

**PRELIMINARY REPORT**  
**FUEL CELL ECONOMIC DEVELOPMENT PLAN**  
**HYDROGEN ROADMAP**

**SUBMITTED TO:**

**Department of Economic & Community  
Development**



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**BY:**

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## **EXECUTIVE SUMMARY**

### **Preliminary Findings**

#### Preamble

In accordance with Section 64 of Public Act 06-187, the Connecticut Center for Advanced Technology, Inc. (CCAT) is pleased to submit to the Connecticut Department of Economic and Community Development (“DECD”), the following Preliminary Plan for fuel cell economic development in Connecticut. This Preliminary Plan has been developed to: (1) identify and assess market conditions for fuel cell and hydrogen technology; (2) analyze Connecticut’s hydrogen and fuel cell industry; and (3) assess the economic potential for Connecticut, including the economic impact of Connecticut’s hydrogen and fuel cell industry.

The following preliminary findings will be validated and refined within the Final Plan, which will be submitted by DECD to the Connecticut General Assembly on or before January 1, 2008:

#### Market Profile

- 1) The emerging markets for fuel cells and hydrogen technology include: stationary power/distributed generation, portable power for handheld electronics, and transportation.
- 2) Worldwide government spending for fuel cell and hydrogen infrastructure approached \$1.5 billion in 2004.
- 3) In 2005, the global sales of fuel cells generated approximately \$400 million in revenue.
- 4) Preliminary studies suggest that the total global fuel cell/hydrogen market is expected to generate as much as \$18.6 billion annually in revenue over the next decade. This would require an employment base of approximately 120,000. If the

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fuel cell/hydrogen industry captures a significant share of the transportation market, projected sales could generate \$35 billion annually in revenue over the next decade. This would require an employment base of approximately 230,000.

### Connecticut's Position in the Fuel Cell Industry

- 1) Connecticut has been the leader and innovator of fuel cell technology and electrochemical technologies, since the 1950s, and pioneered its application for spacecraft, submarines, stationary power, and transportation.
- 2) Connecticut manufacturers and researchers have developed expertise in (1) all fuel cell technologies, including alkaline systems, proton exchange membrane (PEM), phosphoric acid, molten carbonate and solid oxides; (2) alkaline and PEM electrolysis technologies; and (3) applying these technologies to applicable markets.
- 3) Two of the major fuel cell developers and manufacturers in the world are located in Connecticut - FuelCell Energy, Inc. in Danbury and Torrington, and UTC Power in South Windsor. These companies dominate the fuel cell market for stationary power/distributed generation for fuel cells greater than 200 kilowatts (kW).
- 4) Several Connecticut suppliers, educational institutions, research facilities (e.g. Connecticut Global Fuel Cell Center), and the Connecticut Hydrogen-Fuel Cell Coalition, including the Connecticut Clean Energy Fund, support Connecticut's fuel cell industry.
- 5) Connecticut's fuel cell and hydrogen industry currently supports 927 direct jobs and 1,221 indirect jobs for a total of 2,148 jobs statewide. The fuel cell and hydrogen industry supports approximately 7,000 globally.
- 6) Connecticut's fuel cell and hydrogen industry generates 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.

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### Major Issues

- 1) Costs – increased production rates, and improved design and technology will be necessary to reduce costs;
- 2) Performance – recognition of reliability and durability;
- 3) Infrastructure – hydrogen refueling stations will be required to support the fuel cell transportation market;
- 4) Perception – utilization of hydrogen as a fuel has not been fully accepted in the market place and may be perceived as high risk;
- 5) Environmental – the positive environmental benefits of fuel cells and hydrogen are not fully considered;
- 6) Market – distribution channels are not fully developed for both fuel cell and hydrogen production systems;
- 7) Support – favorable government structure including education, workforce development, and policy needed to support market development; and
- 8) Threats – other states’ programs and foreign OEMs entering the market are increasing.

As mandated by Public Act 06-187, Sec. 64, the Final Plan will identify strategies to (1) facilitate the commercialization of hydrogen-based technologies and fuel cells; (2) enhance energy reliability and security; (3) promote the improved efficiency and environmental performance of transportation and electric generation with reduced emissions, reduced greenhouse gases, more efficient use of nonrenewable fuels, and increased use of renewable and sustainable fuels; (4) facilitate the installation of infrastructure for hydrogen production, storage, transportation and fueling capability; (5) disseminate information regarding the benefits of hydrogen-based technologies and fuel cells; (6) develop strategies to retain and expand hydrogen and fuel cell industries in Connecticut; (7) identify areas within the state transportation system that would benefit from the integration of potential mass transit and fleet transit locations with hydrogen or natural gas and hydrogen mixture refueling stations; and (8) identify areas in the electric and natural gas distribution system of the state that would benefit from the development

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of distributed generation through hydrogen or fuel cell technology as a reliability asset necessary for voltage control, grid security, or system reliability, or for the provision of required uninterruptible service at customer sites.<sup>1</sup> The Final Plan will also evaluate what the economic impact of a developed fuel cell and hydrogen industry will have on Connecticut's economy, and propose recommendations that will enhance Connecticut's position as a world leader in the fuel cell and hydrogen market.

CCAT will consult with the Connecticut Hydrogen-Fuel Cell Coalition, the Renewable Energy Investment Fund, the Connecticut Department of Transportation, Connecticut's electric and gas service providers, and Connecticut's hydrogen and fuel cell industrial base to develop the strategies for the Final Plan.

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<sup>1</sup> Public Act 06-187, Sec. 64

## **Forward**

As oil and other non-sustainable hydrocarbon energy resources become scarce, energy prices will increase and reliability for supply will be reduced. With such dependency of the U.S. economy on hydrocarbon energy resources, Americans will be severely affected by shortages of oil and natural gas. Recently Federal Reserve Chairman Ben Bernanke said, “The increase in energy prices is clearly making the economy worse off both in terms of real activity and in terms of inflation. There is no question about it.”<sup>2</sup>

While the threat of such shortages is real and potentially significant, strategic planning to guide consumers to alternative and more efficient energy resources in a timely manner will extend the time of use for available resources and reduce the impact attributable to shortages of hydrocarbon fuels. Further, the use of alternative energy and more energy efficient generation technologies may be able to improve environmental performance, reduce long-term costs, and create opportunities for economic development. Attractive technologies being considered by the energy industry and supported by a number of states are fuel cell and hydrogen generating systems.

As Connecticut is a world leader in the research, design, and manufacture of hydrogen and fuel cell related technologies, the State is uniquely positioned to develop the fuel cell/hydrogen market and facilitate a smooth transition from hydrocarbon fuels using conventional combustion technology to the use of efficient electrochemical technology. Such a transition will open markets for energy management in the industrial, commercial, institutional, and residential sectors, and thereby, develop opportunities for a substantial creation of high-paying jobs in Connecticut.

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<sup>2</sup> AP Jeannine Aversa 7-21-06

## Market Summary

The three primary global markets for fuel cells and hydrogen technology are: (1) stationary fuel cells, (2) portable fuel cells, and (3) fuel cell and hydrogen refueling associated with transportation. These markets are global and Connecticut is well positioned now and well positioned to expand its share for increased employment, increased sales, and increased research and development (R&D). Under existing trends, by the year 2010, Connecticut would be positioned to increase direct employment to over 1,635 jobs (a 12 percent, 716 job gain from 2005); sales would be over \$63 million (a 6.6 percent, \$17 million gain from 2005); and investment in R&D would be \$174 million (an 11 percent, \$71 million gain from 2005).

However, others estimate that hydrogen and fuel cell technology has the potential to be the dominant technology for distributed generation, automotive and transit bus transportation, and portable power as a replacement for batteries. Consequently, some view the hydrogen fuel cell industry as ripe for expansion, and have estimated, to be validated by the final report, that the global fuel cell/hydrogen market, when mature, is expected to generate as much as \$18.6 billion annually over the next decade. This would require an employment base of approximately 120,000. If the fuel cell/hydrogen industry captures a significant share of the transportation market, projected sales could generate \$35 billion annually in revenue over the next decade. This would require an employment base of approximately 230,000.<sup>3</sup> The challenge for Connecticut is to develop a strategic plan that will enhance the development of the fuel cell/hydrogen market, counter the market obstacles which are impeding it, and to ensure that Connecticut maintains and increases its position as a world leader in the industry.

This preliminary assessment of the potential for growth in the fuel cell and hydrogen market is encouraging but suggests that the market drivers have not yet been sufficiently addressed for these technologies to fully replace the use of conventional base technologies. The barriers that are inhibiting market penetration include: high costs,

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<sup>3</sup> Source: Connecticut Department of Economic and Community Development

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unappreciated environmental values, cost consuming interconnections, complicated codes and standards, lack of adequate public awareness, investment needed to undertake advanced research and development, lack of continuous (large scale) automated production, and strong competition from rate-base supported grid generation load. The most significant barrier is cost, including life-cycle costs that raise the following critical issues as to the technologies' market acceptability:

### *Is there a global market sufficient to justify investment by Connecticut?*

Yes. With a 13 percent share of a global market that includes \$353 million in annual sales and \$796 million in annual R&D investment, Connecticut now occupies a favorable position to maintain and expand this share for increased employment and gross state product. However, some estimate that the market will grow substantially, and revenues are expected to generate between \$18.6 billion and nearly \$35 billion annually over the next decade as hydrogen and fuel cell technology takes a larger share of the stationary power, portable power, and transportation markets. With a potential market of this size, Connecticut would be in an enviable position for substantial opportunities to increase employment, sales, revenue, and investment in R&D.

### *Can Connecticut companies capture a larger share of the global market?*

While the question of how to increase Connecticut's share of the global sales, R&D and employment market will be the focus of the Final Report, there are no technical barriers that would preclude Connecticut companies from increasing their share of the global market. The fuel cell and hydrogen industry will need to grow within the same business climate that all industries face in Connecticut. Moreover, if Connecticut does not actively and aggressively seek to increase its share, it may face loss of sales, R&D expenditures and employment as other states and countries compete for fuel cell and hydrogen development activities.

***Can costs drop to a level that will provide for effective competition and increased market penetration?***

Yes. It has been estimated that with increased support for research and development, and if production were to increase, production costs could drop to levels closer to parity with conventional generation.

***Will costs decrease if production were to increase?***

Yes. It has been estimated that increased production could provide continuous manufacturing of fuel cells that will help to support research, testing, and deployment of hydrogen and fuel cell technology and achieve lower unit costs to effectively compete with traditional generation technologies.

***Will supportive measures to be applied to increase market penetration be economically justified to earn a favorable return on public investment?***

Yes. With appropriate support, to be determined by the Final Report, production could increase, unit costs will drop, and employment will increase. With favorable multipliers of 2.31 for employment, 1.84 for industrial revenues, and 1.72 for employee compensation, Connecticut is well positioned to invest in the hydrogen fuel cell industry with the potential for substantial indirect and induced effects.

***Are there favorable locations for deployment and investment in Connecticut for hydrogen and fuel cell technology?***

Yes. Connecticut would benefit substantially through R&D investment and deployment of hydrogen and fuel cell technology. Benefits would include advanced training and education for long-term support of industry needs; improved environmental performance and cleaner air in the state; improved reliability for the electric grid; and reduced costs for

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electric consumers. All of these values will help to create new jobs that are directly and indirectly associated with hydrogen and fuel cell technology.

In summary, data in this preliminary report suggests that there are favorable market conditions for the expansion of the hydrogen fuel cell industry in Connecticut, that public investment is appropriate and justified, that certain investment in hydrogen and fuel cell technology could provide a favorable rate of return for investors, and that there are favorable sites for deployment of hydrogen and fuel cell technology in Connecticut with potential to meet energy needs, improve environmental performance, and increase economic development and the creation of jobs.

This preliminary analysis was undertaken by CCAT with assistance from:

- fuel cell and hydrogen equipment manufacturers, including FuelCell Energy, Inc., GenCell Corporation, Infinity Fuel Cell and Hydrogen, Inc., UTC Power, and Distributed Energy Systems Corp.;
- University of Hartford, Quinnipiac University, and the University of Connecticut Global Fuel Cell Center;
- government agencies including the Connecticut Siting Council, Connecticut Clean Energy Fund, and the Connecticut Department of Economic and Community Development; and
- other members of the Connecticut Hydrogen – Fuel Cell Coalition, including Bradley, Foster & Sargent, Inc., GrowJobs CT, International Association of Machinists & Aerospace Workers, Millennium Cell Inc., and Updike, Kelly & Spellacy, P.C.

The detailed assessment and strategies of this plan will be presented in “The State of Connecticut Fuel Cell Economic Development Plan and Hydrogen Roadmap” and will be finalized on January 1, 2008, per Public Act 06-187.

Preliminary Plan

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## **PART I**

### **Identification and Assessment of Market Conditions for Fuel Cell and Hydrogen Technology**

Fuel cells are energy conversion devices that can provide distributed power, heat, and water from renewable fuels with the greatest efficiency and lowest environmental emissions yet achieved.<sup>4</sup> With a broad range of potential applications, fuel cell technology is a prime example of a transformative technology. Worldwide government spending for fuel cell and hydrogen infrastructure approached \$1.5 billion in 2004.<sup>5,6</sup> As the world's largest energy consumer, the United States has a particularly compelling need for this technology. The consensus of economists seems to be that we will reach "a watershed moment" in our use of energy "in our lifetime."<sup>7</sup>

#### **Global Market Analysis**

From a global prospective, fuel cell technology has been recognized as an asset to improve environmental performance and reduce use of non-renewable natural resources. The global market focus is relatively diverse, but favors stationary power applications with 40 percent of the market involved in such applications (small stationary applications of 50 kW or less at 24 percent, and large stationary applications greater than 50 kW at 16 percent). Other markets include portable power generation at 18 percent, and transportation at 42 percent, including vehicle drive (17 percent), fueling infrastructure (14 percent), and auxiliary power units for vehicles (11 percent).<sup>8</sup>

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<sup>4</sup> For more detailed information regarding fuel cells and hydrogen, see Part III.

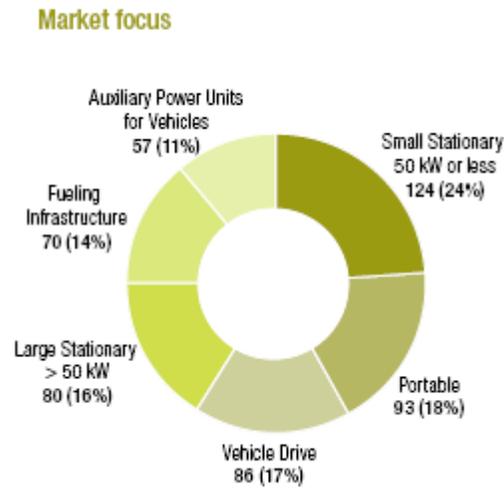
<sup>5</sup> Fuel Cell Industry Report, May 2005, P. 12

<sup>6</sup> World Fuel Cells Study, Freedonia Group, Cleveland, OH, July 2003

<sup>7</sup> The End of Cheap Oil, National Geographic, 205, 6, 2004, 80

<sup>8</sup> US Fuel Cell Council; 2006 Worldwide Fuel Cell Industry Survey

**Figure I.1 – Global Market Focus for the Fuel Cell Industry**



Connecticut is dominant in the large stationary power fuel cell market (> 50 KW), and is well positioned to expand its share in other markets for increased employment, increased sales, and increased R&D.

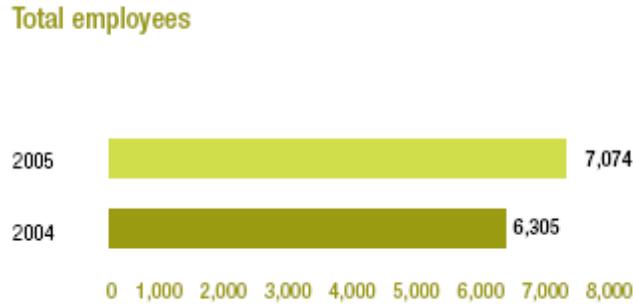
Employment

According to the 2006 Worldwide Fuel Cell Industry Survey (Survey), global employment in 2005 for the fuel cell industry was 7,074. The Survey does not identify the global employment in each market sector. However, if one assumes a direct correlation between market share and employment, the stationary, portable, and transportation market sectors have a potential employment of 2,830, 1,273, and 2,971, respectively.<sup>9</sup>

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<sup>9</sup> US Fuel Cell Council; 2006 Worldwide Fuel Cell Industry Survey

**Figure I.2 – Global Employment**

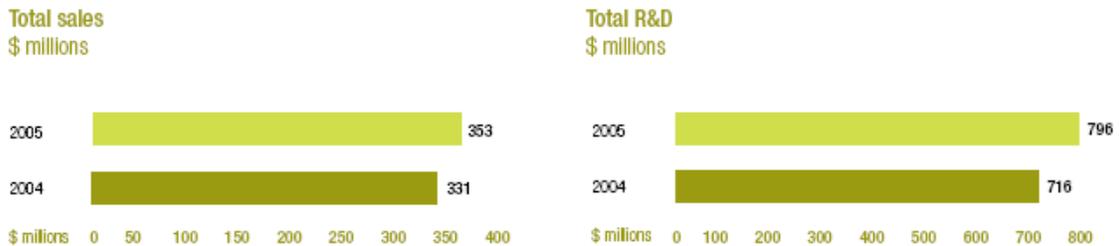


In early 2006, Connecticut’s actual employment involved in the hydrogen and fuel cell industry was 927, establishing an approximate 13 percent share of global employment. By the year 2010, Connecticut could be positioned to increase employment (based on a 12 percent compounded annual increase from 2005) to over 1,635 jobs, an increase of 716 jobs.

Sales and R&D

In 2005, global sales were approximately \$353 million (a 6.6 percent increase from 2004). The majority of these sales were in the U.S. (48 percent), Japan (14 percent), and Germany (12 percent). In 2005, R&D expenditures were \$796 million (an 11 percent increase from 2004). The majority of these expenditures were in the U.S. (58 percent), Canada (20 percent), Germany (8 percent), and Japan (7 percent).<sup>10</sup>

**Figure I.3 – Global Sales and R&D Expenditures**



<sup>10</sup> US Fuel Cell Council; 2006 Worldwide Fuel Cell Industry Survey

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If global sales continue to increase at a rate of about 6.6 percent and Connecticut maintained its relative position, Connecticut could realize over \$63 million in sales by 2010. Similarly, if global R&D continues to increase at a rate of approximately 11 percent and Connecticut maintained its relative position, Connecticut could realize \$174 million in R&D expenditures by 2010.<sup>11</sup>

### **Preliminary Market Assessment for Stationary Fuel Cells, Portable Fuel Cells, and Transportation**

The three primary global markets for fuel cells and hydrogen technology are: stationary power/distributed generation, portable power, and transportation.

#### *Stationary Power Market for Fuel Cells*

According to the Energy Information Administration (EIA) (1), world electric consumption will more than double from 14,780 billion kW in 2003 to 30,116 billion kW in 2030. Most of the growth in demand of electricity is expected to occur in countries outside the Organization for Economic Cooperation and Development (non-OECD) countries where electricity usage will grow at 3.9 percent per year as compared to 1.5 percent in OECD countries.<sup>12</sup> All primary energy sources are expected to grow worldwide. Coal and natural gas remain the most important fuels for electricity generation. The U.S., Europe and Japan represent the roughly one third of the world population that has adequate supplies of electricity. It has been estimated that a third of the world population has no electricity and that the other third of the world has inadequate electricity supply ranging from only intermittent supply to supply with frequent interruptions.

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<sup>11</sup> Based on a 6.6 percent compounded annual increase for sales, and an 11 percent compounded annual increase for R&D expenditures.

<sup>12</sup> International Energy Outlook 2006, Energy Information Administration, Report # DOE/EIA-0484 (2006)

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While most of the capacity additions come from centralized power plants, the share of distributed generation in the overall mix is also increasing. In a 2006 survey conducted by World Alliance for Decentralized Energy (WADE), the share of decentralized power generation in the world market has increased to 7.2 percent by 2004, up from 7 percent in 2002.<sup>13</sup> There are strong indications that a transition from a central power model to a 'hybrid' model that includes central as well as distributed generation is underway, though slowly. This 2006 survey also notes that there was a surge in distribution generation development during 2005, with its share in new power generation addition at around 25 percent, up from 13 percent four years ago.

While there are several market drivers, the main driver appears to be a growing realization that fuel prices are going to remain high thereby necessitating more efficient solutions to meeting the ever growing demand for electricity. Other possible benefits of distributed generation besides direct electricity price reduction and stability, include improved electricity reliability and quality, emission reductions, and a simple feeling of control and/or independence. There is now an increasing awareness on the part of consumers and policymakers that distributed generation presents a viable alternative to expensive transmission and distribution (T&D) upgrades or new systems.

