Connecticut Hydrogen and Fuel Cell Deployment Transportation Strategy

2011-2050

January 2011

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Foreword

As oil and other non-sustainable hydrocarbon energy resources become scarce, energy prices will increase and the reliability of supply will be reduced. The current economy in the United State is very dependent on hydrocarbon energy sources and any disruption or shortage of this energy supply will severely affect many energy related activities, including transportation. Governments are now investigating the use of hydrogen and renewable energy as a replacement of hydrocarbon fuels to reduce price volatility, improve reliability, and reduce greenhouse gas emissions.

Connecticut is in a unique position to help address this problem as it is a world leader in research, design and manufacture of hydrogen fuel cell related technology. Through Public Act 09-186, Connecticut has provided legislative guidance to apply its knowledge and expertise in this field towards a transportation plan that will address refueling concerns as well as hydrogen powered vehicles with a main focus on mass transportation.

In accordance with Public Act 09-186, Section 8, the Connecticut Department of Transportation (ConnDOT) and the Connecticut Center for Advanced Technology, Inc. (CCAT) are pleased to submit to the joint standing committees of the General Assembly the following strategic plan titled: Connecticut Hydrogen and Fuel Cell Deployment Transportation Strategy: 2011-2050.

Public Act 09-186, Section 8 states:

> *"The Department of Transportation shall consult with the Connecticut Center for Advanced Technology, Inc. to develop a plan to implement zero-emissions buses state-wide. Such plan shall include the technological, facility and financial arrangements needed for such a conversion of bus fleets as well as identifying specific locations for hydrogen refueling stations along state highways or at locations that could potentially be utilized by state fleets or other public or private-sector fleets. This shall be part of a larger collaborative effort between the Department of Transportation and the Connecticut Center for Advanced Technology, Inc. to identify strategies to expand the availability and use of hydrogen fuel and renewable energy sources within any such corridor or around such a centralized fleet fueling location. Said plan shall be completed within available appropriated funds designated for the purpose of studying or designing clean fuel or alternative fuel solutions."*

This strategic Plan provides information and direction for the deployment of hydrogen and fuel cell technology to support transportation in the state of Connecticut. As such, this strategic plan is a both a resource and a dynamic document that should reflect the ability to change as opportunities arise.

Executive Summary

Connecticut industrial corporations have been the leaders and innovators of fuel cell and electrolysis technologies since the 1950s, and pioneered applications for spacecraft, submarines, and stationary power. Beginning in the 1990s, Connecticut companies have participated in applying fuel cell and hydrogen generation technology to transportation applications, which is a major component of the economy. The attributes of fuel cell vehicles and the advances in hydrogen production suggest a growing market and opportunity for improvement in transportation systems, economic development, and improved environmental performance.

Markets

Fuel cell vehicles, like electric vehicles, are propelled by electric motors utilizing the fuel cell to create its own electricity using hydrogen fuel and oxygen from the ambient air. Today, fuel cells successfully power cars, trucks, buses and other service vehicles like forklifts. Compared to conventional vehicles, hydrogen-fueled vehicles with fuel cell power plants have many advantages, including:

- high efficiency;
- no emissions of controlled pollutants such as nitrous oxide, carbon monoxide, hydrocarbon gases or particulates from the vehicles themselves;
- no emissions of greenhouse gases (GHG) from the vehicles themselves;
- substantial reduction in GHG emissions on a "well-to-wheel" basis;
- fewer parts resulting in lower maintenance;
- ability to fuel vehicles with indigenous energy sources;
- greater range than all-electric or battery powered vehicles; and
- quiet operation.

Further, as the demand for conventional transportation fuels begins to exceed supply, price volatility will increase, and supply will become less certain. Consequently, there will be an increasingly critical need to begin the process to transition from fossil fuels, which are limited and primarily supplied through the import of foreign oil, to domestically produced energy sources such as hydrogen.

Near term projections developed from this Plan suggest that Connecticut may realize the deployment of between 6 and 20 hydrogen fuel cell buses and 40 passenger vehicles by 2015.With the delivery of an additional fuel cell bus planned for operation in 2011, CTTransit will operate a total of six hydrogen fuel cell buses in Connecticut. Assuming fuel cell buses utilize 25 kg of hydrogen per day and passenger vehicles utilize 1 kg of hydrogen per day, a total of between 190 kg and 540 kg of hydrogen would be needed each day. The total production capacity for the existing and planned hydrogen refueling stations that will be operational by 2011 could provide enough hydrogen fuel to satisfy the refueling requirements for the lower range of vehicles; however, approximately 200 kg of additional hydrogen production, storage, and refueling capacity would be needed to meet the maximum projected demand by 2015.

Longer term, the U.S. Department of Energy has projected that between 15.1 million and 23.9 million light duty fuel cell vehicles will be sold each year by 2050 and between 144 million and 347 million light duty fuel cell vehicles will be in use by 2050 with a transition to a hydrogen economy. These government estimates could be accelerated if political, economic, energy security or environmental polices prompt a rapid advancement in alternative fuels.

In order to meet the projected hydrogen demand for fuel cell vehicles in the United States, the quantity of hydrogen dispensed per day would need to grow from 3,023 kg in 2010 to over 300 million kg by 2050. The average price per gallon equivalent (gasoline) for hydrogen dispensed is assumed to cost $4.67 in 2010 and $3.58 in 2050. However, because of the high efficiency of fuel cells, the price of fuel per mile traveled is much lower for hydrogen than for conventional fuels such as gasoline or diesel.

Economic Development

Economic indices, developed in conjunction with the Connecticut Department of Economic and Community Development, suggest that the hydrogen and fuel cell industry is an emerging economic cluster. Since the 1960s, Connecticut companies pioneered the development of fuel cell technology for stationary power applications and continue to lead the world in this fuel cell application. The major fuel cell original equipment manufacturers (OEM) in Connecticut are also involved with transportation applications and/or generating hydrogen from renewable energy or hydrocarbon fuels such as natural gas. UTC Power has fuel cell power plants in the drive systems of demonstration automobiles for Hyundai and Nissan, in auxiliary power units in BMW's vehicle demonstrations, and in several fuel cell buses in California, Connecticut and Europe.

Connecticut companies have also been involved with hydrogen generation through electrolysis for decades. More recently, Connecticut companies have been involved with hydrogen generation for transportation including the co-production of hydrogen in a fuel cell unit, fuel reforming, and electrolysis. These in-state manufacturers include: FuelCell Energy, UTC Power, Avālence, Proton Energy Systems, Treadwell Corporation, and Precision Combustion, Inc.

In 2010, the hydrogen and fuel cell industry contributed to the State's economy by providing over 1,200 jobs directly associated with research and development and the manufacture of equipment, and over 1,500 indirect jobs for a total of over 2,700 jobs statewide. It is projected that employment in Connecticut would increase as a result of the transition to a hydrogen and fuel cell economy. The employment increase is expected to consist of a transfer of jobs from traditional markets and services. Connecticut's most significant employment increases will be realized in the electrolysis manufacturing sector. Connecticut's employment in this sector is projected to grow from approximately 110 in 2010 to over 31,000 by 2050. Vehicle power plant manufacturing is also expected to increase to over 18,000 jobs by 2050. It is projected that these two sectors would combine to contribute over 50,000 jobs to Connecticut's economy by 2050.

Environmental Performance
The use of fuel cells, and especially fuel cells that directly utilize hydrogen, provides high value for improving air quality and reducing greenhouse gas (GHG) emissions. It has been calculated that the potential annual emissions reductions are between 26.2 and 37.3 pounds of NOx; 0.192 and 0.299 pounds of SO_2; and 10,169 and 15,772 pounds of CO_2 per passenger vehicle and light duty truck, respectively. For each transit bus, the potential emissions reductions have been calculated at approximately 1,020 pounds of NOx; 1.75 pounds of SO_2; and 183,000 pounds of CO_2 annually. Although the efficiency of conventional diesel buses has increased, conventional diesel buses use a hydrocarbon fuel and emit GHG, and have the potential for energy savings using fuel cell applications when compared to most other transportation applications.

Connecticut's transportation sector is also responsible for the most petroleum used in the state and is the largest portion of total statewide petroleum expenditures accounting for 52,573 out of 86,141 barrels of petroleum (61 percent) and $4,104 million out of $6,122 million (67 percent) of fuel expenditures annually. The amount of fuel energy saved using fuel cells for transportation applications ranges from 2,407.40 Btu/mile for passenger cars to 16,264.20 Btu/mile for transit buses. The increased efficiency of using fuel cells and hydrogen for transportation would result in significant fuel savings. The operation of the 2011 CTTransit fleet of six hydrogen-fueled fuel cell buses will use approximately 37,000 kg of hydrogen each year and completely displace approximately 49,000 gallons of diesel fuel annually. This displaced fuel is expected to result in the reduction of over one million pounds of CO_2 annually.

Deployment
On the east coast, initial introduction of hydrogen and fuel cell vehicles has occurred in New York City and more recently in Connecticut. Connecticut is expected to have four hydrogen refueling stations in operation by 2011. With support from the federal and state government and private industry, approximately seven or eight hydrogen refueling stations could be in operation by 2020, and as the market expands this could result in over 1,000 hydrogen refueling stations in operation by 2050.

In considering the locations for these hydrogen fueling stations, it would be advantageous to accommodate public transit, public and private fleet vehicles, and other commercial and private vehicles traveling between Washington and Boston along an East Coast version of California's Hydrogen Highway. Locations on, or with easy access to, major highways must be evaluated, including service plazas along Connecticut's interstates that are being considered for renovation and expansion. Consideration must also be given to locations that could serve public and private fleet vehicles, including transit operations.

The fuel cell buses operated by CTTransit, which are part of a demonstration program, cost over $2 million each; however, with all new technologies, increased production will lead to lower unit costs and increased economic opportunities for Connecticut companies. Hydrogen refueling infrastructure may cost between half a million dollars and $1.5 million for each station depending on how the hydrogen is produced and the production and dispensing capacity of the station. While the cost of a fuel cell bus does not currently

achieve parity with the cost of a conventional diesel bus, as costs decrease for hydrogen fuel cell technology the operation of these buses will provide a positive cost / benefit when considering the fuel savings associated with high efficiency; the air pollution emissions reductions associated with using hydrogen as a fuel; and economic benefits associated with the development and manufacture of fuel cell power plants and hydrogen infrastructure that currently resides in the state. If and when the capital cost of a fuel cell bus achieves parity with a conventional diesel bus, fuel cost savings alone could be significant, and savings would increase as the cost of fossil fuels increases over time.

Implementation for the conversion of conventional technology to hydrogen and fuel cell technology will face challenges, including the availability of fuel cell powered transit buses, cost, funding, and long term durability/reliability of the technology. The schedule for the deployment of vehicles, infrastructure, and associated equipment may be different than identified herein, and will be largely dependent upon the availability of funds. Hence, annual consideration of this plan will be necessary to maximize opportunities to leverage funding, and to account for changes in technology, cost, fuel availability, and public awareness.

Conclusion:
In summary, information in this Plan suggests that a transition to a hydrogen economy and the deployment of zero-emission, hydrogen fuel cell buses state-wide will increase transportation efficiency, improve environmental performance, increase economic development, and create new jobs. The technical and financial arrangements needed for such a transition from conventional vehicles and bus fleets will require initial investment by the state and federal government and private industry; however, such investment is well justified and will become a necessity as concerns about public health and climate change increase and the supply of conventional fuels becomes more limited. Furthermore, the use of domestic fuel and technology manufactured in Connecticut rather than fuel primarily produced overseas and bus engines manufactured out of state will provide value to Connecticut's economy and Connecticut's workers. The Plan also suggests that there are many specific locations for hydrogen refueling stations along state highways or at locations that could potentially be utilized by state fleets or other public or private-sector fleets.

Summary of Recommended Strategies

The following recommendations are intended as a menu of options to consider in support of Connecticut's hydrogen and fuel cell industry:

- Encourage the Department of Transportation and the Department of Administrative services to begin to identify locations clustered around existing transit operations, vehicle fleets, and major transportation routes in and around the following towns and cities to support the recommended deployment schedule for hydrogen fueling, as follows:

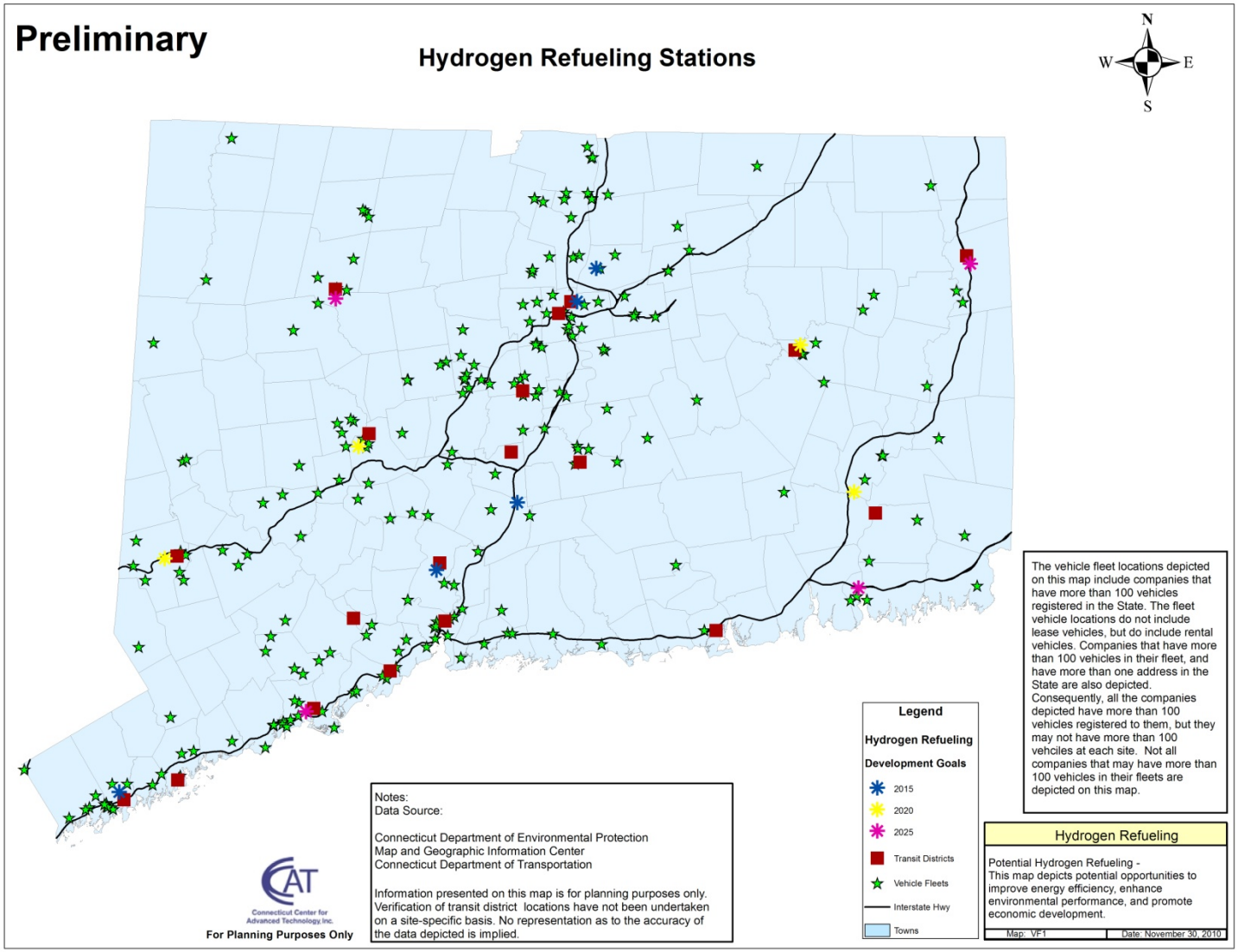
Site	*2015*	*2020*	*2025*
Hartford	✓		
New Haven/Hamden	✓		
Stamford	✓		
Wallingford	✓		
Danbury		✓	
Norwich		✓	
Meriden/Waterbury		✓	
Willimantic		✓	
Torrington			✓
New London			✓
Bridgeport			✓
Danielson			✓

- Establish a state goal for the purchase and operation of a minimum of 1% (40 vehicles) of the state fleet of light duty passenger vehicles with hydrogen fueled vehicles and 1% (10 buses) of the transit bus fleet with hydrogen fueled bus vehicles by 2015, increasing to 10% for both light duty passenger vehicles (400 vehicles) and transit buses (100 buses) by 2025, subject to vehicle availability and funding.

- Begin process for approval of official State signage posted on Interstate exits for hydrogen refueling stations.

- Provide incentives for the purchase and use of fuel cell vehicles, including but not limited to sales tax exemptions, local property tax exemptions, and high occupancy vehicle lanes use.

Potential Hydrogen Refueling Stations

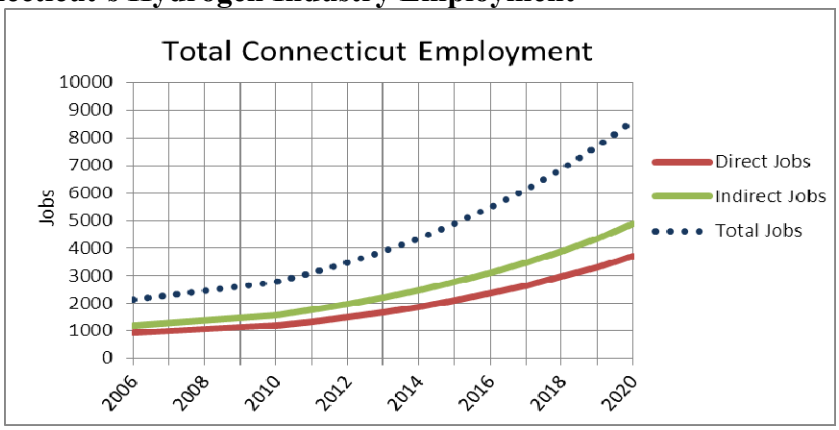


Introduction

Connecticut has long been the leader in the development and deployment of fuel cell and hydrogen production technologies and has recently been provided legislative guidance to apply these technologies to a transportation plan for hydrogen refueling facilities and vehicles, with a focus on zero-emissions buses.[1] Connecticut is part of a region that includes the New England states, New York, and New Jersey, all of which have an active fuel cell and hydrogen industry and supply chain. This region is part of a coordinated and cooperative effort for increased economic development through a program sponsored by the U.S. Department of Energy and the Small Business Administration and implemented by CCAT, the Massachusetts Hydrogen Coalition, Clean Energy States Alliance, New Energy New York and Hydrogen Energy Center.

Connecticut is well positioned to expand its share in the hydrogen transportation markets for increased employment, sales, research and development expenditures. Within Connecticut alone, the strength of the fuel cell industry has manifested into a $340 million gross product for the state with $31 million in tax revenues.[2] The supply chain within Connecticut includes over 600 companies and organizations that research, manufacture, and participate in the development and deployment of hydrogen and fuel cell technology. As shown below, total employment for Connecticut's hydrogen and fuel cell industry has grown 28 percent from 2,141 jobs in 2006 to over 2,960 jobs in 2010 and is projected to grow in the following years.[3] This growth is indicative of an industry that is expanding to meet market demand.

