled on U.S. roads.....</i>	<i>29</i>
<i>Figure 15. 2008 Hydrogen vehicle fuelings in the U.S. ....</i>	<i>30</i>
<i>Figure 16. 2008 Hydrogen consumption by vehicles on U.S. roads.....</i>	<i>30</i>
<i>Figure 17. Operational hydrogen fueling stations in North America (as of 31 October 2009) .....</i>	<i>31</i>
<i>Figure 18. New and cumulative hydrogen fueling stations (as of October 2009).....</i>	<i>32</i>
<i>Figure 19. Total U.S. hydrogen materials handling vehicles in operation (2007-2009) and vehicles planned for operation.....</i>	<i>33</i>
<i>Figure 20. Total U.S. hydrogen materials handling vehicles in operation (2007-2009) and vehicles planned for operation.....</i>	<i>34</i>
<i>Figure 21. Map of U.S. hydrogen materials handling vehicles in operation (2007-2009) and vehicles planned for operation.....</i>	<i>35</i>
<i>Figure 22. Development of students and graduates in hydrogen and fuel cell related degrees .....</i>	<i>38</i>
<i>Figure 23. Educational institutions offering courses in hydrogen/fuel cell-technology (excluding community colleges).....</i>	<i>39</i>

## List of Tables

<i>Table 1. Common hydrogen cylinder sizes for merchant hydrogen sales .....</i>	<i>5</i>
<i>Table 2. Common hydrogen quantities for sale .....</i>	<i>6</i>
<i>Table 3. Capacity ranges for hydrogen delivery .....</i>	<i>6</i>
<i>Table 4. Pipelines in the U.S. in 2006 and 2009.....</i>	<i>7</i>
<i>Table 5. Common volumes of merchant hydrogen sales.....</i>	<i>9</i>
<i>Table 6. Typical prices for some liquid hydrogen sales .....</i>	<i>11</i>
<i>Table 7. Typical prices for some gaseous hydrogen sales.....</i>	<i>11</i>
<i>Table 8. Renewable energy projects active in 2008 .....</i>	<i>21</i>
<i>Table 9. Waste-to-energy projects active in 2008 .....</i>	<i>22</i>
<i>Table 10. Other noteworthy waste and renewable energy projects active in 2008.....</i>	<i>22</i>
<i>Table 11. Hydrogen consumption in thousand kg/day.....</i>	<i>24</i>
<i>Table 12. 2008 data for light-duty hydrogen vehicles .....</i>	<i>26</i>
<i>Table 13. 2008 data for light-duty hydrogen fuel cell vehicles .....</i>	<i>27</i>
<i>Table 14. 2008 data for light-duty hydrogen engine vehicle .....</i>	<i>27</i>
<i>Table 15. 2008 heavy-duty hydrogen buses.....</i>	<i>28</i>
<i>Table 16. Stationary PEM fuel cells installed in the U.S. by December 2008 .....</i>	<i>36</i>
<i>Table 17. Institutions per state that offering hydrogen- and fuel cell-related courses.....</i>	<i>37</i>
<i>Table 18. Overview of hydrogen and fuel cell degree programs (as of 2009) .....</i>	<i>37</i>
<i>Table 19. U.S. jobs in select sectors of the hydrogen industry .....</i>	<i>40</i>
<i>Table 20. U.S. employment projections from 2020-2050 .....</i>	<i>40</i>



## Definitions & Acronyms

Auxiliary power:	A power source that provides a supplemental source of electrical power, often in conjunction with a primary power source. For example, some hydrogen fuel cells are being used as auxiliary power units on heavy-duty vehicles to run refrigeration or provide heat while reducing diesel fuel consumption and overall emissions.
Backup power:	A power source that can provide adequate power to operate critically important equipment until primary power is restored.
Biomass or anaerobic digester gas to hydrogen:	Hydrogen produced from waste products, wastewater, or landfill gases using anaerobic digestion (the breaking down of organic matter in oxygen free conditions) or other reformation processes.
Captive hydrogen:	Hydrogen produced onsite by the user of the hydrogen and never sold to outside customers. Captive hydrogen is a subset of total production.
ccf:	One hundred standard cubic feet (see also: scf).
DOT:	U.S. Department of Transportation.
DOE:	U.S. Department of Energy.
EIA:	Energy Information Administration.
FTE:	Full-time equivalent, as in number of equivalent full-time employees.
Green grid:	Utility grid electricity produced from renewable sources.
Heavy-duty vehicle (HDV):	Vehicle classes 6-8, or over 19,501 lbs by gross vehicle weight (GVW), e.g. city buses.
kg:	Kilogram, a measure of mass. One kilogram of hydrogen has roughly the energy equivalent of one gallon of gasoline.
kW	A kilowatt equals 1,000 Watts. A kilowatt hour (kWh) is the amount of kilowatts of electricity used in one hour of operation of any equipment.
Light-duty vehicle (LDV):	Vehicle classes 1-2, or up to 10,000 lbs by GVW, e.g. everything from a small compact car to a large SUV.
Merchant Hydrogen:	Hydrogen produced by one party for sale to another, or any hydrogen produced by one company for consumption by another company. Large merchant production is usually delivered to the customer via pipeline as a compressed gas. The merchant plant may be on the customer's property, adjacent to the customer's property (commonly referred to as "over the fence") or a few hundred miles away in regions (e.g., Texas Gulf Coast) served by hydrogen pipeline networks. Merchant hydrogen is a subset of total production.

MM:	Million.
MPa:	A pascal is a unit of pressure or a measure of force per unit area. It is defined as one newton per square metre. One megapascal or MPa is equal to 1,000,000 pascals.
NHA:	National Hydrogen Association.
PEM:	Proton exchange membrane, used to describe a lower temperature, solid polymer electrolyte type of fuel cell that uses pure hydrogen for fuel.
PHMSA:	Pipeline and Hazardous Materials Safety Administration.
Primary power:	An electrical power source that supplies the main power for a given load.
psi:	Pounds per square inch, a measurement of pressure.
scf (see also: ccf):	Standard cubic feet.
scf/mo:	Standard cubic feet per month.
Solar to hydrogen:	Hydrogen produced from water using electricity from solar photovoltaic (PV) panels <sup>1</sup> .
TTC:	Technology Transition Corporation, the management and technical services contractor to the NHA and the contractor for the NHA on this project.
USFCC:	U.S. Fuel Cell Council.
Wind to hydrogen:	Hydrogen produced from water using electricity from wind turbines.

---

<sup>1</sup> This definition typically includes solar thermal hydrogen plants, but no solar thermal hydrogen projects were known at the time of data collection.

## **Acknowledgements**

Technology Transition Corporation and the National Hydrogen Association is deeply indebted to several leaders in the hydrogen industry who must remain nameless but who put an extraordinary degree of trust in the report's authors to keep highly sensitive data confidential. This selfless sharing of information allowed the authors to collect data from other companies that did not want to risk being the first, or only, contributor of information. Without these individuals, entire sections of this report would have remained incomplete.

Special thanks to Jay Laskin of Hyenergy Consulting LLC, whose diligent work collecting data on electrolyzers and reformers made it possible for us to complete this study.

*[This page intentionally left blank for 2-sided printing]*

## Executive Summary

The bulk of the hydrogen business revolves around hydrogen's use as an industrial chemical, for petroleum refining, in fertilizer production, and in other settings where hydrogen is sold in very large quantities. Within this merchant hydrogen business is a smaller set of market activities where hydrogen is produced, stored and used for non-chemical and non-industrial needs. This subset of the market (the focus of this report) produces, stores and uses hydrogen as a fuel, a gas that stores energy for immediate or later use.

Published reports exist that deeply examine hydrogen's chemical and industrial uses; this report focuses on presenting today's best dataset on

- merchant hydrogen pricing and typical volumes;
- pipelines and distributed hydrogen production;
- renewable energy to hydrogen projects;
- hydrogen light- and heavy-duty vehicles;
- hydrogen material handling vehicles; and
- hydrogen education and jobs.

This report presents consolidated U.S. data for 2008 only and represents a baseline of data for comparison in future years. Many of the resources used to develop this report were secondary, but this report adds new primary research and consolidates the findings in one comprehensive publication.

### **Production, delivery, and pricing**

More than 20 billion kilograms (kg) of hydrogen were produced in the United States in 2008. Of this total, the percentage classified as merchant hydrogen is reported to be either 14 percent or 52 percent, depending upon the source and interpretation of the data available. This difference could not be resolved in this study, although some explanations for the disparity in reporting are included.

The method of delivery for merchant hydrogen varies primarily with the volume required by the user. For the smallest quantities (individual deliveries of 0.5-50 kg), hydrogen is often bought and sold as a compressed gas in cylinders. Larger quantities (50+ kg) are commonly delivered by tube trailers (with gaseous hydrogen that has been compressed after production) and liquid tanker trucks (with cryogenic liquid hydrogen that has been chilled after production). To satisfy extremely large demand, hydrogen can be delivered by pipeline.

The price of delivered hydrogen, under varying settings, is presented in this report with all the variables that affect pricing, particularly hydrogen delivered as merchant hydrogen to users. The variation results from the volume delivered, the distance it has traveled, the

state in which it is delivered (liquid or gas), pressure, purity, method of delivery, additional equipment necessary, regulatory fees and the competitive environment.

### **Distributed production**

A small but growing segment of merchant hydrogen customers are using solutions that avoid the need for delivery. These customers satisfy their need for hydrogen by producing it onsite. The two most common methods utilized for this purpose are electrolysis and reformation. In 2008, 18 new electrolyzers were installed representing 145 kg/day of hydrogen production capacity (a 5 percent growth in electrolyzer production capacity from 2007). By the end of 2008, the total production capacity of installed electrolyzers in the U.S. was 2,300 kg/day, from 215 units (representing 0.030 percent of total U.S. merchant hydrogen production<sup>2</sup>). In 2008, 11 new reformers were installed representing 1,479 kg/day of hydrogen production capacity (and 45 percent growth from the small reformer production capacity installed at the end of 2007). By the end of 2008, the total production capacity of installed reformers in the U.S. was 4,198 kg/day (representing 0.050 percent of total U.S. merchant hydrogen production<sup>3</sup>).

### **Renewable production**

In 2008, 30 projects actively produced hydrogen from renewable resources, more than half of which were located in California. Overall, most projects are small demonstrations (with a production capacity of less than 3 kg/hour) that are designed to verify the commercial readiness of renewable energy hydrogen production or a new production technology.

### **Transportation**

By the end of 2008, there were approximately 210 hydrogen-powered light-duty vehicles on U.S. roads. In 2008, they drove a total of 1.1 million miles, fueled 11,000 times, and consumed 26,000 kilograms of hydrogen. 12 hydrogen-powered buses were operational in 2008, representing the entire heavy-duty hydrogen vehicle fleet. In 2008, these buses traveled 176,000 miles, fueled 1,670 times, consumed 29,000 kg of hydrogen fuel, and transported 366,000 passengers.

The National Hydrogen Association keeps an online database of fueling stations in North America. As of October 2009, 67 public and private hydrogen fueling stations were in operation in the U.S.; six of these hydrogen fueling stations entered operation in 2008.

### **Material handling and stationary power**

By the end of 2008, there were 200 hydrogen fuel cell-powered forklifts operating in the U.S. These forklifts consumed at least 20,000 kg of hydrogen and were in operation at 16 sites in nine states.

For stationary appliances, at least 13,000 kilowatt (kW) of PEM fuel cells were operational in the U.S. in 2008. Of these, at least 10,000 kW were installed to provide backup power, whereas only a handful of sites (totaling 300 kW) used PEM fuel cells to

---

<sup>2</sup> Assuming the merchant hydrogen market is 14% of total U.S. hydrogen production.

<sup>3</sup> Assuming the merchant hydrogen market is 14% of total U.S. hydrogen production.

provide primary power. Auxiliary power appliances are more numerous, providing 2,761 kW.

### **Education and careers**

More than 130 institutions of higher education offer courses in fuel cell or hydrogen technology, in 40 states and the District of Columbia. California and New York lead the other states, with 16 and 14 institutions, respectively. The number of degree programs has steadily increased from 2006 to 2009, and in 2009, nine institutions offered hydrogen or fuel cell technology degrees. In this same three-year period, the number of students enrolled in specialized hydrogen and fuel cell degree programs increased by 82 percent annually.

Through the data collection and analysis performed for this report, U.S. hydrogen-related employment figures, related to the sectors covered in this report, total nearly 7,000 U.S. full-time equivalent (FTE) employees. The number does not represent the entire number of people employed in the U.S. hydrogen industry in 2008 (e.g. employees engaged in captive hydrogen production—the other 48-86 percent of U.S. hydrogen production).

This first annual report focuses on the lesser reported areas of the hydrogen industry to provide a baseline against which, future years' data can be compared to reveal trends in the energy-related production and use of hydrogen. While the hydrogen energy business is small compared to the existing industrial hydrogen business in refining, fertilizer production and many other chemical processes, it is growing. Moreover, the data collected for this report suggest certain sectors of the hydrogen economy will see significant growth in the next one to two-year timeframe.

*[This page intentionally left blank for 2-sided printing]*



# 1. INTRODUCTION & BACKGROUND

## 1.1 Overview

Hydrogen, the most basic element, has been used as a chemical for decades and is now emerging as a universal energy carrier with important environmental and energy security advantages. Hydrogen can be made from a variety of local resources and is used in many different applications, such as: producing electric power for the electric utility grid or micro-grids; fueling cars and buses; and providing power for materials handling equipment, people movers inside buildings, and remote communications and security equipment. In addition, the military is evaluating hydrogen as a means to power the mobile equipment of military forces and unmanned vehicles because some hydrogen appliances, like fuel cells, are quiet, emit very little heat and can be lighter than loads of rechargeable batteries.

Although hydrogen can be used as a fuel in engines and turbines with near zero emissions, its use with fuel cells offers many further benefits. A fuel cell that uses pure hydrogen as its fuel produces electricity at high efficiency, without combustion, and with zero emissions besides water vapor. It features reliable start-up and can be scaled into small and large power packages. Fuel cells have no moving parts and are manufactured with repetitive processes that have a large potential for cost reduction. As the markets grow for fuel cells (many of which require hydrogen as their fuel), it becomes even more important to understand and begin documenting the state of the marketplace for producing and distributing hydrogen.

Technology Transition Corporation conducted this study for the National Hydrogen Association to improve understanding of the current state of the hydrogen industry. Every day individuals, organizations and governments (at federal, state, regional and municipal levels) make decisions on the use of alternative energy technologies. The goal of this report is to present data reported by industry to better inform those decisions that are related to the production and use of hydrogen.

## 1.2 Methodology

The data gathered in this report is focused in three main areas:

- Hydrogen Production and Delivery.
- Hydrogen Use.
- Education and Jobs.

Information was collected with the commitment to those providing data that any information about individual companies and projects will remain confidential to protect competitive and sensitive information. There are exceptions to this, in instances where a company provided specific permission to present or disaggregate data, despite the potential to infer information about their company or its products. Therefore, most sections in the report state consolidated data for the sector to preserve privacy. Sectors in which the total data obtained represented less than 50 percent of the companies contacted

were not included in this report. Each section of the report lists the companies contacted to give the reader a sense of the organizations active in that part of the industry; however, it does not necessarily reflect the list of companies which provided data for this report.

Each section of this report was reviewed by an ad hoc committee of National Hydrogen Association members, formed to ensure the report was accurate and consistent with what members have observed in the hydrogen and fuel cell industry.

Since different approaches to gather data were used for different sections of this report, based on the availability of information, further details regarding methodology are provided in each section of the report.

## 2. HYDROGEN PRODUCTION & DELIVERY

### 2.1 Overview

While hydrogen in many forms is the most abundant element in the universe, pure hydrogen does not exist in appreciable amounts on Earth.<sup>4</sup> Hydrogen is always connected to other elements, like carbon in plants, petroleum and natural gas, or attached to oxygen as in water. Therefore, to produce pure hydrogen, a primary energy source is required to break the chemical bond and separate the hydrogen from its partner.<sup>5</sup>

Hydrogen can be separated from a wide variety of materials (e.g., natural gas, water, biomass, coal), and there are a number of primary sources of energy (e.g., wind, solar, coal, natural gas, nuclear) that can be used to energize the separation.

As of 2006, 48 billion kilograms (kg)<sup>6</sup> of hydrogen were produced worldwide annually, mainly for industrial uses, including ammonia production for fertilizer, petroleum refining (like sulfur removal from gasoline), and for processing of metals and food.

In the United States, more than 20 billion kg of hydrogen were produced in 2008; the corresponding daily production is shown in *Figure 1*.<sup>7</sup> The list of major industries that use hydrogen in the U.S. is similar to the list of industries worldwide: petroleum refining, ammonia production and metals processing.