In developing countries the grid is often either unreliable or non-existent and those governments do not have the resources to address the situation. As a result, a large number of countries have mandates, initiatives or incentives to promote distributed generation. Although it will take some time to take effect, the future of distributed generation worldwide is quite promising.

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<sup>13</sup> World Survey of Decentralized Energy 2006, World Alliance of Decentralized Energy, May 2006; WADE is an organization that has more than 200 members worldwide. The members include distribution generation organizations, providers, governments, etc. The survey quoted here consists of direct inputs from WADE members.

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The U.S. and the rest of the developed world have well developed generation and T&D infrastructure and has adequate electricity supply. The impetus for distributed generation comes from:

- a need for extremely reliable power for critical commercial, industrial, communication and health care facilities;
- opportunities to conserve resources and reduce emissions through distributed generation in combined heat and power applications; and
- specific situations where placement of new transmission and distribution facilities is constrained by land availability, public opposition, etc.

In the U.S., distributed generation has been rising steadily. It has grown from 10 gigawatt-electric (GWe) in 1990 to about 80 GWe in 2005. That represents approximately 13 percent of the total nameplate capacity of U.S. generation in 2005. There are a number of states, Connecticut being one of the most progressive in this respect, who have introduced various incentives to promote distributed generation. Technology of choice remains reciprocating engines and gas turbines.

All these developments, both in the U.S. and in the international markets, bode very well for fuel cells. Fuel cells so far represent a miniscule share of worldwide distributed generation. According to the Fuel Cell Today survey for 2006, total number of fuel cell units installed worldwide is a little more than 800 representing approximately 100 MW,<sup>14</sup> which is approximately 0.125 percent of the total distributed generation capacity in the U.S. As familiarity and confidence in the reliability and durability of fuel cells grows, as their superior environmental attributes command economic value, and as prices reduce because of increased production volume and technology advances, they will command a greater share of the distributed generation market.

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<sup>14</sup> Fuel Cell market Survey: Large Stationary Applications 2006

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The growth in electric energy consumption over the period 2003 to 2030, if delivered at a load factor<sup>15</sup> of 0.6 requires a generating capacity addition of 4,850 GW. If, as WADE predicts, 25 percent of this additional capacity is distributed generation, the annual distributed generation capacity additions will average 45 GW per year, which at an assumed price of \$2,000/kW would represent annual revenue of \$90 billion per year. Connecticut companies currently employ about 13% of the global fuel cell workforce and probably a higher proportion for stationary fuel cell employment. Consequently, if fuel cell attributes permit the capture of 25 percent of the distributed generation market for units greater than 200 kW and if Connecticut companies capture in excess of 75 percent of the stationary fuel cell market for units greater than 200 kW, revenues to Connecticut companies could be approximately \$17 billion per year when the distributed fuel cell market matures.

### Portable Power Market for Fuel Cells

Fuel cells have the potential to become an important source of power for the ever-growing number of mobile electronic devices. Recent advances in electronics technology, particularly as mobile phones and laptop computers merge to provide users with broadband wireless and multifunctional portable computing capability, will require manufacturers to seek power sources that have greater energy densities than the lithium-ion (Li-ion) or nickel-based batteries in use today. In the year 2000, the total energy usage for personal electronic devices was 3,500 watt-hours (Wh). By the year 2010, this annual energy requirement is predicted to jump to 10,500+ Wh with power requirements ranging from 0.5 to 20 watts.<sup>16</sup>

Miniaturized fuel cells, using a liquid methanol fuel, show promise in meeting these new energy density requirements. The main advantages of fuel cells over battery systems include long run-times, high energy density and storage that allow portable electronic

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<sup>15</sup> Load factor is the ratio of the average load to peak load during a specified time interval. Load factor is an indication of efficient energy use.

<sup>16</sup> Pavio, J., Hallmark, J., Bostaph, J., Fisher, A., Mylan, B., Xie, C.G., Developing Fuel Cells for Wireless Communication, Fuel Cells Bulletin, Volume 2002, Issue 04, April 2002, Pages 8-11

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devices to function for longer periods than those with batteries. Beyond increased operating times, fuel cells also provide reduced weight, and an increased ease of recharging, potentially offering greater consumer appeal than batteries. One very specific advantage of fuel cells over batteries is the decoupling of energy stored from peak power delivered. This allows the fuel cell to be sized to a given application more easily than a battery system offering the consumer reduced size and weight.<sup>17</sup>

Energy dense fuel cells offer the potential to meet the new power and energy demands for mobile phones, laptop computers, palm pilots, power tools, personal pagers, and other remote devices including hearing aids, hotel door locks, smoke detectors, and meter readers.<sup>18</sup> Some estimate that the overall market for portable fuel cells in such electronics will mirror that of battery systems that presently have a 40 percent per year growth rate and a current annual market size in excess of \$10 billion.<sup>19</sup> Other market opportunities exist for the development and manufacture of fueling cartridges and connectors. Allied Business Intelligence, a market research company that tracks new technology, estimates that portable fuel cells will reach annual unit sales of \$200 million to \$500 million by 2011.

Current market participants include fuel cell developers such as Giner Electrochemical Systems, Lynntech Industries, Manhattan Scientific, and MTI Micro Fuel Cells; aerospace integrators such as Ball Aerospace; and well-known electronics participants including Casio, Samsung, Hitachi, Motorola, and Toshiba.<sup>20</sup> Many of these companies are making substantial financial commitments to commercializing these small fuel cell systems. As an example, Hitachi is planning to commercialize a methanol-powered fuel cell for use in electronic devices in 2007 according to Japanese news reports. Hitachi's plans to take the fuel cells to market resulted in the establishment of facilities to produce between 2,000 and 3,000 methanol fuel cells a month.

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<sup>17</sup> Cropper, M., Geiger, S., Jollie, D., Fuel Cells: A Survey of Current Developments, *Journal of Power Sources*, 131 (2004) 57-61

<sup>18</sup> Feder, B.J. (March 16, 2003). For smaller fuel cells, a far shorter wait. Available Online: [NYTimes.com](http://NYTimes.com).

<sup>19</sup> Dyer, C.K., Fuel Cells for Portable Power Applications, *Journal of Power Sources*, 106 (2002) 31-34.

<sup>20</sup> Apanel, G., Johnson, E., Direct Methanol Fuel Cells – Ready to go Commercial?

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Many predict that the market demand for micro fuel cells is building towards mass-market acceptance by 2008. Sales are anticipated to be \$510 million worldwide by 2008, with strong growth occurring in 2007 and 2008. By 2013, micro fuel cell markets are expected to reach \$11 billion. This represents a range of PC, mobile phones, personal digital assistants (PDA), and digital device segments in a variety of industry, military and healthcare segments.<sup>21</sup>

It has been projected that the number of jobs created in the portable fuel cell sector for the year 2021 could range from 2,973 to 3,063 direct jobs.<sup>22</sup> It is estimated that if Connecticut maintains its current relative position of all global jobs related to fuel cells and hydrogen,<sup>23,24</sup> approximately 386 of these jobs will be based in Connecticut.

At the present time, no U.S. company has committed to volume production of DMFC fuel cells, although micro fuel cells have a window of opportunity to start manufacture in the United States.<sup>25</sup>

### Transportation

Nearly all cars and trucks run on gasoline or diesel, and they are the main reason why the U.S. imports more than 55 percent of the oil it consumes (this consumption of oil is expected to grow to more than 68 percent by 2025). Two-thirds of the 20 million barrels of oil Americans use each day is used for transportation.<sup>26</sup> The combustion of fossil fuels is a significant contributor of air pollution. Reducing the dependence of oil and improving environmental performance are two of the main reasons why there is a substantial opportunity for the application of fuel cell technologies for transportation.

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<sup>21</sup> Kamarudin, S., Daud, W., Ho, S., Hasran, U., Overview on the Challenges and Developments of Micro-Direct Methanol Fuel Cells (DMFC), Journal of Power Sources, Article in Press, (2006)

<sup>22</sup> Breakthrough Technologies Estimates for the Year 2021

<sup>23</sup> New Haven Register 6/20/04

<sup>24</sup> Fairfield County Business Journal 5/31/04

<sup>25</sup> National Institute of Standards and Technology; ATP Working Paper Series Working Paper 05-01

<sup>26</sup> <http://www.hydrogen.gov>

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The following table of transportation statistics is the basis for estimating the market for fuel cells in transportation.

**Table I.1 - Selected Transportation Market Statistics**

	United States <sup>27</sup>	Global <sup>28</sup>	Estimated Global Values <sup>29</sup>
Total Vehicles in Use	243 million		1,400 million
Annual Passenger Car Retail Sales	7.5 million		42.8 million
Annual Passenger Car Production		42.8 million	42.8 million
Annual Commercial Vehicle Production		21.1 million	21.1 million
Total Passenger Cars in Fleets	2.95 million		17 million
Total Trucks in Fleets	6.37 million <sup>30</sup>		36 million
Transit Buses in Use	81 thousand <sup>31</sup>		460 thousand
Annual Transit Bus Purchases	6 thousand		35 thousand
Number of Service Stations	121,000 to 169,000 <sup>32</sup>		690 to 963 thousand

A very preliminary estimate of the total global revenues from fuel cells and hydrogen generating equipment was made based on a number of assumptions. Many of these assumptions require further analysis during the balance of this effort to check them against the range of assumptions by others. However, it was judged reasonable to make an initial estimate to provide a rough estimate of the economic impact of hydrogen and fuel cell transportation on Connecticut.

<sup>27</sup>Data from National Transportation Statistics published by the Bureau of Transportation Statistics, Department of Energy unless noted

<sup>28</sup>Data from National Transportation Statistics published by the Bureau of Transportation Statistics, Department of Energy unless noted

<sup>29</sup> Estimated by ratio of Annual Global Passenger Car Production to Annual Retail Sales of Passenger Cars in the United States

<sup>30</sup> Does not include utility company fleets which were 498 thousand in 2000

<sup>31</sup> Data from American Public Transportation Association publication, 2006 Public Transportation Fact Book

<sup>32</sup> 2002 Economic Census, Retail Trade, Gasoline Stations U S Census Bureau and Department of Energy Fact Sheet 389, "More Gasoline Stations in 2005" September 12, 2005

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The estimate below was constructed with the following information and rationale:

- Officials of the Federal Transit Administration have a goal that fuel cell transit buses will represent 10 percent of purchases by 2015.<sup>33</sup>
- Automakers and energy companies project initial sales of hydrogen fuel cell vehicles in the period 2010 to 2020. Shell projects 50 percent of new auto purchases will be fuel cell cars by 2040.<sup>34</sup>
- Fleet vehicles represent the best opportunity for early application because hydrogen supply infrastructure is simplified.
- Penetration of automobiles will range from 5 percent to 50 percent and penetration of heavy duty vehicles will range from 5 percent to 20 percent in the mature model year.
- The U.S. Department of Energy's (DOE) goal for fuel cell cost in 2015 is \$30 per kW.<sup>35</sup> The assumption is that an automobile fuel cell will be rated at 75 kW and heavy duty vehicle fuel cells will be rated at 150 kW.
- Hydrogen refueling stations with either reformers or electrolyzers will cost between \$0.25 and \$0.5 million dollars per station based on interpretation of estimates.<sup>36</sup>
- Ultimately, 5 to 20 percent of the global filling stations will provide hydrogen fuel over the next twenty years.

Based on these assumptions, the potential market for fuel cell technology in passenger vehicles range from 2.1 to 21 million cars per year with total delivered fuel cell capacity between 150 GW and 1,500 GW, and total fuel cell revenues between \$4.5 and \$45 billion. The potential market for heavy duty vehicles range from 1 to 4 million vehicles per year with total delivered fuel cell capacity between 150 GW and 600 GW, and total fuel cell revenues of between \$0.45 and \$1.8 billion annually.

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<sup>33</sup> Sisson, Barbara A. Hydrogen and Fuel Cell Bus Initiative, Paving the Way Nationally and Internationally, U. S. Department of Transportation, Federal Transit Administration

<sup>34</sup> Preparing for the Hydrogen Economy: Transportation Report by The Connecticut Academy of Science and Engineering for The Connecticut Department of Transportation, June 2006

<sup>35</sup> U. S. Department of Energy; Hydrogen, Fuel Cells and Infrastructure Technologies Multi-Year Program Research, Development and Demonstration Plan for 2003-2010, February 2005

<sup>36</sup> "A Near-Term Economic Analysis of Hydrogen Fueling Stations" Jonathan Weinert, 2005, Institute of Transportation Studies, University of California, Davis UCD-ITS-05-04

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Since Connecticut companies face significant competition for fuel cells used in the passenger vehicle sector, it seems reasonable to assume their market share would be 10 to 20 percent or between \$0.5 and \$9 billion annually. There is less competition for the heavy-duty vehicle market; consequently, Connecticut companies' share could be 20 to 40 percent or between \$0.1 to \$0.7 billion annually.

The potential market for filling stations, with the assumptions noted above, would result in 1,700 to 10,000 stations being implemented each year, and revenues from hydrogen generating equipment in these stations resulting in \$0.5 to \$5 billion dollars to the manufacturers of electrolysis or reformer equipment. If Connecticut companies gain between 10 and 25 percent of these revenues, the revenue flow to Connecticut companies would range between \$50 million and \$1.25 billion annually.

Generally the lower end of the ranges of impact described above are associated with more success in alternative technologies to fuel cells and hydrogen, less aggressive promotion in the form of government incentives, and failure to achieve the objectives of fuel cell development programs. The higher end of the range is associated with opposite results for each of these factors.

### Summary of Potential Global Markets

A summary of the mature annual markets for hydrogen and fuel cell technology in stationary, transportation and portable electronics is provided in the table below. These market estimates are preliminary and solely for the purpose of giving a perspective on the economic opportunity for the industry and to Connecticut participants in this industry. A more detailed analysis of the potential markets, and the potential share for Connecticut companies will be undertaken in the Final Plan.

**Table I.2 – Summary of Mature Markets for Stationary and Portable Power, and Transportation**

<b>Market</b>	<b>Global Opportunity</b>	<b>Global Opportunity (Annual Revenues – Billion Dollars)</b>	<b>Opportunity for Connecticut Companies (Annual Revenues— Billion Dollars)</b>
<b>Stationary Power</b>	<b>11.25 (GW)</b>	<b>\$22.5</b>	<b>\$17</b>
<b>Transportation Power</b>	<b>300 to 2,100 (GW)</b>	<b>\$5.5 to \$52</b>	<b>\$0.6 to \$11</b>
<b>Portable Power</b>	<b>10,500 (Wh)</b>	<b>\$11</b>	<b>\$1.4</b>  <b>No CT OEM’s in this market, but activity at CGFCC could provide opportunity</b>

**Other Market Drivers**

*Policy*

Many local, state and federal government agencies have also recognized the public value of hydrogen and fuel cell energy technology as a distributed generation resource, and have helped to strengthen the market with statutory, regulatory, and administrative provisions that help to increase market penetration, as follows:

- the Connecticut General Assembly has already recognized hydrogen and fuel cell technology as a viable Class I renewable resource to meet renewable portfolio standards and that can provide on-site renewable distributed generation;<sup>37</sup>
- the Connecticut Clean Energy Fund is implementing Project 100 and other renewable energy programs that include the development of fuel cells and hydrogen technology;<sup>38</sup>
- the Governor’s commitment to the Regional Greenhouse Gas Initiative (RGGI) to reduce greenhouse gas emissions.<sup>39</sup> The RGGI agreement will stabilize carbon

<sup>37</sup> Connecticut General Statutes, Sec. 16-1. Definitions

<sup>38</sup> Connecticut General Statute section 16-244c

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- dioxide emissions from the region's power plants at current levels from 2009 to 2015. This will be followed by a 10 percent reduction in emissions by 2019;<sup>40</sup>
- the Governor's "Connecticut's Energy Vision for a Cleaner, Greener State" which includes an initiative for "Advance Development of Connecticut's Hydrogen Economy"; and
  - other state and local agencies have engaged in the siting of fuel cell technology, with some of the siting processes streamlined for accelerated development based on community support.<sup>41</sup>

With strategic guidance, applications using hydrogen and fuel cell technology would meet the functional energy needs of the state to improve efficiency, reduce consumption of fuel, and improve the environmental profile for energy production. Identified energy benefit drivers from use of fuel cells and hydrogen technology would also include:

- clean and nearly emission free operation;
- ease of siting and regulatory approval for facility development;
- efficient operation that will conserve on fuel costs, and can reduce the import of foreign oil;
- flexibility to act as a bridge that can lead to widespread use of renewable fuels including methane or ethanol from biomass, and hydrogen produced by solar and wind energy;
- improved reliability with uninterrupted power to critical load centers without the need to build and rely on electric transmission lines; and
- operation that can reduce Federally Mandated Congestion Charges.

Other functional drivers for development include government or government created incentives for renewable energy, research and development, and installation of hydrogen and fuel cell technology.

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<sup>39</sup> Connecticut Climate Change Initiative- <http://ctclimatechange.com/index.html>

<sup>40</sup> Governor Rell Press Release, Governor Rell Says Conn. Taking Critical Steps on Energy Independence and Environmental Protection, December 20, 2005

<sup>41</sup> Connecticut General Statute section 16-50k

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### Energy Supply

According to a study by the Electric Power Research Institute (EPRI Report 1004451, January 2003), the U.S. economy loses from \$104 - \$164 billion annually to power outages.<sup>42</sup> The need for new efficient, cost effective, and clean distributed generation has been well documented. For system-wide planning within New England, the Independent System Operator of New England (ISO) issued their 2006 Regional System Plan with an Installed Capacity Requirement Analysis based on Loss-of-Load-Expectation (LOLE) standards. This analysis, which assumed 2,000 MW of transmission tie-line benefits, concluded that New England would need approximately 173 MW by summer 2009, increasing annually to 4,300 MW by 2015 to meet demand and capacity requirements. ISO also undertook an Operable Capacity Analysis to estimate the net capacity that will be available under specific load scenarios. This analysis concludes that under 50/50 peak load conditions, New England could experience a negative operable capacity margin of approximately 406 MW by 2008 growing to 4,401 MW by 2015. Under 90/10 peak load conditions, New England could experience a negative operable capacity margin of approximately 1,686 MW by 2007 growing to 6,571 MW by 2015. ISO also concluded that adding new resources in the Greater Connecticut sub areas of Norwalk, Southwest Connecticut, and Connecticut would contribute the most to the system resource adequacy compared with adding resources in other sub areas of New England.<sup>43</sup>

Further, pursuant to Public Act 05-01, An Act Concerning Energy Independence (AACEI), the Connecticut Department of Public Utility Control (DPUC) was mandated to issue a request for proposals (RFP) for projects to reduce Federally Mandated Congestion Charges (FMCCs) in Connecticut. London Economics International LLC (LEI) was retained by the DPUC to help develop the RFP required by the AACEI.

The conclusions for this docket are generally consistent with the need for Connecticut to develop additional generation resources to reduce FMCCs and to meet capacity requirements.

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<sup>42</sup> California Distributed Energy resource Guide; [http://www.energy.ca.gov/distgen/markets/end\\_use.html](http://www.energy.ca.gov/distgen/markets/end_use.html)

<sup>43</sup> ISO New England, Inc.; 2006 Regional System Plan, October 2006

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### Air Emissions

#### Primary Air Pollutants

The Clean Air Act requires the Environmental Protection Agency (EPA) to set National Ambient Air Quality Standards (NAAQS) for pollutants considered harmful to public health and the environment. The EPA Office of Air Quality Planning and Standards (OAQPS) has set NAAQS for six principal pollutants, which are called “criteria” pollutants.<sup>44</sup> The Connecticut Department of Environmental Protection (DEP) monitors these six air pollutants -- sulfur dioxide (SO<sub>2</sub>), lead, carbon monoxide (CO), particulates, nitrogen oxides (NO<sub>x</sub>), and ground-level ozone across the state.