Figure I– Connecticut's Hydrogen Industry Employment



Transportation is a major component of the economy. In 2007, over 254 million vehicles were in use in the U.S. comprised of 136 million cars, 7 million motorcycles, 9 million trucks, 101 million "other 2-axle 4-tire" vehicles, and 834,000 buses.[4] These vehicles are served by

[1] State of Connecticut, Substitute House Bill No. 6649, Public Act 09-186, Section 8
[2] Fuel Cell Economic Development Plan – Hydrogen Roadmap; Connecticut Center for Advanced Technology, Inc., January 1, 2008
[3] Connecticut Hydrogen Fuel Cell Industry Status and Direction 2010 And 2011, Connecticut Center for Advanced Technology, Inc., September 2010
[4] U.S. Department of Transportation, Bureau of Transportation Statistics, National Transportation Statistics 2007, October 2009, Table 1-11

approximately 120,000 retail service stations where 176 billion gallons of petroleum fuel are consumed annually. [5,6] Imports of oil constitute approximately 57 percent of the petroleum consumed in the U.S.[7] Because large quantities of petroleum are consumed each year, transportation is a major contributor of greenhouse gas (GHG) emissions and other air pollutants in the U.S., as well as a leading factor in the U.S. trade deficit.

Compared to conventional vehicles, hydrogen-fueled vehicles with fuel cell power plants have many advantages, including:

- high efficiency;
- no emissions of controlled pollutants such as nitrous oxide, carbon monoxide, hydrocarbon gases or particulates;
- no emissions of GHG from the vehicles themselves;
- substantial reduction in GHG emissions on a "well-to-wheel" basis;
- fewer parts resulting in lower maintenance;
- ability to fuel vehicles with indigenous energy sources;
- greater range than all-electric / battery powered vehicles; and
- quiet operation.

Reduction in cost and advances in reliability and performance of low temperature proton exchange membrane (PEM) fuel cells and other types of fuel cells have allowed hydrogen-fueled fuel cells to be used for vehicular applications.[8] These technical achievements coupled with components in battery technology and increased concern for energy independence, noise from diesel buses in urban areas, emissions of controlled pollutants and greenhouse gases provide investors and government an incentive to pursue fuel cell technology. Consistent with the advancement of hydrogen fuel cell vehicles, hydrogen refueling has also advanced significantly with reduced refueling time, and increased pressure for extended driving range.

Currently there are:

- hundreds of hydrogen vehicles (both fuel cell and internal combustion engine) deployed worldwide;[9]
- Approximately 60 hydrogen fueling stations in the U.S. with over 20 being developed or planned;[10]

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[5] U.S. Census Bureau, Economic Census 2002

[6] Energy Information Administration, Estimated Consumption of Vehicle Fuels in the United States, Table C1. 2007 Data, Released April 2009

[7] Energy Information Administration, 2009 Data

[8] Auto company and government efforts currently focus on vehicles fueled with stored hydrogen after prior attempts to develop on-board conversion of gasoline or diesel fuel to hydrogen were unsuccessful. Some effort is underway to develop an on-board conversion of petroleum derived fuels to hydrogen for use in a fuel cell power plant. Efforts are also underway to further develop hydrogen-fueled internal combustion engine vehicles. In addition to technical challenges, size and cost of on-board reforming are major hurdles. Both of these approaches, i.e., hydrogen-fueled internal combustion engines and on-board hydrogen generation, will have some of the attributes noted above, although to a lesser extent than stored-hydrogen vehicles with fuel cell power plants

[9] Database of Cars, Bikes and other Vehicles, www.h2mobility.org, November 2007

[10] "Searchable Database of Hydrogen Stations in North America" http://www.hydrogenassociation.org/general/fuelingSearch.asp, August 2010

- A majority of states (47) and the District of Columbia have some form of fuel cell or hydrogen legislation, demonstration, or other activity.[11]

The attributes of fuel cell vehicles and the widespread progress suggest a growing market and opportunity for improvement in transportation systems, economic development, and improved environmental performance.

Hydrogen and Fuel Cell Vehicles

Passenger Vehicles

Fuel cell vehicles, like electric vehicles, are propelled by electric motors yet use the fuel cell to create its own electricity using hydrogen fuel and oxygen from the ambient air. Today, fuel cells successfully power cars, trucks, buses and other service vehicles like forklifts. Although fuel cell vehicles are not sold in large quantities commercially, these vehicles continually meet federal progress goals and provide driving characteristics that drivers of conventional vehicles are accustomed to.[12] The following vehicle manufacturers are working to bring their vehicles into the commercial market:

- *General Motors* is in its fourth generation fuel cell vehicle with the Chevrolet Equinox Fuel Cell. The Equinox is currently being demonstrated in the New York, Washington D.C., and Los Angeles areas through the Project Driveway program which places the vehicles in consumers' hands to enhance awareness of fuel cell vehicles and to collect data.[13]
- *Mercedes-Benz* B-Class fuel cell vehicle has an electric motor with a peak performance of 100 kW/136 horsepower. This zero-emission fuel cell car consumes the equivalent of approximately one gallon of diesel fuel per 71 miles.[14,15] The first 200 vehicles will be delivered to customers in Europe and the United States in 2010. Larger volume production is planned to begin in 2013 – 2015.
- *Honda* is currently demonstrating the FCX Clarity with consumers in Southern California and plans to deliver about 200 vehicles over three years of the program. Honda has complemented their demonstration program with an effort to develop home energy stations which will generate hydrogen for fuel cell vehicles as well as electricity and heating for homes.
- *Hyundai* is active in the development of fuel cell vehicles and has recently announced the development of its Hyundai Tucson ix35. Hyundai proposes to produce a few thousand Tucson ix35 fuel cell vehicles by 2012, but the company would offer them to Korean-market fleet buyers first.[16]

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[11] "State Activities that Promote Fuel Cell and Hydrogen Infrastructure Development", www.fuelcells.org/info/StateActivity, October 2006 – Update Supplement 2008.
[12] National Fuel Cell Vehicle Learning Demonstration: Gen 2 Progress, California Air Resources Board 2009 ZEV Symposium, September 21, 2009
[13] General Motors; http://www.gm.com/experience/technology/fuel_cells/
[14] Daimler; http://www.daimler.com/dccom/0-5-658451-1-1232162-1-0-0-0-0-0-11979-0-0-0-0-0-0-0-0.html
[15] Car and Driver; http://www.caranddriver.com/reviews/car/09q4/2011_mercedes-benz_b-class_f-cell-first_drive_review
[16] Car and Driver; http://www.caranddriver.com/news/car/10q1/hyundai_tucson_ix35_hydrogen_fuel-cell_electric_vehicle-auto_shows

- *Kia's* second generation Fuel Cell Electric Vehicle (FCEV) is currently being demonstrated in their Borrego vehicle in the United States and Korea. Numerous innovations including a higher output 154 horsepower fuel cell and a 450-volt super capacitor give the Borrego FCEV higher performance, extended driving range and cold-weather starting capability to operate in sub-zero temperatures.[17]
- *Nissan* is involved in the development of zero emission vehicles, including fuel cell powered vehicles, and has been leasing fuel cell vehicles on a limited basis in Japan. In 2009 Nissan leased its newest model, X-Trail FCV, to a Sacramento Coca-Cola Bottling Co.; its first commercial lease in North America.[18]
- *Toyota* recently announced that more than 100 Toyota Fuel Cell Hybrid Vehicle (FCHV) will be placed in a nationwide demonstration program over the next three years. These vehicles will be placed with universities, private companies and government agencies in California, Connecticut, and New York. As new hydrogen stations are developed, additional regions and partners will be added to the demonstration program.[19] This is all to achieve their goal to begin selling fuel cell vehicles by 2015.

Table I - Fuel Cell Vehicle Summary Table[20]

Vehicle	Hydrogen Phase	Hydrogen Pressure (psi)	Hydrogen Capacity (kg)	Vehicle Range (miles)
Chevy Equinox Fuel Cell	Gaseous	10,000	4.2	170 -210
Mercedes Benz B Class F-Cell [21]	Gaseous	10,000	3.7	240
Honda FCX Clarity[22]	Gaseous	5,000	3.9	240
Hyundai Tucson ix35	Gaseous	10,000	5.6	400
Kia Borrego[23]	Gaseous	10,000	7.9	426
Nissan X-Trail[24]	Gaseous	10,000	5.2	310
Toyota FCHV[25]	Gaseous	10,000	6	431

BMW developed a hydrogen powered vehicle, the 7-Series that uses fuel from either a 19.5-gallon tank (gasoline) or a secondary tank with 8 kg (30 gallons) of liquid hydrogen. The BMW Hydrogen 7 Series is the first production-ready vehicle to be powered by liquid hydrogen, which has a range of 125 miles off its hydrogen tank and 300 miles off the gasoline tank.[26] BMW, in partnership with UTC Power, is also currently in development of a fuel-cell hybrid vehicle that will be used in the next generation Mini and a front wheel drive BMW vehicle is planned for

[17] Kia Motors Corporation; http://www.kiamedia.com/secure/corporate112008b.html
[18] http://www.nissan-global.com/EN/NEWS/2009/_STORY/091124-01-e.html
[19] Toyota; http://pressroom.toyota.com/pr/tms/toyota/toyota-fuel-cell-vehicle-demonstration-151146.aspx
[20] California Fuel cell partnership; http://www.fuelcellpartnership.org/progress/vehicles
[21] http://www.benzinsider.com/2009/12/the-new-mercedes-benz-b-class-f-cell/
[22] Honda; http://world.honda.com/FCXClarity/specifications/index.html
[23] Kia; http://www.kiamedia.com/secure/corporate112008b.html
[24] Nissan; http://www.nissan-global.com/EN/TECHNOLOGY/INTRODUCTION/DETAILS/FCV/
[25] Toyota; http://www.sustainablemobility.com/?section=vehicles&sub=fchv
[26] http://blogs.cars.com/kickingtires/2006/09/bmw_hydrogen.html

release in 2014. The vehicle will generate power from a gasoline engine, a 5 kW hydrogen fuel cell drive train, and a 110 hp electric motor. This vehicle is designed to operate emission free when driving within cities.[27]

Figure II– Fuel Cell Powered Automobile Applications

Chevy Equinox:

Kia Borrego

Mercedes B Class F-Cell

Toyota FCHV

Honda FCX Clarity

Nissan FCV

The recent market success of electric vehicles has been advanced by similar market forces being applied to hydrogen vehicles. Hence, there is an expectation that electric vehicles will continue to be successful

[27] UTC Power; http://www.utcpower.com/fs/com/bin/fs_com_Page/0,11491,0333,00.html

for range-limited applications. Longer term, as fuel cell technology matures, the internal combustion engines now used in hybrid electric vehicles will be replaced by fuel cells, and there will be more hybrid fuel cell/battery vehicles that will offer the convenience of unlimited range (with hydrogen fueling stations) and overnight or local parking recharging.

Projected Hydrogen Fuel Cell Vehicle Use

The Department of Energy (DOE) recently completed a study of the likely effects that a transition to a hydrogen economy will have on overall employment in the United States. In this study, the DOE estimated the number of hydrogen fuel cell vehicles sold each year, and the percent of vehicles on the road through 2050 under two scenarios. The first hydrogen adoption scenario uses a market penetration rate consistent with the Hydrogen Fuel Initiative (HFI Scenario), introduced by President Bush in his 2003 State of the Union Address. The second hydrogen adoption scenario assumes a less aggressive rate of market penetration by hydrogen technologies (the Less Aggressive Scenario).

Table II – Projected Hydrogen Fuel Cell Vehicle Use by 2050

		HFI Scenario	Less Aggressive Scenario
Sales	million light-duty vehicles sold/yr	23.9	15.1
	% of all light-duty vehicles sold	100%	63%
Stock	million light-duty vehicles in use	347.5	144
	% of all light-duty vehicles in use	96.0%	38.2%

The HFI Scenario assumes rapid market penetration of hydrogen vehicles with new vehicle sales reaching 100 percent by 2050. The result is that 96 percent of all light duty vehicles in use will be hydrogen fuel cell vehicles by 2050. Market penetration of hydrogen fuel cell vehicles is slower under the Less Aggressive Scenario with new sales at approximately 63 percent by 2050, resulting in overall light duty hydrogen fuel cell vehicle stock of 38 percent by 2050.[28]

Commercial Vehicles

Transit Buses

The Federal Transit Administration (FTA) has reported that there were 834,000[29] buses in the United States in 2007 of which 20 were powered by hydrogen fuel cells and soon another 43 will become operational. In Connecticut, there are approximately 1,000 buses[30] and 480 vans in revenue service that were operated by a public agency or authority, a private transportation provider, or private transportation broker.[31] The transit bus market is ideal for initiating the first steps towards a hydrogen economy because its ability to provide urban and commercial areas the

[28] Effects of a Transition to a Hydrogen Economy on Employment in the United States: Report to Congress, July 2008

[29] This figure includes all transit buses, paratransit buses, and school buses.

[30] This figure is for conventional diesel buses that cost approximately $337,000 per bus. NREL/TP-560-47334-2, January 2010

[31] National Transportation Database; http://www.ntdprogram.gov/ntdprogram/data.htm; 2008 Revenue_Vehicle_Inventory.xls

advantages hydrogen technology has over other transportations methods by promoting its quiet, GHG emissions free abilities.
The first fuel cell bus in Connecticut, which cost approximately $2.4 million[32], was deployed by CTTRANSIT in April 2007. CTTRANSIT is administrated by the Connecticut Department of Transportation and is the largest transit operation in Connecticut. This fuel cell bus was a prototype developed as a collaborative effort by UTC Power, ISE Corporation, and Van Hool.[33] The bus utilizes a hybrid system in which a UTC Power fuel cell and on board ZEBRA batteries provide electricity to two electric drive motors that are coupled to the driveline though a combining gearbox. [34] The bus has a hydrogen storage capacity of 50 kg at 5,000 psi. Fuel for these buses is provided at the UTC Power headquarters in South Windsor, CT.

In 2010, CTTransit added four fuel cell powered buses to its fleet. These buses are similar to the original Van Hool hybrid introduced in 2007; however, several improvements have been made including the use of lithium ion batteries, and less hydrogen storage capacity to match the actual hydrogen demand, and seating/door placement. These changes, which resulted in a weight reduction of 6,000 lbs, have allowed for greater speeds to be achieved expanding the buses service area capabilities.[35] A fifth bus is planned for delivery in 2011, which would give CTTRANSIT a total of six buses, the second largest fleet of hydrogen fuel cell buses in the country and one of the largest in the world[36]. These buses are the result of Connecticut's involvement in the DOE and FTA's National Fuel Cell Bus Program (NFCBP) titled the "Connecticut Nutmeg Fuel Cell Bus Demonstration Program".[37]

Figure III– CT Transit Fuel Cell Bus with UTC Fuel Cell Power Plant (left) and a Paratransit Vehicle[38] (right)

[32] Connecticut Transit Fuel Cell Transit Bus: Third evaluation Report – Appendices; NREL/TP-560-47334-2, January 2010.
[33] CTTRANSIT Operates New England's First Fuel Cell Hybrid Bus, U.S. Department of Energy Hydrogen Program, http://www1.eere.energy.gov/hydrogenandfuelcells/tech_validation/pdfs/42407.pdf, October 28, 2009
[34] www.meridian-int-res.com/projects/Zebra_Pages.pdf
[35] Fuel Cell Buses in U.S. Transit Fleets: Current Status 2009, National Renewable Energy Laboratory, http://www.nrel.gov/hydrogen/pdfs/46490.pdf, October 29, 2009
[36] The CTTRANSIT Hydrogen Fuel Cell Hybrid Bus Program; Presentation to the Connecticut Hydrogen-Fuel Cell Coalition, December 10, 2009.
[37] Storage for hydrogen powered fuel cell transit buses will require modifications to existing transit bus garage facilities, potentially including ventilation, hydrogen detection and safety devices. The costs associated with the modifications will vary depending on the number of buses and the site specific characteristics of the facilities; however, safety measures for fuel cell buses should be considered when designing new facilities or during significant modifications to existing facilities.
[38] Photograph from http://www.masstransitmag.com/images/article/1144352641166_0406_specialreport_7.jpg

The Greater New Haven Transit District (GNHTD) is undertaking an innovative program to explore the performance and commercial viability of hydrogen fueled transit bus technology in south central Connecticut. Led by GNHTD and backed by the Federal Transit Administration (FTA), this project (known as HyRide), consists of a 22-foot plug-in hybrid hydrogen fuel cell transit bus that will be operating in the greater New Haven area by mid 2011. This vehicle will operate in regular revenue operations, including shuttle and paratransit modes.

The proposed HyRide project will feature the following characteristics:[39]

- Fuel - Hydrogen created by clean electrolysis
- ADA features - Enhanced accessibility and ride comfort
- Emissions - Meet or exceed 2010 U.S. EPA standard
- Reliability - Greater than 90% availability
- Fuel Efficiency - Twice that of a comparable diesel transit bus

Figure IV– Hybrid Electric Fuel Cell Bus[40]

Fleets

Fleet vehicles are groups of motor vehicles owned or leased by a business or government agency, rather than by an individual. Typical examples are vehicles operated by car rental companies, taxicab companies, public utilities, public bus companies, and police departments. In addition, many businesses purchase or lease fleet vehicles to deliver goods to customers, or for sales representatives to travel to clients. The State of Connecticut vehicle fleet consists of approximately 4,000 light duty and passenger vehicles.[41] In 2009 President Barack Obama signed Executive Order 13514 on Federal Leadership in Environmental, Energy, and Economic Performance, which sets a goal for federal agencies to reduce greenhouse gas emissions, including those that have fleets with 20 or more vehicles to reduce their petroleum use by 2 percent annually through 2020 relative to a baseline of fiscal year 2005.[42]

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[39] HyRide; http://www.hyride.org/

[40] ebus; http://www.ebus.com/EbusPlug-inElectricFuelCellBus_Specs.pdf

[41] The State Fleet of Cars, Connecticut Office of Legislative Research, 2009-R-0176, April 20, 2009

[42] Executive Order 13514—Federal Leadership in Environmental, Energy, and Economic Performance Section 2.a.iii.C http://edocket.access.gpo.gov/2009/pdf/E9-24518.pdf

Connecticut has approximately 240 locations of vehicle fleets, which have more than 100 vehicles classified as non-leasing and 13 transit districts in Connecticut that provide local, coordinated public transportation in the area they serve. These transit and fleet vehicle locations could be served by hydrogen or hydrogen mixture refueling stations located near Connecticut's major highways. The potential hydrogen refueling stations in/near Hartford and Hamden would support existing and planned fuel cell and hydrogen powered bus projects.

Auxiliary Power Units

Auxiliary power units (APU) for vehicles are currently provided by the vehicle engine. Fuel cells offer attractive features for APUs for automobiles, trucks and recreational vehicles. These features include quiet operation, low emissions, as well as high efficiency, with added benefit in displacing inefficient idling use of the main engine for such units on vehicles. This market is partly being driven by a strong near-term military interest in fuel cell APUs for multiple applications, especially for quietness and survivability benefits. Some companies in the Northeast that are developing fuel cell auxiliary power units include UTC Power in Connecticut, Protonex in Massachusetts, and GM Fuel Cell Group in New York.