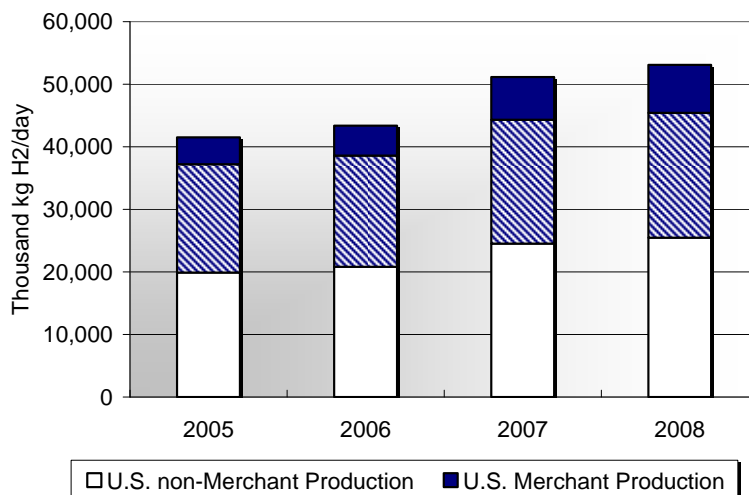
---

<sup>4</sup> Hydrogen is constantly produced by bacteria in anaerobic environments such as wetlands, soil systems, and in groundwater (at some sites, at very, very low concentrations). While not enough is produced to make collection economical to date, some scientists are investigating ways to take advantage of these natural occurrences in concentrated and organized ways in order to change its economic potential (e.g. [http://www.engr.psu.edu/ce/ENVE/logan/bioenergy/psu\\_press/Winery\\_92909.pdf](http://www.engr.psu.edu/ce/ENVE/logan/bioenergy/psu_press/Winery_92909.pdf)).

<sup>5</sup> A common myth is that it takes too much energy to make hydrogen. Energy is required to make all fuels used today. Expending energy to separate hydrogen from a primary energy resource is worthwhile if the resulting hydrogen has benefits that outweigh the energy and financial costs of production. We accept a similar and often larger energy penalty in producing electricity for the same reason – the convenience and utility of having electricity is much greater than the convenience and utility of the original coal or other fuel that was used to make the electricity.

<sup>6</sup> Suresh, Bala, Stefan Schlag, and Masahiro Yoneyama, *CEH Marketing Research Report Hydrogen* (Menlo Park: SRI Consulting, 2007), 8.

<sup>7</sup> U.S. Department of Energy - Hydrogen Analysis Resource Center, “Worldwide and U.S. Total Hydrogen Production”, [http://hydrogen.pnl.gov/filedownloads/hydrogen/datasheets/worldwide\\_us\\_hydrogen\\_production.xls](http://hydrogen.pnl.gov/filedownloads/hydrogen/datasheets/worldwide_us_hydrogen_production.xls), converted to kg/day.



**Figure 1. U.S. daily hydrogen production**

Several sources<sup>8</sup> agree that 20 billion kg of hydrogen were produced in the U.S. in 2008 (representing about 70 percent of capacity, according to private industry sources). However, estimates regarding the amount of U.S. produced hydrogen that is considered captive hydrogen (produced onsite by the user of the hydrogen and never sold to outside customers) versus merchant hydrogen (produced by one party for sale to another) vary by as much as 36 percent, based on the definitions of merchant and captive and the data reported. Specifically, the volume of merchant hydrogen has been reported to represent between 14 percent and 52 percent of all U.S. produced hydrogen.

A source for the data in Figure 1, *CryoGas International*, reports total merchant hydrogen to be 2.8 billion kg/year, 14 percent of all U.S. produced hydrogen. However, industry sources who have conducted private studies estimate the merchant market (using the same definition) to be 10.4 billion kg/year, or 52 percent of all U.S. produced hydrogen. The major source of this discrepancy appears to be the volume of hydrogen delivered by pipeline, which *CryoGas International* reports as 2.6 billion kg/year and other sources report as 10 billion kg/year. Thus Figure 1 shows a shaded area representing the uncertainty of this data. More detail was not available.

Despite the lack of agreement on merchant volume, most sources agree on the definition of merchant hydrogen.<sup>9</sup> The source for Figure 1 defines merchant hydrogen as:

*[Any] hydrogen produced by one company for consumption by another company. A subset of merchant hydrogen, large merchant hydrogen is usually delivered from the production plant to the customer via pipeline as a compressed gas. The*

<sup>8</sup> In this case, “sources” refers to the source cited in Footnote 5 as well as private industry sources who had conducted their own studies of the hydrogen industry. Their data were shared verbally with the authors of this report in the Fall of 2009, since it conflicted with other reported data, to give a more well-rounded picture of the industry.

<sup>9</sup> One exception is an industry source who reported that their company defines merchant hydrogen as any hydrogen needs that are less than 1400 Nm<sup>3</sup>/hr (53,256 scf/hr) or about 90,000 kg/mo. This is a quantitative definition that agrees with actual practice across the industry. Actual practice indicates sales usually only occur for companies who need less than about 100,000 kg/mo. Any entity that requires more than 100,000 kg/mo of hydrogen will typically purchase and install its own production equipment (at which point it would technically become classified as captive hydrogen).

*plant may be on the customer's property, adjacent to the customer's property (commonly referred to as "over the fence") or a few hundred miles away in regions (e.g., Texas Gulf Coast) served by large hydrogen pipeline networks. Merchant hydrogen is a subset of total production.*<sup>10</sup>

Regardless of the discrepancy in this subset of overall U.S. hydrogen production, some agreement exists. This report's sources agree that small merchant hydrogen sales, which include virtually all merchant hydrogen not delivered by pipeline, is 2 percent or less of all U.S. hydrogen production.<sup>11</sup> Most of the hydrogen production and use data in this report refer to this smaller and lesser reported sector of the merchant hydrogen market.

## 2.2 Delivery

### 2.2.1 Methodology

The data on hydrogen delivery were obtained through secondary research as noted in the text and in footnotes, supplemented and guided by individuals in the bulk and merchant hydrogen business. This information has been reviewed by three teams: individuals providing the data; individuals whose reviews were specifically requested; and the ad hoc NHA-member review committee.

*Companies contacted: Air Liquide; Air Products; Linde; Praxair.*

### 2.2.2 Cylinder and Truck Delivery

The merchant hydrogen market generally refers to individual sales that, for one customer over a month, would add up to less than 100,000 kilograms. For the smallest quantities (individual deliveries of 0.5-50 kg), hydrogen is often bought and sold as a compressed gas in cylinders, which allows it to be easily transported between the point of production and the point of use. These cylinders are most commonly made of steel and come in a variety of sizes, holding varying amounts of hydrogen at different pressures. Two of the most common sizes are the "K" (or "200") cylinder and the "T" (or "300") cylinder (see *Table 1*). *Table 2* shows common cylinder quantities.

**Table 1. Common hydrogen cylinder sizes for merchant hydrogen sales**<sup>12</sup>

	Size	Water capacity (l)	Pressure (psi)	Capacity (kg)	Capacity (scf)	Empty Weight (lbs)	Runtime @ 5 kW (hrs)
1 cylinder	200 or K	43.8	2265	0.463	196	124	1.59
1 cylinder	300 or T	49.6	2400	0.617	261	155	1.91

<sup>10</sup> U.S. Department of Energy - Hydrogen Analysis Resource Center, "Worldwide and U.S. Total Hydrogen Production," [http://hydrogen.pnl.gov/filedownloads/hydrogen/datasheets/worldwide\\_us\\_hydrogen\\_production.xls](http://hydrogen.pnl.gov/filedownloads/hydrogen/datasheets/worldwide_us_hydrogen_production.xls), converted to kg/day.

<sup>11</sup> Some private industry sources estimate that of this 2 percent or less ("small merchant" hydrogen production), about 1 - 2 percent is sold as bulk gaseous hydrogen and about 43 percent as bulk liquid hydrogen. See the next section on cylinder and truck deliveries for more information.

<sup>12</sup> This table lists the time that a typical 5 kilowatt (kW) fuel cell would run at full power before running out of fuel in the noted cylinder size. Actual run times will vary based on the manufacturer and other factors, but all fuel cells will run continuously as long as fuel is provided to it. Backup power systems for cell phone towers are typically 5 kW. National Hydrogen Association, "How is hydrogen bought and sold today?" <http://www.hydrogenassociation.org/general/faqs.asp#boughtSold>.

For larger quantities (50+ kg), tube trailers (with compressed gaseous hydrogen<sup>13</sup>) and liquid tanker trucks (with cryogenic liquid hydrogen<sup>14</sup>) are more likely to be used for delivery. Tube trailer quantities range from 100 kg for a “pup trailer” to 300 kg for the large trailers. A common size in the middle is 165 kg. Liquid truck capacities range from about 2,300 to 4,300 kg.

**Table 2. Common hydrogen quantities for sale<sup>15</sup>**

	Size	Capacity (kg)	Capacity (scf)	Runtime @ 5 kW (hrs)
1 cylinder	200 / K	0.463	196	1.59
1 cylinder	300 / T	0.617	261	1.91
6 cylinders	200 / K	2.780	1,176	9.54
6 cylinders	300 / T	3.702	1,566	11.46
12 cylinders	200 / K	5.560	2,352	19.08
12 cylinders	300 / T	7.404	3,132	22.92
18 cylinders	200 / K	8.340	3,528	28.62
18 cylinders	300 / T	11.11	4,698	34.38
72 cylinders	300 / T	44.43	18,792	Almost 6 days
Tube Trailer		165.5	70,000	About 20 days
Liquid Trailer		2,800	1,200,000	About 1 year

**Table 3. Capacity ranges for hydrogen delivery<sup>16</sup>**

	kg	scf
Capacity of large tube trailer	106 - 295	45,000 - 125,000
Common capacity of large tube trailer	165	70,000
Capacity of liquid H <sub>2</sub> trailer	2,363 - 4,253	1,000,000 - 1,800,000
Common capacity of liquid H <sub>2</sub> trailer	2,836	1,200,000

### 2.2.3 Pipeline Delivery

Hydrogen can be delivered by pipeline if the pipeline is nearby and the monthly sales are sufficiently high to justify the connecting costs. In general, while the cost to build a hydrogen pipeline is significant (some estimate costs at \$1 million/mile<sup>17</sup>), once built and connected to the customer site, it is by far the cheapest delivery method for hydrogen.<sup>18</sup>

<sup>13</sup> Typical pressures for gaseous hydrogen tube trailers are 1,800 psi for smaller trailers (45,000 scf) and 2,400 psi for large trailers (125,000 scf).

<sup>14</sup> Hydrogen turns to liquid at -423°F. Liquid hydrogen in trailers is not pressurized; however, as the gas slowly warms up and turns to a gas, the pressure inside builds. Different tanks are rated for different pressures, but all are generally very low. Above the rated pressure, liquid hydrogen tanks are designed to safely vent small amounts of hydrogen gas to relieve the built up pressure. Cryo-compressed hydrogen tanks, which are very well insulated to hold liquid hydrogen and can withstand high pressures so less hydrogen is wasted, are in development.

<sup>15</sup> National Hydrogen Association, “How is hydrogen bought and sold today?”, <http://www.hydrogenassociation.org/general/faqs.asp#boughtSold>

<sup>16</sup> From industry sources who asked their identities to be kept confidential due to the sensitive nature of this information.

<sup>17</sup> From industry sources who asked their identities to be kept confidential due to the sensitive nature of this information.

<sup>18</sup> Excluding amortized construction costs.

The Pipeline and Hazardous Materials Safety Administration (PHMSA) keeps track of hydrogen pipeline systems in the U.S. and is the source for the data in this section.<sup>19</sup>

In 2006 and 2009, 93 percent of hydrogen pipelines were located in only two states, Texas and Louisiana. This development is easily explained by the fact that most hydrogen is used for petroleum refining and the majority of the U.S. refinery industry is located in these two states. Initially, new hydrogen energy markets are likely to rely on hydrogen delivered by truck from existing plants or hydrogen made onsite from small electrolyzers or reformers because of its lower overall cost (including delivery) at smaller volumes (building new hydrogen pipelines will be too expensive to serve limited new markets). However, once new markets create a large demand for hydrogen in a given region, or in the rare case that markets exist near large industrial customers, pipelines a cost-effective delivery option.

**Table 4. Pipelines in the U.S. in 2006 and 2009**

State	Miles of Hydrogen Pipeline	
	2006 <sup>20</sup>	2009 <sup>21</sup>
Texas	848	882
Louisiana	290	232
Alabama	31	30
Indiana	15	14
California	13	13
Michigan	7	10
West Virginia	7	7
Utah	[unknown]	4
Ohio	2	6
New York	1	3
Delaware	1	[unknown]
Pennsylvania	[unknown]	1
<b>TOTAL<sup>22</sup></b>	<b>1213</b>	<b>1202</b>

Refer to *2.1 Hydrogen Production and Delivery Overview*, for more information on how much hydrogen is delivered by pipeline in the U.S.

#### **2.2.4 Onsite Production (No Delivery)**

The merchant hydrogen market is served primarily by companies with large hydrogen production facilities that sell hydrogen to individual customers. However, a small number of merchant hydrogen customers are finding new ways to satisfy their need for hydrogen by producing it themselves. Recently, small hydrogen production units have become more cost-effective, allowing customers to switch from buying hydrogen to buying equipment that allows them to become a small scale producer. While technically, this would make a company that owned one or many of these smaller units a captive hydrogen producer, most in the hydrogen industry still consider these onsite producers to be a part of the merchant gas market.

This portion of the hydrogen market is very small, but growing. This report addresses the market for these units in *2.4 Distributed Production*.

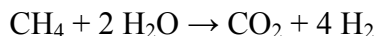
<sup>19</sup> Since hydrogen pipelines were declared sensitive objects in 2001, only overall estimates are available publicly, not exact numbers and locations.

<sup>20</sup> Energy Information Administration, 2008. The Impact of Increased Use of Hydrogen on Petroleum Consumption and Carbon Dioxide Emissions. Washington DC: U.S. Department of Energy.  
<http://www.eia.doe.gov/oiaf/servicerpt/hydro/pdf/oiafcneaf%2808%2904.pdf>.

<sup>21</sup> Preliminary 2009 data from the Pipeline and Hazardous Materials Safety Administration, U.S. Department of Transportation.

<sup>22</sup> Differences between reported numbers and total due to rounding.

Although hydrogen can be made from a variety of resources in many different ways, two hydrogen production methods are most common: reformation and electrolysis. Reformation normally involves separating hydrogen from water and a carbon compound, most typically natural gas (in this case, called steam methane reforming, or SMR) using heat, pressure and a catalyst :



This chemical equation illustrates that in the SMR reaction, for every methane molecule ( $\text{CH}_4$ , the main constituent of natural gas) four hydrogen molecules are produced. Half of this hydrogen comes from water, which is one reason that using hydrogen made from natural gas reduces carbon dioxide emissions by approximately 50 percent compared to using gasoline in a car. Only one carbon dioxide molecule is released for every four hydrogen molecules generated. In general, a steam methane reformer converts natural gas to hydrogen with approximately 75 percent efficiency.<sup>23</sup>

Electrolysis uses electricity to separate hydrogen from oxygen in water. In this case, no carbon dioxide is generated by the electrolyzer, but total greenhouse gas emissions depend on the source of that electricity. Approximately 50 percent of electricity in the U.S. is produced from coal. Hydrogen can also be generated by gasifying solid hydrocarbons such as biomass and coal.<sup>24</sup>

## 2.3 Centralized Hydrogen Production

### 2.3.1 Overview

Four industrial gas companies dominate the U.S. hydrogen business. Most hydrogen is produced by large, steam-methane reformers with subsequent purification via pressure swing adsorption and liquefaction. The prices of centrally produced hydrogen vary greatly, as a function of distance traveled, method of delivery and the volume delivered.

Some hydrogen is produced as a byproduct of other processes, and this is discussed in the following section, 2.3.4 *Byproduct Hydrogen*.

### 2.3.2 Methodology

Most of the industrial gas companies are reluctant to provide information, due to the maturity of the merchant hydrogen business and the high level of competition that exists between the small number of companies operating in the industry. However, some data were made available and, according to these sources, represent the best information currently available and are representative of the entire industry.<sup>25</sup>

---

<sup>23</sup> C.E. Thomas, "Fuel cell and battery electric vehicles compared," *International Journal of Hydrogen Energy* 34 (2009) 6005-6020. [http://www.h2gen.com/Uploads/file/Battery\\_vs\\_FuelCell\\_EVs.pdf](http://www.h2gen.com/Uploads/file/Battery_vs_FuelCell_EVs.pdf)

<sup>24</sup> For more information, see the National Hydrogen Association's Fact Sheets, <http://www.hydrogenassociation.org/general/factSheets.asp>

<sup>25</sup> The list of responding companies is not necessarily the same as the list of companies contacted. More details on the methodology could reveal the sources, thus compromising the confidentiality of the data presented, and are therefore not provided.