The 1980s were a time of transition for air quality. With new automobiles equipped with catalytic converters, nitrogen dioxide (NO<sub>2</sub>), carbon monoxide and volatile organic compounds (VOCs) were greatly reduced. The phasing out of leaded gasoline dropped the lead pollution to lower levels. New air pollution control technologies for stationary sources, including lower sulfur fuels, reduced sulfur dioxide, NO<sub>2</sub> and VOCs. Since 1975, ambient levels of sulfur dioxide and carbon monoxide have decreased by 66 percent; ozone by 60 percent; and nitrogen dioxide by 45 percent. Particulate matter with diameter 10 microns or less (PM<sub>10</sub>) has dropped 45 percent since 1985 and lead has shown the biggest decrease shrinking by 93 percent since 1975. However, even with the decline in monitored levels of all these pollutants, more progress remains to be made.<sup>45</sup>

Violations of the health-based air quality standards have been nearly eliminated for all pollutants except ground-level ozone. In the Earth’s lower atmosphere, ground level, ozone is formed when pollutants emitted by cars, power plants, industrial boilers, refineries, chemical plants, and other sources react chemically in the presence of sunlight. Ozone pollution is a concern during the summer months when the weather conditions needed to form ground-level ozone normally occur.<sup>46</sup> Motor vehicles remain a major source of ozone-forming emissions despite improvements in tailpipe standards. Much of

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<sup>44</sup> U. S. Environmental Protection Agency

<sup>45</sup> Connecticut Department of Environmental Protection

<sup>46</sup> Airnow.gov; Ozone and Your Health; <http://airnow.gov/index.cfm?action=static.ozone2#1>

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the ground-level ozone originates in states west of Connecticut.<sup>47</sup> Consequently, the reduction of pollutants such as VOCs and nitrogen oxides from power plants and vehicles west of Connecticut could significantly reduce the formation of ground-level ozone that adversely affects Connecticut's ambient air quality.

Several groups of people are particularly sensitive to ground-level ozone, especially when they are active outdoors because physical activity causes people to breathe faster and more deeply. Active children are the group at highest risk from ground-level ozone exposure because they often spend a large part of the summer playing outdoors. Children are also more likely to have asthma, which may be aggravated by ground-level ozone exposure. In addition, people with asthma or other respiratory diseases that make the lungs more vulnerable to the effects of ozone will generally experience health effects earlier and at lower ozone levels than less sensitive individuals. 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.<sup>48</sup>

## Greenhouse Gas Emissions

Gases that trap heat in the atmosphere are often called greenhouse gases (GHG). Human activities release GHG emissions and contribute to increasing concentrations of GHG in the atmosphere. CO<sub>2</sub> is the predominant GHG emitted by human sources. Increased production of CO<sub>2</sub> by human sources has caused total GHG emissions to exceed natural absorption rates, resulting in increased atmospheric concentrations. Since the beginning of the industrial revolution, atmospheric concentrations of CO<sub>2</sub> have increased by nearly 30 percent, methane (CH<sub>4</sub>) concentrations have more than doubled, and NO<sub>x</sub> concentrations have risen by approximately 15 percent. Energy-related activities were the

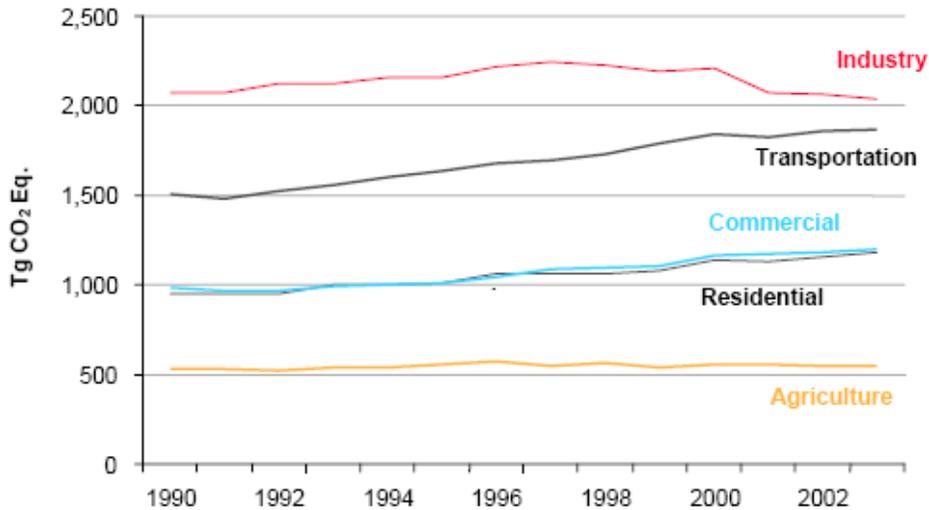
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<sup>47</sup> Council on Environmental Quality, Environmental Quality in Connecticut, 2005 Annual Report, p. 32.

<sup>48</sup> Airnow.gov; Ozone and Your Health; <http://airnow.gov/index.cfm?action=static.ozone2#1>

primary sources of U.S. anthropogenic GHG emissions, accounting for 86 percent of total emissions on a carbon equivalent basis in 2004.<sup>49</sup>

**Figure I.4 - U.S. Greenhouse Gas Emissions by End-Use Economic Sector, 1990–2003<sup>50</sup>**



Source: Derived from U.S. Environmental Protection Agency, 2005. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2003*. Washington, DC, Table 2-18.

Note: GHG emissions from electricity generation are distributed to economic sectors. Also, territories are excluded even though they are reported in the U.S. inventory. Territories comprise less than 1 percent of national emissions.

On December 20, 2005, seven states, including Connecticut, announced an agreement to implement the Regional Greenhouse Gas Initiative (RGGI). RGGI is a cooperative effort by Northeast and Mid-Atlantic states to discuss the design of a regional cap-and-trade program initially covering carbon dioxide emissions from power plants in the region. In the future, RGGI may be extended to include other sources of greenhouse gas emissions, and greenhouse gases other than CO<sub>2</sub>.<sup>51</sup>

Connecticut's goals are to have air that meets all health-based standards every day by the year 2010.<sup>52</sup> In addition, Connecticut is committed to reducing regional GHG emissions to 1990 emissions by 2010 (short-term goal), at least 10 percent below 1990 emissions by

<sup>49</sup> U.S. EPA; *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2004*, April 2006

<sup>50</sup> U.S. EPA; *Greenhouse Gas Emissions from the U.S. Transportation Sector, 1990-2003*, March 2006

<sup>51</sup> Regional Greenhouse Gas Initiative; <http://www.rggi.org>

<sup>52</sup> Council on Environmental Quality, *Environmental Quality in Connecticut, 2005 Annual Report*, p. 32.

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2020 (mid-term goal), and to reducing regional GHG emissions sufficiently to eliminate any dangerous threat to the climate (current science suggests this will require reductions of 75–85 percent below current levels).<sup>53,54</sup>

The use of fuel cells, and especially fuel cells that utilize hydrogen provide high value for improving air quality and reducing GHG emissions. Although the value of this incremental benefit is substantial in terms of health, this value is not easily measurable and often goes unrealized. Nonetheless, such value will be assessed within the Final Plan to help provide information for appropriate long-term decision.

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<sup>53</sup> Connecticut Department of Environmental Protection

<sup>54</sup> New England Governors/Eastern Canadian Premiers - Climate Change Action Plan 2001

## PART II

### Analysis of Connecticut's Hydrogen and Fuel Cell Industry

#### Description of Fuel Cells and Hydrogen<sup>55</sup>

##### Fuel Cells

A fuel cell is a device that uses hydrogen (or a hydrogen-rich fuel) and oxygen to create an electric current. The amount of power produced by a fuel cell depends on several factors, including fuel cell type, cell size, the temperature at which it operates, and the pressure at which the gases are supplied to the cell. A single fuel cell produces enough electricity for only the smallest applications. Therefore, to provide the power needed for most applications, individual fuel cells are combined in series into a fuel cell stack. A typical fuel cell stack may consist of hundreds of fuel cells.

Fuel cells have the potential to replace the internal combustion engine in vehicles and provide power for stationary and portable power applications. They can be used in transportation applications, such as powering automobiles, buses, cycles, and other vehicles. Many portable devices can be powered by fuel cells, such as laptop computers and cell phones. They can also be used for stationary applications, such as providing electricity to power homes and businesses.

Fuel cells are cleaner and more efficient than traditional combustion-based engines and power plants. When pure hydrogen is used to power a fuel cell, the only by-products are water and heat—no pollutants or greenhouse gases are produced. Since fuel cell technology is more efficient than combustion-based technologies, less energy is needed to provide the same amount of power. Finally, because hydrogen can be produced using a wide variety of resources found right here in the United States—including natural gas,

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<sup>55</sup> Refer to Appendix B: Comparison of Fuel Cell Technologies; The Connecticut Hydrogen-Fuel Cell Coalition, February 2006.

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biological material, and even water—using hydrogen fuel cells reduces our dependence on other countries for fuel.<sup>56</sup>

Fuel cells are classified primarily by the kind of electrolyte they employ. This determines the kind of chemical reactions that take place in the cell, the kind of catalysts required, the temperature range in which the cell operates, the fuel required, and other factors. These characteristics, in turn, affect the applications for which these cells are most suitable. There are several types of fuel cells currently under development, each with its own advantages, limitations, and potential applications, including polymer electrolyte membrane (PEM), direct methanol fuel cell (DMFC), alkaline fuel cell (AFC), phosphoric acid fuel cell (PAFC), and solid oxide fuel cell (SOFC).

### Hydrogen

Hydrogen is the lightest and most abundant element in the universe. In its pure form (H<sub>2</sub>), it is a colorless and odorless gas. However, since it combines easily with other elements, hydrogen is rarely found by itself in nature and is usually found as a part of other compounds, including fossil fuels, plant material, and water. Hydrogen is an energy carrier, not an energy source, meaning that it stores and delivers energy in a usable form. Like electricity, the most familiar energy carrier, it can be generated from a wide range of sources. While hydrogen contains more energy per weight than any other energy carrier, it contains much less energy by volume.

Hydrogen can be produced using a variety of domestic energy resources, including fossil fuels, such as coal and natural gas, renewables, such as biomass, electricity from renewable energy technologies, and thermal energy or electric power from nuclear. Since it can be produced from several sources using various methods, hydrogen can be produced at large production plants and transported to users. It can also be produced locally, using small generators, possibly at refueling stations, eliminating the need for long-distance transport. Hydrogen is currently transported by road via cylinders, tube

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<sup>56</sup> U.S. Department of Energy

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trailers, cryogenic tankers, and in pipelines. However, hydrogen pipelines currently only exist in a few regions of the United States. The delivery infrastructure for hydrogen will require high-pressure compressors for gaseous hydrogen and liquefaction for cryogenic hydrogen. Both currently have significant capital and operating costs, and energy inefficiencies. Hydrogen may be stored as a liquid, a high pressure gas, or by chemical methods; all are under intense development.

### Fuel Cells

#### Connecticut Fuel Cell Companies

Connecticut 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 application of fuel cell and hydrogen generation technology to transportation applications.

Table II.1 identifies activity by Connecticut companies in the development and manufacture of fuel cells and fuel cell components.

**Table II.1 - Connecticut Fuel Cell Companies**

Company	Alkaline Fuel Cells	Proton Exchange Membrane Fuel Cells	Phosphoric Acid Fuel Cells	Molten Carbonate Fuel Cells	Solid Oxide Fuel Cells
Aerogel Composite Inc. <a href="http://www.aerogelcomposite.com">www.aerogelcomposite.com</a>		Electrode Catalyst Research			
FuelCell Energy, Inc. <a href="http://www.fce.com">www.fce.com</a>				Commercial for stationary	Research and Development
GenCell Corporation <a href="http://www.gencellcorp.com">www.gencellcorp.com</a>		Components supply		Stationary demonstrations	Components supply
Infinity Fuel Cell and		Research and			

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Hydrogen, Inc. <a href="http://www.infinityfuel.com">www.infinityfuel.com</a>		Development for Regenerative Fuel Cells			
Parker Hannifin Corporation <a href="http://www.parker.com">www.parker.com</a>	Cell stack components	Cell stack components Ancillary components			
US Nanocorp <a href="http://www.usnanocorp.com">www.usnanocorp.com</a>					Research and Development
UTC Power <a href="http://www.utcpower.com">www.utcpower.com</a>	Commercial for Space craft	Bus and Auto Demonstrations, Back-up Power Demonstrations	Commercial for Stationary		

Three of the Connecticut companies are original equipment manufacturers:

- 1) FuelCell Energy, Inc. is headquartered in Danbury with a manufacturing facility in Torrington. FuelCell Energy, Inc. is the global leader in molten carbonate fuel cell products with power plant ratings from 300 to 2,400 kW. To date, installations at over 50 customer sites in the U.S., Europe, and Asia (September 2006 presentation at [www.fce.com](http://www.fce.com)) have generated over 129 million kilowatt hours (kWh) of electricity in stationary applications using natural gas or anaerobic digester gas from waste water treatment plants. Future product research and development involves a combined cycle plant which integrates the molten carbonate fuel cell with a gas turbine, a diesel fueled power plant for shipboard power and a power plant which co-produces hydrogen for use as a vehicle fuel. FuelCell Energy is also involved with R&D of solid oxide fuel cells and leads a project team under the Department of Energy Solid State Energy Conversion Alliance (SECA) program. This R&D is managed in Danbury, but is carried out in Colorado and Canada by Versa, which is partially owned by FuelCell Energy, Inc.
  
- 2) UTC Power is a unit of United Technologies Corporation located in South Windsor. UTC provided the alkaline fuel cell power plants used in the Apollo

lunar program in the 1960s and 1970s; a more advanced alkaline fuel cell by UTC is used in the space shuttle vehicle. UTC pioneered stationary applications of fuel cells with phosphoric acid fuel cells. After demonstration activities in the 1960s, 1970s and 1980s, it produced the initial commercial fuel cell product with deliveries beginning in 1992. The third version of this 200 kW product is now in production. Installations of more than 270 of these power plants have occurred in 85 cities and 19 countries and the fleet has accumulated over eight million hours and 1.4 billion kWh of successful operation to date ([www.utcpower.com](http://www.utcpower.com)). In the 1990s, UTC began development of proton exchange membrane technology for undersea and vehicle applications and currently has demonstration power plants in automobiles of three different manufacturers. The largest demonstration fleet is a 32 vehicle fleet funded under a U.S. DOE program in which UTC is a member of a team that includes Chevron and Hyundai.<sup>57</sup> UTC also provides fuel cells for revenue service transit buses in California that are the most advanced in the world in terms of efficiency, durability, and performance. UTC also has R&D activity ongoing in SOFC and stationary PEM fuel cells.

- 3) GenCell Corporation, located in Southbury, is a fuel cell developer and manufacturer with a “design for continuous manufacture” approach to help make fuel cells economically attractive. GenCell’s system product, a MCFC system suitable for the mid-size stationary power user (40–125 kW) is in its demonstration phase. GenCell also has a fuel cell components business, involving the sale of its metallic bipolar plates to proton exchange and solid oxide fuel cell manufacturers.<sup>58</sup>

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<sup>57</sup> UTC Press Release dated February 18, 2005

<sup>58</sup> GenCell Corporation

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### Core Competencies of Connecticut Fuel Cell Companies

Connecticut companies are unquestioned leaders in AFC, PAFC, and MCFC, are among the global leaders in PEM fuel cells, and a key participant in the SOFC activity sponsored by the U.S. DOE. Connecticut companies are also recognized as leaders in the integrated design of power plants for spacecraft and large (hundreds of kW) stationary applications and among the leaders in vehicle power plant integration. For stationary power plants, the system includes conversion of hydrocarbon fuels such as natural gas, digester gas and petroleum products to hydrogen, conversion of direct current power to alternating current, recovery of useful heat, and operating multiple power plants in parallel with the grid and/or with other power plants. With installation of hundreds of power plants throughout the world, and operation of these power plants for millions of hours, these Connecticut companies have unequalled experience with demonstrations and product support including application design, installation, parts supply and maintenance.

### Market Focus of Connecticut Fuel Cell Companies

The focus of Connecticut OEMs is on spacecraft applications, stationary applications for primary power in the hundreds of kW and above range, and replacement of battery back-up power through hydrogen fuel cells and regenerative fuel cells. Within the stationary power market place, emphasis is on customers with (1) a need for very reliable power, (2) customers with waste gas from anaerobic digester processes, (3) customers with combined heat and power loads which can take advantage of all the outputs of the fuel cell power plants, and (4) customers in situations where the distribution of central station power is extremely costly or where environmental factors are major determinants of purchase decisions.

Connecticut companies who manufacture standard and unique fuel cell components are marketing to fuel cell OEMs throughout the world.

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Connecticut has no companies who are strongly focused on small (several kW) stationary fuel cells or on portable fuel cell applications such as power for personal computers and communications devices.

### Major Issues Facing Connecticut Fuel Cell OEMs

Connecticut's fuel cell companies face the same issues as other fuel cell companies throughout the world. These include:

- Reducing manufactured cost to competitive levels even for specialized application to low volume markets. Fuel cells are not competitive without subsidies for mass markets in stationary and in particular vehicle applications. Costs are still integer multiples of the required levels.
- Demonstrating the durability and reliability in long term commercial service to validate fuel cell technical and economic characteristics.
- Developing market distribution channels and financial product offerings which facilitate use of fuel cells in situations where the ultimate customer focuses on the application of capital expenditures to the core business.
- Uncertainties regarding infrastructure investments needed to provide hydrogen fuel for vehicle fuel cell power plants.
- Uncertainties regarding production of hydrogen-fueled vehicles by vehicle OEMs.
- Securing long-term investment in fuel cell research, development, manufacturing and marketing especially when compelling evidence of market acceptance is lacking.
- Capturing economic value from the environmental characteristics of fuel cells which provide social benefit, but which are not recognized in economic decision-making.
- Instituting government policies which facilitate capturing benefits of distributed generation.

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- Acceptance of standards, codes and regulations associated with the use of stationary fuel cell power plants and hydrogen-fueled vehicles and their infrastructure.
- Government decisions regarding incentives and regulatory policies favorable to hydrogen fueled vehicles.

## Hydrogen

### Connecticut Hydrogen Companies

Connecticut companies have been involved with hydrogen generation for decades; Praxair has been involved with hydrogen supply for industrial and commercial purposes for many years. 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. Table II.2 shows activity by Connecticut Hydrogen Companies. Note that two Connecticut fuel cell companies that generate hydrogen internal to the power plant have hydrogen generation capabilities.

**Table II.2 - Connecticut Hydrogen Companies**

Company	Electrolysis	Generating Hydrogen from Hydrocarbons	Overall Supply of Hydrogen
<b>Avalence</b> <a href="http://www.avalence.com">www.avalence.com</a>	High pressure Systems for industrial and transportation		
<b>Hamilton Sundstrand Div. UTC</b> <a href="http://www.hamiltonsundstrandcorp.com">www.hamiltonsundstrandcorp.com</a>	Electrolysis Systems for oxygen generation aboard spacecraft and submarines		
<b>Praxair</b> <a href="http://www.praxair.com">www.praxair.com</a>			Supplier of industrial gases including hydrogen
<b>Proton Energy Systems</b> <a href="http://www.protonenergy.com">www.protonenergy.com</a>	Electrolysis systems for industrial applications and for demonstration		

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	transportation applications		
<b>Treadwell</b> <a href="http://www.treadwell.com">www.treadwell.com</a>	Electrolysis systems for submarine application		
<b><u>Fuel Cell Companies involved with Hydrogen Generation Technology</u></b>			
<b>FuelCell Energy, Inc.</b> <a href="http://www.fce.com">www.fce.com</a>		By-product hydrogen available from fuel cell power plant	
<b>UTC Power</b> <a href="http://www.utcpower.com">www.utcpower.com</a>		Generation of hydrogen for internal use in fuel cell system	
<b>GenCell Corporation</b> <a href="http://www.gencellcorp.com">www.gencellcorp.com</a>		Generation of hydrogen for internal use in fuel cell system	
<b>Infinity Fuel Cell and Hydrogen, Inc.</b> <a href="http://www.infinityfuel.com">www.infinityfuel.com</a>	Electrolysis systems used to generate hydrogen as part of a regenerative fuel cell system		

Two of the Connecticut Companies involved with electrolysis (Treadwell and the Hamilton Sundstrand Division of United Technologies) focus their electrolysis products on oxygen generation for 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.

Proton Energy Systems, a subsidiary of Distributed Energy Systems Corporation produces electrolysis systems for the purpose of hydrogen generation for industry, utilities, and for demonstrations of hydrogen vehicle systems. The company has installed over 750 hydrogen generators in more than 41 countries.<sup>59</sup> 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.

Praxair is an industrial gas company tracing its business back to 1917. It produces specialty gases including hydrogen and distributes hydrogen by truck and pipeline to

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<sup>59</sup> Distributed Energy Systems Corporation Form 10-K filed on March 10, 2006

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industrial customers throughout the world. Praxair is involved with demonstration projects associated with hydrogen-fueled vehicles and, together with Proton Energy Systems also provides on-site generation of hydrogen through electrolysis.

The major fuel cell OEMs in Connecticut are involved with generating hydrogen from hydrocarbon fuels such as natural gas. UTC uses hydrogen generation technology in its fuel cell power plants as an independent hydrogen generator. FuelCell Energy is developing technology to permit co-production of hydrogen from its fuel cell power plants.