Infrastructure

On the east coast, initial introduction of hydrogen and fuel cell vehicles has occurred in the New York City area with Connecticut poised for regional growth beginning along major arteries between New York City and Boston. The U.S. DOE expects the deployment of over 3,000 hydrogen vehicles in the United States between 2021 and 2025 in the Dallas, Los Angeles and New York City areas.[43] This estimate could be accelerated if political, economic, energy security or environmental polices prompt a rapid advancement in alternative fuels.

Initial deployment of hydrogen vehicles in Connecticut is expected to occur in high demand regions including population centers and high traffic volume areas in central and southwest Connecticut. Connecticut is well suited for the rapid penetration and deployment of hydrogen and fuel cell based infrastructure and vehicles for the following reasons:

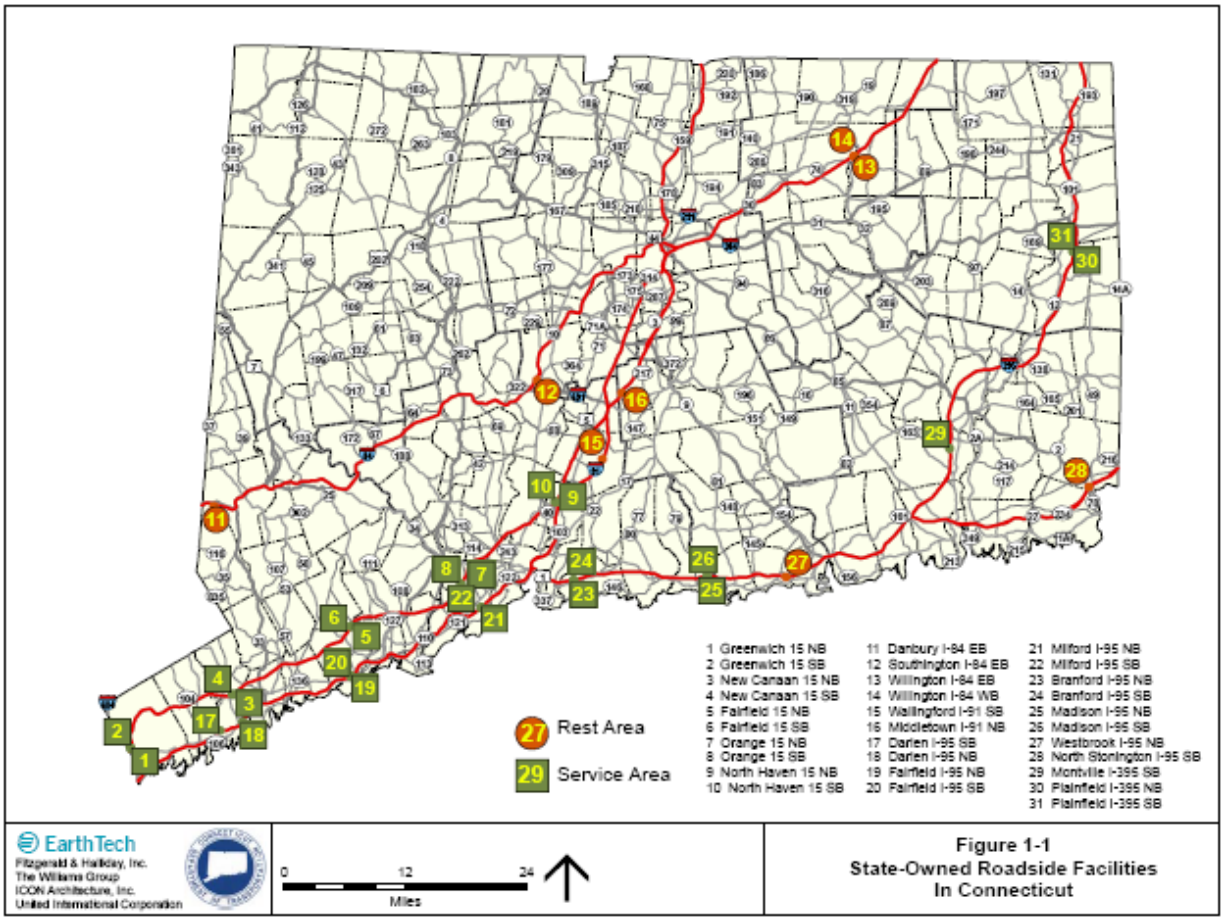
- High population density;
- Adjacent to the New York City area which is now exhibiting deployment of hydrogen passenger vehicles;
- State support and policies for clean energy technology;
- Connecticut Hydrogen-Fuel Cell Coalition and Clean Cities Coalitions' activities; and
- Strong hydrogen and fuel cell industry.

In considering the locations for these hydrogen fueling stations, it would be advantageous to accommodate public transit, public and private fleet vehicles, and other commercial and private vehicles traveling between Washington and Boston along an East Coast version of California's Hydrogen Highway. Potential hydrogen refueling locations that meet these criteria are identified in Figure VI.

[43] Analysis of U.S. Market Transition to a Hydrogen Economy, Fred Joseck, U.S. Department of Energy Hydrogen Program, http://www.iea.org/work/2007/hydrogen_economy/8_joseck.pdf, October 27, 2009

Locations on or those with easy access to the major highways must be considered, including service plazas along Connecticut's interstates that are being considered for renovation and expansion. Consideration must also be given to locations that could serve public and private fleet vehicles, including transit operations. All of the rest areas and service plazas that are located on Connecticut state highways fall under the jurisdiction of, and are operated by, the Connecticut Department of Transportation. Connecticut currently has 23 service plazas and 8 rest areas. Fueling is provided at 23 service plazas with diesel provided at 11 sites along I-95 and I-395[44].

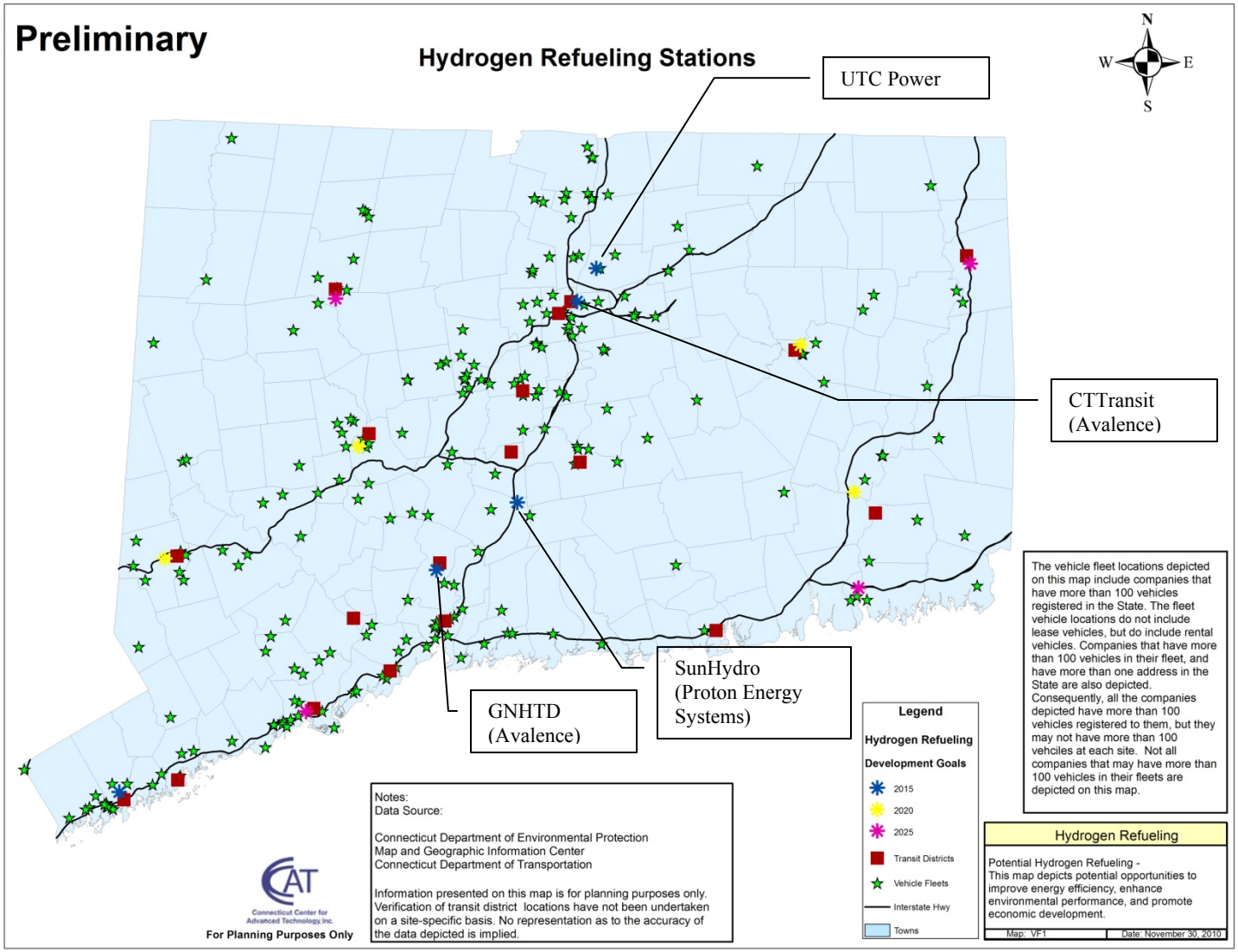
Figure V – State Owned Roadside Facilities in Connecticut[45]



Potential locations for fueling stations within Connecticut can be seen on Figure VI below.

[44] CT Statewide Rest Area and Service Plaza Study - CONN DOT Project No. 170-2533, September 2008
Federal laws prohibit the construction of new fueling stations at rest area locations that are not grandfathered under interstate regulations (e.g. along I-84 and I-91 sites).
[45] CT Statewide Rest Area and Service Plaza Study - CONN DOT Project No. 170-2533, September 2008

Figure VI– Potential Hydrogen Refueling Stations



See Figures VII for UTC Power refueling station and Figure IX for SunHydro's refueling station at Proton Energy Systems' facility

Highways

Connecticut has approximately 21,000 miles of streets and highways, including approximately 3,700 miles of state-maintained roads, and approximately 17,000 town-maintained roads.[46] Connecticut also has approximately 67 miles of limited access state highways designated as parkway, which prohibit commercial motor vehicles, trailers, buses, and vehicles bearing other than passenger, camper, taxicab, vanpool or hearse registrations.[47,48] The Interstates 91, 95, and 84 corridors are the most important of these for alternative-fueled vehicles because they have high average daily traffic (ADT) counts and represent links in what could be an alternative-fuel transportation corridor from one state to another.[49] Along these routes are approximately 23 service facilities that offer vehicle refueling; however, ten of these facilities are on limited access state highways designated as a parkway, which would restrict hydrogen refueling primarily to passenger vehicles only.

Table III – Traffic Counts for Connecticut's Interstate Highways[50]

Interstate	ADT Low	ADT High
91		
I95 to Hartford (I84)	56,700	146,800
I84 to MA Border	72,000	147,800
95		
NY Border to New Haven (I91)	104,700	157,800
New Haven to RI Border	29,900	129,900
84		
NY Border to Hartford (I91)	58,500	168,400
Hartford to MA Border	50,700	160,800

Station Locations and Fuel Demand

The U.S. DOE Alternative Fuels and Advanced Vehicles Data Center and the National Hydrogen Association have reported that there are now approximately 60 operational hydrogen fueling stations in the United States, two of which are in Connecticut.[51] The two existing hydrogen refueling stations in Connecticut are located at the UTC Power facility, located in South Windsor, and at the Proton Energy Systems facility, located in Wallingford. Connecticut has two hydrogen fueling stations in the construction phase including the CTTRANSIT facility in

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[46] Public Road mileage, Connecticut Department of Transportation, December 31, 2008; http://www.ct.gov/dot/lib/dot/documents/dpolicy/publicroad/2008public_roadmileage.pdf

[47] Connecticut Department of Transportation; http://www.ct.gov/dot/cwp/view.asp?A=2137&Q=294976

[48] 2009 Limited Access State Numbered Highways Connecticut Department Of Transportation Bureau Of Policy and Planning Office of Policy and Systems Information Division Of Systems Information, December 31, 2008

[49] Preparing For The Hydrogen Economy: Transportation, Connecticut Academy of Science and Engineering; June, 2006

[50] Connecticut Department of Transportation 2009 Traffic Volumes - State Maintained Highway Network (Traffic Log); http://www.ct.gov/dot/lib/dot/documents/dpolicy/traflog/traflog09.pdf

[51] U.S. DOE Alternative Fuels and Advanced Vehicles Data Center, http://www.afdc.energy.gov/afdc/fuels/stations_counts.html; National Hydrogen Association, http://www.hydrogenassociation.org/general/fuelingResults.asp - November 2010.

Hartford and the Greater New Haven Transit District (GNHTD) facility in Hamden, and one hydrogen fueling station in the planning/development phase - ARRC/H2 station in Stamford.

UTC Power – South Windsor:

UTC Power has an industrial hydrogen storage facility that includes refueling infrastructure for use by its fuel cell vehicles in development and by CTTRANSIT for the hydrogen-powered fuel cell buses. This facility is not for public use. The fueling station stores hydrogen as a liquid, which is delivered by Praxair. This fueling station is capable of refueling the CTTRANSIT bus with up to 50 kg of hydrogen within 35 minutes. This hydrogen refueling station has sufficient capacity to fuel all the fuel cell buses operated by CTTransit Hartford. Hydrogen is supplied to CTTRANSIT at a cost of $4.50/kg[52], which does not include the cost of purchasing, transporting and dispensing the fuel.[53] Figure VII depicts the storage facility for UTC's refueling station.

Figure VII– Liquid Hydrogen Storage Facility – UTC Power, South Windsor, CT

Proton Energy Systems - Wallingford:

Proton Energy Systems is hosting a SunHydro refueling station for use by transit buses utilizing the I-91 corridor and passenger vehicles that are being deployed for demonstration by the automotive OEMs. The SunHydro fueling station features both 350 bar (5,000 psi) and 700 bar (10,000 psi) dispensing. The capacity of the SunHydro fueling station is 100 kg/day, which will support approximately 15 cars per day or 2 transit buses. The SunHydro fueling station is capable of communication fast fills[54] and will feature semi-public access for those who are certified for use on the equipment. All of the hydrogen used at the SunHydro fueling station will be produced by Proton's PEM electrolyzers at the Wallingford site. The power used to make the hydrogen will be from a combination of renewable (there is 75 kW PV installed at the site) and grid power. The SunHydro fueling station depicted in Figure IX is currently operational.

[52] Q&A for Fuel Cell Bus Event at CTTransit, October 15, 2010.
[53] Connecticut Transit Fuel Cell Transit Bus: Second Evaluation Report, May 2009, http://www.nrel.gov/hydrogen/pdfs/45670-1.pdf, October 29, 2009
[54] Communication fast fills include use of a communication link between the vehicle and fueling station to monitor the fueling process for rate and pressure.

SunHydro is also developing a chain of privately funded fueling stations that will provide hydrogen for vehicle refueling from Maine to Florida.

Figure VIII – Proposed SunHydro Locations along an East Coast Hydrogen Highway

Figure IX– Hydrogen Refueling Station Infrastructure
SunHydro at Proton Energy systems Facility, Wallingford, CT

CTTransit – Hartford

Avālance will build this hydrogen fueling station at the CTTransit facility in Hartford, which will have a production capacity of 30 kg per day, 96 kg of storage, and a 20 kg/min (rated) dispenser at 5,000 psi to service Harford's hydrogen transit buses. The commissioning of this facility is expected during 2011.

Greater New Haven Transit District – Hamden

The HyRide program being developed in GNHTD also includes the construction of a hydrogen fueling station with a 24 hour hydrogen generating capacity of 10 kg/day at 5,000 psi, which was developed by Avalence. The fueling facility will have the initial capacity to store up to 48 kg of hydrogen at 6,500 psi and a 20 kg/min (rated) dispenser. The hydrogen refueling station will also provide fuel for a 10 kW fuel cell that will provide backup power to the Hamden Public Works facility. The commissioning of this facility is expected during 2011.

Alternative Fueling Station - Stamford

The ARRC/H2 Alliance plans to design and build a Hydrogen Fueling Station/Information Center in Stamford, along the heavily traveled New York-Boston corridor to support hydrogen fuel cell vehicles. The station would provide hydrogen and other alternative and conventional fuels for private and state vehicles, commercial fleets, and buses 24/7. The proposed fueling station would have a dispensing capacity of between 50 and 100 kg/day at both 5,000 and 10,000 psi. This facility is a conceptual design, with development of this facility expected sometime before 2015.

Refueling Station Projections

Near Term Projections

It has been estimated that Connecticut may realize the deployment of between 6 and 20 fuel cell buses and 40 passenger vehicles by 2015[55]. Assuming hydrogen buses utilize 25 kg of hydrogen per day and passenger vehicles utilize one kg of hydrogen per day, a total of between 190 kg and 540 kg would be needed each day. As discussed above, the total production capacity for the existing and planned hydrogen refueling stations could provide enough hydrogen fuel to satisfy the refueling requirements for the lower range of vehicles. However, approximately 200 kg of additional hydrogen production, storage, and refueling capacity would be needed to meet the maximum projected demand by 2015.

Long Term Projections

The hydrogen refueling industry in Connecticut has characterized the state as one of the leaders in the world in regards to renewable energy; however, a suitable market is needed in order to maintain this leadership role. CCAT has developed assumptions, using a Bass Diffusion Model, which helps explain when and how long it will take for this deployment to absorb the currently dominant petroleum market. [56] This Bass Diffusion Model is premised on a gross level assumption that 95 percent of the existing retail fueling stations will adopt hydrogen refueling capability by 2050. The existing market (*m*) is equal to the number of stations currently in existence in the United States, which are 121,466.

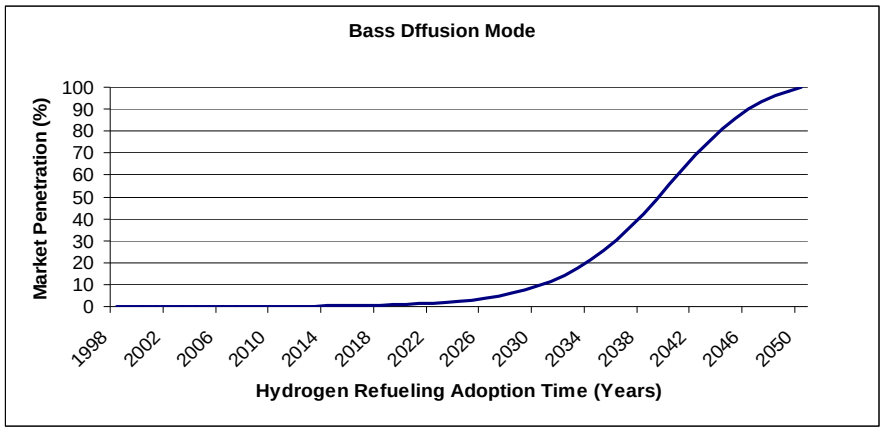
$$N_t = N_{t-1} + p*(m- N_{t-1}) + q*N_{t-1}/m*(m-N_{t-1})$$

[55] Fuel Cell Economic Development Plan; Connecticut Center for Advanced Technology, Inc, January 2008

[56] The Bass diffusion model is frequently used to forecast the adoption of new products and technologies.

Based on historical data from the number of refueling stations opened to date, a *p* value of 0.0000149 and *q* value of 0.26051545 were determined.[57] As depicted in Figure X below, the diffusion curve gradually increases until market penetration begins to take hold at 2050.