*Companies contacted: Air Liquide; Air Products; Linde; Praxair.*

### **2.3.3 U.S. Hydrogen Prices and Common Sales Volumes**

Compared to traditional fuels, the price of hydrogen varies more widely, due to the following factors:

1. Delivery costs, a function of:
  - Proximity to the production plant
  - Volume delivered
  - Regulatory fees
2. State
  - Gaseous
  - Liquid
3. Pressure needed by the customer
  - Gaseous
  - Liquid
4. Purity
  - A typical quality is “five nines” or 99.999% pure hydrogen (may be less for certain industrial applications)
5. Additional charges for installation (for example, rented cylinders, trailers, storage vessels) and dispensing equipment rental
6. The competitive environment

Despite this variation, some sales prices and some sales volumes are more common than others. The data in this section, especially *Tables 5, 6 and 7*, represent prices and volumes common in the hydrogen industry today, as reported by companies in the business of producing and selling hydrogen. Prices include feedstock, production and delivery costs, but do not include installation costs or equipment rental fees. That is, the prices in this report include the costs to get hydrogen delivered to the site, but not the costs at the customer site to hook up and unload any hydrogen or equipment that may need to be installed to store the delivery onsite. The industrial gas companies typically charge a monthly fee to cover the costs of installing and maintaining any delivered equipment that remains onsite like storage tanks, vaporizers, compressors and their respective plumbing. Most industrial gas companies also typically include an energy surcharge (based on the feedstock, e.g. natural gas) in their long-term contracts with customers, so if the price of the feedstock increases, for example, the seller can pass on the increase to the customer. For low volume users of hydrogen, these monthly “facility charges” can become a large portion of the total hydrogen cost.

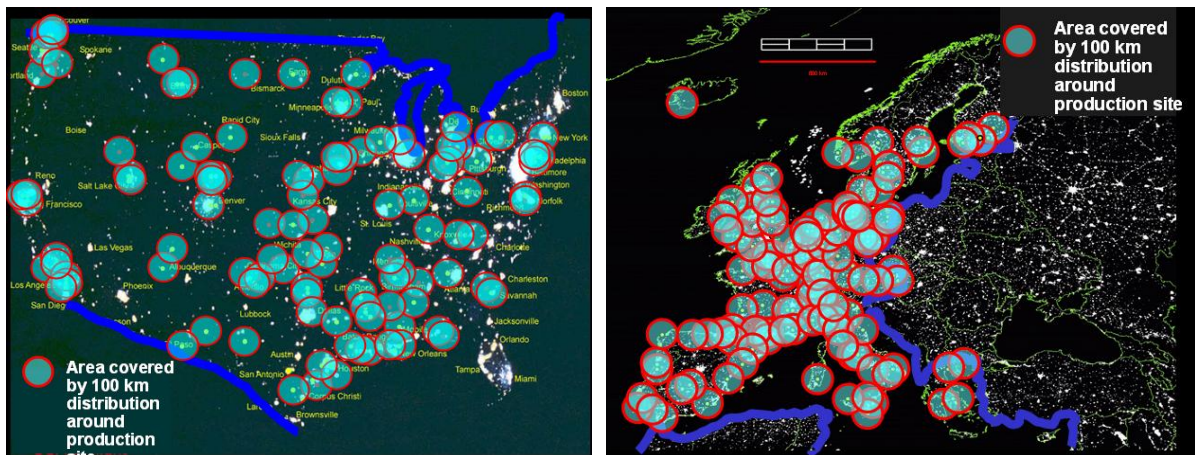
**Table 5. Common volumes of merchant hydrogen sales<sup>26</sup>**

Common Sales Volume		
	(scf/mo)	(kg/mo)
Liquid H <sub>2</sub>	300,000 – 500,000	709 – 1,182
Gaseous H <sub>2</sub>	50,000 – 70,000	118 – 165

<sup>26</sup> From industry sources who asked their identities to be kept confidential due to the sensitive nature of this information.

Generally, for liquid hydrogen, the onsite equipment needed (cryogenic storage tanks, vaporizers and cryogenic plumbing) and installation costs are much higher than those for gaseous hydrogen. As a result, industry sources reported that there is an economic tipping point, below which, gaseous hydrogen, while more expensive to deliver initially, is more affordable overall, due to the relatively lower installation costs. This tipping point was reported to be in the range of 125,000-300,000 scf/mo (295-709 kg/mo). Below this point, gaseous deliveries are likely to be more economical, while above it, liquid hydrogen deliveries may be more cost-effective.<sup>27</sup>

Another tipping point exists based on the distance to the production source. In general, industry sources report that deliveries made less than 100 – 200 miles from the point of production are likely to be cheaper as a delivery of gaseous hydrogen by tube trailer. Beyond that distance, the cost of driving the truck compared to the hydrogen delivered adds too much cost to the delivery. The exception is customers that need high-pressure hydrogen. If high pressure hydrogen is needed by the customer, it is often more economical to drive a high pressure tube trailer to the site, even if more than 200 miles away, than to install compression and storage equipment on site to bring low pressure liquid hydrogen up to the desired pressure. Because of these economics, it is not surprising that a large gaseous hydrogen production site exists today within 60 miles (100 km) of almost every major U.S. and European city.<sup>28</sup>



**Figure 2. Night-time satellite photographs of the United States and Europe overlaid with the locations of major hydrogen production plants and a 100 kilometer (60 mile) radius circle around it. Bright white spots (light) represent cities.**

Tables 6 and 7 provide typical prices for gaseous and liquid hydrogen delivered to the east and west coasts of the U.S.: \$5-10/kg for liquid hydrogen and \$17-20/kg for gaseous hydrogen. Some customers in the U.S. use more than 1 million scf/mo (2,362 kg/mo), but

<sup>27</sup> These tipping points assume a hydrogen pipeline does not exist nearby. See the preceding *Pipeline Delivery* section for more information.

<sup>28</sup> Shell Hydrogen and General Motors, various presentations and slides from GM's Electric Drive University. Some of these production sites produce hydrogen for captive use, not for merchant sale. E.g., B. Gross, I. Southerland, and H. Mooiweer. *Hydrogen Fueling Infrastructure Assessment*. December 2007. <http://www.h2andyou.org/pdf/GM-SH%20HYDROGEN%20INFRA%20PAPER.pdf>.

when amounts grow beyond 10 million scf/mo (23,623 kg/mo), customers likely find it is more economical to install an onsite steam methane reformer to produce the hydrogen, instead of having it delivered from remote production facilities.

**Table 6. Typical prices for some liquid hydrogen sales**

Liquid H <sub>2</sub> Pricing (ccf)			Liquid H <sub>2</sub> Pricing (kg)		
Volume Range (scf/mo)	East	West	Volume Range (kg/mo)	East	West
100,000 – 300,000	\$1.65	\$2.40	236 – 709	\$6.98	\$10.16
300,001 – 600,000	\$1.50	\$2.20	709 – 1,418	\$6.35	\$9.31
600,000 – 1,000,000	\$1.35	\$1.90	1,418 – 2,363	\$5.71	\$8.04
1,000,000+	\$1.15	\$1.65	2363+	\$4.87	\$6.98

**Table 7. Typical prices for some gaseous hydrogen sales**

Gaseous H <sub>2</sub> Pricing (ccf)			Gaseous H <sub>2</sub> Pricing (kg)		
Volume Range (scf/mo)	East	West	Volume Range (kg/mo)	East	West
50,000 – 100,000	\$4.35	\$4.65	118 – 236	\$18.41	\$19.68
100,001 – 200,000	\$4.15	\$4.45	236 – 473	\$17.56	\$18.83
200,001 – 300,000	\$3.95	\$4.25	473 – 709	\$16.72	\$17.99

While these prices are typical for a variety of users and applications, the market is particularly interested in the possible cost of hydrogen at fueling stations. The U.S. Department of Energy (DOE) has reported that when making hydrogen using current (assuming production units are mass produced in quantities of at least 500 units), hydrogen can cost the equivalent of \$3 to \$6 per kilogram at the pump, not including taxes.<sup>29</sup> Hydrogen, compressed to 5,000 psi (350 bar, 35 MPa<sup>30</sup>) to 10,000 psi (700 bar, 70 MPa), can be delivered at the pump within this equivalent price range when made from natural gas, water (using electricity from wind), biomass and coal. (This range is viewed as competitive with gasoline when the hydrogen is used in a fuel cell electric vehicle.) *Table 6* shows a delivered price of \$5-10/kg or an equivalent gasoline price for a fuel cell vehicle of half those amounts (since fuel cell vehicles travel at least twice as many miles on a kilogram of hydrogen as a gasoline car travels on a gallon of gasoline). *Table 7* shows higher costs for gaseous-delivered hydrogen.

Note that the hydrogen prices listed in *Tables 6* and *7* do not include the costs for hydrogen compression to pressures above 5,000 or 10,000 psi (needed to fill the tanks on vehicles), nor the costs of onsite storage and dispensing. The DOE estimates high pressure hydrogen would cost approximately \$3/kg from an onsite SMR, including

<sup>29</sup> The equivalent price takes into account the higher efficiency of a fuel cell vehicle so that a more accurate, “apples to apples” comparison can be made between the cost per kilogram of hydrogen and the cost per gallon of gasoline. A fuel cell vehicle is roughly two to three times more efficient than a gasoline engine vehicle – assume two times. So the cost at the pump for hydrogen might be \$6-12/kg, but since 1 kilogram has the same amount of energy as a gallon of gasoline, and it takes the driver twice as many miles down the road compared to a gasoline vehicle, the cost is equivalent to \$3-6/gal of gasoline. <http://www.h2andyou.org/tenThings.asp>.

<sup>30</sup> A pascal is a unit of pressure or a measure of force per unit area. It is defined as one newton per square metre. One megapascal or MPa is equal to 1,000,000 pascals.

compression, storage and dispensing (CSD). Hydrogen production costs \$1.61/kg, while the CSD system costs about \$1.88/kg.<sup>31</sup>

### **2.3.4 Byproduct Hydrogen**

In addition to the hydrogen production data presented above, a significant volume of hydrogen was also produced in 2008 as a byproduct from some common industrial processes. Hydrogen produced as a byproduct of refinery catalytic reforming processes contributes the largest share of byproduct hydrogen production. Ethylene and chlor-alkali plants are prime examples of byproduct hydrogen sources. Small amounts of byproduct hydrogen are also recovered and used internally at coking facilities.

Typically, byproduct hydrogen is captured and used by the entity which produced it. It also typically needs to be cleaned before being used (non-hydrogen impurities removed), and if transported to a customer or processing plant, also liquefied or pressurized.

In 2004, one company in the hydrogen industry assessed this market and confidentially identified 53 such plants in the U.S. Historically, byproduct hydrogen has been viewed as a waste product which was vented harmlessly into the atmosphere. However, as hydrogen use has grown and energy prices have increased, this hydrogen has been utilized more recently for its energy content. Therefore, it is more common now for it to be captured and used or sold. The most common uses for this byproduct hydrogen are as a:

- Fuel for boilers or turbines; or
- Revenue generator, from selling the hydrogen-rich gas to industrial gas companies for processing (mostly the removal of non-hydrogen elements from the byproduct gas stream) and sale to other customers.

In some cases, byproduct hydrogen can be particularly valuable since with clean-up, other processing, and delivery costs, it may still be less expensive than traditional hydrogen production processes. Therefore, byproduct hydrogen can play an important role in early hydrogen energy markets where other bulk hydrogen production is distant.

At this time, it is hard to determine exactly how much byproduct hydrogen could be available. However, a 2008 Energy Information Administration report<sup>32</sup> estimated the U.S. byproduct hydrogen production capacity at 10,530,000 kg/day (approximately 77 percent of which is byproduct capacity from catalytic reforming at oil refineries). A 2007 SRI Consulting report<sup>33</sup> lists all U.S. producers with byproduct hydrogen capacity from chlor-alkali or sodium chlorate production via brine electrolysis with a the total reported capacity of approximately 1.1 million kg/day. (Actual production would be less.)

---

<sup>31</sup> The U.S. Department of Energy has developed an extensive set of hydrogen cost estimation spreadsheets that estimate the cost of hydrogen for energy applications. These “H2A” spreadsheets can be downloaded from: [http://www.hydrogen.energy.gov/h2a\\_analysis.html](http://www.hydrogen.energy.gov/h2a_analysis.html). DOE notes that these costs are supported by independent review.

<sup>32</sup> Energy Information Administration, 2008. *The Impact of Increased Use of Hydrogen on Petroleum Consumption and Carbon Dioxide Emissions*. Washington DC: U.S. Department of Energy. <http://www.eia.doe.gov/oiaf/servicerpt/hydro/pdf/oiafcneaf%2808%2904.pdf>.

<sup>33</sup> Suresh, Bala, Stefan Schlag, and Masahiro Yoneyama, *CEH Marketing Research Report Hydrogen* (Menlo Park: SRI Consulting, 2007), 61, converted to kg.

### **2.3.5 Employees**

This report estimates, from available data, that the equivalent of approximately 2,300 FTE employees serve the U.S. merchant hydrogen business. The vast majority are employees of industrial gas companies.

## **2.4 Distributed Production**

### **2.4.1 Overview**

The distributed hydrogen production market primarily comprises companies that manufacture and sell two kinds of relatively small hydrogen generation appliances: reformers and electrolyzers.

In simple terms, reformers use heat, pressure and catalysts to separate hydrogen from water and a carbon-based feedstock such as natural gas, ethanol, methanol or other petrochemicals. The feedstock (for example, natural gas) is fed into the reformer, and hydrogen and carbon dioxide are the primary end products (after second stage conversion of carbon monoxide in the interim processing).

Electrolyzers use electricity to dissociate hydrogen and oxygen in water. Water and electricity are supplied to the electrolyzer and pure hydrogen and oxygen are the resulting products (this is actually the reverse of the electrochemical process in a fuel cell, where hydrogen and oxygen are combined to form electric energy and water vapor or steam).

Large scale reformation has been used for decades for bulk hydrogen production. Historically, it has been difficult to scale down this technology into units that are operationally stable, economically viable and small enough to be distributed. However, great progress has been made in introducing new products. In addition to small steam-methane reformers (SMRs), there are partial oxidation reformers (POXs), auto-thermal reformers (ATRs), “crackers” and “membrane” reformers being manufactured and operated today. Small scale reformers for distributed hydrogen production are in their infancy, relative to their ability to penetrate or compete in the U.S. merchant gas market.

Electrolyzers, in relatively small sizes, are also beginning to compete with merchant hydrogen where the cost of electricity is low or where other market considerations make it competitive. There appears to be only one company in the world with the ready capability to build and deliver large electrolysis units (greater than 9 kg/hr production rate).

However, industrial gas company sources have reported at least three electrolyzers in use (installed before 2002) which produce about 22kg/hr: two in the U.S. and one in Canada. At the time of this report, it was unclear who manufactured those units, but they continue to operate.

Electrolysis has been a viable process for the generation of hydrogen for more than 150 years, however, new materials and processes have lead to improvements in efficiencies, operation, life and gas purity, as well as cost reductions. Most modern electrolyzers are of

the “bi-polar” construction type and are either alkaline or solid polymer electrolyte (PEM) types with alkaline dominating the larger unit sizes. Most units are easily adapted to generate the gas directly at pressure (commonly about 100 psi), eliminating the need for voluminous gas holders and some stages of compression. Units are being developed for high pressure (greater than 1500 psi) generation. High temperature (extremely efficient) units have been demonstrated but are not yet commercially available.

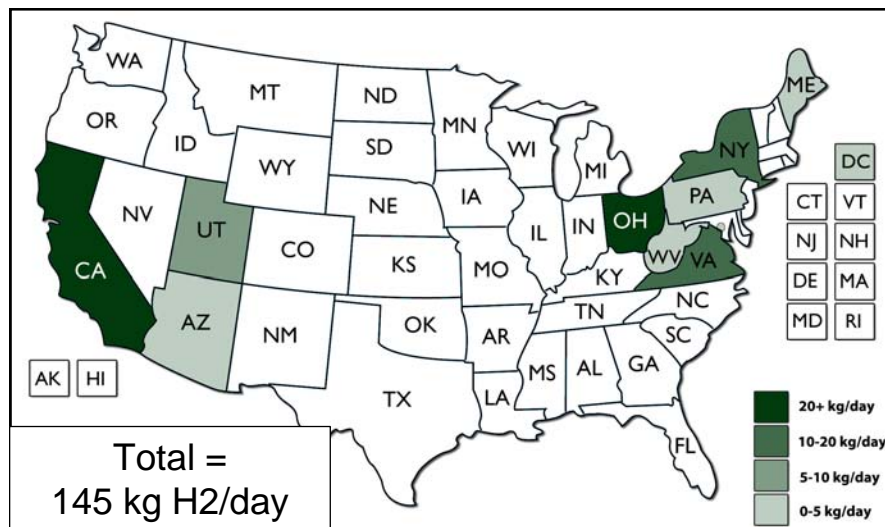
In the near-term, increased demand for onsite hydrogen generation may be stimulated by a number of factors: logistical independence from hydrogen delivery; reduction in cost due to zero delivery costs; ability to generate hydrogen locally with less of an environmental footprint by utilizing electrolysis; and renewable electricity. Interestingly, the demand for these units is currently much stronger in foreign markets since centralized hydrogen production and a developed delivery infrastructure are not as common. Therefore, assumptions regarding the global market, business viability or growth potential of reformers and electrolyzers should not be based solely on U.S. hydrogen production and delivery as presented here.