### *Core Competencies of Connecticut Hydrogen Companies*

Connecticut hydrogen companies have expertise covering the entire range of hydrogen generation and distribution. Manufacture and product support capabilities of stand-alone hydrogen systems is associated with electrolysis systems. (Hydrogen generators are also included in fuel cell power plants manufactured by Connecticut companies.) Praxair is one of several leading industrial gas companies and has experience in the complete range of hydrogen generation and distribution including demonstration activity associated with supply of hydrogen for vehicles. It should be noted that while Praxair is headquartered and distributes hydrogen in Connecticut, its hydrogen generation facilities are located in other states.

### *Market Focus of Connecticut Hydrogen Companies*

Connecticut companies that use electrolysis for on-site production of hydrogen and oxygen focus on industrial, laboratory and utility customers. The integrated industrial gas supply company, Praxair, focuses on hydrogen for industrial and laboratory applications. Many of the Connecticut hydrogen companies are involved with demonstration of hydrogen supply for vehicle use, usually as part of a U.S. DOE or state funded activity.

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### Major Issues Facing Connecticut Hydrogen Companies

The issues faced by Connecticut's Hydrogen Companies are essentially the same as those faced by Connecticut Fuel Cell companies. These issues include cost, commercial service, market distribution, risk, investment, and government/regulatory guidance, as discussed above.

### Fuel Cell and Hydrogen R&D and Manufacturing Companies in Other States

Connecticut companies dominated U.S. and world-side fuel cell efforts through the 1980s. Beginning in the early 1990s, interest increased in fuel cells for vehicles combined with demonstrations of reasonable fuel cell performance in stationary applications and advances in proton exchange membranes. The possibility of extending fuel cell application to vehicles opened a greatly increased fuel cell market and brought the financial strength of the global auto manufacturing industry to bear on the technical problems. As a consequence, OEM fuel cell activity in other states and in other countries has gained significant strength eroding the relative position of Connecticut companies. Other efforts involved with supplying hydrogen to fuel cells also accelerated, and Connecticut's position has been threatened.

A survey by fuel cell industry organizations in the U.S., Canada, Europe, and Japan shows global sales of \$353 million dollars, nearly 7,100 employees and R&D expenditures of \$796 million dollars. Seventy percent of the fuel cell companies responding to the survey are headquartered in the U.S. (40 percent) and Canada (30 percent); Japan and Germany are other countries with large numbers of fuel cell companies. These four countries account for ninety three percent of global fuel cell R&D expenditures and eighty nine percent of the global employment in fuel cells. Technology focus by the respondents is highest for proton exchange membrane (46 percent), solid

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oxide (14 percent) and direct methanol (9 percent) fuel cell companies.<sup>60</sup> The other fuel cell technologies (phosphoric acid, molten carbonate and alkaline) have fewer participants, in part because of the dominance of Connecticut companies in these fields. The survey was sent to 490 organizations and 180 responded.

A directory of North American fuel cell companies listed by Fuel Cell Today ([www.fuelcelltoday.com](http://www.fuelcelltoday.com)) indicates there are over 800 organizations in North America with interests in fuel cells. There are over 100 members of the US Fuel Cell Council ([www.usfcc.com](http://www.usfcc.com)) and 100 members of the National Hydrogen Association ([www.hydrogenassociation.org](http://www.hydrogenassociation.org)). These organizations include OEMs, suppliers to OEMs, fuel cell installers, academic and government institutions, law firms, etc.

### *Other States Where There is Significant OEM or Major Supplier Activity in Fuel Cells and Hydrogen*

Appendix A, Tables IV.1, IV.2, and IV.3 focus on companies in 14 states other than Connecticut where there is significant manufacturing activity. Companies were identified from the member listings in the US Fuel Cell Council, the National Hydrogen Association, and other sources. Many other companies who are involved in fuel cells in a less significant way are not included in the listing.

Appendix A, Tables IV.1 and IV.2 identify key companies in the neighboring States of Massachusetts and New York. In these states, activity in solid oxide fuel cells, lower rated stationary proton exchange membrane fuel cells and direct methanol fuel cells for portable electronic applications exceeds the level of activity for these applications in Connecticut. A recent article indicated there are more than 80 fuel cell related companies

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<sup>60</sup> US Fuel Cell Council; 2006 Worldwide Fuel Cell Industry Survey

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in Massachusetts.<sup>61</sup> New York has the major U.S. auto company fuel cell research and development in GM's efforts in the Rochester area (both Ford and DaimlerChrysler utilize fuel cells by Ballard, a Canadian company, in their vehicles) as well as leading companies in small proton exchange membrane power plants (Plug Power) and fuel cells for portable electronics (MTI Micro Fuel Cells).

Appendix A, Tables IV.3 identifies manufacturing companies in 12 other states who are involved with fuel cells and/or hydrogen. Only one U.S. headquartered energy company, Chevron, is listed although BP and Shell are active in hydrogen in the U.S. Air Products, headquartered in Pennsylvania, and Praxair, headquartered in Connecticut are the U.S. industrial gas companies involved with hydrogen. Air Liquide, Linde and British Oxygen Company are also interested in hydrogen and have U.S. operations, but they are headquartered outside the U.S.

Delaware listings include DuPont and two companies whose business is based on DuPont materials indicating the strength of a significant technology company to generate additional business activity. Michigan and Ohio are both states with significant suppliers to the auto companies and the fuel cell activity in those states is strongly focused on auto applications of fuel cells and hydrogen. Ohio has made an effort to have hydrogen-related companies from other states and countries locate in Ohio. Rolls-Royce recently located its U.S. fuel cell activity in Ohio and UltraCell, a California company is locating its manufacturing activity in Ohio.<sup>62</sup> The decision by Rolls-Royce has attracted interest from Japanese companies to locate/relocate in Ohio as well.<sup>63</sup> Some of the companies identified in Table IV.3 are efforts of companies located elsewhere. For example, Versa Power Systems in Colorado is partially owned by Connecticut's FuelCell Energy, and the Siemens effort in Pennsylvania was part of the acquisition of Westinghouse business activity by Siemens of Germany.

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<sup>61</sup> Tewksbury Advocate, November 17, 2005, reported by Fuel Cell Works

<sup>62</sup> Akron Beacon, December 2, 2006 "Rolls-Royce fuels Ohio's tech plans," Paula Schleis

<sup>63</sup> Cleveland Plain Dealer, November 12, 2006

*Fuel Cell and Hydrogen R&D and Manufacturing Companies in other Countries*

There is significant activity by other companies in other countries, as indicated by the 2006 Worldwide Fuel Cell Industry Survey information presented in PART I. Ninety percent of the fuel cell companies responding to the recent survey are in North America, Europe and Japan. Activity in countries other than the U.S. is summarized below.

Canada has significant activity. British Columbia is the headquarters for Ballard, a leader in PEM Fuel Cells ([www.ballard.com](http://www.ballard.com)), Angstrom Power ([www.angstrompower.com](http://www.angstrompower.com)), and General Hydrogen Corporation ([www.generalhydrogen.com](http://www.generalhydrogen.com)). Ontario is headquarters for another PEM fuel cell company, Hydrogenics ([www.hydrogenics.com](http://www.hydrogenics.com)) and Alberta is one of the locations for Versa Power Systems ([www.versa-power.com](http://www.versa-power.com)). Other Canadian companies involved with fuel cells can be identified through the organization Hydrogen and Fuel Cells Canada ([www.h2fcc.ca](http://www.h2fcc.ca)).

In Europe, two German auto companies have pioneered use of fuel cell power plants in vehicles. DaimlerChrysler has been very active in pioneering use of PEM fuel cells manufactured by Ballard in autos and buses ([www.daimlerchrysler.com](http://www.daimlerchrysler.com)). BMW has experimented with fuel cell auxiliary power units ([www.bmw.com](http://www.bmw.com)). As noted previously, European energy companies, BP ([www.bp.com](http://www.bp.com)) and Shell ([www.shell.com](http://www.shell.com)) are very active globally in developing the technology for hydrogen infrastructure and demonstrating it throughout the world. Also, as noted previously, the industrial gas companies located in Europe, Air Liquide ([www.airliquide.com](http://www.airliquide.com)), British Oxygen Company ([www.bocindustrial.co.uk](http://www.bocindustrial.co.uk)), and Linde ([www.linde-gas.com](http://www.linde-gas.com)) are also involved with the hydrogen infrastructure. Other European companies involved with fuel cells are identified in the member listings for Fuel Cell Europe ([www.fuelcelleurope.org](http://www.fuelcelleurope.org)).

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Japan has many companies involved with fuel cells including:

- the major auto companies, Honda, Nissan and Toyota who have their own research, development and demonstration programs,
- major industrial companies such as Asahi Glass, Fuji, Hitachi, Mitsubishi Electric, Sanyo and Toshiba, and
- energy companies such as Nippon Oil, Osaka Gas, Tokyo Gas and Tokyo Electric Power.

Other Japanese companies are identified on the member listing of the Fuel Cell Commercialization Conference of Japan ([www.fccj.jp](http://www.fccj.jp)).

Other efforts are being carried out in Korea where Hyundai ([www.Hyundai-motor.com](http://www.Hyundai-motor.com)) is developing fuel cell powered automobiles and is a participant in the U.S. DOE fuel cell demonstration project with UTC Power and in Australia where Ceramic Fuel Cells Ltd. ([www.cfcl.com](http://www.cfcl.com)) is developing Solid Oxide Fuel Cells.

### *Connecticut Companies' Positioning in Fuel Cells and Hydrogen*

Tables II.3 and II.4 illustrate the position of Connecticut companies in fuel cells and hydrogen, compared to other states. The assessment of position is based on information provided in the sections above.

**Table II.3 - Connecticut Companies' Fuel Cell Position Compared to other States<sup>64</sup>**

	Alkaline	PEM	DMFC	PAFC	MCFC	SOFC
Spacecraft and Submarines	Dominant	Good				
Small Stationary		Poor	Poor			Fair
Large Stationary				Dominant	Dominant	Fair
Vehicle		Good		Good		Fair
Portable		Poor	Poor			

While the activity in fuel cells for new spacecraft and submarines is limited, alkaline fuel cells supplied by a Connecticut company have been the only source of electric power for manned spacecraft since the 1960s. Connecticut companies have been involved with application of both alkaline and PEM fuel cells to submarines and no other state has significant achievements in this area. Siemens (Germany) activity with fuel cells in submarines is currently the most extensive. UTC Power continues to have activity in this area with PEM fuel cells.

PEM fuel cells are under intensive development with applications including small stationary, vehicles and portable applications. While Connecticut companies participate in small stationary back-up power development with PEM, efforts by New York and Massachusetts companies involve significant numbers of demonstration units. Although many companies, including captive efforts by auto companies, are involved with PEM fuel cells for vehicles, at least one Connecticut company is involved with both automobile and bus applications with different automobile and bus OEMs. Individual

<sup>64</sup> Where a blank occurs in this table, there is no significant application of that fuel cell technology for the particular application.

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efforts by vehicle OEMs and Canadian company, Ballard, are at the same level or involve more extensive demonstration activity than Connecticut.

With the exception of contract efforts at the Connecticut Global Fuel Cell Center (CGFCC), Connecticut has no activity in DMFC. A number of companies including captive efforts by electronics companies and efforts by other companies in the U.S. including those from Massachusetts and New York are significant in the DMFC and PEM efforts for portable fuel cells.

Connecticut companies are global leaders in the application of PAFC and MCFC technologies to larger (hundreds of kW to megawatts (MW)) stationary power applications. There are development efforts in Japan in both technologies and one small activity in the US, but there are no companies approaching the level of Connecticut companies.

Connecticut participates in SOFC through R&D by UTC, and by FuelCell Energy through a partially owned company with facilities in Colorado and Canada, but that company has not achieved the level of demonstration achieved by companies in other states and countries.

***Table II.4 - Connecticut Companies' Hydrogen Position Compared to other States***

Electrolysis	Hydrocarbon Processing	Storage	Distribution
Excellent	Fair	Poor	Excellent

Three Connecticut companies are involved with electrolysis systems; however two restrict their activity to defense applications. Competition is primarily from a Canadian

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company. While Connecticut fuel cell companies have deep experience with processing hydrocarbons to hydrogen, they are not currently active in applying their knowledge to stand-alone hydrogen generation as are other U.S. companies working in this arena. There are no known efforts by Connecticut companies in hydrogen storage, which is a key technical hurdle that must be overcome, for hydrogen-fueled transportation. A Connecticut electrolysis company and an industrial gas company headquartered in Connecticut are participating in demonstrations of hydrogen fueling stations. This industrial gas company (one of two headquartered in the U.S.) also has extensive experience with transportation of hydrogen in the form of gas or liquid by truck and gas by pipeline.

### *Efforts in Support of Hydrogen and Fuel Cell Manufacturers*

Many states have public or private efforts supporting their fuel cell and hydrogen industry.

Comparisons are made with seven states that have a significant activity. These states include: California, Florida, Massachusetts, Michigan, New York, Ohio, Pennsylvania, and South Carolina. Note that Florida and South Carolina do not have any significant fuel cell industry, but some of them have significant fuel cell research activities.

### *Demonstration and Installation Activity*

One result of a favorable policy is the increased level of demonstration and installation activity. Table II.5 identifies hydrogen filling and stationary fuel cell installation activities in these states.

**Table II.5 - Hydrogen Filling Stations and Stationary Fuel Cell Installations<sup>65</sup>**

	<b>Hydrogen Filling Stations</b>	<b>Stationary Fuel Cell Installations (Total/Large)</b>
California	29	59/43
Florida	0	7/1
Massachusetts	0	10/7
Michigan	6	5/2
New York	1	55/26
Ohio	1	10/2
Pennsylvania	1	13/5
South Carolina	0	3/0
<b>Connecticut</b>	<b>1</b>	<b>20/15</b>

The data in Table II.5 can be somewhat misleading because the installation count associated with small, residential size fuel cell power plants reflects a much lower expenditure than the installation of larger fuel cell installations (more than 100 kW). It should be noted that some of the installations have more than one fuel cell power plant associated with them. Planned, but not completed stations/installations were not included.

Clearly, California has the largest demonstration activity for vehicles as well as the largest number of stationary fuel cell installations. This is true even though none of the installed fuel cells were manufactured in California. This is probably because California is a very large market, has more severe environmental problems, and is reacting to the environmental problems with legislation and demonstration program activity. Both California and Michigan are involved with the U.S. DOE vehicle demonstration activity accounting for the larger number of hydrogen filling stations in these states. The large number of stationary fuel cell installations in New York and Connecticut reflect the

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<sup>65</sup> The data were obtained from the World Wide Hydrogen Filing Stations database and the Worldwide Stationary Fuel Cell Database available on the Fuel Cells 2000 website ([www.fuelcells.org](http://www.fuelcells.org)).

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presence of fuel cell manufacturers in and near these states as well as the environmentally impacted conditions these states share with California.

The ingredients of state support for hydrogen and fuel cell development include state planning documents, partnerships among stakeholders, research centers, research and development expenditures, financial support of demonstrations, incentives for purchase and use. A comprehensive report on these issues was issued in July 2006 by the Breakthrough Technologies Institute Inc. “State Activities that Promote Fuel Cells and Hydrogen Infrastructure Development.”<sup>66</sup>

### *Planning and Partnerships*

State plans regarding fuel cells and hydrogen are often linked with partnerships in the form of industry trade groups, and development clusters. Appendix A, Table IV.4 describes planning and partnership activities for Connecticut and other states which are the focus of this section. Although Connecticut has provided support for the development of this guidance document and for the Connecticut Hydrogen-Fuel Cell Coalition, planning and partnership efforts for Connecticut generally lag those of other states.

### *Research Centers and Support*

A number of the states have significant research center activity supported by federal and state funding for fuel cell and hydrogen research. Appendix A, Table IV.5 describes the research and development centers and key state funding initiatives. This table identifies only those research facilities in the state that are specifically directed at alternative energy including fuel cells and hydrogen. Many of the other states have federally funded energy research facilities that provide a support infrastructure for hydrogen and fuel cell

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<sup>66</sup> The report is available at the Fuel Cells 2000 website ([www.fuelcells.org](http://www.fuelcells.org)).

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development. For example, South Carolina was able to establish a federally sponsored National Fuel Cell Center with limited state industry, and modest state funding.

Research support from universities is an important factor in state involvement with fuel cells. In Connecticut, the CGFCC at the University of Connecticut (UConn) undertakes scientific research and technology development. Naugatuck Valley Community College has a training and certification program for fuel cell technicians. California universities with fuel cell involvement include University of California Campuses at Berkeley, Davis and Irvine. In Ohio, Case Western Reserve University has long been a leader in fuel cell research activity. These are just some of the universities involved.

### State Assistance for Stationary Fuel Cells

Appendix A, Table IV.6 identifies state assistance for stationary fuel cells. The first three columns address regulatory programs, which can impede or support stationary fuel cell installations. These programs include renewable portfolio standards (RPS) for electric generation. In Connecticut, “Class I renewable energy source” means energy derived from solar power, wind power, a fuel cell, methane gas from landfills, and other sources as defined in Connecticut General Statutes.<sup>67</sup> Other states consider fuel cells as renewable energy only if they use a renewable fuel. Interconnection standards deal with requirements for connecting to the utility network. In the past, without standards, utility companies could impose burdensome and sometimes costly requirements that deterred installation of fuel cells or other distributed generation. With establishment of standards, this impediment is reduced. Net metering regulations require each electric supplier or any electric distribution company providing standard offer, transitional standard offer, standard service or back-up electric generation service to give a credit for any electricity generated by a residential customer from a Class I renewable energy source or a

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<sup>67</sup> Connecticut General Statutes, Sec. 16-1. Definitions

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hydropower facility.<sup>68</sup> Unlike some other states, Connecticut has a net metering law that will help to facilitate the development of distributed generation.

Manufacturing incentives are financial incentives designed to encourage the relocation or establishment of advanced energy companies in the state.

Incentives for the purchase of renewable energy or renewable energy equipment along with self generation incentives are methods to encourage use of distributed power and alternative energy generation by improving economic competitiveness. Connecticut recently established a program that provides a one-time subsidy of \$450/kW (and \$500/kW if the distributed resource is sited in southwest CT) for capital costs associated with projects for customer-side distributed resources. In addition, Connecticut has established “Project 100”, a program designed to encourage and fund the development of 100 MW of renewable generation.

All the states considered have demonstration programs for distributed generation including fuel cells. California, New York and Connecticut’s programs are more aggressive than those in the other states.

The number of stationary fuel cell installations in Table II.5 reflects these state assistance efforts.

### *State Assistance for Hydrogen-Fueled Vehicles*

Appendix A, Table IV.7 shows state assistance for hydrogen fueled vehicles. Hydrogen infrastructure support is dominated by California’s Hydrogen Highway program, which couples a requirement on vehicle manufacturers to meet targets for alternative fueled

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<sup>68</sup> Connecticut General Statutes, Sec. 16-243h. Credit to residential customers who generate electricity; metering.

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vehicles. Government vehicle purchase requirements and other incentives for private purchase of these vehicles to make California the clear leading state in regard to alternative fueled vehicles including hydrogen vehicles. That lead is reflected in the number of hydrogen fueling stations in Table II.5. Florida and New York are other states which have assistance noted, but they are at a very low level compared to those in California. Connecticut has very little assistance available for hydrogen fueled vehicles which is in sharp contrast to the situation for stationary power applications.

### **Hydrogen and Fuel Cells in Transportation**

Transportation is a major component of the economy. Over 231 million vehicles were registered in the U.S. in 2003 with 136 million of these being cars, 95 million being trucks and 777 thousand being buses. New vehicle sales are significant with over 17 million vehicles sold in 2003, most of which were cars and light duty trucks.

Transportation is the primary use of petroleum with the United States consuming 140 billion gallons of gasoline and 44 billion gallons of diesel fuel annually.<sup>69</sup> Imports constitute approximately 55 percent of the petroleum consumed in the U.S.<sup>70</sup>

Consequently, transportation is a major contributor to the U.S. greenhouse gas and other emissions and to the balance of payments deficit.

Transportation is also a significant infrastructure component with nearly 4 million miles of streets and highways in the U.S.<sup>71</sup> served by approximately 180,000 retail service stations.<sup>72</sup>

Transportation is a huge market for equipment and energy. If the 17 million vehicles sold annually each had a 75 kW power plant (a conservative estimate), total power delivered with these vehicles would be 1,275 million kW which exceeds the total installed U.S. electric generating capacity of 968 million kW. The business opportunity associated with

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<sup>69</sup> Energy Information Administration, 2005 Data

<sup>70</sup> Energy Information Administration, 2003 Data

<sup>71</sup> 2006 Statistical Abstract

<sup>72</sup> American Petroleum Institute

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supplying fuel for transportation is also huge. International opportunities add to the opportunity in the U.S.