Figure X– Bass Diffusion Model – Market Penetration



Based upon efficiency gains with the use of hydrogen vehicles, the average station size in 2050 will require approximately 8,500 kg of hydrogen to be dispensed each day, assuming an annual growth rate of 1.14 percent.[58] The average price per gallon equivalent (gasoline) for hydrogen dispensed is assumed to cost $4.67 in 2010 and $3.58 in 2050.[59] In the United States, the number of kg dispensed per day will grow from 3,023 kg to over 300 million kg. The Bass Diffusion Model estimated the number of refueling stations to increase to over 110,000 in 2050, or 95 percent of the current existing refueling stations. Table IV below provides a summary of U.S. refueling station projections through 2050.

Table IV– U.S. Refueling Station Projections

Year	2010	2020	2035	2050
Number of Refueling Stations	60[60]	669	19,100	110,300
Average Capacity of New Refueling Stations (kg/Day)	50	180	1,200	8,500
Kg of Hydrogen Dispensed / Day	3,023	84,030	15,700,000	362,000,000
Price/Gallon Equivalent (Hydrogen)[61]	$4.67	$3.91	$3.65	$3.58

Long term projections by the U.S. DOE Energy Information Agency indicate that the retail price for gasoline is projected to be $38.99 per MMBTU ($4.45 per gallon) in the year 2050. [62] The

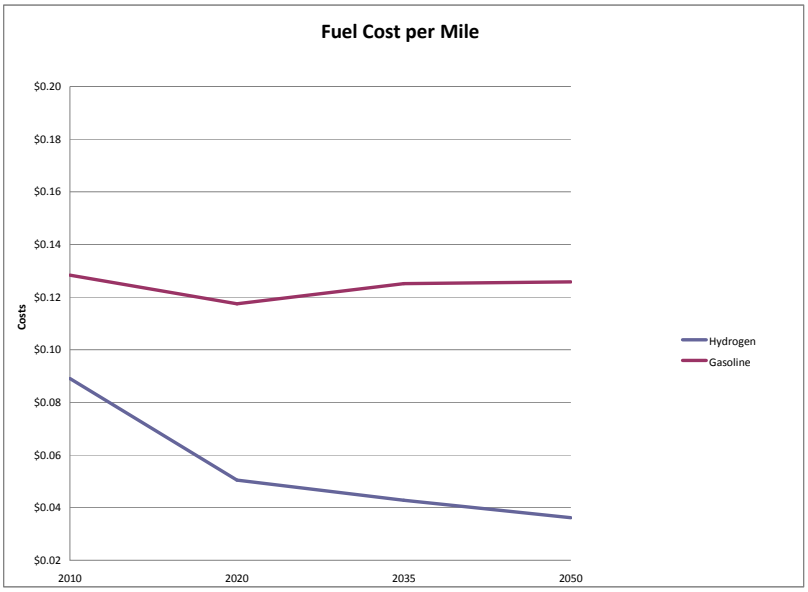
[57] The coefficient p is called the coefficient of innovation, external influence or advertising effect. The coefficient q is called the coefficient of imitation, internal influence or word-of-mouth effect.
[58] Hydrogen vehicle efficiency is based upon a weighted average of passenger vehicles, light trucks, and buses based upon the "Fuel Cell Economic Development Plan" Connecticut Center for Advanced Technology, Inc, January 2008
[59] "Hydrogen Demand, Production, and Cost by Region to 2050," Argonne National Laboratory and TA Engineering, Inc., August 3, 2005
[60] http://www.hydrogenassociation.org/general/fuelingResults.asp accessed 12-1-10
[61] "Hydrogen Demand, Production, and Cost by Region to 2050," Argonne National Laboratory and TA Engineering, Inc., August 3, 2005 page 43. Based on the values for years 2010, 2020, 2030, and 2050.

retail price per gallon equivalent of hydrogen is projected to be $3.58 in 2050, which indicates that hydrogen will be less expensive over the long term when compared to gasoline. As shown below (Table V), the margin of difference between hydrogen and gasoline costs per mile is expected to expand as hydrogen costs decrease while gasoline costs increase (Figure XI).

Table V - 2010 Hydrogen to Gasoline Comparison ($2010)

Parameter	Hydrogen[63]	Gasoline[64]
Mpg (equiv.)	52	22.6
Fuel Cost ($/kg, $/gal)	$4.67	$2.90
Fuel Tank size (kg, gal)	5.2	12
Range (miles)	270	272
Cost Per Fill-up	$24.28	$34.8
Cost per mile	$0.089	$0.128

Figure XI– Fuel Cost per Mile of Hydrogen and Gasoline[65]



[62] Assuming the trend stays the same for an additional 15 years in the Annual energy outlook 2010, table 3 Energy Sector by Sector and Source: http://www.eia.doe.gov/oiaf/aeo/aeohighmac.html

[63](52 mpg is mentioned in energy efficiency Impacts); Validation of Hydrogen Fuel Cell Vehicle and Infrastructure Technology, NREL/FS-560-42284 • October 2007

[64] U.S. Department of Transportation, Research and Innovative Technology Administration, Table 4-23: Average Fuel Efficiency of U.S. Passenger Cars and Light Trucks

[65] Assumes a 10 percent fuel efficiency improvement through 2050, except for gasoline in 2020, which is based on CAFÉ standards.

Potential Hydrogen Fuel Benefits

The use of fuel cells, and especially fuel cells that utilize hydrogen, provide high value for improving air quality and reducing GHG emissions. With over 240 million cars in the U.S., vehicles are responsible for the majority of the GHG emissions being produced. The advantages fuel cells have is that they create no yield of GHG emissions at all.

The value of this "Class I Renewable Energy", as recognized by Connecticut State law, is further supported by the Connecticut Energy Advisory Board's 2007 Energy Plan which set a Renewable Portfolio Standard (RPS) of 20 percent by 2020 and a 20 percent reduction of fossil fuel consumption by 2020.[66] The plan was reinforced on June 2, 2008 when Governor Jodi Rell signed into law HB5600, setting a statewide GHG reduction target of 10 percent below 1990 levels by 2020 and 80 percent below 2001 levels by 2050.[67]

Ambient Air Quality Standards

The Clean Air Act requires the Environmental Protection Agency (EPA) to provide a national ambient air quality standard (NAAQS) for six air pollutants. It consists of a ***Primary standard*** that protects the public health, including the health of "sensitive" populations such as asthmatics, children, and the elderly, as well as a ***Secondary standard*** that protects public welfare, including protection against decreased visibility, damage to animals, crops, vegetation and buildings. [68]

Table VI– National Ambient Air Quality Standards Chart

Ambient Air Quality Standards				
	Primary Standards		Secondary Standards	
Pollutant	Level	Average Time	Level	Averaging Time
NO_2	0.053 ppm	Annual	Same as Primary	
SO_2	0.03 ppm	Annual	0.5 ppm	3-hour (1)
	0.14 ppm	24-hour (1)		
CO	9 ppm	8-hour (1)	None	
	35 ppm	1-hour (1)		
O_3	0.075 ppm	8-hour	Same as Primary	
PM_{10}	150 $\mu g/m^3$	24-hour	Same as Primary	
$PM_{2.5}$	15 $\mu g/m^3$	Annual	Same as Primary	
	35 $\mu g/m^3$	24-hour		
Lead	0.15 $\mu g/m^3$	3-month average	Same as Primary	
	1.5 $\mu g/m^3$	Quarterly Average	Same as Primary	

(1) Not to be exceeded more than once a year.
Units of measure are parts per million (ppm) or micrograms per cubic meter (µg/m3) of air

[66] http://www.ctenergy.org/energy.html
[67] http://www.cga.ct.gov/2008/ACT/PA/2008PA-00098-R00HB-05600-PA.htm
[68] http://www.epa.gov/air/criteria.html

For the last 22 years, Connecticut has been challenged to reduce ozone, which is caused by the increase in car emissions and population growth in urban and rural areas[69]. Several groups of people are particularly sensitive to ground-level ozone, especially active children and the elderly. Ozone may irritate one's respiratory system, reduce lung function, aggravate asthma, inflame and damage cells that line one's lungs, aggravate chronic lung diseases such as emphysema and bronchitis and reduce the immune system's ability to fight off bacterial infections in the respiratory system.[70] The Connecticut Clean Air Task Force estimated that from April to October 1997, ground-level ozone was responsible for approximately 100,000 asthma attacks as well as about 2,600 emergency room visits for all respiratory problems in Connecticut.[71]

Air Pollution Impacts on Health

Connecticut has over three million registered vehicles which account for approximately fifty percent of all man-made air pollution emitted in Connecticut. [72,73] Transportation emissions of GHG make up 39 percent of the state's GHG inventory and are the leading source of GHG emissions in Connecticut.[74] Passenger cars and light duty trucks are responsible for 61 percent of GHG emissions attributed to transportation.

In 2005, the Connecticut Fund for the Environment released a study of diesel emissions, air quality, and human health risks in the State of Connecticut which estimated that the total average health cost associated with diesel exposures triggered by smog and $PM_{2.5}$ was $298,599,294 for 1998. "In 1998…there were 8,264 hospitalizations for heart attacks/acute myocardial infarctions, at an average cost per patient of $15,858, and 9,835 hospitalizations for congestive heart failure, at an average cost per patient of $9,256. In that same year, Connecticut hospitals recorded 3,715 hospitalizations for asthma, with a cost of $5,138 per patient and 8,352 hospitalizations for chronic obstructive pulmonary disease, at an average cost of $6,876."[75] Patients admitted for these problems have not increased significantly since 1998 (Figure XII); however, the costs that each patient must pay for the hospitalizations have increased as shown in Figure XIII below.[76] Because of this, even a modest reduction in the number of hospitalizations would provide savings in the millions of dollars.

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[69] Although vehicle emission standards have become more stringent, the increased number of vehicles and vehicle miles has resulted in ozone levels that exceed ambient air quality standards during certain times of the year.
[70] Airnow.gov; "Ozone and Your Health"; http://airnow.gov/index.cfm?action=static.ozone2#1, November 2007
[71] "The Drive for Cleaner Air in Connecticut", Connecticut Fund for the Environment, September 2003.
[72] Man-made air pollution includes hydrocarbons, carbon monoxide, carbon dioxide, nitrogen oxides, sulfur dioxides and other particulate matter.
[73] U.S. Department of Transportation, Federal Highway Administration, Highway Statistics 2007, October 22, 2009, Table MV-1; Connecticut Department of Environmental Protection, "Mobile Sources", http://www.ct.gov/dep/cwp/view.asp?a=2684&Q=322142&depNav_GID=1619&depNav=|, October 22, 2009
[74] Connecticut Department of Environmental Protection; http://ct.gov/dep/cwp/view.asp?a=2684&q=322142&depNav_GID=1619
[75] "Diesel Emissions & Unhealthy Air in Connecticut"; A Study of Diesel Emissions, Air Quality and Human Health Risks in Connecticut, Connecticut Fund for the Environment, May 2, 2005
[76] 1998-2007 Connecticut Department of Health: Hospitalization Statistics

Figure XII– Hospitalizations in Connecticut

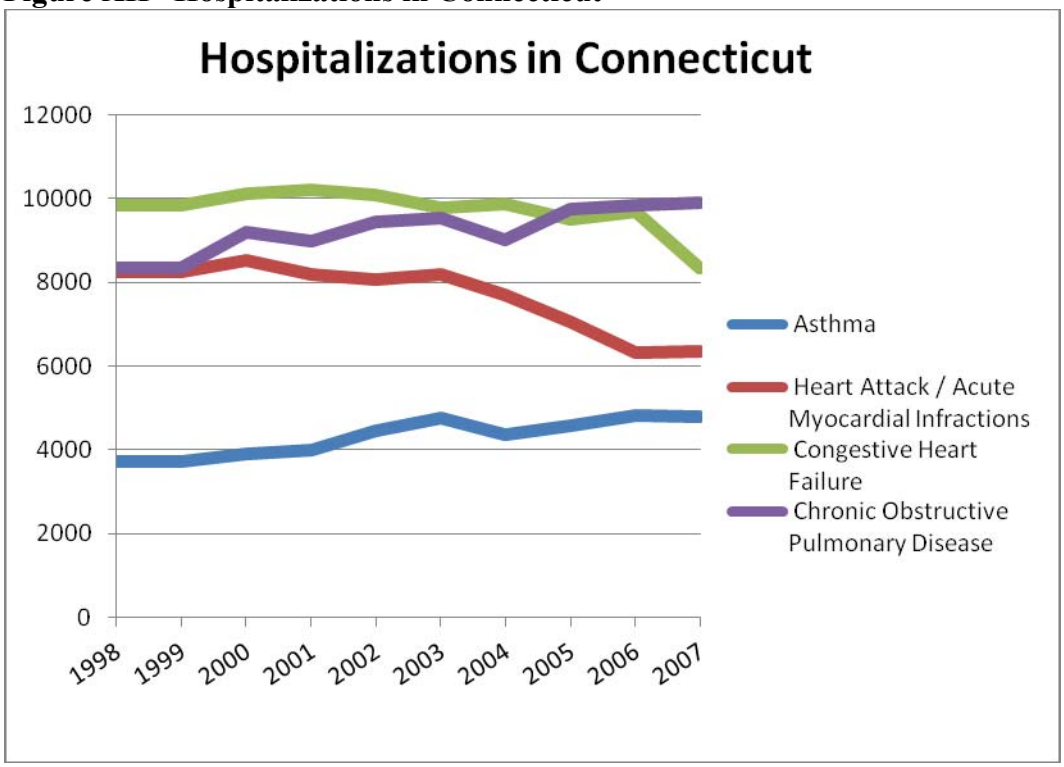
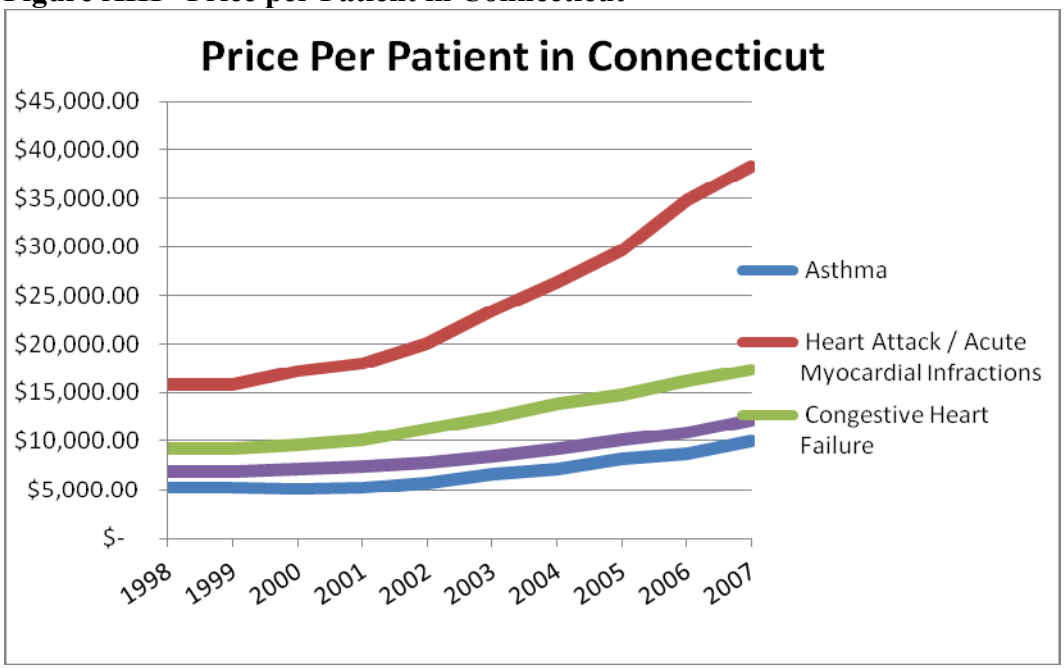


Figure XIII– Price per Patient in Connecticut



The use of fuel cells for transportation applications provides significant emission reductions in NOx, SO_2, and CO_2 for passenger vehicles and mass transit; as detailed in Table VII:

Table VII - Transportation Emissions Comparison

Vehicle Emissions Comparison (grams/mile)				
	Emissions from Conventional Gasoline Powered Passenger Cars	Emissions from Conventional Gasoline Powered Light Trucks	Emissions from Conventional Diesel Transit Buses	Emissions from Hydrogen Fuel Cells[77]
NO_X	0.95	1.22	12.5	0
SO_2	0.007	0.0097	0.0214	0
CO_2	369	511	2,242.7	0

Fuel cell vehicles running on hydrogen produced from renewable resources virtually eliminates all GHG emissions compared to conventional fossil fuel powered vehicles. Passenger car emissions of NO_x are reduced by 0.95 grams/mile, SO_2 by 0.007 grams/mile, and CO_2 by 369 grams/mile. Gasoline powered light truck emissions are also reduced by 1.22 grams/mile of NO_x, 0.0097 grams/mile of SO_2, and 511 grams/mile of CO_2. Diesel transit bus emissions of NO_x are reduced by 12.5 grams/mile, SO_2 by 0.0214 grams/mile and CO_2 by 2,242.7 grams/mile.

It has been calculated that the potential annual emissions reductions are between 26.2 and 37.3 pounds of NOx; 0.192 and 0.299 pounds of SO_2; and 10,169 and 15,772 pounds of CO_2 per passenger vehicle and light duty truck, respectively. For each transit bus, the potential annual emissions reductions have been calculated at approximately 1,020 pounds of NOx; 1.75 pounds of SO_2; and 183,000 pounds of CO_2, as shown in Table VIII below.

Table VIII - Potential Annual Emission Reductions Using Hydrogen Fuel Cells[78]

Potential Annual Emission Reductions per Vehicle Using Hydrogen Fuel Cell Propulsion Systems (pounds/year)			
	Possible Emission Reductions per year from Replacement of a Gasoline Fueled Passenger Car	Possible Emission Reductions per year from Replacement of a Gasoline Fueled Light Truck	Possible Emission Reductions per year from Replacement of a Conventional Diesel Transit Bus
NO_X	26.2	37.7	1,019.9
SO_2	0.192	0.299	1.746
CO_2	10,169	15,772	182,984

"Well To Wheel" Analysis of Greenhouse Gas Emissions

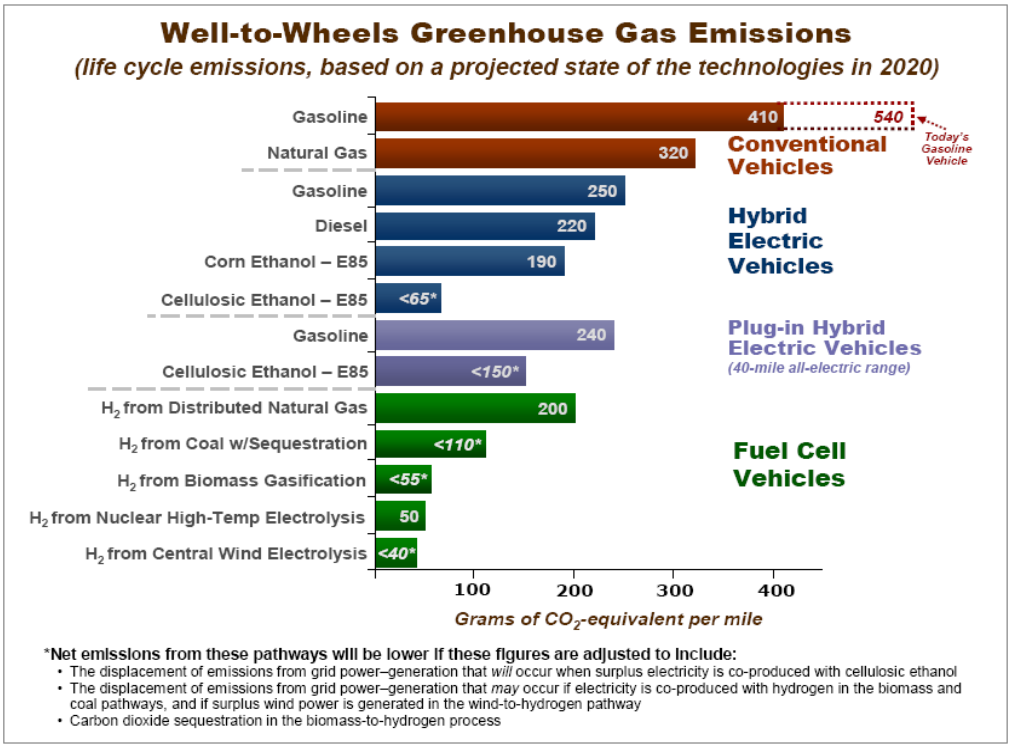
A well to wheel analysis takes into account emissions associated with different vehicle propulsion systems and fuel types from fuel production to energy used in driving a vehicle.