#### **2.4.2 Methodology**

Data for this *Distributed Production* section were compiled from email and phone correspondence with companies who manufacture reformers and electrolyzers and from internet websites. The list of responding companies is not necessarily the same as the list of companies contacted as some organizations have either the technological capability and are not commercially active, or they declined to provide data. However, we believe we have received data from all active electrolyzer manufacturers. While some reformer organizations declined to participate, we believe the data presented here is representative of about 85 percent of the companies active in the U.S. Data for very small units such as those used to supply hydrogen to gas chromatographs was not gathered as the total production capability of these units is insignificant relative to the units considered.

*Companies contacted: Avalence; BAMAG & LURGI (ELT GmbH); Caloric; Chevron; Coting Industries; Genesis Fuel Tech; Giner; H2Gen; Harvest Energy Tech; Hidroenergia; Hy9 Corp; Hydrogenics; HyGear BV; HyRadix; Innova Tek; Nuvera; Precision Combustion; Proton Energy Systems; REB; Statoil; Teledyne Energy Systems; WS Reformer GmbH.*

### 2.4.3 Electrolyzers



*Figure 3. Electrolyzers: hydrogen production capacity installed in 2008*

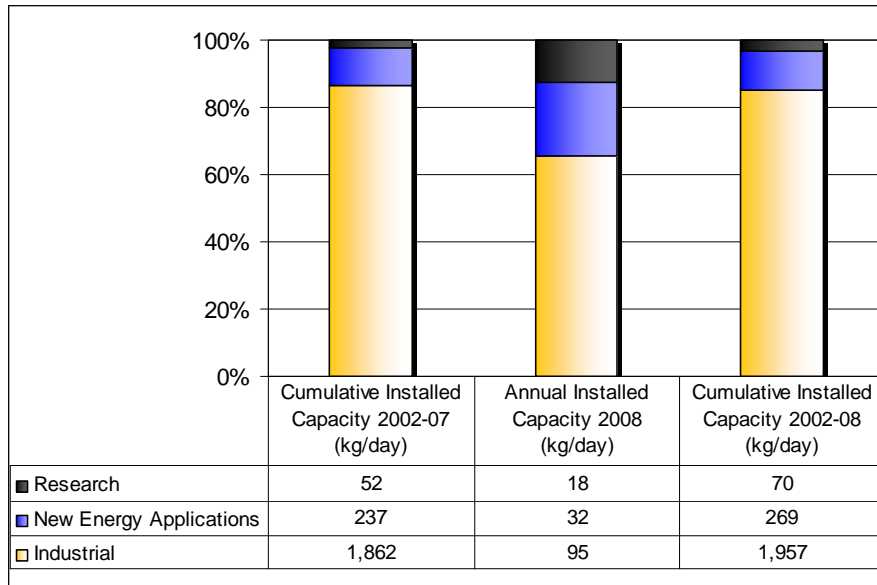
The market for electrolyzers was small during the years 2002-2008, but is growing. By the end of 2008, total production capacity of installed electrolyzers in the U.S. was 2,300 kg/day, from 215 units, which represented 0.030 percent of the total merchant hydrogen production in the U.S. of a little less than 8 million kg/day<sup>34</sup>). In 2008, 18 new electrolyzers were installed representing 145 kg/day of hydrogen production capacity, which corresponds to a 5 percent growth in production capacity from 2007.

The dominant uses for electrolyzers operating in 2008 that can produce between 2 and 125 kg/day<sup>35</sup> were industrial applications such as electric generator cooling, metals processing and semi-conductor manufacturing. The second most popular electrolyzer market was "new energy" applications such as hydrogen fueling stations.

<sup>34</sup> Assuming that the merchant hydrogen production is 14 percent of total U.S. hydrogen production.

<sup>35</sup> The range was smaller for only 2008, 2 -32 kg/day. All data on electrolyzers in this report refer to units within this range.





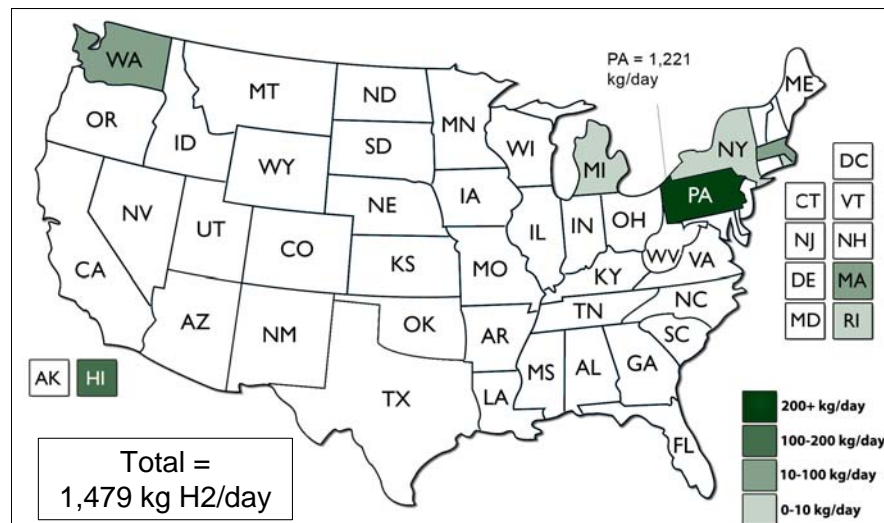
**Figure 4. Electrolyzers: total installed hydrogen production capacity by application (2002-2008)**

#### 2.4.4 Reformers

The market share for small reformers, with a capacity range of 2-924 kg/day,<sup>36</sup> has also been small between 2002 and 2008, but is about twice as large as the market share for electrolyzers, and is growing more rapidly in terms of overall hydrogen production. In 2008, 11 new reformers were installed representing 1,479 kg/day of hydrogen production capacity and 45 percent growth from the production capacity installed at the end of 2007. The majority of these reformers are used for distributed, not centralized, hydrogen production. By the end of 2008, total production capacity of installed reformers in the U.S. was 4,198

kg/day (representing 0.050 percent of total U.S. merchant hydrogen production<sup>37</sup>).

Several factors influence the larger total installed production capacity of reformers, the most significant



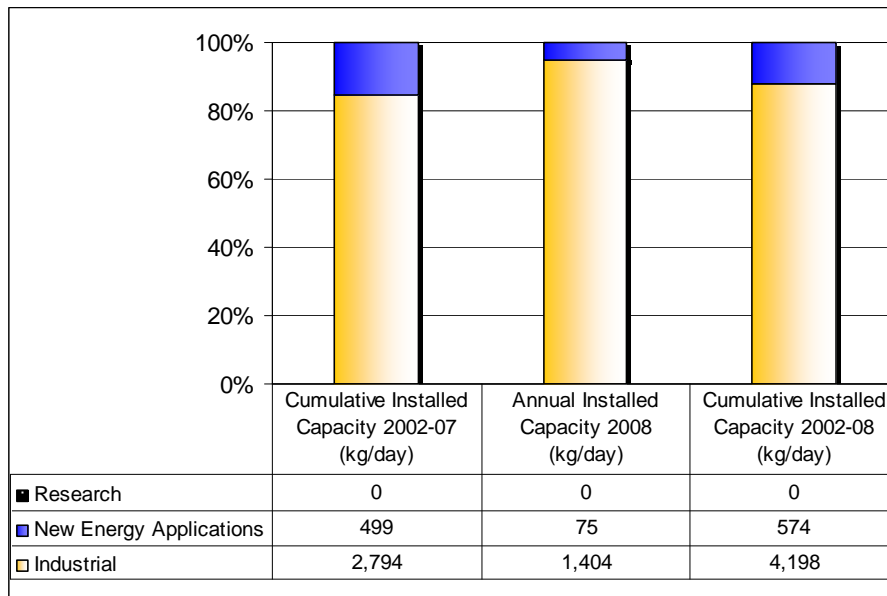
**Figure 5. Reformers: Annual installed hydrogen production capacity in 2008**

<sup>36</sup> For 2008 only, the range was 2-610 kg/day. All data on reformers in this report refer to units within this range.

<sup>37</sup> Assuming that the merchant hydrogen market is 14 percent of total U.S. hydrogen production.



being the hydrogen production capacity of the units. Compared to electrolyzers, reformers are much more readily available in sizes that produce 200-900 kg/day. These sizes, while large compared to electrolyzers, are still very small compared to the medium and large hydrogen production equipment that supplies most of the hydrogen used in the U.S.



**Figure 6. Reformers: Total installed hydrogen production capacity by application (2002-2008)**

The above reforming analysis does not include the internal reforming used to produce hydrogen for high temperature fuel cells.<sup>38</sup>

### 2.4.5 Employees

At least 386 FTE employees work in the U.S. for companies who manufacture reformers, and at least 141 FTEs, for companies who manufacture electrolyzers.

### 2.4.6 Electrolyzer and Reformer Comparisons

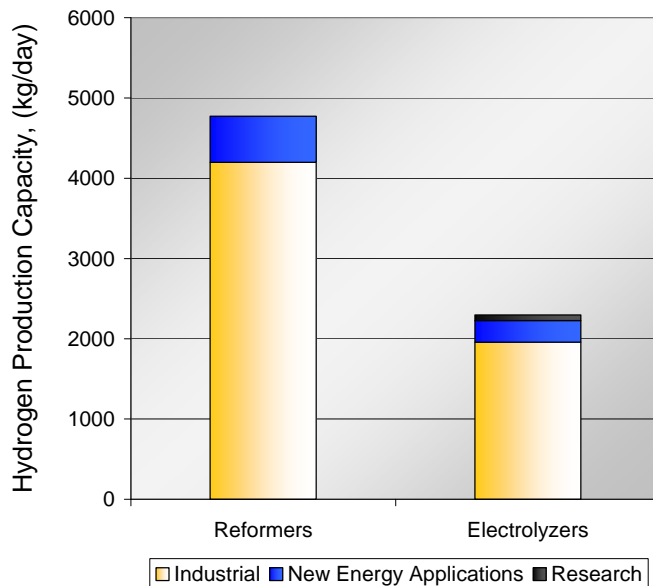
When comparing the applications and markets for electrolyzers and reformers, both the availability of feedstocks and application requirements play important roles. Economics plays an important part in the selection of which alternative, but it's important to remember electrolyzers and reformers do not necessarily compete but rather, are complementary alternatives in the distributed generation of hydrogen. .

Part of this complementary nature can be seen in the geographical distribution of the different alternatives across the U.S. Reformers make more hydrogen, but only in some areas of the U.S. where hydrogen needs are greater. Electrolyzers are better positioned to

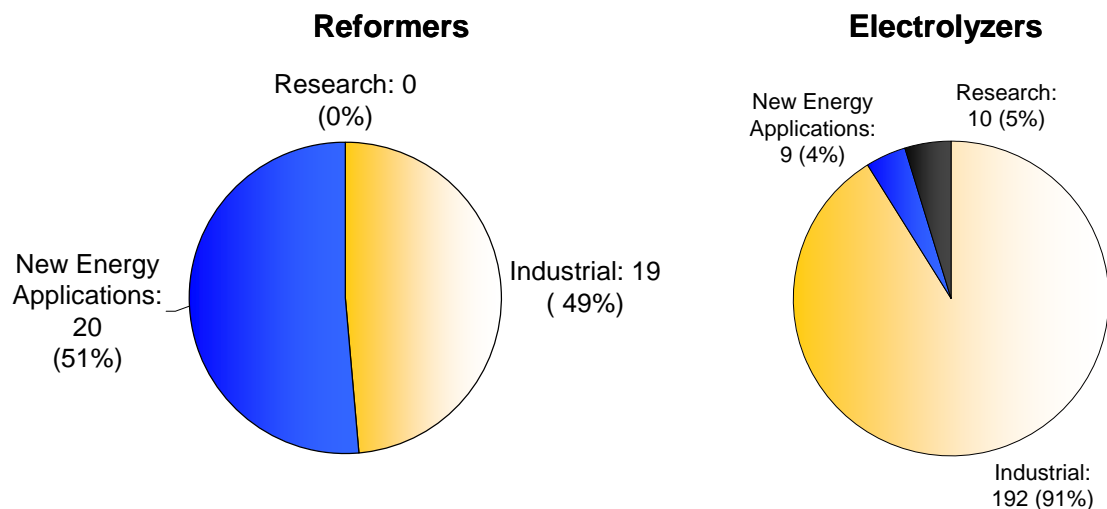
<sup>38</sup> These units produce approximately 2 kg hydrogen/day/kW of power and approximately 25 percent of this hydrogen could be exported to support other applications.

meet a variety of the smaller needs for industrial hydrogen, resulting in a greater geographical distribution of units.

The market for both kinds of units could change rapidly if the research or new energy sectors becomes more vibrant. For example, accelerated growth in the material handling industry requires that the fueling infrastructure for lift trucks grows as well. Deliveries of centrally produced hydrogen, as well as onsite production options like electrolyzers and reformers are well suited to meet this growing demand.



**Figure 7. Electrolyzers and Reformers: installed production capacity, 2002-2008**



**Figure 8. Electrolyzers and Reformers: number of installed units by application, 2002-2008**

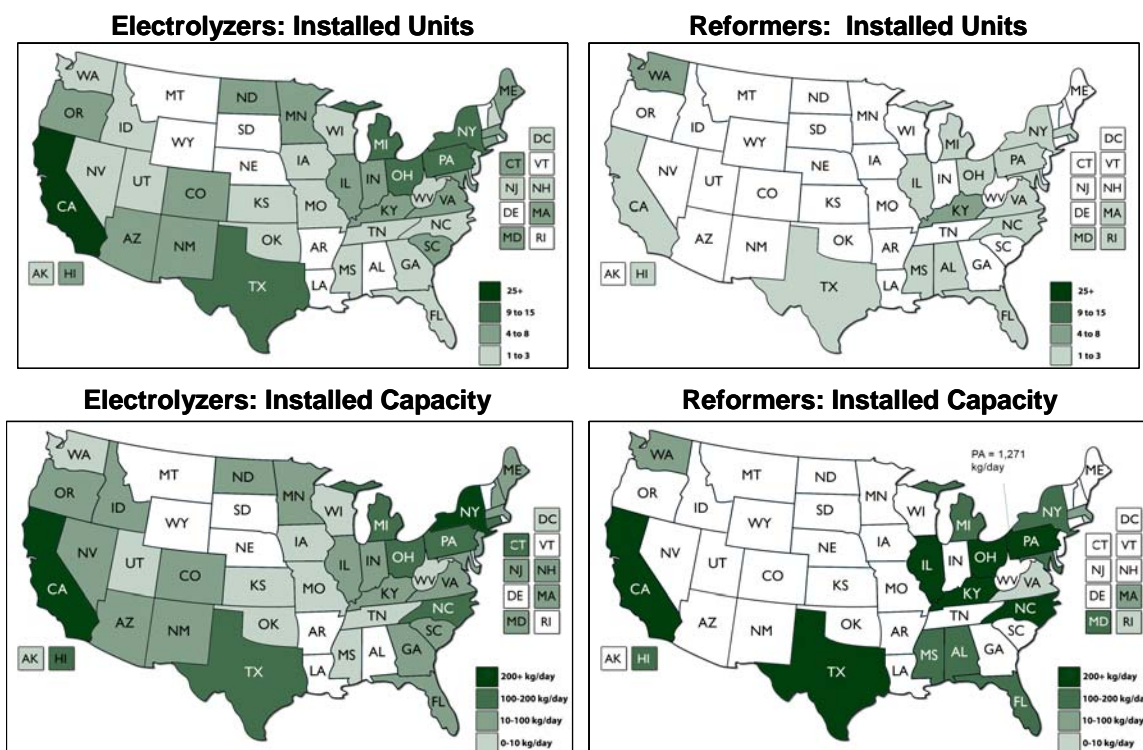


Figure 9. Electrolyzers and Reformers: installations from 2002-2008

## 2.5 Renewable Hydrogen Production

### 2.5.1 Overview

Through 2008 and previously, hydrogen production in the U.S. has been heavily reliant on reformation of natural gas. This process, while very efficient (about 75 percent),<sup>39</sup> does release carbon dioxide. Compared to other fossil fuels, these emissions are relatively small and the use of natural gas reformed hydrogen with fuel cells reduces transportation emissions by more than 50 percent,<sup>40</sup> but there is strong interest in production methods that produce zero or near-zero emissions (reductions of up to 100 percent).

This section focuses on the projects that produce hydrogen with zero emissions and utilize renewable resources. “Projects” in this report are defined as demonstration- or commercial-scale installations and therefore exclude laboratory experiments. While the

<sup>39</sup> And 70 percent efficient with compression, C.E. Thomas, “Fuel cell and battery electric vehicles compared,” *International Journal of Hydrogen Energy* 34 (2009) 6005-6020, [http://www.h2gen.com/Uploads/file/Battery\\_vs\\_FuelCell\\_EVs.pdf](http://www.h2gen.com/Uploads/file/Battery_vs_FuelCell_EVs.pdf).