Advances in performance and cost of proton exchange membrane fuel cells and reliability and endurance demonstrations of other types of fuel cells used in stationary applications caused hydrogen-fueled fuel cells to be considered seriously for development for vehicle use. These technical achievements coupled with increased concern for energy imports, noise from diesel buses in urban areas, emissions of controlled pollutants and greenhouse gas production provide investor and government incentive to pursue the technology.

These programs address key issues associated with achieving success including:

- hydrogen production cost and efficiency;
- hydrogen transportation and storage size, cost, and efficiency;
- developing a hydrogen fuel infrastructure; and
- fuel cell operability and cost.

In addition to the risks associated with developing hydrogen fueled transportation itself, investors and governments also face risks associated with development of alternative transportation technologies which could reduce the benefits associated with hydrogen fueled transportation. These alternative technologies include:

- advances in performance of conventional internal combustion engine technology;
- hybrid vehicles;
- natural gas vehicles; and
- biofuels such as ethanol and bio-diesel.

A review of the U.S. government program to advance the technology by a committee of the National Research Council<sup>73</sup> stated that:

- “This is a broad, very challenging research effort ... that will enable the vision of a clean and sustainable transportation energy future;

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<sup>73</sup> Review of the FreedomCAR and Fuel Partnership, First Report by Committee on Review of the FreedomCAR and Fuel Cell Research Program, Phase 1 of the National Research Council of the National Academies, 2005

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- Research goals have been established ... that, if attained, promise to overcome the multiple high-risk barriers to achieving that vision;
- The committee believes that research in support of this vision is justified by the potentially enormous beneficial impact for the nation; and
- Funding levels and the consequent research results during the next few years should allow future reviews to make a more firmly based assessment.”

A summary of the research and development challenges, alternative technologies and the efforts to overcome them is contained in a report prepared by The Connecticut Academy of Science and Engineering (CASE) for the Connecticut Department of Transportation (DOT).<sup>74</sup> The report also identifies organizations and individuals who are interested parties in regard to the use of hydrogen in Connecticut and describes their concerns as well as suggested efforts to address the concerns.

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

- a business opportunity for Connecticut companies;
- development of legislation and regulations for transportation use of hydrogen;
- development of hydrogen fuel infrastructure in Connecticut; and
- competition from other states.

These effects are also discussed in the CASE report and they are summarized below.

### *Business Opportunity for Connecticut Companies*

Connecticut companies described elsewhere in this document are involved with development 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 electricity to hydrogen fuel and the infrastructure business of producing and

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<sup>74</sup> CASE, “Preparing for the Hydrogen Economy: Transportation”, June 2006

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delivering hydrogen for transportation use. These companies are participating in demonstrations of their product technology that are sponsored by technology developed and produced by Connecticut companies. This technology could be used to convert natural gas or petroleum fuels to hydrogen and a Connecticut company is developing a fuel cell that produces hydrogen as a co-product along with electricity and heat.

Most of the global auto companies have activity in hydrogen fuel cell powered vehicles. Currently General Motors, Honda and Toyota have internal programs to develop hydrogen fuel cell powered automobiles, and Ford and DaimlerChrysler use fuel cells from Ballard, a Canadian company in their vehicles. A Connecticut company, UTC Power, has fuel cells in Honda, Nissan and BMW vehicles. Many hydrogen fuel cell buses are manufactured by DaimlerChrysler and use Ballard fuel cell power plants. UTC Power also has its fuel cell power plants in buses manufactured by U.S. and European Companies. Hydrogenics, another Canadian company, has fuel cells in buses as well. The U.S. DOE has four fuel cell automobile demonstration programs with auto company and oil company partnerships. The teams are DaimlerChrysler/British Petroleum, Ford/British Petroleum, General Motors/Shell and Hyundai/Chevron. UTC Power is a member of the Hyundai/Chevron team and Ballard participates with both Ford and DaimlerChrysler. GM uses a fuel cell developed in part at its facilities at Honeoye Falls, New York.

Proton Energy Systems, a Connecticut company, is one of the leading electrolysis manufacturers for industrial, utility and research applications and its electrolysis systems are involved with a number of the hydrogen filling stations in California and Vermont. Hydrogenics, a Canadian company is a competitor for this electrolysis business.

Praxair is an industrial gas company that generates hydrogen and distributes it by compressed gas and liquid hydrogen tanker trucks and by compressed gas hydrogen pipelines. Praxair is involved with a number of fueling station demonstration sites in California. Air Products is the other U.S. industrial gas company involved with hydrogen

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fueled vehicle demonstrations, and British Oxygen, Linde and Air Liquide are European competitors in the hydrogen business.

### *Development of Legislation and Regulations Associated with the Use of Hydrogen*

Use of hydrogen is well established in the industrial environment and appropriate codes and standards are in place. Substantial experience with natural gas vehicles and filling stations also contributes to the basis for developing standards, codes and regulations for use of hydrogen in transportation. Significant effort is underway to develop national and international standards governing use of hydrogen as a transportation fuel. The CASE report, referenced above, has a comprehensive listing of standards activity associated with hydrogen and a U.S. DOE website ([www.fuelcellstandards.com](http://www.fuelcellstandards.com)) provides the latest status on the standards activity. The Connecticut Fire Academy offers a training module for fires involving industrial hydrogen, and Connecticut codes and standards are updated regularly to reflect changes to national and international codes and standards as discussed in the CASE report.

Connecticut has significant legislation and state-sponsored effort in support of stationary fuel cells; however, little effort or planning is in place in regard to transportation applications of hydrogen and fuel cells as discussed in the CASE report.

### *Hydrogen Infrastructure in Connecticut*

Hydrogen infrastructure in Connecticut is limited to storage facilities for industrial use of hydrogen and experimental facilities at fuel cell and hydrogen companies. Proton Energy Systems tested a demonstration filling station prior to its being delivered to a Vermont demonstration site, and UTC Power has a filling station for use with its experimental fuel cell vehicles. The UTC Power station will also be used for a bus demonstration planned for 2007 by Connecticut Transit.

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Connecticut's infrastructure requirements are indicated by the following statistics for transportation in Connecticut which were provided in the CASE report:

- Connecticut has nearly three million vehicles that include over two million automobiles. In addition to vehicles registered in Connecticut, the infrastructure must serve vehicles crossing state borders. Over 350,000 vehicles cross the state border each day and it is estimated that nearly 43,000 of these are vehicles traversing the state between New York, Massachusetts and/or Rhode Island.
- Eighty one thousand vehicles in Connecticut are associated with 858 fleets of more than 25 vehicles each. Of these fleets, 91 have one hundred or more vehicles.
- State fleets include 4,200 automobiles or vans. Connecticut Transit and other transit agencies that receive state support have 650 full-size buses and more than 450 smaller buses and vans. There are over 300 vans in the Ride Share program for which the state provides purchase funding reimbursed over time by the riders.
- Connecticut has approximately 21,000 miles of streets and highways, including approximately 3,700<sup>75</sup> miles that are maintained by the state, that are served by more than 1,000 retail filling stations. Twenty-three of these stations are located in service plazas along the Merritt and Wilbur Cross Highways and Interstates 95 and 395. Another 500 stations are estimated to be for private use in fleet filling stations. All these stations deliver 1.4 billion gallons of gasoline<sup>76</sup> and over 300 million gallons of diesel fuel per year.<sup>77</sup>

The best early use of hydrogen for transportation would likely be in state-owned fleets used in urban areas like buses because their environmental benefits would have highest

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<sup>75</sup> Connecticut Department of Transportation; Bureau of Policy and Planning – Policy and Systems Information, as of Dec. 31, 2004

<sup>76</sup> CASE, “Preparing for the Hydrogen Economy: Transportation”, June 2006

<sup>77</sup> Energy Information Administration

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value in these locations and because fleet operations would minimize infrastructure requirements. Use of hydrogen fuel cell power would reduce noise and pollution from buses in congested urban areas. After pioneering the application with buses, other fleets with high use in urban areas could be targeted. At the same time, strategic sites to make hydrogen available for vehicles crossing the state could be located near the interstates in Connecticut, including I-95, I-395, I-91, and I-84. Diffusion of the infrastructure to additional sites would then follow as the fleet of hydrogen fueled vehicles increases in number. It has been proposed that sales of vehicles be concentrated in a few areas to provide economic use of hydrogen filling stations during the build out of these vehicles. Further, it is suggested that opening fleet fueling sites (including state owned sites) to retail sales be considered as part of the transition to a mature business.

### Competition from Other States

Other states are much more active in hydrogen fueled transportation than Connecticut. This puts Connecticut companies pursuing this opportunity at a disadvantage because they have to rely on demonstration efforts located some distance away to contribute to product development. Distance increases the cost of demonstration efforts and degrades the information obtained from those efforts. These other states also gain early experience which will help them realize the benefits of hydrogen fueled transportation more quickly because their codes and regulations will be in place and state personnel will be familiar with hydrogen issues. Currently, California and Michigan have the largest efforts in demonstrating hydrogen vehicles with California's effort being much larger. A few other states, including New York also have hydrogen vehicle demonstrations at a lesser level. It should be noted that New York and Michigan probably have the largest number of hydrogen and fuel cell employees other than Connecticut, with New York probably equal to or larger than Connecticut in this regard.

States without companies involved in hydrogen-fueled transportation also have economic development efforts associated with protecting auto industry employment in their states. Ohio and Michigan are examples of these states and they have research funding,

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commercialization funding and educational infrastructure efforts directed at the economic development objective. Ohio has a long-standing activity for university research at Case-Western Reserve University as well as a number of smaller fuel cell and materials companies. Michigan has a company, Energy Conversion Devices, which is involved with hydrogen storage, a key factor in making hydrogen-fueled vehicles practical.

Other states concentrate on research centered around federal laboratory facilities and/or universities. South Carolina is an example of a state with no hydrogen or fuel cell industry, which has built on the capability at the University of South Carolina and federal research at the Savannah River National Laboratory to win a National Science Foundation award for the Industry/University Cooperative Research Center on Fuel Cells at University of South Carolina.

Pennsylvania has strength in fuel cells and hydrogen through location of Air Products, an industrial gas company active in hydrogen, Siemens, a company active in solid oxide fuel cells, and in a fuel cell test center at Concurrent Technologies Corporation.

### **Research and Development**

In 2003, President Bush announced a \$1.2 billion Hydrogen Fuel Initiative, which included \$159 million in FY04 and \$227 million in FY05, and proposed expenditures for FY06 and FY07 projected to be approximately \$243 and \$290 million dollars, respectively. The Hydrogen Fuel Initiative also includes approximately \$720 million in federally-sponsored R&D funding through the Department of Energy.<sup>78</sup> As stated previously, global expenditures for R&D exceeded \$795 million in 2005.

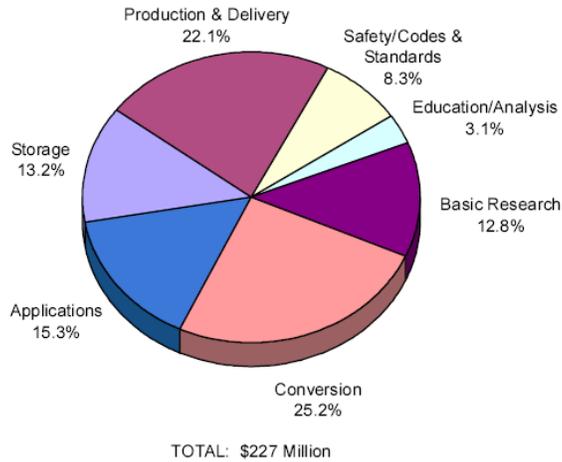
### **Figure II.1 – U. S. DOE Hydrogen Technology Budget Request Program Areas (FY05)<sup>79</sup>**

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<sup>78</sup> U.S. Department of Energy, <http://www.hydrogen.energy.gov>

<sup>79</sup> U.S. Department of Energy, An Integrated Research, Development, and Demonstration Plan, February 2004

## Preliminary Plan



### Connecticut Global Fuel Cell Center - Research Capabilities

As detailed above, the global market in fuel cell technology continues to grow, and is projected to be a multi-billion dollar industry. However, to some extent, the industry is still in the early stages of development in certain market sectors, and major barriers to product development remain. In particular, fuel cell scientific research and technology development progress has not been linked to integrated product development processes, and limitations in the supporting technical, human, and commercial infrastructure have resulted in serious problems with product cost and durability. Several national studies of the state of the art reflect the need to address cross-cutting challenges.<sup>80,81,82,83</sup> According to the U. S. DOE Report to Congress, “Proving full performance and reliability of fuel cell systems over the required life in field applications is a prerequisite for all applications.”<sup>84</sup>

Recognizing the need for fuel cell scientific research and technology development, the CGFCC was established at UConn in 2001. Over 40 faculty and 60 students are conducting contract research on fuel cell science and related technologies at the CGFCC’s dedicated 16,000-ft<sup>2</sup> facility. Six \$1 million faculty chairs have been allocated

<sup>80</sup> National Hydrogen Energy Roadmap, United States Department of Energy, November 2002.

<sup>81</sup> Fuel Cells for Transportation, United States Department of Energy, March 2002.

<sup>82</sup> Engineering and Public Policy, Committee on Science, On Being a Scientist: Responsible Conduct in Research, National Academy Press, 1995.

<sup>83</sup> U.S. Department of Energy’s Hydrogen Future;

<http://www.eere.energy.gov/hydrogenandfuelcells/fuelcells/why.html>.

<sup>84</sup> Fuel Cell Report to Congress, Department of Energy, ESECS EE-1973, Feb. 2003.

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to the CGFCC, anchored in part by an investment of the Connecticut Clean Energy Fund. The contract research program for the CGFCC in 2005 served 21 clients. In spring 2004, the CGFCC proposed to the American Society of Mechanical Engineers (ASME), the creation of the International Journal of Fuel Cell Science and Technology; now fully operational, this is the nation's first archival engineering journal exclusively serving the fuel cell engineering community. Through these efforts and, especially through interactions with industry, UConn faculty has identified the need to focus on the systems that can benefit from the incorporation of fuel cells, fully integrated from the electrical, thermal, mechanical, chemical, and geometrical standpoints.

Fuel cell research has been conducted at UConn for over 20 years, led by groups in polymers, catalysts, nanostructured materials, hydrogen storage, and transport/conduction. In the last three years, the \$15 million investment in fuel cell engineering and science at UConn has created a strong base for contract research on a full range of nano- to systems-level topics associated with PEM fuel cells, direct methanol fuel cells DMFCs, and SOFCs.<sup>85</sup>

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<sup>85</sup> Connecticut Global Fuel Cell Center

### PART III

#### Assessment of the Economic Potential for Connecticut

Knowledge of the full supply chain will potentially increase the value of the industry through increased efficiency, reduced waste, and improved integration of manufacturing components. As part of the Final Plan a full supply chain analysis is anticipated.

In terms of economic value, legislative decisions to support the hydrogen and fuel cell industry are appropriate because the hydrogen and fuel cell industry is a key industry that contributes to the economy of the State of Connecticut, as discussed below.

##### Economic Impacts of Connecticut's Hydrogen and Fuel Cell Industry

In 2006, Connecticut's hydrogen and fuel cell industry consists of six OEMs employing a total of 927 employees, as detailed in the following table:

**Table III.1 - Employment for the Hydrogen and Fuel Cell Industry in Connecticut**

<b>Company<sup>86</sup></b>	<b>Current Employees</b>
Avalence, LLC	—
FuelCell Energy, LLC	—
GenCell Corporation	—
Infinity Fuel Cell and Hydrogen, Inc.	—
Proton Energy Systems	—
UTC Fuel Cells	—
<b>TOTAL</b>	<b>927</b>

The economic impact of the industry on Connecticut's economy is presented in the following table.

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<sup>86</sup> Data for each company may be considered proprietary.

**Table III.2 - Economic Impacts of CT Hydrogen and Fuel Cell Industry**<sup>87,88</sup>

	<b>Industry Revenues (\$MM)</b>	<b>Employment</b>	<b>Employee Compensation (\$MM)</b>
Direct Impacts	204.36	927	76.47
Indirect Impacts	89.21	489	28.99
Induced Impacts	82.22	732	26.04
Total Impacts	375.79	2,148	131.05
Multiplier	1.84	2.31	1.72

It is estimated that the hydrogen and fuel cell industry received just over \$204 million in revenues. The indirect and induced impacts amounted to an additional \$171.4 million within the state. The revenue multiplier is 1.84, indicating that for each dollar of revenue generated by the hydrogen and fuel cell industry, an additional 84 cents of revenue is received by Connecticut businesses through indirect and induced impacts.

The employment multiplier is estimated at 2.31. Each job in the hydrogen and fuel cell industry supports an additional 1.31 jobs elsewhere in Connecticut's economy. Indirect jobs are those in the supply chain for the industry where 489 jobs are supported and an additional 732 jobs are supported through induced effects for a total employment impact of 2,148 jobs.

Employers within the hydrogen and fuel cell industry pay approximately \$76.5 million in employee compensation annually. As a consequence, indirect and induced impacts amounted to an additional \$55 million in compensation paid by other employers. The compensation multiplier of 1.72 indicates that for every \$1.00 paid to employees within the hydrogen and fuel cell industry, an additional 72 cents is paid by other employers.

<sup>87</sup> Analysis provided by Mark A. Thompson, PhD, Dean School of Business - Quinnipiac University. The data used to estimate the economic impacts of the hydrogen and fuel cell industry were provided by the Connecticut Center for Advanced Technology, Inc.

<sup>88</sup> Refer to the following page for an explanation of direct, indirect and induced effects.

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The analysis conducted for this report made exclusive use of the IMPLAN input-output model. This model estimates total local economic activity generated as a result of the economic activity of a particular business or industry sector. A business or industry requires inputs, some of which are purchased from other businesses within the area. The purchase of inputs causes additional economic activity. IMPLAN furnishes estimates of the overall economic activity. The model also provides estimates of a chain reaction of economic activity.

The concepts of direct, indirect and induced impacts are considered in this analysis. *Direct impacts* are those related to the initial economic stimulus. In this case, direct impacts are derived from the revenues received by the industry. *Indirect impacts* are those associated with the succeeding rounds of purchases through the supply chain. When a fuel cell company purchases an input, its supplier must in turn purchase inputs to fulfill the request. In turn, the supplier's supplier must make purchases and so on. *Induced impacts* are the regional household spending patterns that occur as the result of direct and indirect impacts. For example, the employment and income generated by direct and indirect impacts allows for spending in restaurants and retail outlets.

Economic impacts are assessed through multipliers. Multipliers reflect the magnitude of the impact on a regional economy resulting from a locally produced good or service. The production of a good by one business requires increased production on the part of businesses that supply inputs, which in turn stimulates other business. Ultimately, regional income and employment increase, stimulating more activity. The multipliers used for this study are related to the State of Connecticut's economy and its unique economic structure and trade flows. As a result, the multipliers in this study may be smaller or larger than those in other studies of the same industry.

The table of economic impacts of the hydrogen and fuel cell industry reveal the estimated direct, indirect and induced impacts on Connecticut's economy. The impacts are measured in three ways:

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1. The first measure is the impact of *industry revenue*. This is equal to total industry sales plus what is placed in inventory.
2. The second measure is *employment*. This is the full and part-time employment associated with the industry and through various economic impacts.
3. The third measure is *employee compensation*. This measures total payroll including wages, salaries and the monetary value of benefits.

Economic indices developed in conjunction with the hydrogen and fuel cell industry, with assistance from DECD suggest that the hydrogen and fuel cell industry can be an emerging economic cluster. As previously identified, the hydrogen and fuel cell industry currently contributes to the State's economy by providing over 900 jobs associated with research and development, and the manufacture of equipment; 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.

Global growth is encouraging suggesting that the market drivers, functional values, and economic values are being recognized and the market is growing. Nonetheless, these market drivers, functional values, and economic values have not yet been sufficient to fully replace the use of larger conventional base load technology on the grid and some lower cost distributed generation technology. The barriers that have slowed market penetration of hydrogen and fuel cell technology includes high initial costs with non-internalized and unappreciated environmental values, cost consuming interconnections, complicated codes and standards, lack of adequate public awareness, investment needed to undertake advanced research and development, lack of continuous (large scale) automated production, and strong competition from rate base supported grid generation load that could view distributed generation as a disruptive technology. With cost as the major barrier, critical questions raised and answered here are:

***Is there a global market sufficient to justify investment by Connecticut?***

Yes. With a 13 percent share of a global market that includes \$353 million in annual sales and \$796 million in annual R&D investment, Connecticut now occupies a favorable position to maintain and expand this share for increased employment and gross product. However, some estimate that the market will grow substantially, and revenues are expected to generate between \$18.6 billion annually and nearly \$35 billion annually over the next decade as hydrogen and fuel cell technology takes a larger share of the stationary power, portable power, and transportation markets.<sup>89</sup> With a potential market of this size, Connecticut would be in an enviable position for substantial opportunities to increase employment, sales, revenue, and investment in R&D.