[77] This assumes hydrogen generated completely from renewable resources

[78] Calculations based upon average annual passenger car mileage of 12,500 miles and 14,000 miles for light trucks (U.S. EPA) and 37,009 average miles/year per bus (U.S. DOT FTA, 2007)

Fuel cell vehicles running on hydrogen produced from renewable resources virtually eliminates all GHG emissions compared to conventional fossil fuel powered vehicles. Hydrogen produced from fossil fuels such as coal or natural gas has well to wheel emissions ranging from approximately 110 to 200 grams of CO2 equivalent per vehicle mile. By comparison, gasoline powered conventional vehicles have well to wheel emissions of approximately 540 grams of CO_2 equivalent per vehicle mile as depicted in Figure XIV below.

Figure XIV - Well to Wheel Greenhouse Gas Emissions[79]



Energy Efficiency Impacts

Connecticut's transportation sector is responsible for the majority of the petroleum used in the state and petroleum expenditures accounting for 52,573 out of 86,141 barrels of petroleum (61 percent) and $4,104 million out of $6,122 million (67 percent), annually respectively.[80] The amount of fuel energy saved using fuel cells for transportation applications ranges from 2,407.40 Btu/mile for passenger cars to 16,264.20 Btu/mile for transit buses. Table IX below depicts the potential equivalent energy savings using fuel cells for transportation applications compared to conventional fuels and technologies.

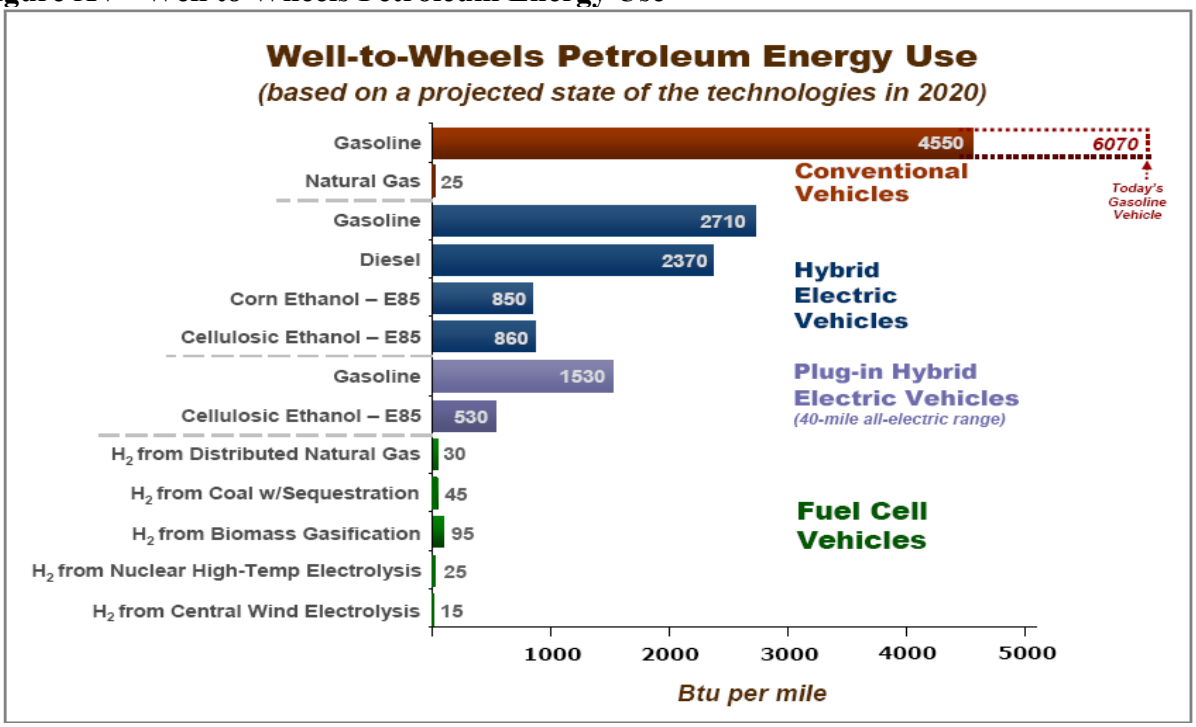
[79] Source: DOE Hydrogen Program Record #: 9002, March 25, 2009
[80] 2007 Energy Plan For Connecticut, Connecticut Energy Advisory Board, February 6, 2007

Table IX– Energy Savings Using Hydrogen Fuel Cells

Energy Savings from Replacement of Conventionally-Powered Vehicles with Hydrogen-Fueled Fuel Cell Vehicles (Btu/mile)		
Replacement of Gasoline Powered Passenger Cars	Replacement of Gasoline Powered Light Trucks	Replacement of Conventional Diesel Transit Buses
2,407.40	4,505.10	16,264.20
gal/mile equivalent energy savings		
0.019	0.037	0.12

Results of a well to wheels analysis show that fuel cell vehicles using natural gas use the least amount of energy per mile and consequently emit the least amount of greenhouse gases.

Figure XV– Well to Wheels Petroleum Energy Use[81]



Hydrogen produced from renewable energy will have well to wheel petroleum energy use of approximately 15 Btu/mile. Currently natural gas shows the greatest potential to serve as a transitional fuel for the near future hydrogen economy.

[81] DOE Hydrogen Program Record #: 9002, March 25, 2009 http://www.hydrogen.energy.gov/ pdfs/9002_well-to-wheels_greenhouse_gas_emissions_petroleum_use.pdf

Hydrogen Production, Storage, Delivery, and Cost

Hydrogen Production

It is expected that hydrogen fuel will be introduced as an energy carrier for the transportation sector in small quantities. Consequently, it is anticipated that distributed production of hydrogen may be a viable approach, which would initially require less capital investment for the development of facilities with lower production capacity, as compared to centralized hydrogen generation systems. In addition, distributed hydrogen generation would not require a substantial hydrogen transport and delivery infrastructure.

Three promising distributed hydrogen production technologies are (1) reforming of natural gas or liquid fuels, including bio-derived liquids, such as ethanol and bio-oil, (2) small-scale electrolysis located at the point of use, and (3) electrochemical hydrogen separation.

Fuel Reformation

Steam methane reformation is a common method for hydrogen generation today. It occurs when methane reacts with steam under pressure in the presence of a catalyst to produce hydrogen, carbon monoxide and a small amount of carbon dioxide.[82] Steam methane reforming often occurs at larger central plants where the hydrogen is produced and transported to the refueling site via truck. Some companies are currently exploring development of smaller steam methane reforming systems that could lead to on-site high quality hydrogen production at refueling stations. On-site fuel reformation may not directly reduce GHG emissions, but does offer a means to produce hydrogen for local fuel distribution systems.

The generation of hydrogen containing syngas at the point of use is especially valuable for military and public transportation applications due to security concerns and the availability of conventional fuels. Purifying a syngas stream to hydrogen remains technically and economically challenging, plus any remaining impurities in the hydrogen reformate stream can contaminate fuel cell catalysts, shortening the life of the fuel cell stack. Development work in this area is ongoing.

Precision Combustion, a Connecticut company, is developing and selling on prototype basis Microlith® fuel processors that could be used in onboard reforming for SOFC or HTPEM fuel cells. Microlith® also functions as a compact steam methane reformer that could provide the basis for a fueling station hydrogen plant converting liquid fuel or natural gas to hydrogen for vehicles and other uses.

Electrolysis

Electrolyzers produce medium to high pressure, high purity hydrogen using electricity and water. Fueling stations that utilize electrolysis units typically produce between 2 and 100 kg of hydrogen per day. Proton Energy Systems and Avālence are both Connecticut companies that

[82] Energy Efficiency and Renewable Energy Fuel Cell Technologies Program, U.S. Department of Energy, http://www1.eere.energy.gov/hydrogenandfuelcells/production/natural_gas.html, October 28, 2009

have extensive experience in supplying equipment for hydrogen vehicle fueling applications. The FuelGen™ electrolyzer system is the latest offering from Proton Energy Systems for vehicle fueling. FuelGen electrolyzer systems are modular and can be sized for small home fuelers, as well as fleet and bus applications. They can also operate under diverse duty cycle ranges that are ideal for intermittent renewable electricity sources, and for lower cost off-peak electricity rate structures.

Figure XVI– Proton's FuelGen-65 (left) and Avālence's Hydrofiller-50 (right)

Avālence's electrolyzer called the *Hydrofiller*™ is unlike other models of electrolyzers in that the Hydrofiller's design has eliminated the need for a compressor in order to store high quantities of hydrogen. Instead the hydrogen is created and pressurized all in the same chamber. This removal of a complex component significantly reduces the maintenance costs of Avālence's units. Current models of this design are able to produce quantities of hydrogen needed for individual vehicles and small fleet applications.

Combined Heat Hydrogen and Power (CHHP)

Combined heat and power systems (CHP) are systems that generate electricity and heat. These systems have been used all over the world to provide needed electricity and heat to schools, hospitals, prisons, industrial plants and district heating systems in cities. However, new technology is being developed that builds off of this design by providing a tri-generation concept, incorporating hydrogen production into the system.

FuelCell Energy, a Connecticut-based company, has developed a combined heat, hydrogen and power (CHHP) technology known as an electrochemical hydrogen separator (EHS). This device has the capability to produce electricity, thermal energy, and hydrogen. A sub-megawatt EHS system is capable of producing 250 kW to 300 kW of electricity, and up to 135 kg/day of hydrogen as well as 300,000 BTU/hour of thermal energy.[83] The EHS system is modular and can be expanded to meet the requirements of the host site, or if the power, thermal and hydrogen requirements warrant, a megawatt-sized EHS system can be used.

A CHHP system can be deployed in the same locations where current CHP systems are found and where hydrogen production is desired. However they are currently more favorable for

[83] FuelCell Energy;
http://www.fuelcellenergy.com/files/Electrochemical%20Hydrogen%20Separator%20fact%20sheet.pdf
http://www.fuelcellenergy.com/files/10-05-09%20CERL%20Award%20Final.pdf

maintenance or fleet centers that service hydrogen vehicles 24 hours a day by providing the necessary power, heat, and fuel for the facility and vehicles.

According to the U.S. Department of Transportation (DOT), there are approximately 5,000 truck stops in the U.S. that offer parking and other services, including fueling stations. Because the DOT mandates that truckers rest after driving for 11 hours, truckers often park at truck stops for several hours. Long-haul truckers typically idle 6 hours per day, or 1,830 hours per year, but some may not turn their engine off. Truck stop idling wastes fuel, pollutes the environment, and causes wear and tear on the equipment. Truck stop electrification would allow truckers to "plug in" vehicles to operate necessary systems without idling the engine. In Connecticut alone there are approximately 20 truck stops/public rest areas in addition to five commercial truck stops located along Interstates 95 and 84. An EHS located at one of these stops would provide the necessary electricity to reduce truck idling as well as provide fuel for hydrogen vehicles along with heat and electricity for the truck stop facility.

Hydrogen Fueling Station Costs

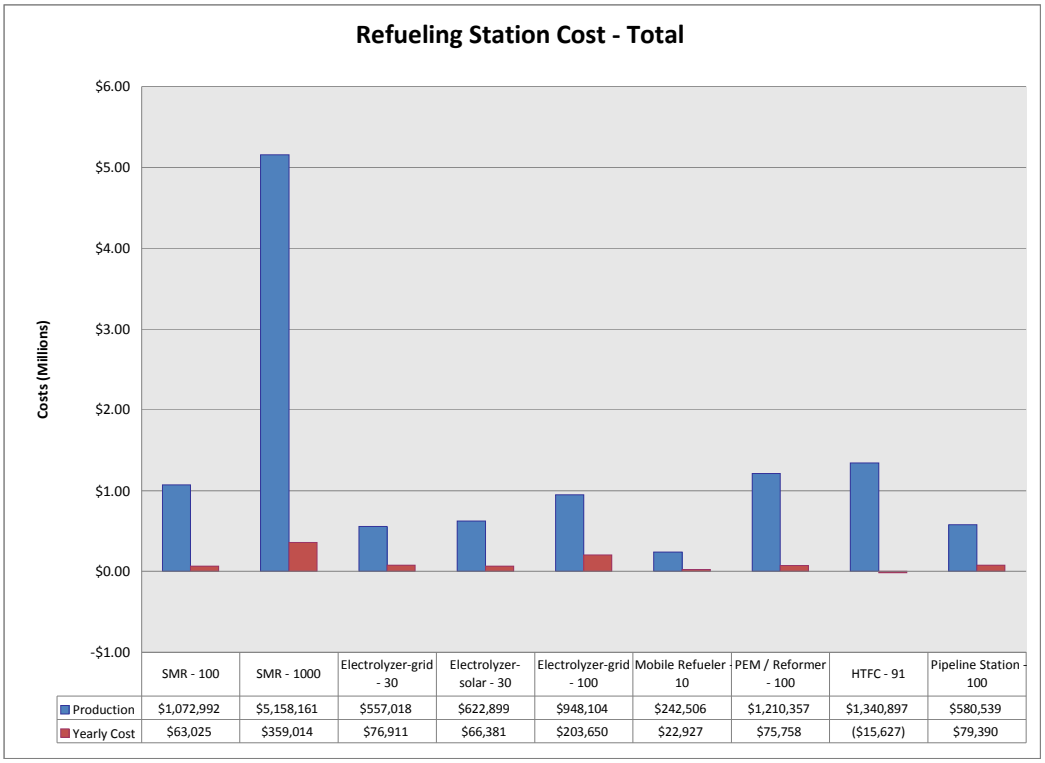
California initiated the development of a Hydrogen Highway for the purpose of accelerating the introduction of hydrogen-fueled vehicles. With this, California became the current leader in hydrogen refueling stations in the U.S. with 21 stations as of 2010 and another eight planned for 2011. Estimates for the costs of building the hydrogen refueling stations, including the cost of equipment, installation and operation for several hydrogen production technologies are summarized below. This estimate compares station and unit costs for on-site hydrogen with steam methane reformers (100 kg/day and 1000 kg/day); electrolyzers using electricity from the grid (30 kg/day and 100 kg/day) and solar (30 kg/day); a mobile refueler (10 kg/day); a proton exchange membrane (PEM) reformer (100 kg/day); high temperature fuel cell (HTFC) (910 kg/day); and hydrogen that is brought in through a pipeline (100 kg/day). The model used to estimate the cost of developing hydrogen infrastructure utilizing various technologies assumed that the hydrogen refueling capacity would be integrated into existing gasoline stations with 8 dispensers total. Small station use was estimated to have one hydrogen dispenser and large station use was estimated to have three hydrogen dispensers. [84]

Production costs include production, storage, compression, and dispensing equipment as well as engineering, site development, installation and contingency. Yearly operating costs include electricity, natural gas, hydrogen, insurance, and taxes, but at this time maintenance costs have not been confirmed and have not been included.

As detailed in Figure XVII and Figure XVIII below, steam methane reformation with a capacity of 1,000 kg had the highest production cost, but the lowest cost for each kg of hydrogen produced. Hydrogen pipelines had one of the lowest production costs and one of the lowest cost for each kg of hydrogen produced; however, there are no hydrogen pipelines in Connecticut at this time.

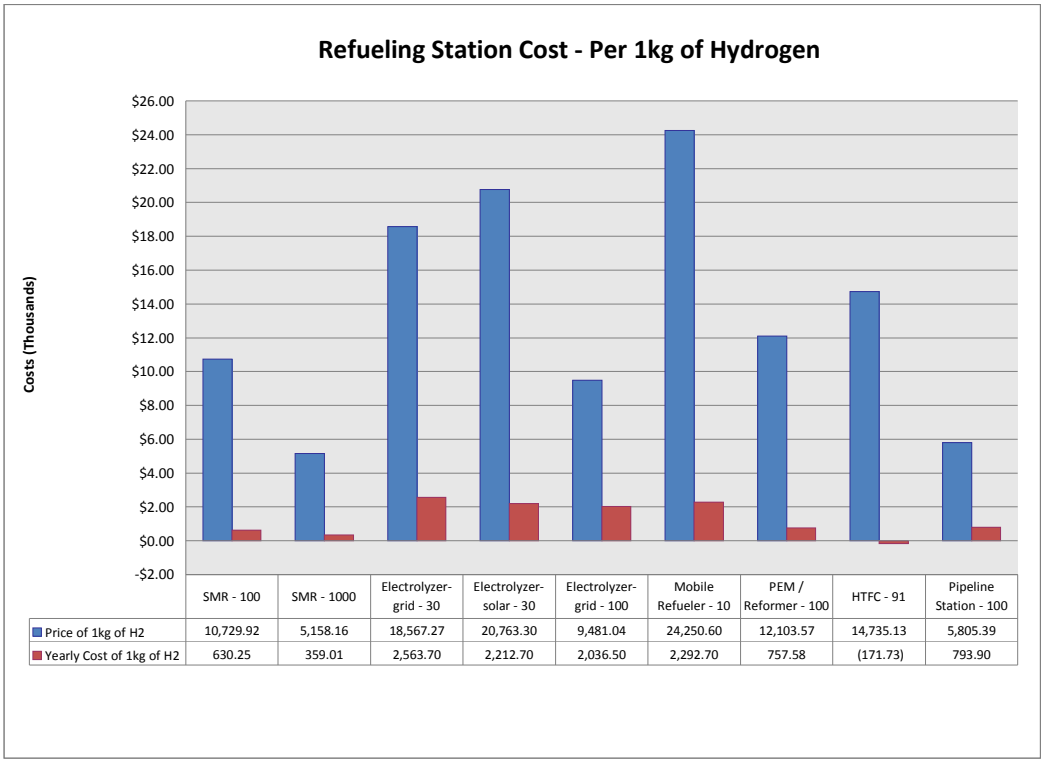
[84] Economy Topic Team Report, California 2010 Hydrogen Highway Network. Economy Topic, January 5, 2005

Figure XVII– Hydrogen Refueling Station Cost[85]



	SMR - 100	SMR - 1000	Electrolyzer-grid - 30	Electrolyzer-solar - 30	Electrolyzer-grid - 100	Mobile Refueler 10	PEM / Reformer - 100	HTFC - 91	Pipeline Station - 100
Production	$1,072,992	$5,158,161	$557,018	$622,899	$948,104	$242,506	$1,210,357	$1,340,897	$580,539
Yearly Cost	$63,025	$359,014	$76,911	$66,381	$203,650	$22,927	$75,758	($15,627)	$79,390

Figure XVIII– Hydrogen Refueling Station Costs per 1kg of Hydrogen



	SMR - 100	SMR - 1000	Electrolyzer-grid - 30	Electrolyzer-solar - 30	Electrolyzer-grid - 100	Mobile Refueler - 10	PEM / Reformer - 100	HTFC - 91	Pipeline Station - 100
Price of 1kg of H2	10,729.92	5,158.16	18,567.27	20,763.30	9,481.04	24,250.60	12,103.57	14,735.13	5,805.39
Yearly Cost of 1kg of H2	630.25	359.01	2,563.70	2,212.70	2,036.50	2,292.70	757.58	(171.73)	793.90

[85] Economy Topic Team Report, California 2010 Hydrogen Highway Network. Economy Topic, January 5, 2005

Hydrogen Transportation and Storage

Currently, the hydrogen refueling station in South Windsor is supplied with liquid hydrogen trucked from a generating plant near Niagara Falls where the hydrogen is produced by hydro-powered electrolysis units. Hydrogen can also be delivered through pipelines to be stored and dispensed at refueling stations. However, adequate pipeline infrastructure does not exist in the northeastern United States. Natural gas transmission pipelines could be converted to hydrogen, but would still require a delivery system between the transmission pipeline and the consumer. In addition, storing liquid hydrogen on site is costly due to cryogenic storage for hydrogen that must be kept at -425 degrees Fahrenheit. Longer term, central plants with local and then regional distribution via hydrogen pipelines may be the most cost effective source of hydrogen, but this will require a significant number of fueling stations with robust demand to make them economically viable.