<sup>40</sup> Producing hydrogen from natural gas and using it in a fuel cell vehicle, emits 63 percent fewer greenhouse gases (GHGs) than today’s gasoline vehicles, and 37 percent fewer GHGs than natural gas vehicles based on the projected state of technology in 2020. Joseck, Fred 2009. *Well-to-Wheels Greenhouse Gas Emissions and Petroleum Use*. Washington DC: U.S. Department of Energy - Hydrogen Analysis Resource Center, [http://www.hydrogen.energy.gov/pdfs/9002\\_well-to-wheels\\_greenhouse\\_gas\\_emissions\\_petroleum\\_use.pdf](http://www.hydrogen.energy.gov/pdfs/9002_well-to-wheels_greenhouse_gas_emissions_petroleum_use.pdf).

Also see:

Air Resources Board - Stationary Source Division 2009. *Proposed Regulation to Implement the Low Carbon Fuel Standard Volume I*. Sacramento: State of California - California Environmental Protection Agency, <http://www.arb.ca.gov/regact/2009/lcfs09/lcfsisor1.pdf>.

renewable projects running today do not produce large amounts of hydrogen, they represent the beginning of the enormous potential for zero-emission hydrogen production.

Renewable hydrogen projects operational in 2008 can be categorized as follows:

1. **Wind to Hydrogen projects:** produce hydrogen from water using electricity from wind turbines.
2. **Solar to Hydrogen projects:** produce hydrogen from water using electricity from solar photovoltaic (PV) panels.<sup>41</sup>
3. **Green Grid projects:** produce hydrogen from water using one or more renewable electricity resources from the grid. The electricity used may be “dedicated renewable electricity from one or more specific sources” (e.g. hydroelectric plants); purchased renewable electricity through an agreement with the local utility or a project developer; or purchased carbon offsets or renewable energy credits or tags on top of grid-supplied electricity.
4. **Biomass or Anaerobic Digester Gas projects:** produce hydrogen from wastewater or biowaste, using anaerobic digestion to produce biogas or landfill gas which then is processed by reformation to produce hydrogen. This process is very similar to natural gas reformation with the exception that biogas contains many trace gases which are corrosive to the materials in most reformers and therefore, requires a more sophisticated cleaning process to produce hydrogen.

### 2.5.2 Methodology

The data for this section were obtained primarily through secondary research and interviews with industry stakeholders. Most sites were confirmed via phone or email correspondence with site operators or project partners.

### 2.5.3 Projects

In 2008, 30 projects at 27 sites across the U.S. actively produced hydrogen from renewable resources. More than half these sites, 17, were located in California. Of the 30 projects, seven were located in the Northeast U.S., and three were in the central U.S., According to the National Renewable Energy Laboratory, the central U.S. has the highest potential for renewable hydrogen production.<sup>42</sup>

Overall, most projects are small demonstration or experimental, with a production capacity of less than 3 kg/hour. They generally produce hydrogen for limited time periods, under a research or demonstration plan, and are designed to verify the commercial readiness of a renewable energy source or new production technology. For example, hydrogen has great potential to store electricity produced from wind and, although wind turbines are becoming much more common, hydrogen projects remain small as the industry learns how to account for very unsteady electrical input due to variability in wind speeds.

---

<sup>41</sup> Solar thermal hydrogen plants are typically included in this definition, but excluded in this report since no solar thermal hydrogen projects are known at the time of data collection.

<sup>42</sup> Milbrandt, Anelia and Margaret Mann, *Potential for Hydrogen Production from Key Renewable Resources in the United States* (Golden: National Renewable Energy Laboratory, 2007), 13. <http://www.nrel.gov/gis/hydrogen.html>.

All commercial sized projects produce hydrogen from wastewater through anaerobic digestion and internal reformation in a molten carbonate fuel cell system. Due to the almost constant availability of wastewater and higher supply of the resource at one centralized site, these projects produce a relatively large amount of hydrogen compared to hydrogen projects using electrolysis (see *Tables 8 and 9*).

**Table 8. Renewable energy projects active in 2008**

<b>Electrolysis</b>			<b>Capacity in kg/hr<sup>43</sup></b>
<b>Source</b>	<b>Project</b>	<b>Location</b>	
Wind	Wind-to-Hydrogen Wind2H2 <sup>44</sup>	Golden, CO	1.00
Wind	Wind-to-Hydrogen Project Fueling Station <sup>45</sup>	Minot, ND	2.70
Hybrid	Solar and Wind-to-Hydrogen Fueling Station <sup>46</sup>	Taos, NM	.08
Solar	Schatz Solar Hydrogen Project <sup>47</sup>	Trinidad, CA	.40
Solar	Sacramento Municipal Utility District Solar Fueling Station	Sacramento, CA	.50
Solar	Honda Solar Hydrogen Refueling Station <sup>48</sup>	Torrance, CA	.14
Solar	Toyota Torrance Solar Hydrogen Station <sup>49</sup>	Torrance, CA	1.00
Solar	SunLine Transit Clean Fuels Mall Hydrogen Station <sup>50</sup>	Thousand Palms, CA	.10
Solar	Solar Hydrogen Fueling Station LV Valley Water District <sup>51</sup>	Las Vegas, NV	.57
Solar	Solar-Hydrogen Residence <sup>52</sup>	Hopewell, NJ	.10
Solar	Exact Project/Location Unknown <sup>53</sup>	CT	.75
Solar	Exact Project/Location Unknown <sup>54</sup>	CT	3.00
Solar	Exact Project/Location Unknown <sup>55</sup>	MI	3.00
Solar/Green Grid	SCAQMD Hydrogen Station	Diamond Bar, CA	.50
Green Grid	West Los Angeles Shell Hydrogen Fueling Station <sup>56</sup>	West LA, CA	N/A <sup>57</sup>
Green Grid	White Plains Shell Hydrogen Fueling Station <sup>58</sup>	White Plains, NY	N/A <sup>59</sup>
Green Grid	E-Vermont Hydrogen Fueling Station <sup>60</sup>	Burlington, VT	.50

<sup>43</sup> Numbers in italics represent the actual average hydrogen production rate per hour. To accurately convert to kg/day, multiplication by 24 is not usually appropriate since the sun and wind are intermittent resources. One must take into account seasonal and geographical variability of these resources.

<sup>44</sup> For more information see: [http://www.nrel.gov/hydrogen/proj\\_wind\\_hydrogen.html](http://www.nrel.gov/hydrogen/proj_wind_hydrogen.html).

<sup>45</sup> For more information see: [http://www.basinelectric.com/Electricity/Generation/Wind/Wind-to-Hydrogen\\_Project/index.html](http://www.basinelectric.com/Electricity/Generation/Wind/Wind-to-Hydrogen_Project/index.html).

<sup>46</sup> For more information see: <http://www.angels-nest.org>.

<sup>47</sup> For more information see: [http://www.schatzlab.org/projects/real\\_world/schatz\\_solar.html](http://www.schatzlab.org/projects/real_world/schatz_solar.html).

<sup>48</sup> For more information see: <http://www.ieahia.org/pdfs/honda.pdf>.

<sup>49</sup> For more information see: <http://www.fuelcells.org/dbs/project.php?id=962>.

<sup>50</sup> For more information see: <http://www.fuelcells.org/dbs/project.php?id=992>.

<sup>51</sup> For more information see:

<http://www.airproducts.com/Products/MerchantGases/HydrogenEnergy/Projects/AutomobilesProjects.htm>.

<sup>52</sup> For more information see: <http://www.scientificamerican.com/article.cfm?id=hydrogen-house>.

<sup>53</sup> Data provided by manufacturer.

<sup>54</sup> Data provided by manufacturer.

<sup>55</sup> Data provided by manufacturer.

<sup>56</sup> For more information see:

[http://www.shell.com/home/content/media/news\\_and\\_library/press\\_releases/2008/la\\_hydrogen\\_station\\_26062008.html](http://www.shell.com/home/content/media/news_and_library/press_releases/2008/la_hydrogen_station_26062008.html)

<sup>57</sup> Information not available.

<sup>58</sup> For more information see:

[http://hydrogen.pnl.gov/filedownloads/hydrogen/datasheets/Operational\\_Hydrogen\\_Fueling\\_Stations.xls](http://hydrogen.pnl.gov/filedownloads/hydrogen/datasheets/Operational_Hydrogen_Fueling_Stations.xls).

<sup>59</sup> Information not available.

<sup>60</sup> For more information see: [http://www.hydrogen.energy.gov/pdfs/progress05/iv\\_h\\_4\\_garabedian.pdf](http://www.hydrogen.energy.gov/pdfs/progress05/iv_h_4_garabedian.pdf).

<b>Electrolysis</b>			<b>Capacity in kg/hr<sup>43</sup></b>
<b>Source</b>	<b>Project</b>	<b>Location</b>	
Green Grid	Chewonki Renewable Hydrogen Project <sup>61</sup>	Portland, ME	.04
<b>Total</b>			<b>14.37</b>

*Table 9. Waste-to-energy projects active in 2008*

<b>Wastewater / Organic Conversion<sup>62</sup></b>			<b>Capacity in kg/hr</b>
<b>Source</b>	<b>Project</b>	<b>Location</b>	
Anaer. Dig. Gas	El Estero Fuel Cell Project - Hydrogen Fueling Station	Santa Barbara, CA	42.52
Anaer. Dig. Gas	Los Angeles County Palmdale	Palmdale, CA	21.26
Anaer. Dig. Gas	King's County Waste-Water Treatment Plant	King County, WA	85.03
Anaer. Dig. Gas	Sierra Nevada Brewery	Chico, CA	85.03
Anaer. Dig. Gas	Wastewater Treatment Facility	Tulare, CA	63.78
Anaer. Dig. Gas	City of Rialto's wastewater treatment facility	Rialto, CA	76.53
Anaer. Dig. Gas	Turlock Irrigation District	Turlock, CA	102.04
Anaer. Dig. Gas	Eastern Municipal Water District (EMWD)	Moreno Valley, CA	63.78
Anaer. Dig. Gas	Dublin San Ramon	San Ramon, CA	51.02
Anaer. Dig. Gas	Gills Onion Plant	Gills Onion, CA	51.02
Anaer. Dig. Gas	Riverside Treatment Plant	Riverside, CA	85.03
Bioreactor	Welch's Grape Juice Factory	North East, PA	N/A <sup>63</sup>
<b>Sum</b>			<b>727.04</b>

*Table 10. Other noteworthy waste and renewable energy projects active in 2008*

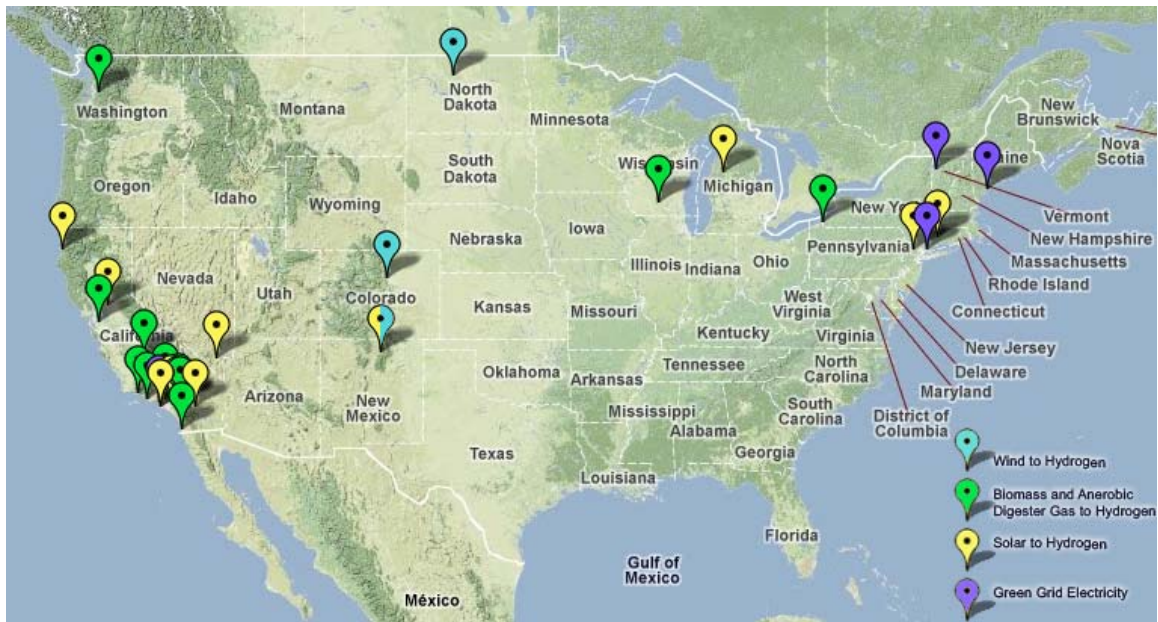
<b>Other Noteworthy Waste and Renewable Projects</b>			<b>Capacity in kg/hr</b>
<b>Source</b>	<b>Project</b>	<b>Location</b>	
	Waste Ethylene Glycol and Glycerol to Hydrogen	Madison, WI	.55
	By-Product Hydrogen and Hydropowered Liquefaction	Niagara Falls, NY	1,666.67

<sup>61</sup> For more information see: <http://www.chewonkih2.org>.

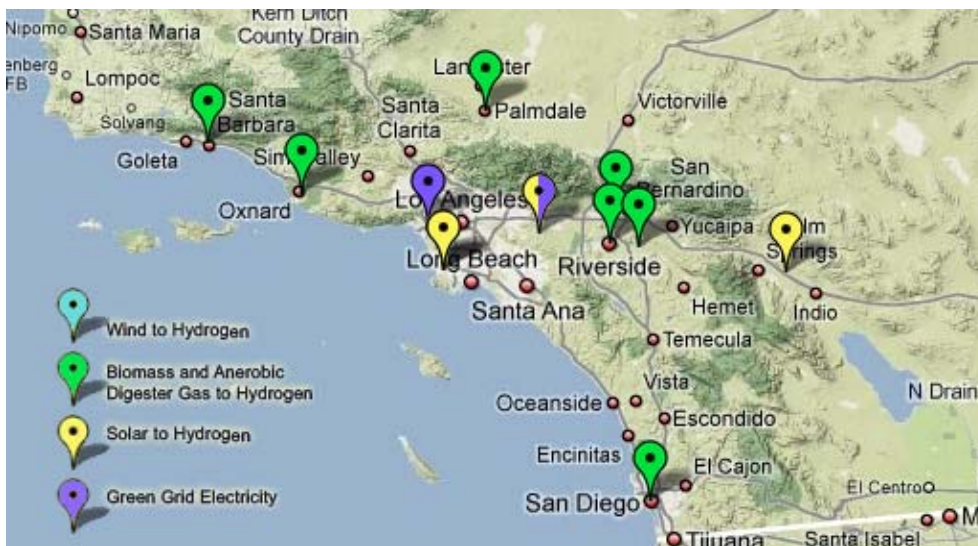
<sup>62</sup> The only major company in this sector is FuelCell Energy. Information on their Direct Fuel Cell is available on their website, [www.fuelcellenergy.com](http://www.fuelcellenergy.com). Demonstration projects on hydrogen from landfill gas have existed in the 1990s, but have been decommissioned. See the U.S. Environmental Protection Agency's Landfill to Market Outreach Program: <http://www.epa.gov/landfill/res/fuelcell.htm>

<sup>63</sup> Information not available.





*Figure 10. Renewable energy projects active in 2008*



*Figure 11. Renewable energy projects active in 2008 in the Greater Los Angeles area*

### 3. HYDROGEN USE

#### 3.1 Overview

Hydrogen is used for a wide variety of applications. Over the past several decades, it has been used as a chemical in industrial applications to make things like peanut butter, glass, stainless steels, semiconductor chips and light bulbs. Today, hydrogen is used in a very different way, to produce energy (in most cases, electricity) to powering buildings, vehicles and even consumer electronics. This section explores both uses, with an

emphasis on energy applications, as other studies have covered industrial uses in some detail.<sup>64</sup>

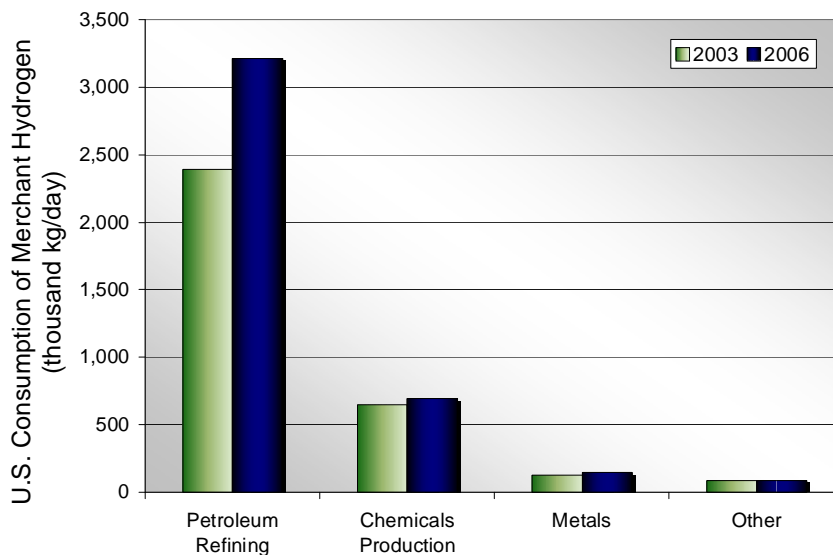
## 3.2 Industrial Use

Hydrogen is an important gas in many industrial processes, most notably for petroleum refining and making ammonia, metals, electronics and food products. From 2003 to 2006, hydrogen consumption decreased from 20,757,000 kg/day to 19,509,000 kg/day, which represents a 6 percent drop. While the hydrogen consumed in petroleum refining has steadily increased, the hydrogen consumption for ammonia and methanol production decreased sharply during the period.