***Can Connecticut companies capture a larger share of the global market?***

While the question of how to increase Connecticut's share of the global sales, R&D and employment market will be the focus of the Final Report, there are no technical barriers that would preclude Connecticut companies from increasing their share of the global market. The fuel cell and hydrogen industry will need to grow within the same business climate that all industries face in Connecticut. Moreover, if Connecticut does not actively and aggressively seek to increase its share, it may face loss of sales, R&D expenditures and employment as other states and countries compete for fuel cell and hydrogen development activities.

***Can costs drop to a level that will provide for effective competition and increased market penetration?***

Yes. It has been estimated that with increased support for research and development, and if production were to increase, production costs could drop to levels closer to parity with conventional generation.

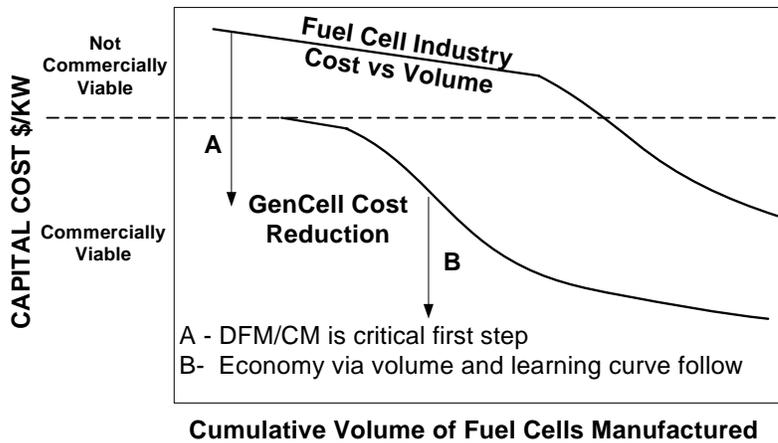
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<sup>89</sup> Connecticut Department of Economic and Community Development

***Will costs decrease if production were to increase?***

Yes. It has been estimated that increased production could provide continuous manufacturing of fuel cells that will help to support research, testing, and deployment of hydrogen and fuel cell technology and achieve lower unit costs to effectively compete with traditional generation technologies.

**Figure III.1 – Example: GenCell Fuel Cell Cost vs. Production Volume**



***Will supportive measures to be applied to increase market penetration be economically justified to earn a favorable return on public investment?***

Yes. With appropriate support, to be determined by the Final Report, production could increase, unit costs will drop, and employment will increase. With favorable multipliers of 2.31 for employment, 1.84 for industrial revenues, and 1.72 for employee compensation, Connecticut is well positioned to invest in the hydrogen fuel cell industry with the potential for substantial indirect and induced effects.

***Are there favorable locations for deployment and investment in Connecticut for hydrogen and fuel cell technology?***

Yes. Connecticut would benefit substantially through R&D investment and deployment of hydrogen and fuel cell technology. Benefits would include advanced training and education for long-term support of industry needs; improved environmental performance and cleaner air in the state; improved reliability for the electric grid; and reduced costs for electric consumers. All of these values will help to create new jobs that are directly and indirectly associated with hydrogen and fuel cell technology.

## **PRELIMINARY CONCLUSION**

Based on this analysis, support from the State of Connecticut to facilitate the targeted development of hydrogen and fuel cell technology is well justified for functional and economic reasons. Support of R&D and the targeted development of fuel cell applications will increase employment, improve energy reliability, enhance environmental quality, and help to reduce energy costs. The implementation of strategies must be dedicated over a long-term schedule. Inaction by Connecticut in addressing this opportunity may result in the erosion of the industry in state, loss of valuable jobs directly associated with the industry and the supply chain, and loss of a chance to synchronize an economic development strategy with the functional improvement of the energy supply infrastructure of the state. Favorable sites for the development of stationary power/distributed generation with fuel cells includes sites that require premium power, reliable power, and/or combined heat and power, and sites that will support the electric grid. These sites have the potential for hundreds of MWs of load; 85 MW have been identified as high value opportunities for fuel cell and hydrogen applications. Although the potential number of vehicles and refueling stations has not been estimated for this Preliminary Plan, deployment will be estimated for the final plan based on potential partnerships and targeted strategies aimed at fleets, transit buses, and urban refueling centers. Portable power applications have also not been estimated; however, commercial and military applications will be investigated for the final plan.

Future activities, consistent with Public Act 06-187, will include the development of strategies and an action plan for implementation.

Attention will be given to identify targeted applications to increase reliability and security, provide necessary voltage control and grid security, provide specialized and premium power for required uninterruptible service at customer sites, promote the improved efficiency and environmental performance with reduced emissions and greenhouse gases, and to provide more efficient use of nonrenewable fuels and increased use of renewable and sustainable fuels.

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**Appendix A: Tables**

*Table IV.1 - Example Fuel Cell and Hydrogen Companies in Massachusetts*

<b>State</b>	<b>Company</b>	<b>Product(s)/Technology(ies)</b>	<b>Application(s)</b>	<b>Status</b>
<b>MA.</b>				
	Acumentrics Corporation <a href="http://www.acumentrics.com">www.acumentrics.com</a>	Solid Oxide Fuel Cells	Small natural gas or propane fueled power generation	5 kW demonstrations
	Analytic Power <a href="http://www.analytic-power.com/">www.analytic-power.com/</a>	Proton Exchange Membrane and Solid Oxide Fuel Cells	Research and Development for clients	Continuing Research and Development Activity
	Electrochem, Inc. <a href="http://www.fuelcell.com">www.fuelcell.com</a>	Proton Exchange Membrane Fuel Cells	Small Fuel Cell components. Contract Research	Components available, research activity underway
	Giner, Inc. and Giner Electrochemical Systems, LLC <a href="http://www.ginerinc.com">www.ginerinc.com</a>	Proton Exchange Membrane Fuel Cells and Electrolysis Systems	Research and Development for Clients	Continuing research and development activity
	Nuvera <a href="http://www.nuvera.com">www.nuvera.com</a>	PEM Fuel Cells and Hydrogen Generation from Natural Gas and Petroleum	Back-up power, Auto power, Bus Power Rail power	Demonstrations
	Protonex Technology Corporation <a href="http://www.protonex.com">www.protonex.com</a>	Proton Exchange Membrane Fuel Cells	Portable Applications	Demonstrations
	ZTEK <a href="http://www.ztekccorporation.com">www.ztekccorporation.com</a>	Solid Oxide Fuel Cells, Steam reforming systems	Stationary power including combined cycle systems	Demonstrations

**Table IV.2 - Example Fuel Cell and Hydrogen Companies in New York**

State	Company	Product(s)/Technology(ies)	Application(s)	Status
<b>New York</b>				
	BAE Systems <a href="http://www.na.baesystems.com">www.na.baesystems.com</a>	Drive System Integration	Bus OEMs	Demonstration Hybrid Bus Drives
	Corning <a href="http://www.corning.com">www.corning.com</a>	Solid Oxide Fuel Cell Stacks	OEMs	Research and Development
	ENrG Inc <a href="http://www.enrg-inc.com">www.enrg-inc.com</a>	Solid Oxide Fuel Cell Components	OEMs	Research and Development
	General Electric <a href="http://www.ge.com/research">www.ge.com/research</a>	Solid Oxide Fuel Cells	Large Central Stations with coal gasifier and bottoming cycle	6kW Stack Operation See October 12, 2006 Press Release
		Integration of fuel cells and buses	Buses	New Program See October 23, 2006 Press Release
		Hydrogen Programs	Electrolysis, carbon capture and sequestration, storage	Research effort at Global Research
	General Motors <a href="http://www.gm.com/company/gmability/adv_tech/400_fcvt/index.html">www.gm.com/company/gmability/adv_tech/400_fcvt/index.html</a>	PEM fuel cells	Automobiles, Military, Stationary	In demonstration vehicles
	MTI Micro Fuel Cells Inc <a href="http://www.mtimicrofuelcells.com">www.mtimicrofuelcells.com</a>	Direct Methanol Fuel Cell (DMFC)	Portable electronics—commercial and military	Prototype delivered for customer evaluation Fuel Distribution Partnership
	Plug Power <a href="http://www.plugpower.com">http://www.plugpower.com</a>	Proton Exchange Membrane Fuel Cells Home fuelers for hydrogen vehicles	Hydrogen Fueled Back-up power, Small Stationary Power with natural gas or propane, Home hydrogen refuelers for fuel cell vehicles	Many demonstrations, strategic partnerships in place

**Table IV.3.1 - Example Fuel Cell and Hydrogen Companies in Other States**

State	Company	Product(s)/Technology(ies)	Application(s)	Status
<b>CA</b>				
	Chevron Corporation <a href="http://www.chevron.com">www.chevron.com</a>	Hydrogen Fuel	Vehicles	Demonstrations
	ISE Corporation <a href="http://www.isecorp.com">www.isecorp.com</a>	Integrated drive systems for hybrid and fuel cell buses	Buses	Demonstrations
	Jadoo Power <a href="http://www.Jadoodpower.com">www.Jadoodpower.com</a>	Hydrogen-fueled fuel cell power plants for portable applications	Military, first responders, telecommunications	Demonstrations, products available for sale
	Polyfuel <a href="http://www.polyfuel.com">www.polyfuel.com</a>	Hydrocarbon Membranes for Direct Methanol and Proton Exchange Membrane Fuel Cells	OEMs	Demonstrations
<b>CO</b>				
	Versa Power Systems <a href="http://www.versa-power.com">www.versa-power.com</a> Note: Partial Ownership by FuelCell Energy of CT	Solid Oxide Fuel Cells	Auxiliary Power Units, Combined Cycle Power Plants	Research and Development
<b>DE</b>				
	DuPont <a href="http://www.dupont.com">www.dupont.com</a>	Fuel Cell Membranes and Membrane Materials for Proton Exchange Membrane Fuel Cells and Electrolyzers	OEMs	Primary Supplier of Fuel Cell Membrane Material. Major Global Materials Supplier
	W. L. Gore & Associates <a href="http://www.gore.com">www.gore.com</a>	Fuel Cell Membranes and Membrane Electrode Assemblies (MEAs) for Proton Exchange Membrane Fuel Cells and Electrolyzers	OEMs	Major Supplier of Fuel Cell Membranes and MEAs, Global Supplier of Materials
	Ion Power Inc. <a href="http://www.ion-power.com">www.ion-power.com</a>	Fuel Cell Membranes and MEA's for Proton Exchange Membrane Fuel Cells and Electrolyzers	OEMs	Research and Development

**Table IV.3.2 - Example Fuel Cell and Hydrogen Companies in Other States**

<b>MI</b>				
	Delphi <a href="http://www.delphi.com">www.delphi.com</a>	Solid Oxide Fuel Cells	Vehicles Auxiliary Power Units, Combined cycle power plants	Research and Development of fuel cells. Component supplier to the auto industry
	DaimlerChrysler <a href="http://www.daimlerchrysler.com">www.daimlerchrysler.com</a>	Fuel Cell Automobiles	Automobiles, Buses	Demonstration
	Eaton Corp <a href="http://www.eaton.com">www.eaton.com</a>	Fuel Cell Ancillary Components	OEMs	Demonstration
	Energy Conversion Devices Inc. <a href="http://www.ovonic.com">www.ovonic.com</a>	Hydrogen Energy Storage and Hydrogen Fuel Dispensers	Automobiles, vehicle fueling stations	Demonstrations
	Ford Motor Company <a href="http://www.ford.com">www.ford.com</a>	Fuel Cell Automobiles	Automobiles	Demonstration
	General Motors Corporation <a href="http://www.gm.com">www.gm.com</a>	Fuel Cell Automobiles	Automobiles	Demonstration
<b>MN</b>				
	3M <a href="http://www.mmm.com">www.mmm.com</a>	Membrane Electrode Assemblies for Proton Exchange Membrane Fuel Cells	OEMs	Demonstrations
<b>NJ</b>				
	Millennium Cell Inc. <a href="http://www.millenniumcell.com">www.millenniumcell.com</a>	Hydrogen Storage in Chemical Hydrides for Portable fuel cell products	OEMs	Demonstration, Relationships with Fuel Cell Companies
<b>Ohio</b>				
	Dana Corporation <a href="http://www.dana.com">www.dana.com</a>	Fuel Cell Stack and Balance of plant components	Fuel Cell OEMs	Supplier of components to vehicle industry and others
	GrafTech International <a href="http://www.graftech.com">www.graftech.com</a>	Graphite Electrodes and Other Fuel Cell graphite parts	Fuel Cell OEMs	Supplier of commercial graphite products
	Nextech Materials, Ltd. <a href="http://www.nextechmaterials.com">www.nextechmaterials.com</a>	Solid Oxide Fuel Cell Materials and Fuel Processing Catalysts	Fuel Cell and Fuel Processors	Supplier to OEMs
	Rolls-Royce Fuel Cell Systems (US) Inc. <a href="http://www.rolls-royce.com">www.rolls-royce.com</a>	Solid Oxide Fuel Cells	Megawatt fuel cell-turbine combined cycle power plants	Research and Development
	SOFCO-EES Holdings, LLC <a href="http://www.sofco-efs.com">www.sofco-efs.com</a>	Solid Oxide Fuel Cells and Fuel Processors	Stationary and Vehicle Auxiliary Power	Laboratory Demonstrations
	UltraCell Corporation <a href="http://www.ultracellpower.com">www.ultracellpower.com</a> (Note: California Company with production facility in Ohio)	High volume manufacturing of small reformer-Proton Exchange Membrane Fuel Cells	Portable Electronics for Commercial and Military Use	Beta Units available to customers

**Table IV.3.3 - Example Fuel Cell and Hydrogen Companies in Other States**

<b>OR</b>				
	Idatech <a href="http://www.idatech.com">www.idatech.com</a>	Small Fuel Cell Power Plants up to 15 kW for portable power applications operating on hydrogen or hydrocarbon fuels	Military, commercial, residential applications	Demonstrations
<b>PA</b>				
	Air Products <a href="http://www.airproducts.com">www.airproducts.com</a>	Global Industrial Gas Company	Hydrogen Fueling Stations for Vehicles	Demonstrations in US and Europe
	Franklin Fuel Cells <a href="http://www.franklinfuelcells.com">www.franklinfuelcells.com</a>	Solid Oxide Fuel Cells	Range of power from kilowatts to hundreds of kilowatts	Research and Development
	Siemens (US Fuel Cell Activity) <a href="http://www.siemens.com">www.siemens.com</a>	Solid Oxide Fuel Cells	Fuel Cells and Fuel Cell-Turbine Combined Cycle power plants	A number of Demonstrations
<b>UT</b>				
	Ceramatec Inc. <a href="http://www.ceramatec.com">www.ceramatec.com</a>	Solid Oxide Fuel Cells	Research and Development	Advanced technology materials for fuel cell and other applications.
<b>VA</b>				
	H2 Gen Innovations Inc. <a href="http://www.h2gen.com">www.h2gen.com</a>	Natural gas to hydrogen generators	Industrial Hydrogen and Hydrogen for Vehicles	Commercial products
<b>WA</b>				
	Hydrogen Power Inc. <a href="http://www.hydrogenpowerinc.com">www.hydrogenpowerinc.com</a>	Hydrogen Storage based on reaction of water and aluminum	Military and commercial portable power, vehicles	Demonstration
	Relion <a href="http://www.Relion-inc.com">www.Relion-inc.com</a>	Hydrogen-fueled fuel cell power plants for back-up applications	Military, telecommunications, commercial	Demonstrations, Certified Products available

**Table IV.4 - Planning Documents and Partnerships for Key States**

<b>State</b>	<b>Planning</b>	<b>Partnerships</b>
California	California Hydrogen Highway Network Plan (2004) Alternative Transportation Fuel Plan (2005) Executive Order S-06-06 Use of Alternative Fuels (2006)	California Fuel Cell Partnership (1999) California Hydrogen Business Council California Stationary Fuel Cell Collaborative
Florida	H2 Florida (2003)	The Florida Hydrogen Business Partnership (2004) Florida Hydrogen Initiative, Inc.
Massachusetts	Legislative Action Requested by Industry (2006)	Massachusetts Hydrogen Coalition (2004)
Michigan	Fuel Cell Report	
New York	New York State Hydrogen Energy Roadmap (2005)	New York State Fuel Cell Network (2005)
Ohio	Ohio Fuel Cell Initiative (2002) Ohio Fuel Cell Roadmap	Ohio Fuel Cell Coalition Wright Fuel Cell Group (2004)
Pennsylvania		Pennsylvania Hydrogen and Fuel Cell Consortium
South Carolina	SC H2—The South Carolina Hydrogen Economy, Capitalizing on the States R&D Assets (2005)	Engenuity SC South Carolina Hydrogen and Fuel Cell Alliance South Carolina Hydrogen Coalition (2002) South Carolina Next Energy Initiative USC Columbia Fuel Cell Collaborative (2005) Cluster Forming
<b>Connecticut</b>	<b>Hydrogen and Fuel Cell Planning Effort Begins (2006)</b>	<b>Connecticut Hydrogen and Fuel Cell Coalition (2005)</b> <b>Cluster Formation (2007)</b>

*Table IV.5 - Research Support for Hydrogen and Fuel Cells in Key States*

<b>State</b>	<b>Research and Development Centers</b>	<b>State Funding for research and Development</b>
California	National Fuel Cell Research Center at UCAL Irvine Institute for Transportation Studies at UCAL Davis	California Energy Commission Clean Energy Funding
Florida	--	--
Massachusetts	--	Massachusetts Technology Collaborative
Michigan	NextEnergy Center Michigan Alternative and Renewable Energy Center Center for Fuel Cell System and Power Integration	Michigan NextEnergy Authority NextEnergy Energy Office of Michigan
New York		New York State Energy Research and Development Authority Long Island Power Authority New York Power Authority
Ohio	Fuel Cell Prototyping Center	Third Frontier Project
Pennsylvania	Fuel Cell Test Center at Concurrent Technologies Corporation Hybrid and Hydrogen Research Center at Pennsylvania State University	--
South Carolina	Center for Hydrogen Research at Savannah River National Laboratory University of South Carolina National Fuel Cell Center International Center for Automotive Research at Clemson University James E. Clyburn Transportation Center at South Carolina State University	--
<b>Connecticut</b>	<b>Connecticut Global Fuel Cell Center</b>	<b>Connecticut Innovations, Inc.</b> <b>Connecticut Clean Energy Fund</b> <b>New Energy Technology Grants</b>

*Table IV.6 - State Assistance for Stationary Fuel Cells*

State	Renew. Portfolio Standard	Interconnect Standard	Net Meter	Mftr Inct.	Sustain. Bldg Policy	Renewable Energy Purchase	Renew. Purch Incent	Self Generation Incentives	Back-up Power Rate Relief	Demo Funding
California	Renewable Fuel Only	Yes	Yes		San Diego	San Francisco (Bonding)	Yes	Yes		Yes
Florida				Yes						Yes
Massachusetts	Renewable Fuel Only	Yes	Yes <60 kW	Yes			Yes			Yes
Michigan		Yes	Yes <30 kW	Yes			Yes			Yes
New York	Yes	Yes				Yes	Yes	Yes		Yes
Ohio		Yes	Yes	Yes			Yes			Yes
Pennsylvania	Yes	Yes	Yes	Yes			Yes			Yes
South Carolina										
<b>Connecticut</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>			<b>Yes, State Facilities</b>		<b>Yes</b>	<b>Yes</b>	<b>Yes</b>

*Table IV.7 - State Assistance for Hydrogen Fueled Vehicles*

<b>State</b>	<b>Hydrogen Infrastructure Support</b>	<b>AFV Sales Rqmt</b>	<b>Government Purchase of AFV</b>	<b>ZEV Bus Purchase Requirement</b>	<b>Vehicle/Fuel Purchase Incentive</b>	<b>HOV/Parking Incentives for AFV</b>	<b>Manufact'r Incentives</b>	<b>Demonstrations</b>
California	Yes	Yes	Yes	Yes	Yes	Yes		Yes
Florida	Yes		Yes		Yes		Yes	Yes
Massachusetts			Yes		Yes			
Michigan							Yes	Yes
New York	Yes	Yes	Yes	Yes				Yes
Ohio							Yes	Yes
Pennsylvania			Yes		Yes		Yes	Yes
South Carolina								
<b>Connecticut</b>			<b>Yes</b>		<b>Yes</b>			

## **Appendix B: High Value Opportunities for Fuel Cell & Hydrogen Applications**

As an exercise to identify the technical potential and strategic targets for Connecticut, CCAT has assessed and analyzed potential applications for stationary power/distributed generation and transportation. These strategic targets include commercial buildings with potentially high electricity consumption (inpatient healthcare, education, lodging, food sales, food service, and public order and safety), selected town and state buildings, energy intensive industries, telecommunications facilities, selected public works facilities, alternative fueling stations, and state fuel dispensing locations. These targeted applications have been estimated at approximately 85 MW.