Hydrogen Refueling Station Infrastructure

In general, there are three major components of a hydrogen fueling station:

1. Dispenser – the equipment that physically fills the on-vehicle hydrogen storage tank;
2. Compressor – equipment that increases the pressure of the hydrogen to the desired pressure for the vehicle. This pressure is dictated by the vehicle manufacturer.
3. Hydrogen storage – this may vary for each application depending upon if the hydrogen is liquid or gaseous, delivered to the station by truck or generated onsite.[86]

In addition to these three major components, hydrogen refueling stations typically have control equipment, auxiliary equipment, piping, and a vehicle interface, as depicted in Appendix 4

Hydrogen Dispenser

Hydrogen dispensing involves the transfer of hydrogen fuel from storage containers to hydrogen-fueled vehicles. Hydrogen can be dispensed in either liquid or compressed gas form. Dispensing hydrogen is similar to dispensing gasoline, but the equipment is different to accommodate the pressure associated with storing hydrogen.

For gaseous hydrogen, hydrogen fueling stations offer nozzles at two pressure levels of fuel (i.e., one for 5,000 psi and one for 10,000 psi) to prevent accidental fueling of, for example, 10,000-psi hydrogen gas into a 5,000-psi vehicle tank. These hydrogen dispensers include over-pressure protection, remote shut-off capability, and automatic-off breakaway nozzles and hoses to ensure safety. An infrared communication device is also becoming a standard component of refueling to determine if/when the tank is full. Infrared communication is an upgraded version of its predecessor that required a separate communications connector to be plugged into the vehicle in addition to the one dispensing the hydrogen. Separate communications connectors are still common in older refueling stations; however, this configuration that uses a separate communicator connector may not be compatible with newer vehicles.

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[86] Technical Report to the Connecticut Center for Advanced Technology -Hydrogen & Fuel Cell Codes & Standards: Reference Guide for Connecticut; Hydrogen Safety, LLC, April 23, 2008

Hydrogen dispensing must follow strict codes and standards addressing equipment requirements, leak detection, fire suppression, dispensing procedures, temperature and pressure limits, and operator training much like current fueling stations.[87]

Refueling Time

In typical public-station "fast-fill" dispensing, drivers can fuel their hydrogen-powered vehicles in several minutes. The actual time depends on the vehicle's onboard tank capacity and the dispensing equipment used. However, the refueling times for hydrogen vehicles are typically around 0.8 kg per minute. For a typical passenger type fuel cell vehicle with approximately 5 kg of storage, refueling times would be approximately 4 to 5 minutes, which is comparable with existing fueling times for passenger type gasoline vehicles. For a fuel cell bus with a storage capacity of 30 – 50 kg, refueling would take approximately 25 - 35 minutes. Future research goals aim to bring this time down to the equivalent of an 11-12 minute fill up for a fuel cell powered bus in addition to increasing hydrogen storage capacity to enable longer commuting distances.

Hydrogen Storage

The amount of storage for a hydrogen refueling station will be highly dependent upon the projected demand. A station serving one passenger vehicle will have a demand of 1 to 8 kg per day, depending upon the specific vehicle it is serving. A station serving one large transit bus will have an approximate demand of 30 kg per day. The dispensable quantity of stored hydrogen is typically about one third to one half of the gross quantity stored. This is required because the pressure in the storage vessels drops as the hydrogen is being dispensed. For example, if the daily vehicle demand is 30 kg, the refueling station may be designed to have at least 60 kg of storage. If fast fill capacity is desired for the hydrogen refueling station in this example, the amount of hydrogen storage may be as much as 90 kg.

Gaseous Hydrogen Storage Systems

Hydrogen can be stored in a gaseous state, typically under pressure, in order to reduce volumetric requirements for the storage system. Higher pressure storage vessels typically cost more, but must be considered to reduce refueling times and to increase vehicle storage and driving range.

Liquid Hydrogen Storage Systems

Liquid hydrogen is stored in double walled vacuum insulated storage tanks (cryogenic storage) which can be placed above or below ground. Liquid storage allows hydrogen to be stored in larger quantities due to its denser properties, yet requires liquefaction processing and cryogenic storage tanks. As the market matures, the use of liquid hydrogen may be a more cost effective way to store hydrogen fuel for vehicle use as opposed to the traditional method of using hydrogen gas under pressure.

[87] http://www.hydrogen.energy.gov/permitting/stations_dispensing.cfm

Delivered Cost of Hydrogen

One of the defining features and benefits of hydrogen for use as a transportation fuel is the ability for it to be produced from a number of different sources, including renewable energy, fossil fuels, and nuclear power. The wide range of hydrogen sources means that a hydrogen economy is not dependent on any single resource for energy[88]. The cost of the hydrogen produced depends on the type and size of the dispensing station as well as the source of the hydrogen. Steam methane reformed (SMR) hydrogen has prices per kg ranging from $2.19 to $3.51 per kg. Hydrogen from renewable energy currently ranges in prices from $1.30 per kg for hydrogen produced from large hydroelectric turbines to over $40 per kg for hydrogen produced from the most expensive photovoltaic (PV) power systems.[89] Currently, CTTransit pays approximately $4.50/kg for liquid hydrogen trucked from a generating plant near Niagara Falls where the hydrogen is produced by hydro-powered electrolysis units.

Connecticut Industry: Economic Assessment

Economic indices, developed in conjunction with the Connecticut Department of Economic and Community Development, suggest that the hydrogen and fuel cell industry is an emerging economic cluster.

Connecticut Fuel Cell Companies

Connecticut's industry has been involved with hydrogen and fuel cell technologies since the 1950s. Connecticut companies were involved early with electrolysis systems for submarines and spacecraft applications and with fuel cells for spacecraft. Since the 1960s, Connecticut companies pioneered application of fuel cell technology to stationary power applications and continue to lead the world in this fuel cell application. Beginning in the 1990s, Connecticut companies have participated in applying fuel cell and hydrogen generation technology to transportation applications.

Connecticut Hydrogen Companies

Connecticut companies have also been involved with hydrogen generation through electrolysis for decades. Delivery of electrolysis units by Connecticut companies began with installation of an electrolysis unit on the submarine Nautilus in the 1950s. While the desired product from these electrolysis units is oxygen, they also produce hydrogen. More recently, Connecticut companies have been involved with hydrogen generation for transportation, laboratory and industrial hydrogen needs. Table X below shows some of these companies and the activity they perform.

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[88] One kg of hydrogen is approximately equal to one gallon of gasoline. DOE Hydrogen Program Record # 9002 March 25, 2009. http://www.hydrogen.energy.gov/pdfs/9002_well-to-wheels_greenhouse_gas_emissions_petroleum_use.pdf

[89] CCAT Regional Resource Center: Hydrogen Generation from Renewable Technology http://energy.ccat.us/energy/models/hydrogen2.php

Table X– Connecticut Hydrogen Companies

Connecticut Hydrogen Companies			
Company	**Electrolysis**	**Generating Hydrogen from Hydrocarbons**	**Overall Supply of Hydrogen**
Avālence www.avalence.com	High pressure systems for industrial, premium power and transportation		
FuelCell Energy, Inc. www.fce.com		Electrochemical hydrogen separator	
Hamilton Sundstrand Div. UTC www.hamiltonsundstrandcorp.com	Electrolysis systems for oxygen generation aboard spacecraft and submarines		
Praxair www.praxair.com			Supplier of industrial gases including hydrogen
Precision Combustion, Inc. www.precision-combustion.com/		Compact fuel reformers and fuel processors for reforming conventional fuels to a hydrogen-rich gas and hydrogen	
Proton Energy Systems www.protonenergy.com	Electrolysis systems for industrial applications and for demonstration transportation applications		
Treadwell www.treadwell.com	Electrolysis systems for submarine, stationary, and automotive applications		

Core Competencies of Connecticut Hydrogen Companies

Connecticut hydrogen companies have expertise covering the entire range of hydrogen production, storage, and distribution. There are four electrolysis manufacturers in the State: Avālence, Proton Energy Systems, Hamilton Sundstrand Division of United Technologies and Treadwell.

Avālence, LLC based in Milford, CT offers electrolytic technology to produce high-pressure hydrogen gas for clean energy infrastructure applications. Avālence is a spin-off of two longstanding Connecticut firms with more than 150 years combined experience in the fields of

hydrogen and air-separation equipment design and manufacture. Avālence's market focus is on commercializing a high pressure electrolyzer for use in industrial and fueling applications.

Two other Connecticut companies involved with electrolysis include Treadwell and the Hamilton Sundstrand Division of United Technologies who use their technology for oxygen generation on submarines and spacecraft. Treadwell systems have been installed on over 100 submarines in the U.S. Navy fleet beginning with the submarine Nautilus in the 1950s. Treadwell has also developed hydrogen systems for FuelCell Energy and General Motors.[90]

Proton Energy Systems (Proton) produces electrolysis systems for the purpose of hydrogen generation for industry, utilities, and transportation. To date, fifteen fueling stations, utilizing variants of Proton's commercial HOGEN® hydrogen generators have been installed in environments ranging from southern California to northern Vermont for hydrogen vehicle systems. Proton's electrolyzer technology has been demonstrated in more than 1,200 commercial installations, located in 60 countries worldwide. Proton is also involved with application of its hydrogen generators in combination with a fuel cell power generator for use as an electric energy storage device.

Precision Combustion (PCI) is developing Microlith® compact reformers and fuel processors for efficiently converting conventional fuels such as diesel, gasoline, and biofuels to hydrogen-containing syngas for SOFC and HTPEM fuel cells. Primary applications include use on vehicles where the technology's small size, fast transient response and high syngas output add value. A Microlith® natural gas steam reformer is in development for integration into a hydrogen production system for distributed use applications such as refueling stations. PCI's technology is primarily development stage, though it has sold fuel reformers for both natural gas-fueled and liquid-fueled fuel cell systems.

Praxair is an industrial gas company that produces specialty gases including hydrogen, and distributes compressed gas and liquid hydrogen by tanker trucks and by compressed gas hydrogen pipelines to industrial customers throughout the world. It should be noted that while Praxair is headquartered and distributes hydrogen in Connecticut, its hydrogen generation facilities are located in other states.

The major fuel cell OEMs in Connecticut are involved with transportation applications and/or generating hydrogen from hydrocarbon fuels such as natural gas. UTC Power has fuel cell power plants in the drive systems of demonstration automobiles for Hyundai and Nissan, in auxiliary power units in BMW's vehicle demonstrations, and power plants in several fuel cell buses in California, Connecticut and Europe. Both UTC Power and FuelCell Energy incorporate on-site generation of hydrogen by reforming natural gas in their stationary fuel cell power plants and have installed over 300 units in multiple countries around the globe. Together, they are the leaders in on-site fuel reformation to generate hydrogen for the input into fuel cell facilities. Other fuel cell companies in Connecticut, such as Infinity Fuel Cell and Hydrogen LLC incorporate hydrogen storage in regenerative fuel cell systems

[90] http://www.treadwellcorp.com/mphg.htm

Connecticut's Hydrogen and Fuel Cell Industry Supply Chain

Supply chain refers to the distribution channel of a product, from its sourcing, manufacture, and delivery to the end use consumer.[91] The future state of Connecticut's fuel cell industry supply chain, which includes the hydrogen supply chain, can conceivably consist of hundreds of suppliers and tens of thousands of employees. This fuel cell industry supply chain will include suppliers of fuel, fuel storage, fuel processing, fuel cell stack manufacturing, peripherals and controls manufacturing, power conditioning and management and fuel cell applications, plus all the integration, service and support that goes along with a power generation industry. Connecticut is fortunate to have over 40 of these core suppliers already involved in the hydrogen and fuel cell industry.

In 2010, the hydrogen and fuel cell industry contributed to the State's economy by providing over 1,200 jobs directly associated with research and development and the manufacture of equipment, and over 1,500 indirect jobs for a total of over 2,700 jobs statewide. In addition, the hydrogen and fuel cell industry contributed approximately $29 million annually in State tax revenue; approximately $2 million annually in local tax revenue; and over $340 million annually in gross state product.[92]

Business Opportunities for Connecticut Companies

Many Connecticut companies are involved with development, demonstration, and commercialization of products and services for hydrogen fueled transportation. These products include: fuel cell power plants for use in automobiles and buses, electrolysis systems to convert water to hydrogen fuel, fuel reformers for on-board and stationary conversion of conventional fuels to hydrogen fuel, and the infrastructure business of producing and delivering hydrogen for transportation use.

The advent of hydrogen-fueled transportation will have the following impacts on Connecticut:

- business opportunities for Connecticut companies;
- development of hydrogen fuel infrastructure in Connecticut;
- improved environmental performance; and
- increased transportation efficiency.

Challenges for Hydrogen Fuel Infrastructure and Vehicles

Development of a hydrogen fuel infrastructure and vehicles using hydrogen fuel cells for power has technical challenges including:

- cost and efficiency of clean generation of hydrogen;
- cost, efficiency and scale of hydrogen distribution;
- size and cost of hydrogen storage on vehicles, refueling stations and for distribution;
- fuel cell power plant ability to operate consistently with current operating environment and power demands of vehicles; and
- fuel cell power plant durability and reliability.

[91] www.learnthat.com
[92] Based on REMI analysis performed by DECD, 2006

In addition, there are significant business challenges:

- the general public is not educated enough on the topic of hydrogen;
- building code officials are not sufficiently familiar with the technology and the code and standards required for developments;
- there is uncertainty regarding the availability of hydrogen supply infrastructure on the part of vehicle manufacturers and potential purchasers. There is also uncertainty in regard to the vehicle market demand for hydrogen fuel on the part of the hydrogen infrastructure companies;
- alternative technologies focusing on similar objectives create uncertainties in regard to investment in hydrogen and fuel cell vehicles;
- fuel cell component cost; and
- fuel cell power plant cost.

U.S. Employment Projections

A U.S. Department of Energy report notes that the lower New England and the upper Mid-Atlantic regions will increase its employment base by an additional 140,000 jobs by 2050 in a transition to a hydrogen economy from a petroleum based economy. Most new jobs will be in the professional and technical services sector. [93,94] This report, summarized below in Table XI, also states that "gains are primarily in the production and delivery of hydrogen" given that the region is a "large importer of oil-based products, including gasoline."

Table XI– U.S. Employment Projections

U.S. Employment Projections				
Year	**2010**	**2018**	**2035**	**2050**
Conventional Fueling Stations[95]	834,000	768,000	-	926,000
H2 Refueling Stations	6	187	67,000	880,000
Electrolysis Production Manufacturing	440	3,322	161,200	311,000

Refueling Stations Employment

Today, U.S. refueling stations average 7.6 jobs per station.[96] It is estimated that fueling station employment will decline 8.8 percent between 2008 and 2018.[97] While the number of employees per fueling station is expected to decrease, more refueling stations will likely be constructed to accommodate projected increases in population and development. With the transformation to a

[93] Includes Connecticut, Massachusetts, Rhode Island, New York, New Jersey and Pennsylvania
[94] Effects of a Transition to a Hydrogen Economy on Employment in the United States: Report to Congress, July 2008
[95] U.S. Department of Labor, Bureau of Labor Statistics for the year 2008.
[96] 2002 Economic Census, based on 5 day 33 hour work week, or a 6.6 hour work day
[97] U.S. Department of Labor, Bureau of Labor Statistics http://data.bls.gov:8080/oep/servlet/oep.nioem.servlet.ActionServlet; Service Station Attendants only.

hydrogen economy, and the capture of 95 percent of this workforce, it is anticipated that over 880,000 jobs will be required at refueling stations nationally that provide hydrogen by 2050. It is assumed that these jobs will initially be shared with conventional fueling stations that offer both conventional fuels and hydrogen.

Electrolysis Manufacturing

It is estimated that approximately 44 GW of electrolysis units would be manufactured for hydrogen refueling applications by 2050. Using a Crawford and Wright analysis, the number of direct jobs associated with the manufacture of electrolysis units is estimated to increase from approximately 440 jobs in 2010, to 3,322 in 2018, to over 311,000 by 2050. [98] An economic multiplier of 2.31 can be used to estimate the additional indirect and induced jobs for this industry sector. Using this economic multiplier, the projected number of indirect and induced employment is expected to increase from approximately 576 jobs in 2010 to over 407,400 by 2050. These indirect and direct jobs may include material and equipment delivery; real estate, banking/finance; architectural and engineering services; environmental and technical consulting services; construction; and other professional and technical services.

Vehicle Manufacturing

Jobs associated with the manufacture of fuel cell vehicles were estimated to increase in tandem with the availability of hydrogen refueling infrastructure, ultimately penetrating 95 percent of the current vehicle market. It is estimated that employment in the motor vehicle and parts manufacturing industry is expected to decline nationally from approximately 877,000 jobs to 734,000 jobs, or by 16 percent between 2008 and 2018. "Although more automobiles and light trucks will be manufactured in the U.S. over this period, productivity improvements will enable manufacturers to produce these vehicles and parts with fewer workers."[99] Direct jobs associated with the manufacture of fuel cell vehicles, which is estimated to reach approximately 15 million vehicles per year or 63 percent of all light duty vehicles sold in 2050[100], are projected to increase to over one million jobs in 2050. However, most vehicle manufacturing jobs will be outside of Connecticut.