*Table 11. Hydrogen consumption in thousand kg/day*

	Total		Merchant	
	2003	2006	2003	2006
<b>Petroleum Refining</b>	10,960	12,737	2,395	3,218
<b>Chemicals Production</b>	9,543	6,501	647	692
<b>Metals</b>	128	149	125	145
<b>Other</b>	127	124	83	88
<b>TOTAL</b>	<b>20,758</b>	<b>19,510</b>	<b>3,250</b>	<b>4,143</b>

While hydrogen use in the U.S. decreased overall, the merchant hydrogen market experienced growth from 2003-2006 by 9 percent per year. This was heavily influenced by petroleum refining which increased at 11 percent per year, while hydrogen use for all other uses increased by 2-5 percent per year (see *Table 11* and *Figure 12*).<sup>65</sup>



*Figure 12. U.S. merchant hydrogen<sup>66</sup> consumption by industry*

<sup>64</sup> Suresh, Bala, Stefan Schlag, and Masahiro Yoneyama, *CEH Marketing Research Report Hydrogen* (Menlo Park: SRI Consulting, 2007).

<sup>65</sup> *ibid.*, 63.

<sup>66</sup> The definition of merchant hydrogen varies. See the Definitions and Acronyms section at the beginning of this report for the definition used here.



## 3.3 Energy Use

### 3.3.1 Vehicles

Today, cars and buses use hydrogen across the United States to produce energy to move their wheels and power a number of onboard systems. In 2008, the majority of these vehicles (approximately 90 percent) used onboard compressed gaseous hydrogen<sup>67</sup>, while others used liquid hydrogen. Likewise, the vast majority of vehicles (also approximately 90 percent) used a drive train utilizing an electric motor powered with electricity supplied by a fuel cell. The balance used a drive train utilizing an internal combustion engine (ICE) fueled by hydrogen.

For the purposes of this report, vehicles are classified into light-duty or heavy-duty classes. These are determined by gross vehicle weight as follows:

- **Light-duty vehicle (LDV):** vehicle classes 1-2, or up to 10,000 lbs by gross vehicle weight (GVW), e.g. everything from a small compact car to a large SUV.
- **Heavy-duty vehicle (HDV):** vehicle classes 6-8, or over 19,501 lbs by GVW, e.g. city buses.

Because of the related nature of vehicles and infrastructure, a short chapter on hydrogen fueling stations follows this section.

#### 3.3.1.1 Methodology

The data for the LDV section were collected through primary research with major automotive manufacturers with hydrogen vehicle programs. The data for the HDV section were collected primarily through interviews with bus operators with hydrogen bus demonstration programs. Most car companies and bus operators contacted responded. The content for the section on hydrogen fueling stations comes directly from the National Hydrogen Association's online Hydrogen Fueling Station Database.

*Light-Duty vehicle manufacturers contacted: BMW; Daimler/Mercedes Benz; Ford; General Motors; Honda; Hyundai-Kia; Mazda; Nissan; Toyota; Volkswagen.*

*Bus operators contacted: AC Transit; CT Transit; Hickam Air Force Base; Santa Clara Valley Transportation Authority; SunLine Transit Agency; University of Delaware; University of Texas.*

#### 3.3.1.2 Light-duty Vehicles

By the end of 2008, approximately 210 hydrogen-powered light-duty vehicles were traveling on U.S. roads. Although some of these vehicles entered service partway through the year, together, they drove a total of 1.1 million miles. The vehicles in 2008 included both hydrogen internal combustion engine and hydrogen fuel cell electric system drive trains. They also include vehicles which entered service before 2008 but were still operating throughout 2008. With only 22 ICE vehicles in the 2008 hydrogen fleet, fuel cells powered the vast majority of hydrogen LDVs. Regardless of the drive train, most vehicles were passenger vehicles or crossover SUVs carrying six or fewer passengers.

---

<sup>67</sup> Compression to 5,000 or 10,000 psi was most common.

In 2008, each hydrogen LDV traveled an average of 5,400 miles, or just under half the distance of an average U.S. passenger car, which averaged 12,293 miles in 2007.<sup>68</sup>

As shown in *Table 12*, hydrogen LDVs fueled 11,000 times at hydrogen fueling stations around the U.S., consuming 26,000 kilograms of hydrogen, an average of 2.4 kilograms per fueling. From discussions with automotive manufacturers, this average fueling is lower than initially expected since the typical storage volume onboard a hydrogen vehicle is 4 to 6 kilograms. However, conversations with drivers have revealed a behavioral reason for the low volume per fuel. Automotive manufacturers believe that because the number of fueling stations is relatively low, hydrogen vehicle drivers have a natural tendency to fill up whenever a station is close, instead of filling up when the tank is nearly empty (a more common behavior observed for gasoline vehicle drivers). As a result, independent of storage capability onboard the vehicle, the amount of hydrogen dispensed per fueling is expected to increase as the availability of fueling stations grows.

In 2008, a total of 8,700 drivers got behind the wheel of hydrogen LDVs. They were a mix of ride and drive participants and drivers who had long-term relationships (one to 12 months) with automotive manufacturers as market testers or lease customers.

Fuel economy varied significantly between hydrogen internal combustion engine vehicles and fuel cell vehicles, since the fuel cell drive train is more than twice as efficient. The average fuel economy from the 2008 fuel cell LDV fleet, including all vehicles on the road that year, was 47 miles per kilogram of hydrogen, whereas the hydrogen internal combustion engine LDV fleet showed an average of 19 miles per kilogram. For a comparison, the fuel economy for all U.S. passenger cars, including gasoline and diesel, averaged 22.4 miles per gallon (gasoline) in 2006.<sup>69</sup>

*Table 12. 2008 data for light-duty hydrogen vehicles*<sup>70</sup>

Category	Data	<b>2008 Averages: All Hydrogen LDVs</b> <ul style="list-style-type: none"> <li>• 44 miles/kg average fuel economy for vehicles in operation</li> <li>• 5,400 miles traveled per vehicle</li> <li>• 51 fuelings completed per vehicle</li> <li>• 120 kilograms of hydrogen dispensed per vehicle</li> <li>• 42 drivers drove each vehicle</li> <li>• 130 miles were driven per driver</li> <li>• 2.4 kg/fueling</li> </ul>
Vehicles on the Road	210 vehicles	
Miles Driven	1,100,000 miles	
Hydrogen Used	26,000 kg	
Hydrogen Fuelings	11,000 fuelings	
Drivers	8,700 drivers	
Employees (FTEs, US-only)	800+ employees	

<sup>68</sup> U.S. Department of Transportation, Bureau of Transportation Statistics  
[http://www.bts.gov/publications/national\\_transportation\\_statistics/html/table\\_04\\_11.html](http://www.bts.gov/publications/national_transportation_statistics/html/table_04_11.html).

<sup>69</sup> 2006 is the most recent year available. New passenger cars in 2008 averaged 31.2 mpg. U.S. Department of Transportation, Bureau of Transportation Statistics  
[http://www.bts.gov/publications/national\\_transportation\\_statistics/html/table\\_04\\_23.html](http://www.bts.gov/publications/national_transportation_statistics/html/table_04_23.html).

<sup>70</sup> All reported data in this chapter is rounded to two significant digits to reflect the degree of accuracy of the currently reported information. The numbers on the right reflect averages calculated from the raw data set and may differ from the rounded data in *Tables 11-13*.

**Table 13. 2008 data for light-duty hydrogen fuel cell vehicles**

Category	Data
Vehicles on the Road	190 vehicles
Miles Driven	1,100,000 miles
Hydrogen Used	23,000 kg
Hydrogen Fuelings	9,800 fuelings
Drivers	8,200 drivers
Employees (FTEs, US-only)	800+ employees

**Table 14. 2008 data for light-duty hydrogen engine vehicle**

Category	Data
Vehicles on the Road	22 vehicles
Miles Driven	48,000 miles
Hydrogen Used	2,500 kg
Hydrogen Fuelings	750 fuelings
Drivers	500 drivers
Employees (FTEs, US-only)	14 employees

#### **2008 Averages:**

##### **Hydrogen Fuel Cell Vehicles Only:**

- 47 miles/kg average fuel economy for vehicles in operation
- 5,700 miles traveled per vehicle
- 53 fuelings completed per vehicle
- 120 kilograms of hydrogen dispensed per vehicle
- 44 drivers drove each vehicle
- 130 miles were driven per driver
- 2.3 kg/fueling

#### **2008 Averages:**

##### **Hydrogen Engine Vehicles Only:**

- 19 miles/kg average fuel economy for vehicles in operation
- 2,200 miles traveled per vehicle
- 34 fuelings completed per vehicle
- 110 kilograms of hydrogen dispensed per vehicle
- 23 drivers drove each vehicle
- 97 miles were driven per driver
- 3.4 kg/fueling

### **3.3.1.3 Heavy-duty Vehicles**

Twelve hydrogen-powered buses were operational in 2008, representing the entire heavy-duty hydrogen vehicle fleet. Buses using hydrogen and compressed natural gas blends or any heavy-duty vehicles using aftermarket hydrogen injection systems were not included in this section.

As shown in *Table 15*, the 12 hydrogen buses operating in 2008 consumed 28,740 kg of hydrogen fuel, traveling 176,000 miles and transporting about 366,000 passengers. The vast majority of these buses were hydrogen fuel cell and battery hybrids, but some buses had hydrogen internal combustion engine drive trains.

While there were 20 light-duty vehicles for every bus on the road in 2008, total hydrogen consumption was similar (see *Figure 16*), illustrating a compelling justification for the parallel introduction of bus and early light-duty vehicle fleets: more demand for hydrogen leads to the expansion of hydrogen fueling infrastructure. Although limited in number compared to light-duty vehicles, the majority of buses in 2008 operated in regular revenue service. Transit agencies relied on their hydrogen buses just as they would their more familiar diesel or natural gas buses, while riders benefited from a quieter, less polluting ride.

The average fuel economy for hydrogen buses in 2008 was 6.1 miles/kg (6.9 diesel equivalent miles per gallon). There is a fair amount of deviation in any average presented in this section due to the variety of bus designs, sizes, and duty cycles. However, several hydrogen bus operators have documented between 45-75 percent higher fuel efficiency from hydrogen fuel cell hybrid buses compared to their own average, baseline diesel fleet vehicles in comparable usage patterns and greater than 200 percent in comparison to compressed natural gas (CNG) buses.<sup>71</sup> A comparable baseline for the diesel or CNG bus market was not available.

Starting in 2008, the hydrogen bus sector is on pace to show significant growth in next two to three years. The number of buses on U.S. roads will more than double by the end of 2010 with the addition of more than 20 hydrogen buses going into service.<sup>72</sup>

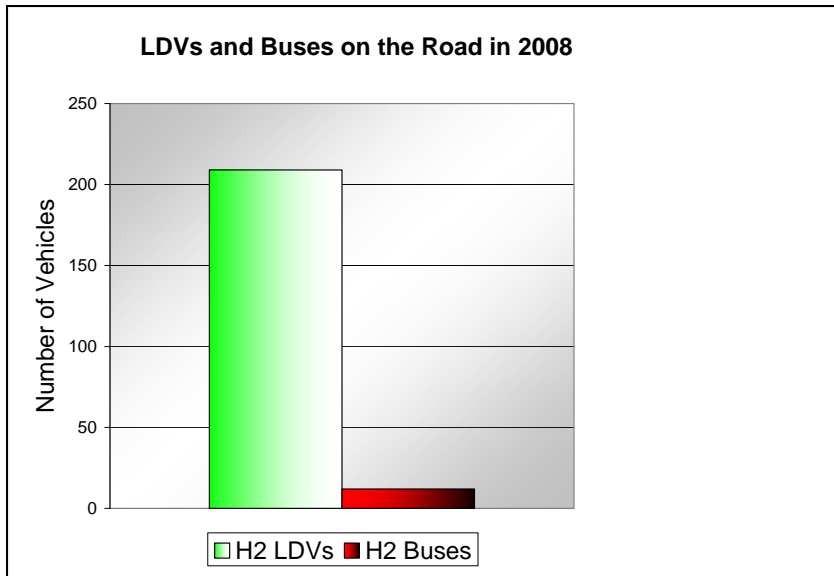
In addition to buses, pre-commercial work on other hydrogen heavy-duty transportation applications is occurring on vehicles like class 8 trucks and rail locomotives. Very small numbers are expected to be entering the demonstration stage in 2009 and 2010.

**Table 15. 2008 heavy-duty hydrogen buses**

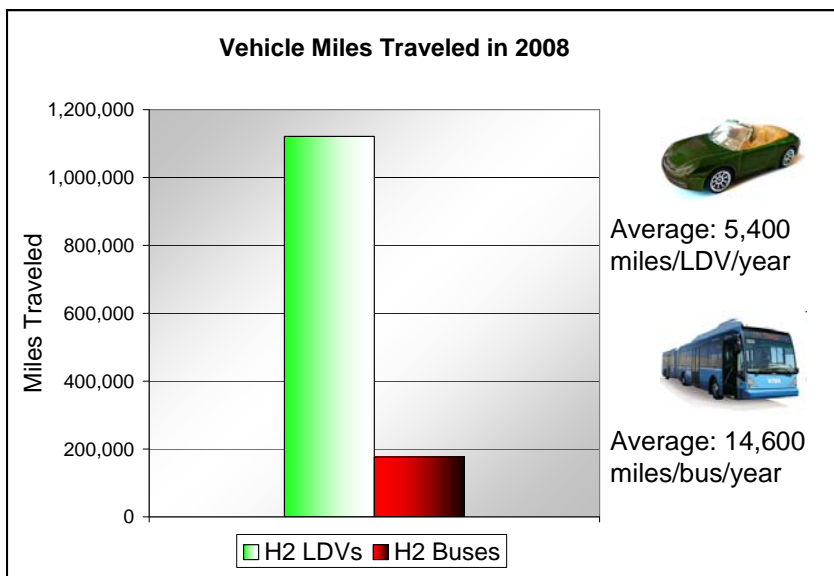
Categories	Data
Total number of vehicles	12 vehicles
Miles driven	176,000 miles
Hydrogen consumed	28,740 kg
Hydrogen fuelings	1,670 fuelings
Passengers	366,000 passengers
Full time equivalent employees directly employed to operate buses in 2008	30 employees
Average hydrogen fuel economy in 2008	6.1 miles/kg (6.9 diesel equivalent miles per gallon)

<sup>71</sup> National Renewable Energy Laboratory, *Hydrogen and Fuel Cell Research Presentations and Publications by Demonstration Site*. [http://www.nrel.gov/hydrogen/proj\\_fc\\_bus\\_eval\\_sites.html](http://www.nrel.gov/hydrogen/proj_fc_bus_eval_sites.html).

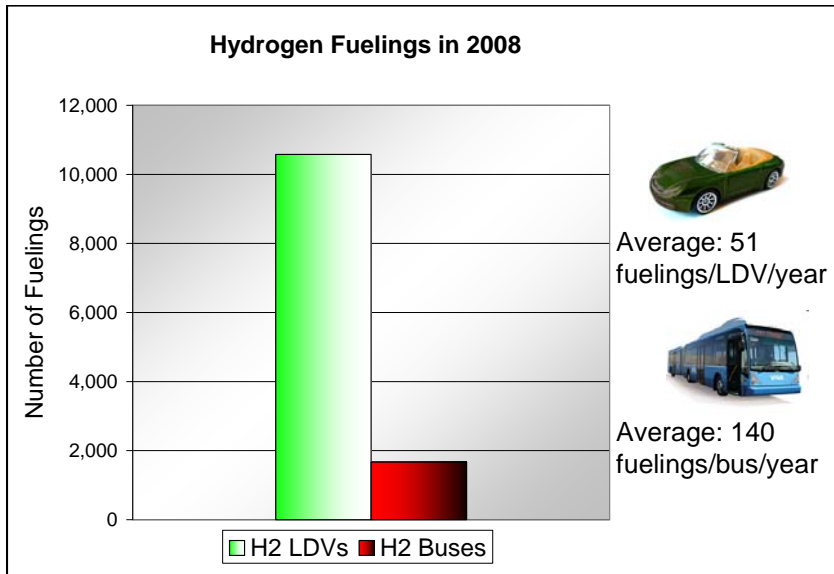
<sup>72</sup> Eudy, Leslie, Kevin Chandler and Christina Gikakis, *Fuel Cell Buses in U.S. Transit Fleets: Current Status 2009* (Golden, National Renewable Energy Laboratory, 2009), <http://www.nrel.gov/hydrogen/pdfs/46490.pdf>.