The development of fuel cells and hydrogen equipment is appropriate, and the application of this technology is well justified at strategic locations throughout the state for the following reasons:

- fuel cells are extremely efficient and can help to reduce the dependence on foreign oil, and contribute greatly to the reduction of air pollutants, especially SO<sub>2</sub>, NO<sub>x</sub>, and VOC;
- fuel cells have a high availability rate and can provide premium, stand-by, and emergency power for a variety of applications;
- fuel cells provide renewable energy for compliance with renewable portfolio standards, and the Governor's directive for state building renewable energy purchases; and
- fuel cells and hydrogen equipment are developed and manufactured in the state providing direct benefits including high-skilled and high-paying jobs, and indirect benefits associated with the supply chain.

## **Potential Fuel Cell Installations**

### Commercial Building Types with Potentially High Electricity Consumption

Commercial building types with potentially high electricity consumption have been identified as potential locations for on-site generation and combined heat and power systems based on data from the EIA's Commercial Buildings Energy Consumption Surveys (CBECS). These commercial building types, as defined by the EIA, include inpatient healthcare, education, lodging, food sales, food service, and public order and safety. These commercial building types represent the top principal building activity classifications that reported the highest value for electricity consumption on a per building basis.<sup>90</sup> These commercial buildings with potentially high electricity consumption may have high and potentially advantageous load factors for the favorable application of CHP and advanced distributed generation technologies, including fuel cells.

### Education

According to the EIA, buildings classified as "education" are those used for academic or technical classroom instruction.<sup>91</sup> The Connecticut State Department of Education reports that there are approximately 383<sup>92</sup> non-public schools and 1,031 public schools, including magnets, charters, alternative schools and special facilities in Connecticut. Of the 1,031 public schools, 306 school facilities have had no major renovations in the past 20 years, and 260 school facilities have had major renovations or construction within the past 11-20 years.<sup>93</sup> In addition, there are 50 colleges and universities in Connecticut, including 22 public institutions and 28 private institutions.<sup>94</sup> There is currently a fuel cell installed at the South Windsor High School and Yale University.<sup>95</sup> The fuel cells installed at the Connecticut

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<sup>90</sup>EIA, Table C14. Electricity Consumption and Expenditure Intensities for Non-Mall Buildings, 2003; [http://www.eia.doe.gov/emeu/cbecs/cbecs2003/detailed\\_tables\\_2003/2003set10/2003pdf/c14.pdf](http://www.eia.doe.gov/emeu/cbecs/cbecs2003/detailed_tables_2003/2003set10/2003pdf/c14.pdf)

<sup>91</sup> Energy Information Administration, Description of CBECS Building Types; [http://www.eia.doe.gov/emeu/cbecs/building\\_types.html](http://www.eia.doe.gov/emeu/cbecs/building_types.html)

<sup>92</sup>Connecticut State Department of Education; [http://www.csde.state.ct.us/public/cedar/edfacts/schools\\_by\\_type.htm](http://www.csde.state.ct.us/public/cedar/edfacts/schools_by_type.htm)

<sup>93</sup> Annual Report on the Condition of Connecticut's Public School Facilities - December 2005; Section 1. [http://www.csde.state.ct.us/public/dgm/ed050/reports\\_2005/sec1.pdf](http://www.csde.state.ct.us/public/dgm/ed050/reports_2005/sec1.pdf)

<sup>94</sup> Connecticut Department of Higher Education, Fall 2006 College and University Headcount in Connecticut, November 2006; <http://www.ctdhe.org/info/pdfs/2006/2006Enrollment.pdf>

<sup>95</sup> Connecticut Clean Energy Fund

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Global Fuel Cell Center at the University of Connecticut (Storrs) are primarily laboratory sized units for testing and evaluation.<sup>96</sup> (See Appendix B - Figure 7: Education)

The technical potential of energy at the older 306 public schools and the 50 colleges and universities has been estimated at approximately 12 MW of load, which could be provided by 46 to 58 fuel cell units. However, if just five percent of the 356 education buildings were powered by current fuel cell technology, approximately 18 units could be deployed for a total capacity of between 3.6 and 4.5 MW.

### Food Sales

According to the EIA, buildings classified as “food sales” are those used for retail or wholesale of food, including grocery stores, food market, convenience stores.<sup>97</sup> There are over 3,000 businesses in Connecticut that may be engaged in the retail sale of food,<sup>98</sup> including 817 food stores that have obtained a grocery store beer permit for the retail sale of beer.<sup>99</sup> The application of a fuel cell at a small convenience store may not be economically viable, based on the electric demand and operational requirements. Consequently, CCAT has identified approximately 230 larger businesses in Connecticut engaged in the retail sale of food that have more than 25 employees at the site. There are currently no fuel cells installed at food sales establishments in Connecticut; however, there is one fuel cell installed at the Pepperidge Farms manufacturing facility in Bloomfield. (See Appendix B - Figure 3: Food Sales)

The technical potential of energy at the larger 230 food stores has been estimated, using a conservative average of load per building, at approximately seven MW of load, which could be provided by 29 to 36 fuel cell units. However, if just five percent of the large food stores were powered by current fuel cell technology, approximately 12 units could be deployed for a total capacity of between 2.4 and 3 MW.

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<sup>96</sup> Connecticut Global Fuel Cell Center

<sup>97</sup> Energy Information Administration, Description of CBECS Building Types; [http://www.eia.doe.gov/emeu/cbecs/building\\_types.html](http://www.eia.doe.gov/emeu/cbecs/building_types.html)

<sup>98</sup> Proprietary market data.

<sup>99</sup> Connecticut Department of Consumer Protection, Liquor Control Division

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### Food Service

According to the EIA, buildings classified as “food service” are those used for the preparation and sale of food and beverages for consumption, including restaurants, and fast food establishments.<sup>100</sup> There are over 6,400 businesses in Connecticut that may be classified as food service establishments.<sup>101</sup> Again, the application of a fuel cell at a small restaurant may not be economically viable, based on the electric demand and operational requirements. Consequently, CCAT has identified approximately 820 businesses in Connecticut engaged in the preparation and sale of food and beverages for consumption that have more than 25 employees at the site. There are currently no fuel cells installed at food sales establishments in Connecticut. (See Appendix B - Figure 2: Food Service)

The technical potential of energy at the 820 food service establishments has been estimated at approximately 20 MW of load, which could be provided by 80 to 100 fuel cell units. If just five percent of the 820 food service establishments were powered by current fuel cell technology, approximately 41 units could be deployed for a total capacity of between 8.2 and 10.25 MW.

### Inpatient Healthcare

According to the EIA, buildings classified as “inpatient healthcare” are those buildings used as diagnostic and treatment facilities for inpatient care, including hospitals and inpatient rehabilitation facilities, but not including convalescent homes and skilled nursing facilities.<sup>102</sup> CCAT has identified approximately 99 inpatient healthcare facilities in Connecticut.<sup>103</sup> Specific attention is encouraged for CHP applications to increase efficiency and reduce fuel consumption. This application will also have special value to provide increased reliability to mission critical facilities associated with Homeland Security and healthcare. There is currently one fuel cell installed at Saint Francis Hospital and Medical Center in Hartford. (See Appendix B - Figure 4: Inpatient Healthcare)

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<sup>100</sup> Energy Information Administration, Description of CBECS Building Types; [http://www.eia.doe.gov/emeu/cbecs/building\\_types.html](http://www.eia.doe.gov/emeu/cbecs/building_types.html)

<sup>101</sup> Proprietary market data.

<sup>102</sup> Energy Information Administration, Description of CBECS Building Types; [http://www.eia.doe.gov/emeu/cbecs/building\\_types.html](http://www.eia.doe.gov/emeu/cbecs/building_types.html)

<sup>103</sup> Connecticut Department of Public Health, Facilities Licensing & Investigations Section

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The technical potential of energy from the 99 buildings, classified as inpatient healthcare, has been estimated at approximately 75 MW of load. However, if each of the 99 inpatient healthcare facilities were powered by current fuel cell technology, approximately 20 to 25 MW of electricity could be generated.

### Lodging

According to the EIA, buildings classified as “lodging” are those used to offer multiple accommodations for short term and long term residents, including hotel, motels, inns, convalescent homes, and skilled nursing facilities.<sup>104</sup> There are approximately 690 businesses in Connecticut that may be classified as lodging establishments.<sup>105</sup> Again, the application of a fuel cell at a small inn or motel may not be economically viable, based on the electric demand and operational requirements. Consequently, CCAT has identified approximately 180 businesses in Connecticut that would be classified as lodging that have more than 25 employees at the site. In addition, there are 237 convalescent homes and skilled nursing facilities in Connecticut.<sup>106</sup> There are currently no fuel cells installed at lodging establishments in Connecticut. (See Appendix B - Figure 6: Lodging)

The technical potential of energy at the larger 417 lodging establishments (larger hotels and convalescent homes and skilled nursing facilities) has been estimated at approximately 23 MW of load, which could be provided by 92 to 115 fuel cell units. If just five percent of the 417 lodging establishments were powered by current fuel cell technology, approximately 21 units could be deployed for a total capacity of between 4.2 and 5.25 MW.

### Public Order and Safety

According to the EIA, buildings classified as “public order and safety” are those buildings used for the preservation of law and order, or public safety, including police and fire stations, jail or penitentiary, and courthouses. There are approximately 811 facilities in Connecticut

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<sup>104</sup> Energy Information Administration, Description of CBECS Building Types; [http://www.eia.doe.gov/emeu/cbecs/building\\_types.html](http://www.eia.doe.gov/emeu/cbecs/building_types.html)

<sup>105</sup> Proprietary market data.

<sup>106</sup> Connecticut Department of Public Health, Facilities Licensing & Investigations Section

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that may be classified as public order and safety.<sup>107</sup> However, many small towns lack a police or fire department that is staffed 24 hours per day, seven days a week and the application of a fuel cell at such a facility may not be economically viable, based on the electric demand and operational requirements. Consequently, CCAT has identified 75 state-owned facilities in Connecticut that are used by the Connecticut State Police, state penitentiaries, state armories and the State's Supreme, Appellate, and Superior Courts.<sup>108</sup> There are currently no fuel cells installed at public order and safety facilities in Connecticut.<sup>109</sup> (Appendix B - Figure 5: State Public Order and Safety)

The technical potential of energy from the 75 buildings, classified as public order and safety has been estimated at approximately 2MW of load. However, if each of the 75 state-owned public order and safety facilities were powered by current fuel cell technology, approximately 15 to 18.75 MW of electricity could be generated.

These potential locations represent favorable opportunities for the application of advanced distributed generation technologies to provide uninterrupted power during grid outages. Policy directives at the local, State and Federal levels to provide increased reliability for mission critical facilities associated with Homeland Security will help to support this initiative. According to the EIA's 1999 CBECS data, 63 percent of inpatient healthcare facilities reported having electricity generation capability, and 54 percent reported actually used the capability to generate electricity. Likewise, 61 percent of public order and safety facilities also reported having electricity generation capability; however, only 32 percent reported actually using the capability to generate electricity.<sup>110</sup>

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<sup>107</sup> Proprietary market data.

<sup>108</sup> It should be noted that some of these facilities have multiple buildings that may be ideal for the application of a fuel cell; however, this analysis assumes no more than one fuel cell at each location.

<sup>109</sup> Connecticut Clean Energy Fund

<sup>110</sup> EIA, Electricity Generation Capability, 1999 CBECS;  
<http://www.eia.doe.gov/emeu/cbecs/pba99/comparegener.html>

**Appendix B Table V.1 – Summary of Energy Potential: Commercial Building Types with Potentially High Electricity Consumption**

Category	Total Sites	Potential Sites	Electric Consumption Per Building (1000 KWh) <sup>111</sup>	Convert to MW (100 percent Capacity Factor)	Potential Capacity (MW)
Education	1,464	356	283	12	4 - 5
Food Sales	3,000+	230	276	7	2 - 3
Food Service	6,400+	820	213	20	8 - 10
Inpatient Healthcare	99	99	6,628	75	20 - 25
Lodging	690	417	483	23	4 - 5
Public Order and Safety	811	75	237	2	15 - 19
<b>Total:</b>		<b>1,997</b>		<b>139</b>	<b>53 - 67</b>

As shown above, the analysis provided here estimates that there are approximately 2,000 potential locations identified in this analysis, within the category of commercial building types with potentially high electricity consumption, for the application of fuel cell stationary power applications. Assuming the demand for electricity was uniform throughout the year and the generation resource had a capacity factor of 100 percent, approximately 556 to 695 fuel cell units with a capacity of 200 – 250 kW could be used to meet a projected load of 139 MW. However, approximately 67 MW might be a more measured expectation if existing technology were deployed at selected sites.

Energy Intensive Industries

According to the EIA, the most energy-intensive industries in the United States are those that manufacture aluminum, chemicals, forest products (such as paper and wood products), glass, metalcasting, petroleum and coal products, and steel.<sup>112</sup> Energy intensive industries with high electricity consumption has also identified as potential locations for on-site generation and combined heat and power systems based within the State. CCAT has identified 198 industrial facilities that, according to their standard industry classification (SIC) codes, are involved in the manufacture of aluminum, chemicals, forest products, glass, metalcasting, petroleum and coal products, or steel. There are currently no fuel cells installed at energy

<sup>111</sup> EIA, CBECS: Table 14. Electricity Consumption and Expenditures for Non-Mall Buildings, 2003

<sup>112</sup> EIA; <http://www.eia.doe.gov/emeu/mecs/iab/index5e.html>

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intensive industry sites that are included in these seven industry classifications in Connecticut.<sup>113</sup> (See Appendix B - Figure 1: Energy Intensive Industries)

If just five percent of the 198 energy intensive industry sites were powered by current fuel cell technology, approximately 10 units could be deployed for a total capacity of between 2 and 2.5 MW.

### Public Buildings: Municipal and State Government

CCAT has identified 254 buildings that are public buildings, including 169 Town and City Halls, and 85 selected state buildings. These potential locations represent opportunities for the application of advanced energy technologies, including CHP and fuel cells. Policy directives at the State level to increase the use of renewable energy and fuel cells at public buildings may further accelerate the development and acceptance of these technologies. The application of renewable and advanced technologies will also have unique value for active and passive public education associated with the high public usage of the buildings and potential for structured energy education at facility sites. There are currently no fuel cells installed at any Town or City Hall in Connecticut. The Connecticut Juvenile Training School in Middletown, Connecticut currently has six fuel cells installed at that facility.<sup>114</sup> (See Appendix B - Figure 9: Town & City Halls, and Selected State Buildings)

If all of the 85 selected state buildings were powered by current fuel cell technology, approximately 17 - 21 MWs of electricity could be generated. However, if just five percent of the 169 City or Town Halls were powered by current fuel cell technology, approximately 8 units could be deployed for a total capacity of between 1.6 and 2 MW.

### Telecommunications Facilities with Potential for Onsite Generation

There are approximately 1,475 wireless telecommunications sites in Connecticut.<sup>115</sup> CCAT has identified 59 wireless telecommunications sites owned or operated by the State of

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<sup>113</sup> Connecticut Clean Energy Fund

<sup>114</sup> UTC Press Release March 20, 2002; <http://www.utc.com/press/releases/2002-03-20.htm>

<sup>115</sup> Connecticut Siting Council

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Connecticut. These facilities represent opportunities to provide premium and uninterrupted power for continuous operation through the application of on-site generation including the use of fuel cells. This application will have special value to provide increased reliability to critical facilities associated with emergency communications and Homeland Security. There is currently one fuel cell installed at a private telecommunications site in Enfield, Connecticut.<sup>116</sup> (See Appendix B - Figure 10: Telecommunications Sites)

Some of these state-owned and operated telecommunications facilities are located at a building that may be classified as a public order and safety facility or a selected state building. Consequently, to avoid double counting, if half of the 59 state-owned or operated telecommunications sites were powered by current fuel cell technology, approximately 6 – 7.5 MWs of electricity could be generated.

### Sewage Treatment Plants

There are approximately 140 public and private sewage treatment plants in the State of Connecticut.<sup>117</sup> CCAT has identified 50 sewage treatment plants that have a design flow of more than two million gallons per day. These potential locations represent favorable opportunities for the application of uninterruptible power for necessary services such as water supply, waste management, and the provision of public services. Some of these facilities have the potential to use fuel cells with reformers that can utilize methane, produced as a by-product of waste management. There is currently a fuel cell installed at each of the sewage treatment plants in Fairfield and New Haven, Connecticut. (See Appendix B - Figure 8: Sewage Treatment Plants)

If all of the 50 sewage treatment plants were powered by current fuel cell technology, approximately 10 – 12.5 MWs of electricity could be generated.

It is not known at this time if the total capacity from these themes is sufficient to meet and/or exceed the target production levels of the industry to achieve an improved economy of scale.

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<sup>116</sup> Connecticut Clean Energy Fund

<sup>117</sup> Connecticut Department of Environmental Protection

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However, as a strategy going forward, these themes and potential sites can be prioritized and refined as part of a final report and comprehensive plan for guidance.

## Potential Hydrogen Applications

### Alternative Fuel Station Location

As stated above, there are approximately 1,500 retail transportation fuel dealers in Connecticut.<sup>118</sup> However, very few of these provide fuel for alternative fueled vehicles. There are approximately 31 public and private stations within the state that provide either compressed natural gas, bio-diesel, propane, or electricity for alternative-fueled vehicles.<sup>119</sup> In addition, the Connecticut Department of Transportation operates eight sites that provide alternative fuels, including six sites that dispense bio-diesel and two sites that dispense E85 – Ethanol.<sup>120</sup> There are no public transportation fueling stations in Connecticut that provide hydrogen for alternative fuel vehicles. (See Appendix B - Figure 11: Alternative Fuel Station Locations)

### State Fuel Dispensing Stations

There are approximately 150 fuel dispensing stations operated by the State,<sup>121</sup> including 70 operated by the Connecticut Department of Transportation.<sup>122</sup> As stated previously, strategic sites to make hydrogen available for vehicles crossing the state could be located near the interstates. An analysis of state-owned fueling stations in Connecticut indicates that approximately 85 of the state-owned fuel dispensing stations are located within two miles of an interstate in Connecticut. (See Appendix B - Figure 12: State Fuel Dispensing Locations)

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<sup>118</sup> Connecticut Department of Consumer Protection, Food and Standards Division

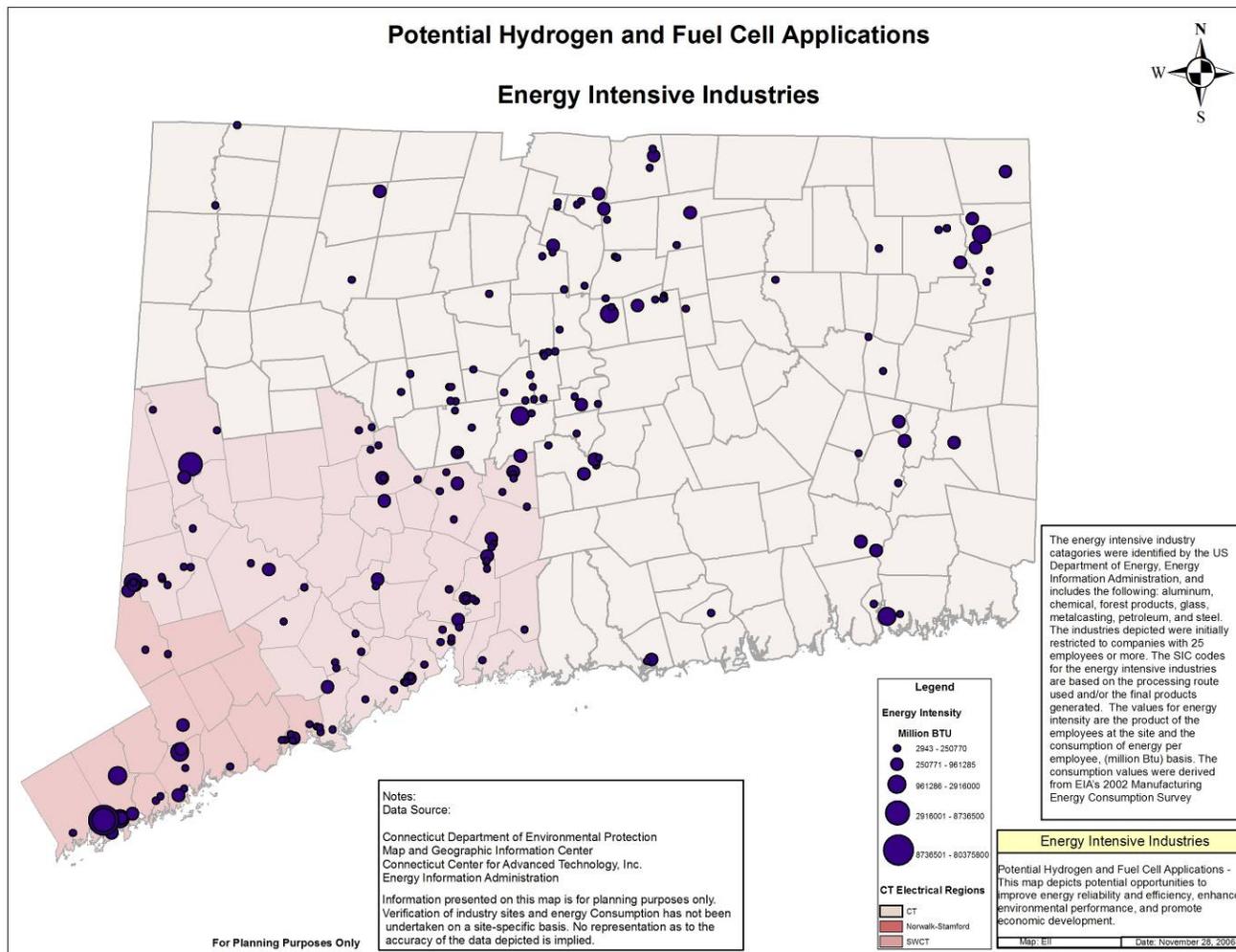
<sup>119</sup> Alternative Fuels Data Center; <http://www.eere.energy.gov/afdc/infrastructure/locator.html>