Connecticut Refueling Station Projections

As detailed in Table XII below, Connecticut is expected to have approximately seven hydrogen refueling stations on line by 2020 and 189 by 2035. Station capacity in Connecticut is expected to increase from an average of 50 kg per day in 2010/2011 to an average of 1,500 kg per day by 2035. Hydrogen dispensed is expected to increase from approximately 150-200 kg/day in 2010 to approximately 284,000 kg in 2035 The average price per kg of hydrogen dispensed is assumed to decrease from $4.67 in 2010 to cost $3.65 in 2035 (current dollars).[101] These projections are based on the percentage of traditional refueling stations in Connecticut.

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[98] A National "Green Energy" Economic Stimulus Plan Based on Investment if the Hydrogen and Fuel Cell Industry, Connecticut Center for Advanced Technology, Inc, November 2009

[99] U.S. Department of Labor, Bureau of Labor Statistics; http://www.bls.gov/oco/cg/cgs012.htm

[100] Effects of a Transition to a Hydrogen Economy on Employment in the United States: Report to Congress, July 2008

[101] "Hydrogen Demand, Production, and Cost by Region to 2050," Argonne National Laboratory and TA Engineering, Inc., August 3, 2005.

Table XII - Connecticut Refueling Station Projections

Connecticut Refueling Station Projections				
Year	**2010/2011**	**2020**	**2035**	**2050**
Refueling Stations	4	7	189	1,090
Average Station Capacity (kg/day)	50	150	1,500	12,000
Hydrogen Dispensed (kg/day)	200	1,050	283,500	13,080,000
Price/kg Hydrogen	$4.63	$3.91	$3.65	$3.58

Connecticut Sales Projections

Connecticut's sales projections are based upon Connecticut capturing a significant portion of the sales nationally. Connecticut's hydrogen industry can expect to remain a leader in electrolysis unit sales, and increase its market share of passenger vehicle power plants. If the numbers of refueling stations increases as projected, electrolysis equipment sales for Connecticut's hydrogen industry is projected to increase from over $3 million in 2010 to over $1 billion in 2035; and vehicle power plants sales are expected to increase to over $180 million by 2035.

Connecticut Employment Projections

The projected increase in Connecticut employment that may result from a transition to a hydrogen and fuel cell economy is expected to consist of a transfer of jobs from traditional markets and services. Connecticut's most significant employment increases would be realized in the electrolysis manufacturing sector. Connecticut's employment in this sector is projected to grow from approximately 110 in 2010 to over 31,000 by 2050. Vehicle power plant manufacturing is also expected to increase to over 18,000 jobs by 2050. It is projected that these two sectors would combine to contribute over 50,000 jobs to Connecticut's economy by 2050.

Financing and Incentives

The United States uses a variety of financial incentives to promote green technology on both a federal and state level. Each of these incentives can consist of a different type of aid, of which the most used include sales and property tax exclusions, rebates and loans.[102] Connecticut is no exception as it provides a number of unique incentives to encourage businesses and individuals to invest in alternative fuel sources. However, a large portion of the funding provided for the hydrogen refueling industry is supplied by federal entities.

State Funding

The Connecticut Clean Energy Fund (CCEF)/Connecticut Innovations (CI)

The Connecticut Clean Energy Fund provides a variety of financial incentives and educational programs to encourage homeowners, companies, municipalities, and other institutions to support renewable energy. Among its many activities, the CCEF manages the Operational Demonstration

[102] http://www.dsireusa.org/

Program and On-Site Renewables Distributed Generation (DG) Program. Connecticut Innovations manages the Connecticut Clean Energy Fund.

Operational Demonstration Program[103]

The Operational Demonstration Program (Op Demo) is designed to accelerate commercialization of emerging clean energy technologies in Connecticut. The program funds installation, testing and demonstration of pre-commercial technologies at host sites in Connecticut that are representative of typical customers. Program participants conduct testing in order to qualify a product/process for commercial application and validate performance and cost advantages. Op Demo projects can be full systems or system components representing product or manufacturing process innovations in eligible technology areas, including fuel cells and hydrogen production. The new Op Demo program offers unsecured loans of between $150,000 and $500,000 with favorable repayment terms and requires a minimum 25 percent cost share.

On-Site Renewable DG Program

The On-Site Renewable DG Program provides grants to support the installation of systems that generate electricity at commercial, industrial or public buildings. The On-Site Renewable DG Program is competitive, and includes a Best of Class solicitation and a Public Buildings solicitation. The Best of Class solicitation, which is a two-year, $8.86 million competitive, financial support program, is designed to stimulate demand for on-site renewable distributed generation (OSDG) installations at for-profit, not-for-profit and municipal buildings in Connecticut[104]. The Public Buildings solicitation, which is a two-year, $4 million competitive support program, is designed to stimulate demand for on-site renewable distributed generation installations at municipal and governmental sites in Connecticut.[105]

Connecticut Clean Tech Fund[106]

The Connecticut Clean Tech Fund makes investments in seed and early-stage companies focused on innovations which conserve energy and resources, protect the environment, or eliminate harmful waste. A company may receive investments of up to $1 million from the Clean Tech Fund. Clean technology includes wind power, solar power, biomass, hydropower, biofuels, information technology, green transportation, electric motors, lighting, and energy efficiency technologies.

Federal Funding

Clean Cities Grant

Clean Cities is a government-industry partnership sponsored by the U.S. Department of Energy's (DOE) Vehicle Technologies Program. The goal of Clean Cities is to expand and stimulate alternative fuel and advanced technology markets to reduce petroleum consumption. A Department of Energy Clean Cities Grant funds cost-share projects, submitted by its Clean Cities

[103] Connecticut Clean Energy Fund; http://www.ctcleanenergy.com/Portals/0/Op%20Demo%20Fact%20Sheet.pdf
[104] Connecticut Clean Energy Fund; http://www.ctcleanenergy.com/Portals/0/OSDG%20Best%20of%20Class%20RFP.pdf
[105] Connecticut Clean Energy Fund; http://www.ctcleanenergy.com/Portals/0/OSDG%20Public%20Buildings%20RFP.pdf
[106] Connecticut Innovations; http://www.ctinnovations.com/funding/cleantech/cleantech_about.php

Coalitions, that meet the goals of the program. In 2009, nearly $300 million was awarded to 25 projects nationwide. One of these projects included the Connecticut Clean Cities Future Fuels Project, which received over $13 million and included funding for a new hydrogen refueling station in Hartford, CT.

United States Department of Energy - Loan Guarantee Program

Title XVII of the Federal Energy Policy Act of 2005 (EPAct 2005) authorized the Department of Energy to issue loan guarantees for projects that "avoid, reduce or sequester air pollutants or anthropogenic emissions of greenhouse gases; and employ new or significantly improved technologies as compared to commercial technologies in service in the United States at the time the guarantee is issued." Hydrogen fuel cells for stationary and or vehicular applications are eligible. This program focuses on projects with an estimated cost of over $25 million. If approved, full repayment is required over a period not to exceed the lesser of 30 years or 90% of the projected useful life of the physical asset to be financed.

Federal Transit Administration (FTA)[107]

The FTA provides a number of programs that allow transportation companies, both private and state, to expand and improve their fleet. In 2005, President George W. Bush signed the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) which provided $500 billion in guaranteed funding for federal surface transportation programs. However, this transportation law has gone through multiple extensions with its current extension expiring in March 2011.[108] A majority of the financing for renewable energy transit vehicles comes from these programs.

Bus and Bus Facilities Program

The Bus and Bus Facilities Program provided by the FTA under the SAFETEA-LU provides capital assistance towards new and replacement buses and their facilities. The funds provided can also be used for bus maintenance facilities, service/fleet expansion, bus rebuilds, accessory and miscellaneous equipment such as mobile radio units, computers and garage equipment. Of the $972 million allocated for this program $13 million is available to 3 non-profit organizations in geographically diverse areas that will use it towards fuel cell buses.

Clean Fuels Grant Program

The Clean Fuels Grant Program was developed under SAFETEA-LU to assist non-attainment and maintenance areas in achieving or maintaining the National Ambient Air Quality Standards for ozone and carbon monoxide as well as support emerging clean fuel and advanced propulsion technologies for transit buses and markets for those technologies. Those who received grants associated with this program could use the money for purchasing or leasing clean fuel buses or constructing facilities to serve the buses.

[107] Federal Transit Administration; http://www.fta.dot.gov/grants_financing.html
[108] http://www.asla.org/NewsListingDetails.aspx?id=24478

TIGGER Program

The Transit Investment for Greenhouse Gas and Energy Reduction Program (TIGGER) works directly with public transit agencies to implement new strategies for reducing greenhouse gas emissions or reduce energy usage from their operations. These strategies can be implemented through operational or technological enhancements or innovations. To align the TIGGER Program with other strategic initiatives, FTA encourages a variety of projects including those that will demonstrate innovative electric drive and related technology approaches to achieving these goals. Electric drive initiatives and TIGGER supported projects could include, but are not limited to:

- On-Board Vehicle Energy Management (energy storage, regenerative braking, fuel cells, turbines, engine auto start/stop, etc)
- Electrification of Accessories (air conditioning, air compressor, power steering, etc.)
- Bus Design (lightweight materials, component packaging, maintainability, etc.)
- Locomotive Design (energy storage, regenerative braking, fuel cells, turbines, engine auto start/stop, lightweight material etc).

First initiated as part of the American Recovery & Reinvestment Act (ARRA) of 2009, the TIGGER Program has been continued in subsequent appropriations bills.

Flexible Funding for Highway and Transit – Congestion Mitigation and Air Quality Improvement Program (CMAQ)

The CMAQ program was first initiated in 1991 under the Intermodal Surface Transportation Efficiency Act (ISTEA) and then reauthorized with SAFETEA-LU which now funds CMAQ with approximately $1.7 billion per year. The CMAQ funds are apportioned to States based on a formula that considers the severity of their air quality problems. CMAQ projects and programs are often innovative solutions towards achieving the Clean Air Acts National Ambient Air Quality Standards.[109]

Traditional and Non-Traditional Funding Mechanisms for Transportation

Traditional Funding Mechanisms[110]

The majority of revenues to fund transportation improvements in Connecticut are derived from federal funds, fuel taxes, sales taxes on fuel or additional fuel industry taxes, bond proceeds, vehicle registration fees, and other mechanisms.

[109] http://tea21.ky.gov/air_quality_files/CMAQ_pdf/CMAQ_FedBrochure.pdf
[110] U.S. Department of Transportation, Federal Highway Administration, 2008; http://www.fhwa.dot.gov/policyinformation/statistics/2008/sf1.cfm

Non-Traditional Funding Mechanisms

Non-traditional funding mechanisms include "Innovative Finance" mechanisms for transportation that the Federal Highway Administration has broadly defined as a combination of specially designed techniques that: supplement traditional highway financing methods with a goal to maximize the ability of states and other project sponsors to leverage Federal capital for needed investment in the nation's transportation system; more effectively utilize existing funds; move projects into construction more quickly than under traditional financing mechanisms; and make possible major transportation investments that might not otherwise receive financing.[111] Some of these non-traditional funding mechanisms, summarized in Table XIII, include state infrastructure banks, Federal Credit Assistance, GARVEE Bonds, Private Activity Bonds, and the Flexible Match program.

State Infrastructure Banks (SIB)
SIB is an infrastructure investment fund established to facilitate and encourage investment in eligible transportation infrastructure projects sponsored by public and/or private entities. Through a SIB, a state can use its initial capital, provided by its federal-aid highway apportionment, federal transit allocations, and non-federal monies to make loans, provide credit enhancement, serve as a capital reserve for bond or debt financing, subsidize interest rates, issue letters of credit, finance purchase and lease agreements, provide debt financing security, or provide other forms of financial assistance for construction of projects qualified under the federal-aid highway program and transit capital projects. The revolving loan fund allows pooled vehicle purchases that may help reduce acquisition costs. In addition, it provides a mechanism for states to make loans (with interest) or leases to transit operators who might not be able to finance transactions on their own. The SIB can make new financial assistance available to other eligible projects, continually recycling the initial monies, thus leveraging the initial funds available. Local grantees may be able to use subsequent years' rural or urban grant funds to make loan or lease payments, including reasonable interest.[112]

Transportation Infrastructure Finance and Innovation Act (TIFIA)
The TIFIA program provides Federal credit assistance in the form of direct loans, loan guarantees, and standby lines of credit to finance surface transportation projects of national and regional significance. TIFIA credit assistance provides improved access to capital markets, flexible repayment terms, and potentially more favorable interest rates than private capital markets (currently 3.98% interest rate for 35-year loans). Many surface transportation projects such as highway and transit projects are eligible for assistance. Each dollar of Federal funds can provide up to $10 in TIFIA credit assistance. These funds may be used for projects that cost at least $100 million ($30 million for projects principally involving the installation of an intelligent transportation system) or 50 percent of a State's most recent year's Federal-aid highway apportionments, whichever is less. The project must be supported at least in part by user charges or other dedicated revenue sources, and must be included in a state transportation plan and an approved State Transportation Improvement Program.[113]

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[111] U.S. Department of Transportation, Federal Highway Administration, Innovative Finance Primer
[112] Transit Cooperative Research Program, LEGAL RESEARCH DIGEST, August 1999.
[113] http://www.fhwa.dot.gov/reports/fifahiwy/ffahappn.htm

This type of funding mechanism could be used as a transformational mechanism for the state and regional mass transportation system. Significant portions of public transit fleets could be converted to hydrogen fuel cell technology. The transformation could provide significant regional and national economic benefits through the development of a cleaner, less petroleum dependent mass transportation system while generating significant economic opportunities in the region's hydrogen and fuel cell industry.

Grant Anticipation Revenue Vehicles (GARVEE)
GARVEE bonds permit states to utilize future streams of federal highway aid to pay for debt service and other bond related expenses. States sell bonds backed by the future federal highway aid. GARVEE projects are generally large enough to merit debt, rather than a grant, financing and the costs of delay outweigh the costs of financing. Also, these projects typically lack another revenue stream required for obtaining financing, including state appropriations. Lastly, the state sponsor, generally the state DOT, must be willing to reserve a portion of future federal aid highway funds to satisfy debt service requirements. Consequently, this mechanism may be most useful for advancing the timeline of existing projects.

Private Activity Bonds (PABs)
PABs were authorized for highway and intermodal transfer stations in 2005. That year, the Safe, Accountable, Flexible, and Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) amended the Internal Revenue Code to include "qualified highway or surface freight transfer facilities" as eligible projects for tax-exempt private activity bonds, which can meet certain public purpose criteria. The total amount of private activity bonding that a state can issue is subject to annual federal limits."[114]

PABs are issued on behalf of a local government to provide debt financing for private user projects. This results in lower financing costs due to the fact that interest income on the bonds is not subject to federal income taxes. However, state and local governments do not usually pledge their credit for payment of the debt. Bonds are payable only from payments made by the private user of the property financed. Because the bonds are both private borrowings and tax-exempt, they require their issuers to fully comply with a series of requirements and limitations set forth by the IRS. In addition, those obligated to pay the debt service on the bonds are required to provide yearly operational and financial data to all national information repositories sanctioned by the S.E.C. Lastly, the issuers must also comply with all state laws governing the conduct of the issuers and the issuance of the bonds.[115]

Flexible Match
The Federal-Aid Highway Program has traditionally required that recipients of Federal assistance contribute toward the total cost of any given project. Historically, Federal law placed limits on both the types of contributions that can satisfy the matching requirement and the sources of those contributions. Cash contributed by state and local governments could satisfy the

[114] NGA Center for Best Practices Environment, Energy, and Natural Resources Division, How States and Territories Fund Transportation, 2009
[115] Financing with Private Activity Bonds, 2009; http://www.azcommerce.com/doclib/FINANCE/Financing%20with%20P%20A%20B.PDF

matching requirement while other types and sources of funding for Federally-assisted transportation projects simply reduced the total project cost. The standard matching requirement continued to apply to the remaining project cost.

Provisions in the National Highway System (NHS) Designation Act and the Transportation Equity Act for the 21 Century TEA-21 introduced new flexibility to the Federal-Aid Highway Program's matching requirements by allowing certain public donations of cash, materials, and services to satisfy the non-Federal matching requirement. These legislative changes, known collectively as flexible match provisions, increase a state's ability to fund its transportation programs by:

- Accelerating certain projects that receive donated resources;
- Allowing states to reallocate funds that otherwise would have been used to meet Federal-aid matching requirements; and
- Promoting public-private partnerships by providing incentives to seek private donations."[116]

Table XIII – Summary of Non-Traditional Funding Mechanisms

H2 Transportation Funding Table		
	Pro	**Con**
State Infrastructure Banks	Revolving line of credit, no inherent rigidity in how funds are used	Requires funds to start
Federal Credit Assistance (TIFIA)	Can provide for large scale improvements; multiple types of assistance available; potential for direct application to the federal government	Significant project size required (>$100M)
GARVEE Bonds	Used to advance the timeline of existing transportation projects	Based on future revenue streams which may conflict with state priorities
Private Activity Bonds	Lower financing costs	State, local governments don't pledge their credit for payment of debt
Flexible Match	Can accelerate certain projects that receive donated resources, allow states to reallocate funds that would have been used to meet matching requirements, promote public-private partnerships	Limitations on publically-contributed services

[116] U.S. Department of Transportation, Federal Highway Administration, 2008; http://www.fhwa.dot.gov/policyinformation/statistics/2008/sf1.cfm

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Appendix 1: Hydrogen Refueling Station Codes and Setback Distances[117]

2006 Editions of the International Building Code, International Mechanical Code and International Fuel Gas Code with references to the International Fire Code

Typical hydrogen storage siting criteria for quantities less than 4,226 standard cubic feet (scf) and 4,226 to 21,125 scf		**Controlling Code**	**Setback < 4,226 scf[a]**	**Setback 4,226 to 21,125 scf[a]**
Telecom Cabinets, Enclosures, and Telecom Equipment	RT cabinet; CPS cabinet; Power Pedestal; Transfer/Disconnect switches; BTS; BSC; AC meter	IFC Table 3504.2.1	5 ft	10 ft
Buildings on the same property	Non-rated construction or openings within 25 feet	IFC Table 3504.2.1	5 ft	10 ft
	2-hour construction and no openings within 25 feet	IFC Table 3504.2.1	0 ft	5 ft
	4-hour construction and no openings within 25 feet	IFC Table 3504.2.1	0 ft	0 ft
Underground flammable or combustible liquid storage, distance to vent or fill opening		IFC Table 3504.2.1	5 ft	10 ft
Ignition sources (including appliance burner igniters, hot work and hot surfaces capable of igniting flammable vapors)		IFC Table 3504.2.1	5 ft	10 ft
Overhead Electric utilities	Overhead electric wire	IFC Table 3504.2.1	5 ft	10 ft
	Overhead bus, trolley or train wire	IFC Table 3504.2.1	5 ft	10 ft
Public streets, alleys, ways		IFC Table 3504.2.1	5 ft	10 ft
Outdoor areas of public assembly		IFC Table 3504.2.1	5 ft	10 ft
Public sidewalks and parked vehicles		IFC Table 3504.2.1	5 ft	10 ft
Line of adjoining property that can be built upon		IFC Table 3504.2.1	5 ft	10 ft
Dry vegetation and combustible materials		IFC 2703.12/ 2704.11	15 ft	25 ft
Air intake openings		IFC Table 3504.2.1	5 ft	10 ft
Above ground flammable or combustible liquid storage	Diked, distance to dike	IFC Table 3504.2.1	5 ft	10 ft
	Not diked, distance to tank	IFC Table 3504.2.1	5 ft	10 ft
Additional flammable gas storage areas		IFC Table 3504.2.1	5 ft	10 ft

a. The minimum required distances shall not apply when fire barriers without openings or penetrations having a minimum fire-resistance rating of 2 hours interrupt the line of sight between the storage and the exposure. The configuration of the fire barrier shall be designed to allow natural ventilation to prevent the accumulation of hazardous gas concentrations.