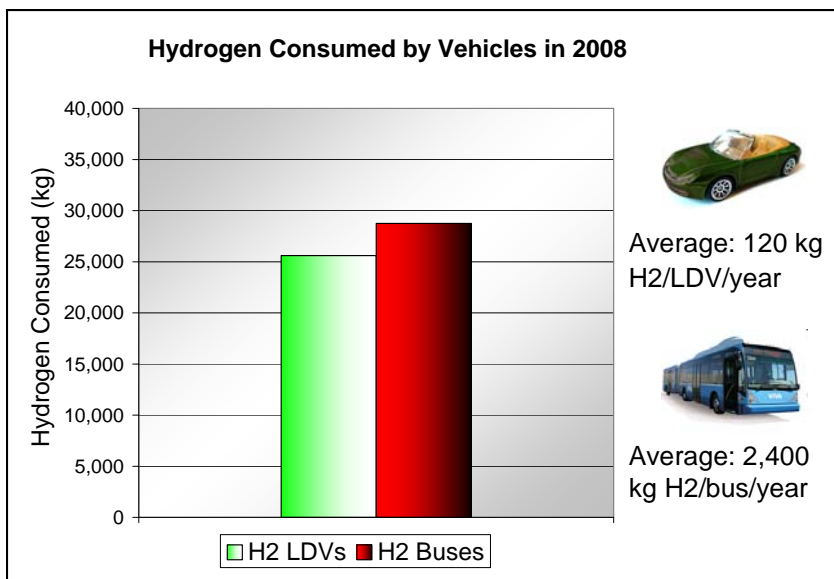
**Figure 13. Light-duty hydrogen vehicles and buses on U.S. roads**



**Figure 14. 2008 Hydrogen vehicle miles traveled on U.S. roads**



**Figure 15. 2008 Hydrogen vehicle fuelings in the U.S.**



**Figure 16. 2008 Hydrogen consumption by vehicles on U.S. roads**

### 3.3.1.4 Hydrogen Fueling Stations

The National Hydrogen Association keeps an online database of fueling stations in North America.<sup>73</sup> By the end of 2008, there were 61 operational public and private hydrogen fueling stations in the U.S. (76, including Canadian stations). The database also tracks stations planned to open in the next 12-18 months.

Information on station capacity, feedstocks, whether hydrogen is delivered or produced onsite and other details, is on the NHA's Hydrogen Fueling Station Database at the link in the footnote.



Figure 17. Operational hydrogen fueling stations in North America (as of 31 October 2009)

Figure 18 uses information about when stations entered service to display the number of new stations that have opened each year, dating back to 1993. The chart also includes a curve showing the cumulative number of hydrogen fueling stations. However, the cumulative curve excludes decommissioned stations while the other curve does not (due to available data). As a result, since the decommissioned stations have been removed from the cumulative curve, some earlier years show fewer stations than actually existed. However, the current total and general growth overall is accurate.

#### New Stations Opened in 2008:

- Center for Hydrogen Research Mobile Fueler (SC)
- Humboldt State University's Schatz Energy Research Center (CA)
- Missouri University of Science and Technology Hydrogen Station (MO)
- Nuvera PowerTap Hydrogen Generation and Dispensing System (MA)
- Sacramento Municipal Utility District (SMUD) Solar Fueling Station (CA)
- West Los Angeles Shell Station (CA)

<sup>73</sup> For more information, see the National Hydrogen Association's Hydrogen Fueling Station Database <http://www.hydrogenassociation.org/general/fuelingSearch.asp>.

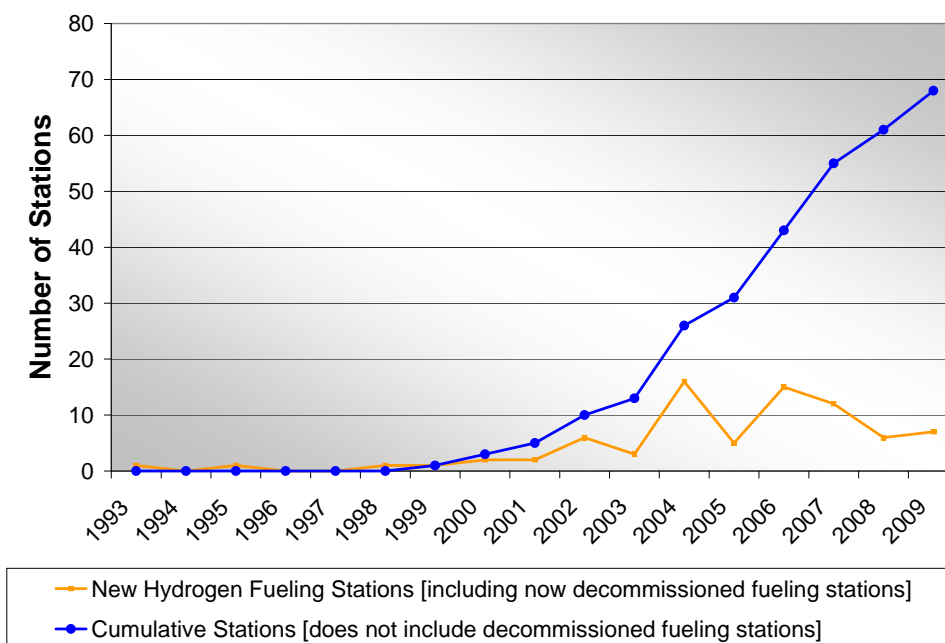


Figure 18. New and cumulative hydrogen fueling stations (as of October 2009)

### 3.3.2 Material Handling Vehicles

#### 3.3.2.1 Overview

Forklifts and other material handling vehicles are used to transport loads in warehouses, manufacturing facilities, and in other commercial and industrial locations. An emerging market exists for the replacement of traditional lead-acid battery and fossil-fueled forklifts with hydrogen fuel cell-powered alternatives. The market opportunity for replacement is quite large: in 2007 alone, 235,000 battery or fossil fuel-powered lift trucks were ordered for shipment to customers in the U.S.<sup>74</sup>

Forklifts are categorized by one of seven vehicle classes. Vehicles included in this report are Class I, II, or III forklifts, which are typically powered by battery electric systems. Class IV-VII forklifts are typically powered by fossil fuels and have not yet seen significant displacement by hydrogen fuel cells because they are often used in outdoor areas that do not require the emission-free benefits that hydrogen fuel cell and battery forklifts offer.<sup>75</sup> This report only includes vehicles in the U.S. market.

#### 3.3.2.2 Methodology

The data for this section were collected through secondary research and discussions with fuel cell manufacturers, system integrators, truck manufacturers, and customers. The

<sup>74</sup> Kator, Corinne, "Top 20 Lift Truck Suppliers" *Modern Materials Handling Magazine*. (August 1, 2008), <http://www.mmh.com/article/CA6583192.html>.

<sup>75</sup> Gaines, J.L., A. Elgowainy, and M.Q. Wang, *Full Fuel-Cycle Comparison of Forklift Propulsion Systems*. Oak Ridge, Argonne National Laboratory, Center for Transportation Research, 2008. <http://www.transportation.anl.gov/pdfs/TA/537.pdf>.



data collected include information on vehicles in operation in 2007, 2008, and 2009<sup>76</sup>, with additional data on planned vehicles through 2010.

*Contacted Organizations: Defense Logistics Agency (DOD), GENCO, Fuel Cells 2000, Hydrogenics Corporation, LiftOne, National Renewable Energy Laboratory, Nuvera Fuel Cells, Plug Power, Raymond Corporation.*

### 3.3.2.3 Findings

There were 200 hydrogen fuel cell-powered forklifts in operation in the United States by the end of 2008. These forklifts consumed at least 20,000 kg of hydrogen and were in operation at 16 sites in nine states.

In October 2009, there were 450 hydrogen fuel cell-powered forklifts in operation in the United States. These preliminary numbers for 2009, in addition to the known planned projects in 2010, show a market that is continuing to grow rapidly. The market has doubled each of the past two years and is projected to double again by the end of 2010. Vehicles are currently in operation or planned for operation at 33 sites in 16 states.

Much of the expected near-term growth is due to government support through the American Recovery and Reinvestment Act of 2009 (ARRA). In April 2009, the U.S. Department of Energy announced \$9.7 million in ARRA funding for materials handling vehicles powered by fuel cells. These awards will support the replacement of at least 360 battery-powered forklifts with those powered by hydrogen fuel cells at nine different sites.<sup>77</sup>

<b>Hydrogen Fuel Cell-Powered Material Handling Vehicles (U.S.)</b>	
<b>Total Installed Vehicle Base 2007:</b>	70 vehicles
<b>Total Installed Vehicle Base 2008:</b>	200 vehicles (186% annual market growth)
<b>Total Installed Vehicle Base 2009*:</b>	450 vehicles (125% annual market growth)
<b>2010 Projections:</b>	980 vehicles (117% annual market growth)

\* as of October 2009

**Figure 19. Total U.S. hydrogen materials handling vehicles in operation (2007-2009) and vehicles planned for operation**

<sup>76</sup> Data collected through October 2009.

<sup>77</sup> The U.S. Department of Energy FY 2009 Financial Awards news release includes the replacement of 304 battery-powered forklifts with hydrogen fuel-cell powered versions. Industry sources claim an additional 56 forklifts as a part of the GENCO award. Sources: U.S. Department of Energy, hydrogen and fuel cell program: FY 2009 Financial Awards. [http://www1.eere.energy.gov/hydrogenandfuelcells/2009\\_financial\\_awards.html](http://www1.eere.energy.gov/hydrogenandfuelcells/2009_financial_awards.html); *Progressive Grocer*, August 2009, <http://bit.ly/9mKpnH>; Albany Business Review, August 2009, <http://albany.bizjournals.com/albany/stories/2009/08/24/daily43.html>; industry interviews.

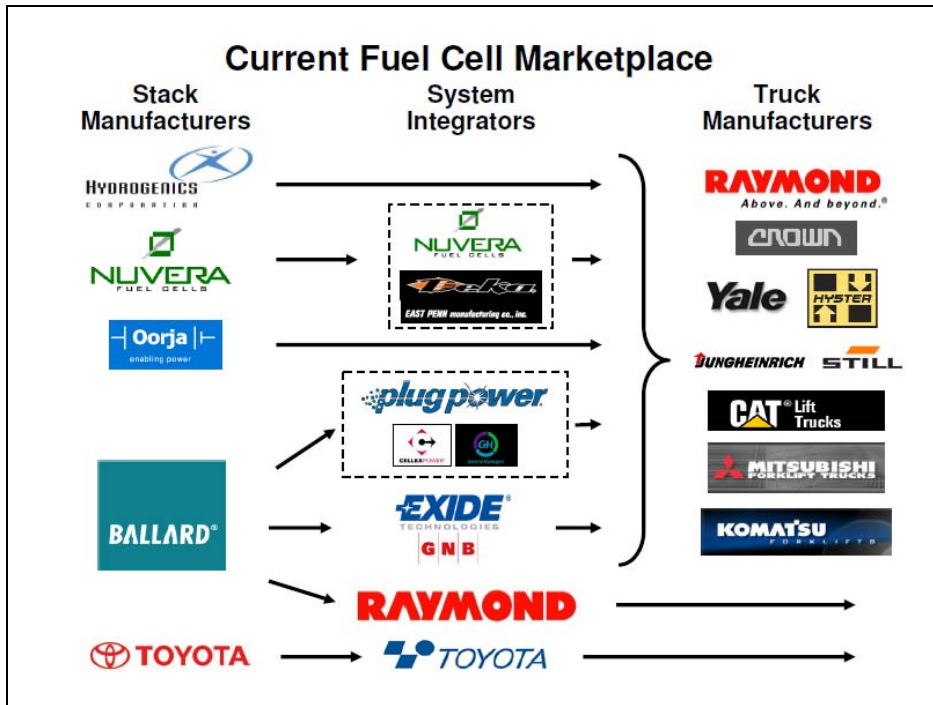


Figure 20. Key companies involved in the fuel cells for materials handling applications market, 2008. Includes non-PEM fuel cell manufacturers <sup>78</sup>

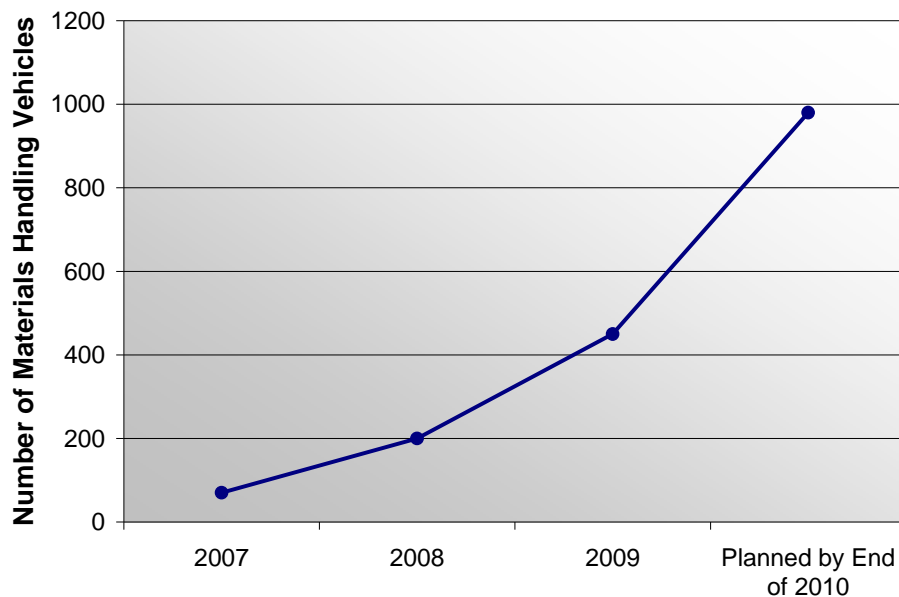
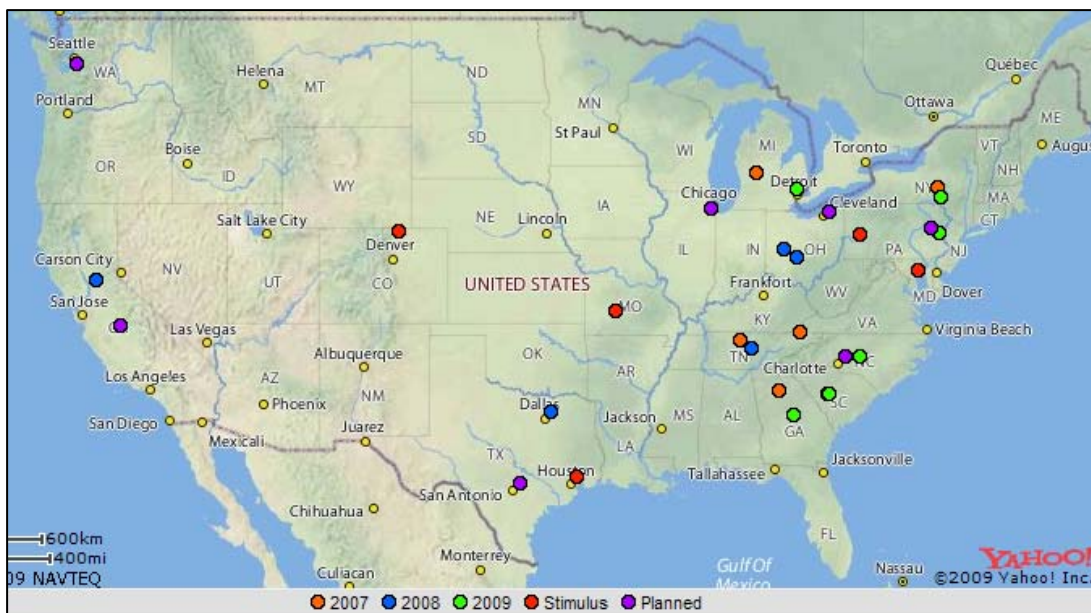


Figure 20. Total U.S. hydrogen materials handling vehicles in operation (2007-2009) and vehicles planned for operation

<sup>78</sup> Courtesy of Steve Medwin, Raymond Corporation



**Figure 21. Map of U.S. hydrogen materials handling vehicles in operation (2007-2009) and vehicles planned for operation**

### 3.3.3 Stationary Power<sup>79</sup>

#### 3.3.3.1 Overview

While the entire market for hydrogen in energy applications is still in early stages of development, stationary power applications using hydrogen have advanced and reached market penetration status. Hydrogen fuel cells can deliver power reliably when needed; can be installed grid-independent; and have storage systems that do not lose energy when not in use. These advantages have been recognized by industry.

#### 3.3.3.2 Methodology

For this section, PEM fuel cell manufacturers and system integrators, identified through secondary research, NHA and USFCC catalogues, were approached directly to provide information on their sector of the hydrogen industry. These interviews were conducted via email and telephone.

*Contacted Companies: Alteryx; Ballard; ClearEdge; Hydrogenics; Idatech; Infinity; Intelligent Energy; Plug Power; ReliOn.*

#### 3.3.2.3 Findings

In the United States, at least 13,000 kW of PEM fuel cells for stationary appliances were operational in 2008.<sup>80</sup> Responses from industry suggest that at least 10 megawatts (MW) of PEM fuel cells for backup power were in operation in 2008 in the U.S. Only a handful

<sup>79</sup> This report did not focus on the portable power market.

<sup>80</sup> This number reflects only U.S. manufactured PEM fuel cells. The total number of PEM fuel cells would include PEM fuel cells from foreign manufacturers and cannot be estimated at this point. The number of PEM fuel cells manufactured in the U.S. is much higher, since the share of exported PEM fuel cells of the total production reach 50 percent at some companies.

of sites exist in which hydrogen provides primary power, totaling 300 kW. Auxiliary power appliances are more numerous, providing 2,761 kW.<sup>81</sup>

The range of hydrogen efficiency varies considerably, by technology and the size of the installation. The average industry efficiency is approximately 41 percent (73 g/kWh), with a range of  $\pm 16$  percent, encompassing the entire spectrum of available products.

Backup power systems in the U.S. run very rarely, with one company estimating an average annual runtime of ten hours. Therefore, the yearly hydrogen consumption for these systems is very low, at approximately 7,350 kg. A general run time for other systems cannot be given, as the type of usage is the determining variable for run time.

*Table 16. Stationary PEM fuel cells installed in the U.S. by December 2008*

<b>Total number of kW of fuel cells operational in 2008</b>		13,092 kW
<b>Hydrogen consumed per kWh if running at maximum load</b>		73 g/kWh
<b>Production capacity of fuel cells for</b>	<b>Primary power</b>	300 kW
	<b>Auxiliary power</b>	2,761 kW
	<b>Back-up power</b>	10,072 kW
<b>FTE employees</b>		812

## 4. EDUCATION & JOBS

### 4.1 Education

#### 4.1.1 Overview

Educational institutions and the population of students in degree-producing curricula represent an important aspect of an emerging industry. Highly educated personnel are required for technology innovation. The trend in student numbers and graduates of any specialization indicate to what degree young people believe in future employment opportunities in this field. This section provides an overview of available hydrogen and fuel cell-related courses, as well as available degree programs. The degree programs exemplify the trend of students committed to working towards a future in which hydrogen and fuel cells play an important role.

#### 4.1.2 Methodology

Research for this section was conducted through secondary research of available reports and primary research with university departments. Fuel Cells 2000<sup>82</sup> and the DOE's

<sup>81</sup> A primary power source is an electrical power source that supplies the main power for a given load. A backup power source is a power source that can provide adequate power to operate critically important equipment until primary power is restored. An auxiliary power source is a power source that provides a supplemental source of electrical power, often in conjunction with a primary power source. For example, some hydrogen fuel cells are being used as auxiliary power units on heavy-duty vehicles to run refrigeration or provide heat while reducing diesel fuel consumption and overall emissions.

<sup>82</sup> Fuel Cells 2000, Career and Education Center. <http://www.fuelcells.org/ced/career/university.htm>.

Office of Energy Efficiency and Renewable Energy's hydrogen and fuel cell program<sup>83</sup> have extensive databases on educational programs, including university courses. Additional information was gathered on degree programs by contacting Registrar offices and Heads of Departments.

### 4.1.3 Findings

More than 130 institutions<sup>84</sup> of higher education<sup>85</sup> offer courses in fuel cell or hydrogen technology, in 40 states and the District of Columbia. California and New York are front-runners, with 16 and 14 institutions, respectively.

*Table 17. Institutions per state that offering hydrogen- and fuel cell-related courses*

Number of Institutions	16	14	8	7	4	3	2	1
State	CA	NY	OH	FL	KS	AZ	AL	DC
				MA	NC	IL	CO	GA
				MI	PA	NM	CT	IA
				TX	TN		DE	IN
							HI	KY
							LA	MD
							MN	MO
							MT	MS
							NJ	ND
							NV	RI
							SC	UT
							VA	WA
								WI
								WV
								WY

The number of degree programs has steadily increased from 2006 to 2009; in 2009, nine institutions offered hydrogen or fuel cell technology degrees.<sup>86</sup>

*Table 18. Overview of hydrogen and fuel cell degree programs (as of 2009)*

Institution	Location	Degrees	Start Date
Kettering University	Flint, MI	Mechanical Engineering Degree Program with a Fuel Cell Minor	Fall 2004
Kettering University	Flint, MI	Electrical Engineering Representative Degree Program with a Fuel Cell Minor	Fall 2004
Wayne State University	Detroit, MI	Bachelor of Science Degree with an Alternative Energy Technology Concentration (strong FC focus)	Fall 2004
Wayne State University	Detroit, MI	Alternative Energy Technology Graduate Certificate Program (strong FC focus)	Fall 2004

<sup>83</sup> U.S. Department of Energy, hydrogen and fuel cell program, [http://www1.eere.energy.gov/hydrogenandfuelcells/education/related\\_prog.html](http://www1.eere.energy.gov/hydrogenandfuelcells/education/related_prog.html).

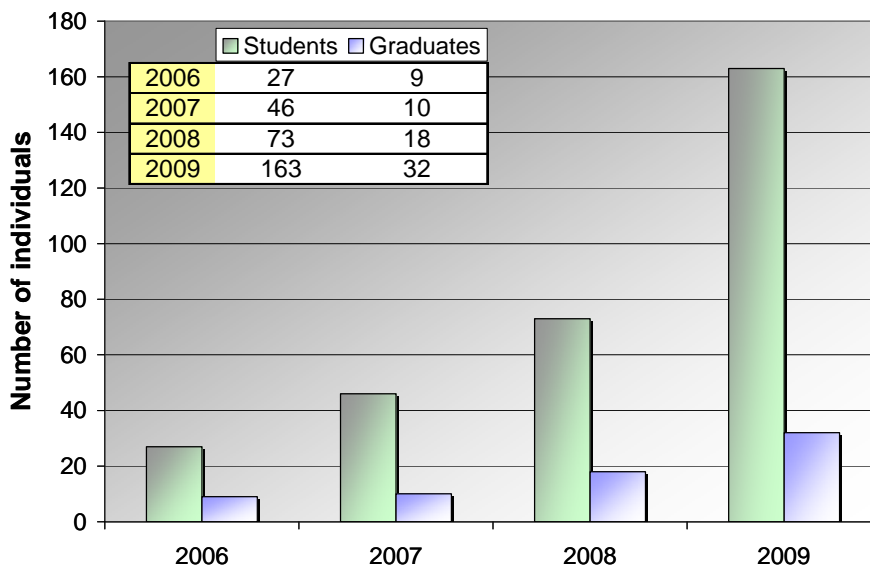
<sup>84</sup> This does not include fuel cell laboratories and other experimental institutions.

<sup>85</sup> Information on Community Colleges was not available and is excluded in this total.

<sup>86</sup> These degree programs are heavily focused on fuel cell and hydrogen technology. Other universities may offer degrees which emphasize hydrogen and fuel cell technology but, with the exception of Wayne State University, are not included in this year's overview because they did not have "hydrogen" or "fuel cell" in their title.

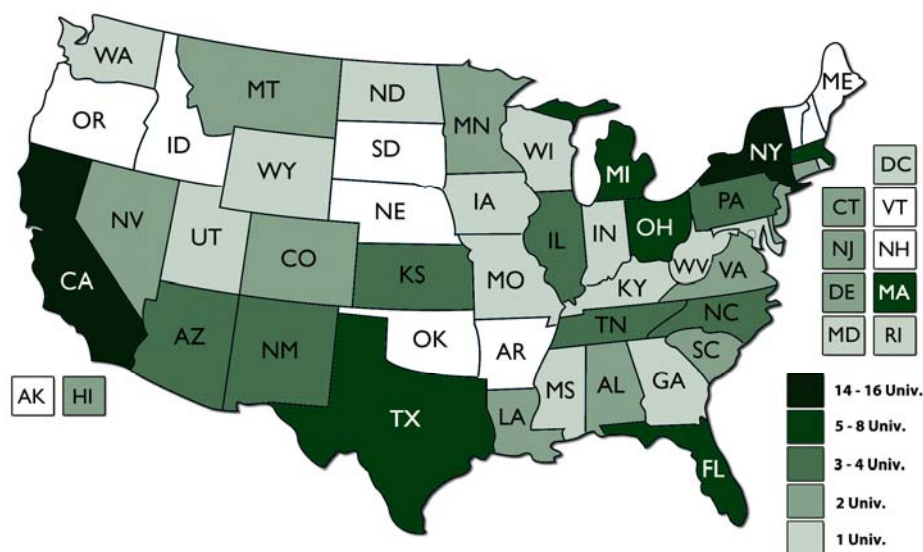
Institution	Location	Degrees	Start Date
Wayne State University	Detroit, MI	Alternative Energy Technology Master of Science Degree Program (strong FC focus)	Fall 2004
Texas State Technical College, Waco	Waco, TX	A.A.S. Degree in Fuel Cell Technology	Fall 2005
Rensselaer Polytechnic Institute	Troy, NY	Fuel Cell Integrative Graduate Education and Research Traineeship Program - Ph.D. Program	Fall 2005
Hocking Technical College	Logan, OH	A.A.S. Degree in Alternative Energy and Fuel Cells	Fall 2008
Hocking Technical College	Logan, OH	A.A.S. Degree in Automotive Hybrids and Fuel Cells	Fall 2008
Michigan Technological University	Houghton, MI	Interdisciplinary Minor in Hydrogen Technology	Fall 2009
Houston Community College, Northeast	Houston, TX	A.A.S. Degree in Instrumentation and Controls Engineering Technology with Certificate in Fuel Cell Specialization	Fall 2009
Naugatuck Valley Community College	Naugatuck, CT	Fuel Cell Technology Certificate program	?
Stark State College of Technology	North Canton, OH	A.A.S. Degree in Mechanical Engineering Technology - Ohio Board of Regents Fuel Cell Certificate	?
Stark State College of Technology	North Canton, OH	A.A.S. Degree in Mechanical Engineering Technology - Certificate of Competency	?
Stark State College of Technology	North Canton, OH	A.A.S. Degree in Engineering Technology - Fuel Cell Technology	?

In the same time period, the number of students enrolled in the specialized degree programs increased from 27 in 2006 to 163 in 2009, an annual increase of 82 percent. In 2006, only nine students graduated; this number more than tripled to 32 graduates in 2009, signifying an annual increase of 53 percent.



**Figure 22. Development of students and graduates in hydrogen and fuel cell related degrees**





*Figure 23. Educational institutions offering courses in hydrogen/fuel cell-technology (excluding community colleges)*

## 4.2 Jobs

### 4.2.1 Overview

Data on U.S. hydrogen-related employment figures in full-time equivalents (FTEs) are provided throughout this report. This section compiles and discusses these figures.

### 4.2.2 Methodology

These data were collected through direct correspondence and primary research with merchant hydrogen producers; automotive manufacturers with hydrogen vehicle programs; companies that manufacture reformers and electrolyzers; companies that manufacture PEM fuel cells for stationary and materials handling applications; and universities active in conducting hydrogen and fuel cell research. Most organizations responded, and any necessary projections were made based on research, collected data, and TTC's market knowledge and interviewing.

*Organizations contacted: all NHA members.*

### 4.2.3 Findings

As provided earlier in this report, U.S. hydrogen-related employment figures total 2,300 in merchant hydrogen production: 527 in the electrolyzer and reformer industries and 800 from the automobile industry. In addition, through the data collection and analysis performed for this report, we have identified approximately 850 U.S. FTE employees located in the stationary and material handling sector and 2,300 FTEs (including research and teaching positions) in the 130 U.S. universities and colleges offering courses in hydrogen and fuel cell technologies.

*Table 19. U.S. jobs in select sectors of the hydrogen industry*

<b>U.S. Jobs in select sectors of the hydrogen industry</b>	
Merchant Hydrogen Production	2,300
Electrolyzer and Reformer Manufacturers	527
Automobile Industry	800
Stationary and Material Handling Fuel Cell Manufacturing <sup>87</sup>	850
University (research and teaching)	2,300
<b>Total Jobs Related to H<sub>2</sub> in the Categories Included in Report</b>	<b>6,777</b>

As shown in *Table 19*, these jobs total nearly 7,000 U.S. FTE employees. It is important to note, however, this figure only covers the sectors of the hydrogen industry covered in this report; the number is in no way representative of the number of people employed in the entire U.S. hydrogen industry in 2008 as many significant categories are excluded from the scope of this report (such as various components manufacturers, hydrogen-related consultancy services, etc.). Also note that this report only includes PEM fuel cells for stationary and material handling applications, since they use hydrogen as their primary fuel; many jobs support non-PEM sectors of the fuel cell industry. And finally, these employment figures do not include portable, military, or other transportation fuel cell applications.

Many hydrogen technologies are pre-commercial and are just beginning to enter the marketplace. Through the research, analysis, and data gathering for this report, it is reasonable to expect growth in the majority of market segments investigated. Projecting future growth is complex and outside the scope of this report. However, some research on the effect of a transition to a hydrogen economy on overall U.S. employment was performed by the Department of Energy in 2008.<sup>88</sup> As noted in *Table 20*, transitioning to a hydrogen economy is projected to yield a net increase in U.S. employment.

*Table 20. U.S. employment projections from 2020-2050*

<b>U.S. Employment projections from 2020-2050<sup>89</sup></b>	
<b>Year</b>	<b>Net Employment Increase in U.S.</b>
2020	58,010 - 182,840
2050	360,740 - 674,500

## 5. LOOKING AHEAD

This report is intended to create a baseline for information about many parts of the hydrogen and fuel cell industry to which future years can be compared. For 2009, the

<sup>87</sup> Includes PEM fuels for stationary and materials handling applications only; does not include portable, military, or other transportation applications.

<sup>88</sup> "Effects of a Transition to a Hydrogen Economy on Employment in the United States: Report to Congress," July 2008, U.S. Department of Energy, [http://www.hydrogen.energy.gov/pdfs/epact1820\\_employment\\_study.pdf](http://www.hydrogen.energy.gov/pdfs/epact1820_employment_study.pdf).

<sup>89</sup> *ibid.*



authors hope to cover the same topics and expand the data collection into a few new areas that were not able to be covered within the scope of this report on 2008 data.

## **5.1 Overview**

During data collection, the authors uncovered a few pieces of valuable information that were collected while doing the research for this report, but fell outside its scope which focuses on 2008 data. Instead of withholding this information for the next report, it is shared here to give the reader an idea of what might lie ahead for the industry. These sections suggest that certain sectors of the hydrogen economy will see significant growth in the next one to two-year timeframe.

## **5.2 Distributed Hydrogen**

Emerging technology to co-produce hydrogen from high temperature fuel cells has been proven in commercial scale equipment. A full demonstration of this technology using renewable fuel is planned for 2010 to produce more than 100 kg/day of hydrogen and 250 kW of power. In this system, methane reforming is done within the fuel cell and excess hydrogen is separated and exported from the fuel cell. This system will produce distributed hydrogen efficiently and with essentially none of the emissions normally associated with reforming, except carbon dioxide. It is suitable for the direct use of low purity biomethane fuel such as anaerobic digester gas. This system is often referred to as CHP, a combined heat and power generation unit.

## **5.3 Renewable Hydrogen Projects**

- In 2009, four additional anaerobic digester gas to hydrogen projects were finished or under construction in California, adding approximately 700 kg/hr of hydrogen production capacity and almost doubling the current capacity from wastewater treatment.
- At least two new solar hydrogen projects became operational in 2009, including a small commercial project in Florida.
- One experimental microbial fuel cell demonstration project began operation in Napa Valley, CA with the expected production rate of 29.5 kg/hr.
- The first steps for renewable hydrogen production were taken in Hawaii as part of a “Renewable Hydrogen Program” during fall, 2009.

## **5.4 Hydrogen Fueling Stations**

New Stations opened in 2009:

- Point Lookout Hydrogen Station (NY)
- Yeager Airport Hydrogen Station (WV)
- Shell Hydrogen Station at JFK Airport (NY)
- Sage Valley Hydrogen Fueling Station (SC)
- Columbia Hydrogen Fueling Station (SC)
- NREL Renewable Hydrogen Station (CO)
- Proterra Mobile Hydrogen Refueler (CO)
- Shell Hydrogen Bronx Fueling Station (NY)

## **5.5 Heavy-Duty Vehicles**

More than 20 new hydrogen buses will be placed in service in 2009 and 2010. Twelve were operational in 2008.

## **5.6 Material Handling Vehicles**

Data collected in 2009 suggest there will be considerable growth in this sector from 2008 to 2009. Much of this growth will be due to the American Recovery and Reinvestment Act (ARRA) of 2009, also popularly known as the stimulus package. ARRA resources have already funded several material handling projects, recognizing that hydrogen fuel cells in material handling applications can be cost-effective and represent a growth market with the potential to create jobs and revenue for American companies.

## **5.7 Stationary Power**

A 1 MW PEM fuel cell for stationary power will be tested in 2010 to provide peak load support at approximately 50 percent efficiency. Substantial growth in PEM based peak power generation is expected as these systems are ideal for handling load variation with their quick response and high efficiency operating at less than 100 percent capacity—circumstances when other technologies would be operating sub-optimally. This capability can be used efficiently to stabilize the power generated by wind and solar, maximizing the net renewable power provided to the grid.