[117] Technical Report to the Connecticut Center for Advanced Technology -Hydrogen & Fuel Cell Codes & Standards : Reference Guide for Connecticut; Hydrogen Safety, LLC, April 23, 2008

Appendix 2: Codes and Standards That May Be Applicable to the Construction of a Hydrogen Fueling Station[118]

ASME B31.3, Process Piping (American Society of Mechanical Engineers, 2006)

- F323.4(5) Specific Material Considerations-Metals
- IX K305 Pipe
- IX K306 Fittings, Bends, and Branch Connections
- IX K307 Valves and Specialty Components

CGA G-5.4, Standard for Hydrogen Piping Systems at Consumer Locations (Compressed Gas Association, 2005)

- 3.0 Piping System Criteria
- 3.1 General
- 3.2 Piping Materials
- 3.3.2 Isolation Valves
- 3.3.3 Emergency Isolation Valves
- 3.3.4 Excess Flow Valves
- 3.3.5 Check Valves
- 3.3.7 Gasket and Sealing Materials
- 3.3.8 Additional Requirements
- 5.0 Installation
- 5.1 Installation General
- 5.1 Piping Installation General
- 5.2 Piping Installation Above Ground Installation
- 5.3 Piping Installation Underground Installation

CGA G-5.5, Hydrogen Vent Systems (Compressed Gas Association, 2004)

- 6.0 Vent System
- 6.2 Sizing
- 6.3 Design
- 6.4 Materials
- 6.5 Components
- 7 Installation
- 9 Maintenance

CGA P-1, Safe Handling of Compressed Gases in Containers (Compressed Gas Association, 2006)

- 4.1 Transportation Regulating Authorities
- 4.2 Container Regulations
- 4.3 Container Filling Regulations
- 4.4 Regulating Authorities of Employee Safety and Health
- 6.2 Flammable Gases

[118] U.S. Department of Energy; http://www.hydrogen.energy.gov/permitting/elearning/query2.cfm

CGA PS-20, Direct Burial of Gaseous Hydrogen Storage Tanks (Compressed Gas Association, 2006)

CGA PS-21, Adjacent Storage of Compressed Hydrogen and Other Flammable Gases (Compressed Gas Association, 2005)

CGA S-1.3, PRD Standards Part 3 - Stationary Storage Containers for Compressed Gases (Compressed Gas Association, 2005)

- 5.3.2 Nonliquid Compressed Gases

International Fire Code (International Code Council, 2006)

- 404 Fire Safety and Evacuation Plan
- 406 Employee Training and Response Procedures
- 407 Hazard Communication
- 906 Portable Fire Extinguishers
- 907 Fire Alarm and Detection Systems
- 911 Explosion Control
- 2201 Scope
- 2201.1 Scope
- 2201.5 Electrical
- 2204 Dispensing Operations
- 2204.3.5 Emergency Procedures
- 2205.4 Sources of Ignition
- 2209.2 Equipment
- 2209.2.1 Approved Equipment
- 2209.2.3 Electrical Equipment
- 2209.3 Location on Property
- 2209.3.1 Separation from Outdoor Exposure Hazards
- 2209.3.2.3 Indoors
- 2209.3.2.6 Canopy Tops
- 2209.3.3 Canopies
- 2209.4 Dispensing into Motor Vehicles at Self-Service Hydrogen Motor Fuel-Dispensing Facilities
- 2209.5 Safety Precautions
- 2209.5.2 Emergency Shutoff Valves
- 2209.5.2.1 Identification
- 2209.5.3.1 System Requirements
- 2209.5.4 Venting of Hydrogen Systems
- 2209.5.4.2 Pressure Relief Devices
- 2209.5.4.2.1 Minimum Rate of Discharge
- 2211.3.1 Equipment
- 2211.7 Repair Garages for Vehicles Fueled by Lighter-than-Air Fuels
- 2211.8 Defueling of Hydrogen from Motor Vehicle Fuel Storage Containers
- 2211.8.1.2 Atmospheric Venting of Hydrogen from Motor Vehicle Fuel Storage Containers

- 2211.8.1.2.4 Grounding and bonding
- 2703.2.1 Design and Construction of Containers, Cylinders, and Tanks
- 2703.2.2 Piping, Tubing, Valves, and Fittings
- 2703.9.3 Protection from Vehicles
- 2703.9.4 Electrical Wiring and Equipment
- 2703.10.1 Valve Protection
- 2705 Use, Dispensing, and Handling
- 2705.1.10 Liquid Transfer
- 3003 General Requirements
- 3003.2 Design and Construction
- 3003.3 Pressure Relief Devices
- 3003.6 Valve Protection
- 3003.8 Wiring and Equipment
- 3003.16.8 Connections
- 3003.16.14 Classified Areas
- 3005.3 Piping Systems
- 3005.4 Valves
- 3005.5 Venting
- 3005.7 Transfer
- 3203.1.3 Foundations and Supports
- 3203.2 Pressure Relief Devices
- 3203.2.2 Vessels or Equipment Other than Containers
- 3203.2.6 Shutoffs Between Pressure Relief Devices and Containers
- 3203.3 Pressure Relief Vent Piping
- 3203.5.3 Securing of Vaporizers
- 3203.5.4 Physical Protection
- 3203.7 Electrical Wiring and Equipment
- 3203.8 Service and Repair
- 3204.4.5 Venting of Underground Tanks
- 3205.1.2 Piping Systems
- 3205.1.2.3.2 Shutoff Valves on Piping
- 3205.3.2 Emergency Shutoff Valves
- 3501.1 Scope
- 3503 General Requirements
- 3503.1.2 Storage Containers
- 3503.1.3 Emergency Shutoff
- 3503.1.5.1 Bonding of Electrically Conductive Materials and Equipment
- 3504 Storage
- 3505 Use

International Fuel Gas Code (International Code Council, 2006)

- 101.2.1 Gaseous Hydrogen Systems
- 703.3 Pressure Relief Devices
- 703.4 Venting
- 704 Piping, Use, and Handling
- 705 Testing of Hydrogen Piping Systems
- 706.3 Outdoor Gaseous Hydrogen Systems

- 708 Design of Liquefied Hydrogen Systems Associated with Hydrogen Vaporization Operations

NFPA 30A, Code for Motor Fuel Dispensing Facilities and Repair Garages (National Fire Protection Association, 2003)

- 6.7 Emergency Electrical Disconnects
- 8 Electrical Installations
- 9.2.2 Tank Filling and Bulk Delivery
- 9.4 Operating Requirements for Attended Self-Service Motor Fuel Dispensing Facilities
- 9.5 Operating Requirements for Unattended Self-Service Motor Fuel Dispensing Facilities

NFPA 52, Vehicular Fuel Systems Code (National Fire Protection Association, 2006)

- 5.3 Design and Construction of Containers
- 5.4 Pressure Relief Devices
- 5.5 Vent Pipe Termination
- 5.6 Pressure Gauges
- 5.7 Pressure Regulators
- 5.8 Fuel Lines
- 5.9 Valves
- 5.10 Hose and Hose Connections
- 5.11 Vehicle Fueling Connection
- 9.2 General System Requirements
- 9.2.3 Equipment Security and Vehicle Protection
- 9.2.4 General System Requirements
- 9.2.5 General System Requirements
- 9.2.6 General System Requirements
- 9.2.7 General System Requirements
- 9.2.8 General System Requirements
- 9.2.9 General System Requirements
- 9.2.10 General System Requirements
- 9.2.11 General System Requirements
- 9.2.12 General System Requirements
- 9.2.13 General System Requirements
- 9.2.14 General System Requirements
- 9.2.15 General System Requirements
- 9.2.16 General System Requirements
- 9.3 System Siting
- 9.3.1 General
- 9.3.1.3 General
- 9.3.2.3 Outdoors
- 9.3.3 Indoors
- 9.3.3.12 Warning Signs
- 9.3.3.3 Indoors
- 9.6 Installation of Pressure Regulators

- 9.7 Installation of Pressure Gauges
- 9.8 Installation of Piping and Hoses
- 9.9 System Testing
- 9.11 Installation of Electrical Equipment
- 9.12 Stray or Impressed Currents and Bonding
- 9.13 System Operation
- 9.14 Fire Protection
- 9.15 Maintenance System
- 14.2.4 Indoor Fueling
- 14.4.3 Liquid Hydrogen Vehicle Dispensing Systems
- 14.6 Pressure Relief Devices
- 14.8 Stationary Pumps and Compressors

NFPA 55, Standard for Storage, Use and Handling of Compressed Gases and Cryogenic Fluids in Portable and Stationary Containers, Cylinders and Tanks (National Fire Protection Association, 2005)

- 4 General Requirements
- 6.12 Hazard Identification Signs
- 7.1.2.5 Pressure-Relief Devices
- 7.1.4 Security
- 7.1.6 Separation from Hazardous Conditions
- 7.3.1.10 Use and Handling
- 10.2.1 Pressure-Relief Devices
- 10.2.1.1 Pressure-Relief Devices
- 10.2.4 Marking
- 10.3.2 Specific Requirements
- 10.3.2.1 Specific Requirements
- 10.3.2.2 Minimum Distance
- 11.2.3 Piping, Tubing, and Fittings
- 11.2.5 Liquefied Hydrogen Vaporizers
- 11.3.1.4 General

SAE J2600, Compressed Hydrogen Surface Vehicle Refueling Connection Devices (Society of Automotive Engineers, 2002) Permitting Process for Hydrogen Fueling Stations

Appendix 3: Codes and Standards That May Be Applicable to the Operation of a Hydrogen Fueling Station[119]

CGA G-5.4, Standard for Hydrogen Piping Systems at Consumer Locations (Compressed Gas Association, 2005)

- 7.0 Maintenance and Repair

CGA G-5.5, Hydrogen Vent Systems (Compressed Gas Association, 2004)

- 9 Maintenance

International Fire Code (International Code Council, 2006)

- 105.6.8 Compressed Gases
- 105.6.10 Cryogenic Fluids
- 105.6.39 Repair Garages and Motor Fuel-Dispensing Facilities
- 404 Fire Safety and Evacuation Plan
- 404.3.2 Fire Safety Plans
- 406 Employee Training and Response Procedures
- 406.2 Frequency
- 407 Hazard Communication
- 901.6.2 Records
- 906 Portable Fire Extinguishers
- 907 Fire Alarm and Detection Systems
- 907.2 Inspection, Testing, and Maintenance
- 2204 Dispensing Operations
- 2204.2 Attended Self-Service Motor Fuel-Dispensing Facilities
- 2204.3 Unattended Self-Service Motor Fuel-Dispensing Facilities
- 2204.3.5 Emergency Procedures
- 2205.1 Tank Filling Operation for Class I, II, or IIIA Liquids
- 2206.2.1.1 Inventory Control for Underground Tanks
- 2209.3.2.3.2 Smoking
- 2209.3.2.3.3 Ignition Source Control
- 2209.3.2.6.2 Fire-Extinguishing Systems
- 2209.3.2.6.3 Signage
- 2209.4 Dispensing into Motor Vehicles at Self-Service Hydrogen Motor Fuel-Dispensing Facilities
- 2209.5.1 Protection from Vehicles
- 2209.5.2 Emergency Shutoff Valves
- 2209.5.2.1 Identification
- 2209.5.3 Emergency Shutdown Controls
- 2209.5.4 Venting of Hydrogen Systems
- 3204.5.2 Corrosion Protection

[119] U.S. Department of Energy; http://www.hydrogen.energy.gov/permitting/elearning/query1.cfm

- 3205.4 Filling and Dispensing
- 3503.1.4 Ignition Source Control

NFPA 30A, Code for Motor Fuel Dispensing Facilities and Repair Garages (National Fire Protection Association, 2003)

- 6.2 General Requirements
- 6.3 Requirements for Dispensing Devices
- 6.3.7 Requirements for Dispensing Devices
- 7.3.5 Fixed Fire Protection
- 9.2.2 Tank Filling and Bulk Delivery
- 9.4 Operating Requirements for Attended Self-Service Motor Fuel Dispensing Facilities
- 9.5 Operating Requirements for Unattended Self-Service Motor Fuel Dispensing Facilities

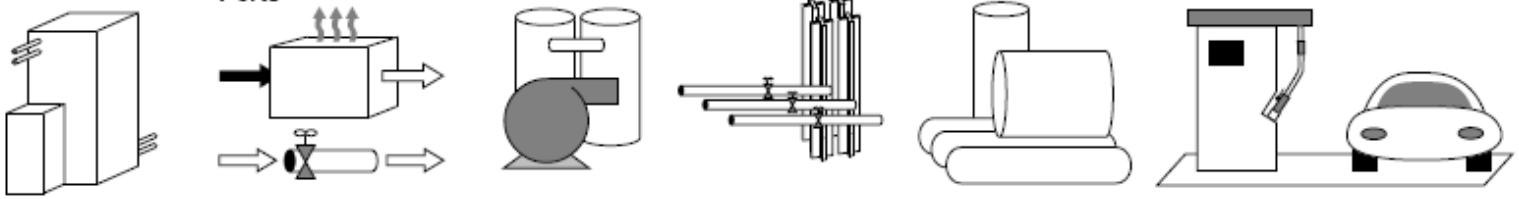
NFPA 52, Vehicular Fuel Systems Code (National Fire Protection Association, 2006)

- 9.2.3 Equipment Security and Vehicle Protection
- 9.2.15 General System Requirements
- 9.2.16 General System Requirements
- 9.3.3.12 Warning Signs
- 9.10.5 Installation of Emergency Shutdown Equipment
- 9.13 System Operation
- 9.14 Fire Protection
- 9.15 Maintenance System
- 14.2.1.6 General
- 14.4.1 Liquid Hydrogen Vehicle Dispensing Systems
- 14.4.2 Liquid Hydrogen Vehicle Dispensing Systems
- 14.4.3 Liquid Hydrogen Vehicle Dispensing Systems
- 14.4.5 Liquid Hydrogen Vehicle Dispensing Systems
- 14.4.11 Liquid Hydrogen Vehicle Dispensing Systems

NFPA 55, Standard for Storage, Use and Handling of Compressed Gases and Cryogenic Fluids in Portable and Stationary Containers, Cylinders and Tanks (National Fire Protection Association, 2005)

- 4.1 Permits
- 4.2 Emergency Plan
- 4.6 Personnel Training
- 4.7 Fire Department Liaison
- 4.8 Ignition Source Controls
- 4.9 Signs
- 6.12 Hazard Identification Signs
- 7.1.6 Separation from Hazardous Conditions
- 7.6.3 Ignition Source Control
- 10.2.4 Marking
- 10.3 Location of Gaseous Hydrogen Systems
- 11.3.1.4 General

Appendix 4: Typical Hydrogen Fueling Station Components[120]



	Control Equipment	Hydrogen Generators and/or Receiving Ports	Auxillary Equipment	Piping, Distribution, & Heat Exchangers	Hydrogen Storage	Compressed H_2 Dispenser	Vehicle Interface
EQUIPMENT & COMPONENTS (varies by station)	Various electrical assemblies, pneumatic valve controllers	Electrolyzers, reformers, direct delivery fuel receiving ports (gas or liquid)	Pressure swing absorbers (PSA), compressors	Low and high pressure hydrogen safe piping and valving, ambient finned vaporizers	Cryogenic, low and high pressure gaseous hydrogen vessels	Cryogenic, 250, 350, or 700 bar gaseous service	Nozzle, user access interface
PURPOSE	Station systems control, valve operation, telematics, other uses	Generate hydrogen on-site from local available utilities, or receive hydrogen bulk fuel from truck or pipeline	Pressure Swing Absorber (PSA) - H2 clean up if created on-site; Compression for storage and fueling	Hydrogen distribution between station systems, liquid to gaseous vaporization where needed	On-site hydrogen storage	Houses fuel vehicle fuel delivery equipment, meters and controls flow	Where the customer interacts with the fuel
SYSTEMS SAFETY	Process control, E-stop, telemetric monitoring, shut-offs, others	Varies by equipment, pressure relief, real-time monitoring controls, others	Real-time monitoring controls, pressure relief, others	Pressure relief devices, direct welding, hydrogen compatible materials, others	Pressure relief, burst disks, temperature-activated PRDs, hydrogen compatible materials, safety venting, others	E-stop, break-aways, restricted access, temperature compensation, vehicle grounding, venting, pressure-specific nozzle compatibility, IR/UV fire detection, leak detection, impact sensors, excess flow control, others	

GENERAL SAFETY & DESIGN ELEMENTS

Close-loop design, engineering safety margins and analysis (HAZOP, FMEA, etc.), construction and siting to established regulations, telemetric monitoring, fire detection, hydrogen compatible materials selection, cross-hatching for user attention, signage, fire extinguisher placement, others

last updated 7/5/07

NOTE: this document is provided for high-level informational purposes only and is not intended to cover all known stations, fueling systems, safety systems, codes, standards, and regulations.

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[120] California Hydrogen Fueling Stations – Reference Materials; Prepared by the California Fuel Cell Partnership, www.cafcp.org

Appendix 5: Comparison of Hydrogen Properties with Other Gases[121]

Gas	Hydrogen	Natural Gas	Propane	Gasoline Vapor
Buoyancy (Density Relative to Air)	0.07	0.55	1.52	3.0
Molecular Weight	2	16	44	107
Density (kg / m^3) at NTP	0.084	0.651	1.87	4.4
Auto-ignition Temperature [1] (^0F)	918 - 1018	960-1170	842	50
Diffusion Coefficient in still air at NTP (cm^2 / s)	0.61	0.16	0.12	0.05
Theoretical Explosive Energy (kg TNT/cubic meter of gas volume)	2	7	18	44
Flammability Range (% by volume in air)	4 to 75	5 to 17	2 to 10	1 to 8
Detonation Range (% by volume)	18 to 59	6 to 14	3 to 7	1 to 3
Minimum Ignition Energy (mJ)	0.02	0.29	0.26	0.24
Maximum Burning Velocity in Air (cm /s)	346	43	47	42

Notes:

1: Auto-ignition Temperature is the minimum temperature required to cause self-sustained combustion in the absence of a spark or of a flame.

Sources:

Fire Protection Guide to Hazardous Materials –13th Edition, NFPA
Avoiding Static Ignition Hazards in Chemical Operations – L.G. Britton, American Institute of Chemical Engineers, 1999
Safety Standard for Hydrogen and Hydrogen Systems, NSS 1740.16,
National Aeronautics and Space Administration, 1997
Bureau of Mines, Bulletin 680, page 35 (Hydrogen's auto-ignition temperature range in 200cc vessel)
Stuart Energy Systems, G. Howard, "Comparison of Gaseous Hydrogen Properties with Natural Gas", February 2004

[121] Hydrogen Safety, LLC