<sup>120</sup> Connecticut Department of Transportation, Fuel Station Listing, 10/26/06

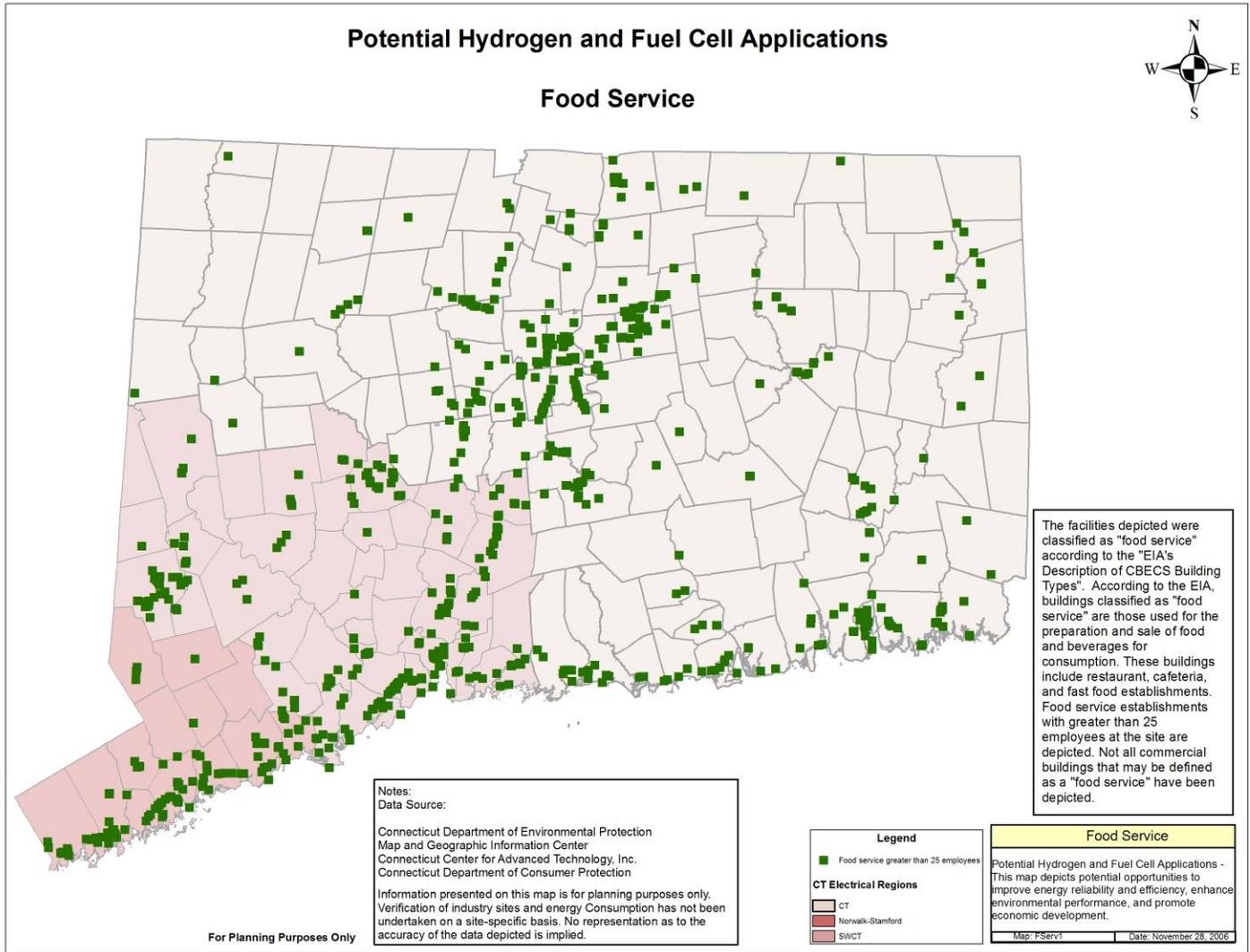
<sup>121</sup> Connecticut Department of Environmental Protection, Bureau of Materials Management and Compliance Assurance Emergency Response and Spill Prevention Division Site Assessment and Support Unit

<sup>122</sup> CASE Report - Preparing for the Hydrogen Economy: Transportation, June 2006, p. 34

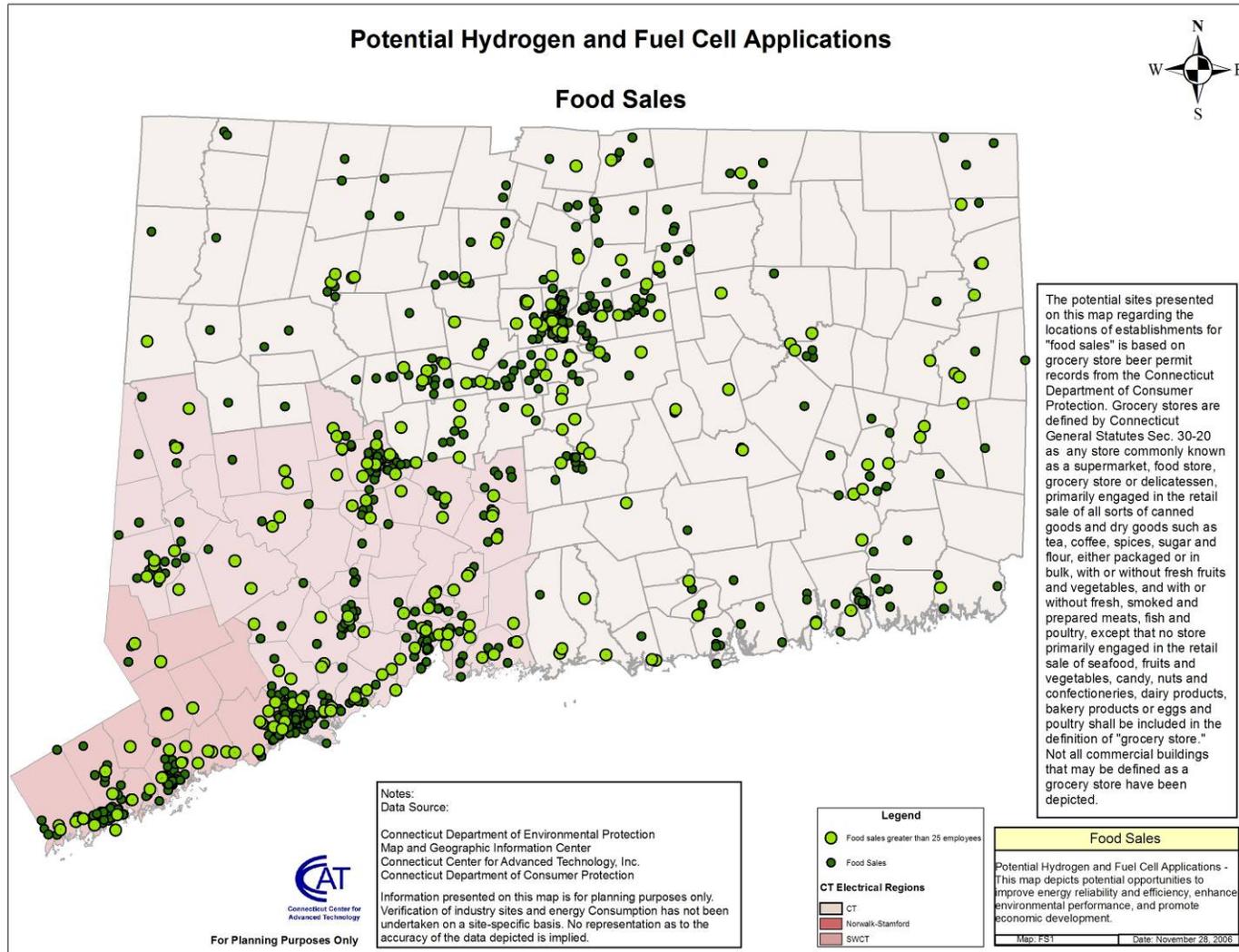
Appendix B - Figure 1: Energy Intensive Industries



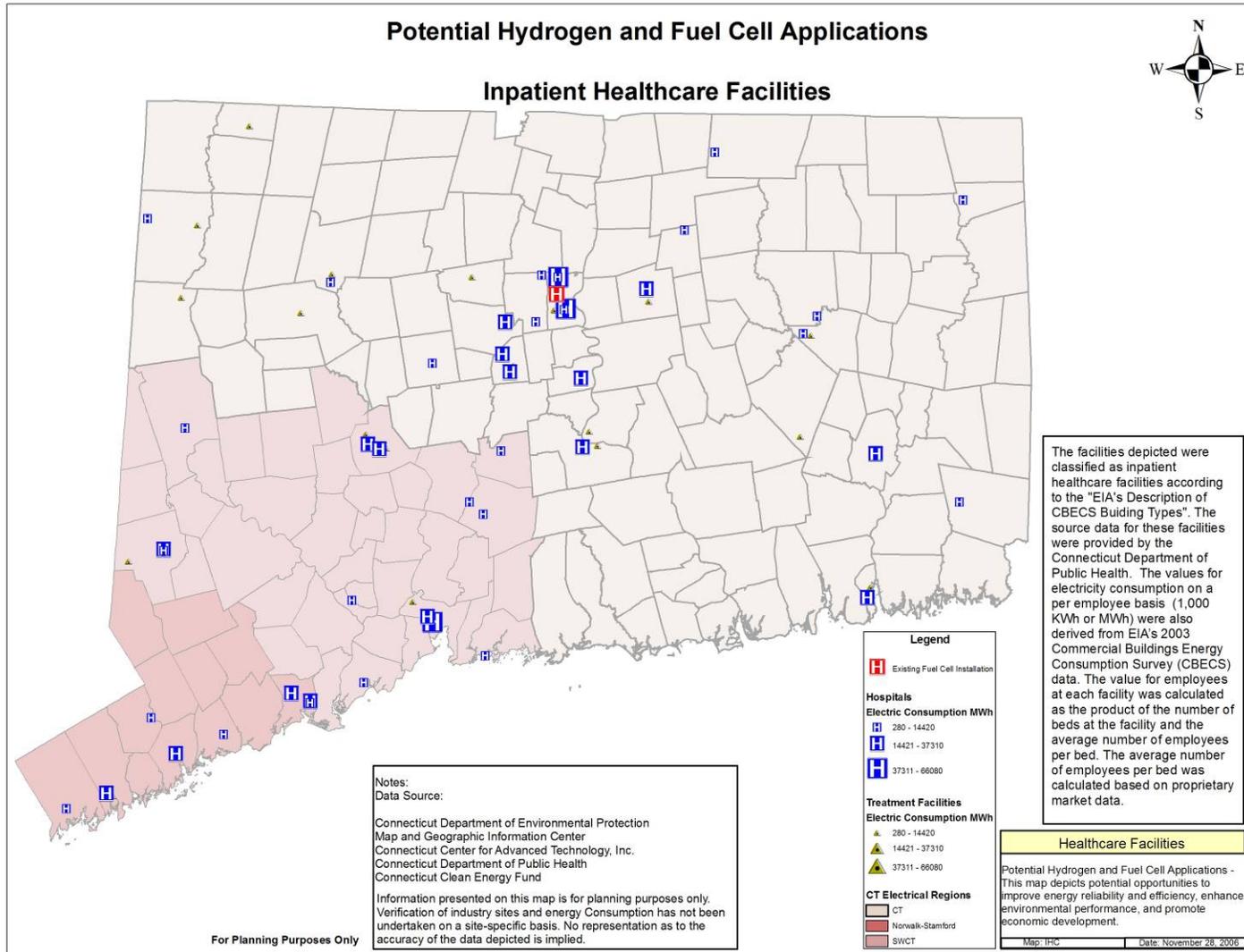
Appendix B - Figure 2: Food Service



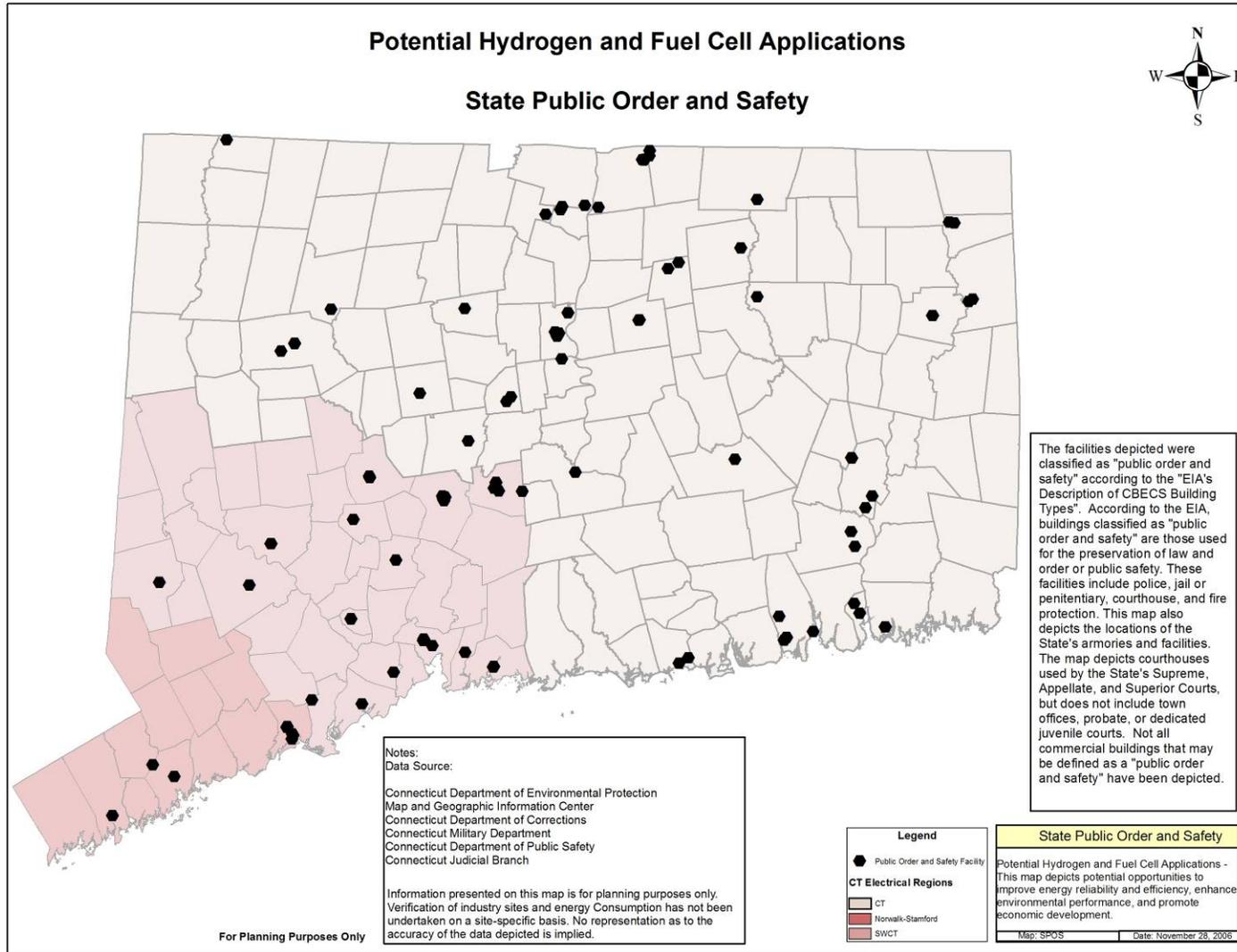
Appendix B - Figure 3: Food Sales



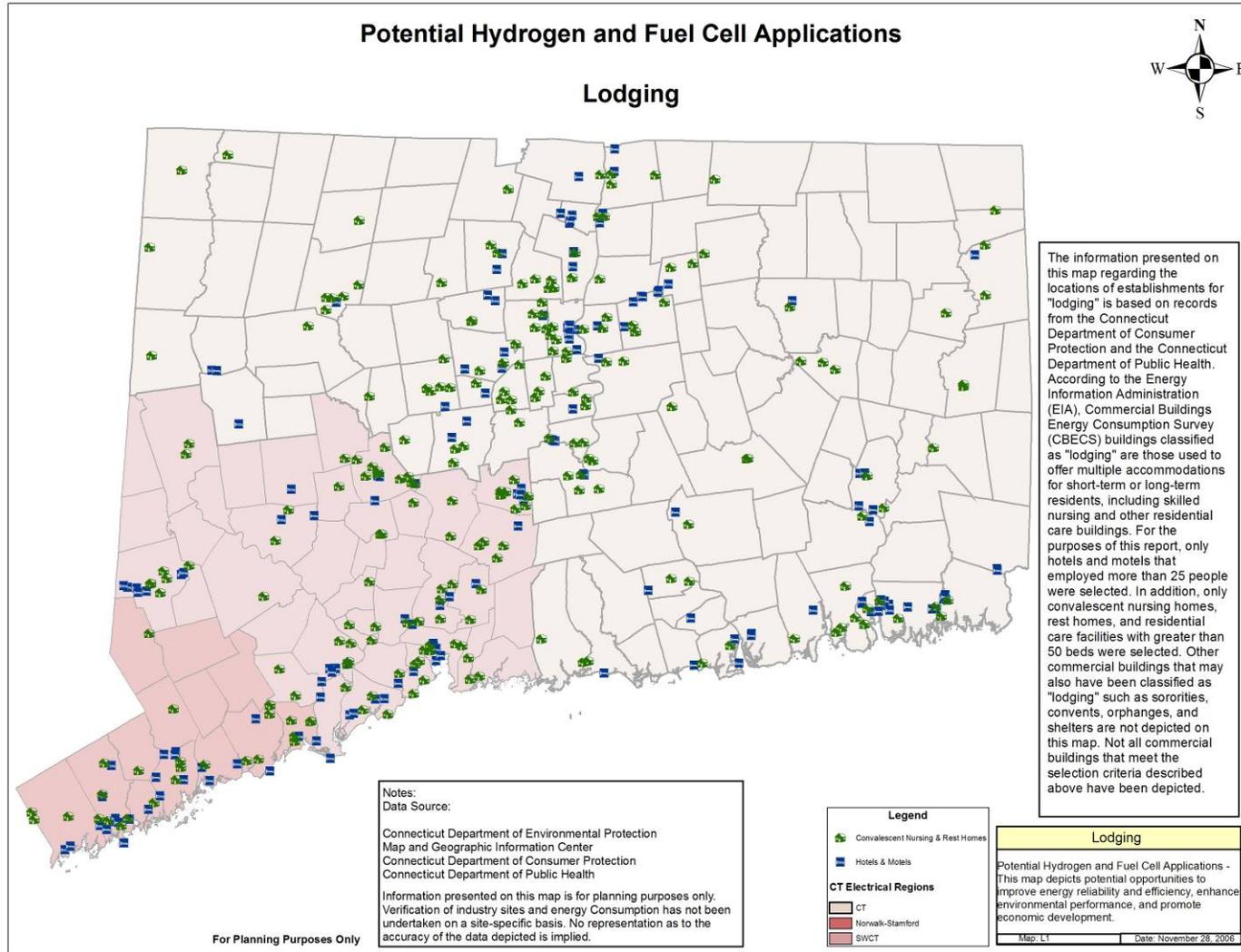
Appendix B - Figure 4: Inpatient Healthcare



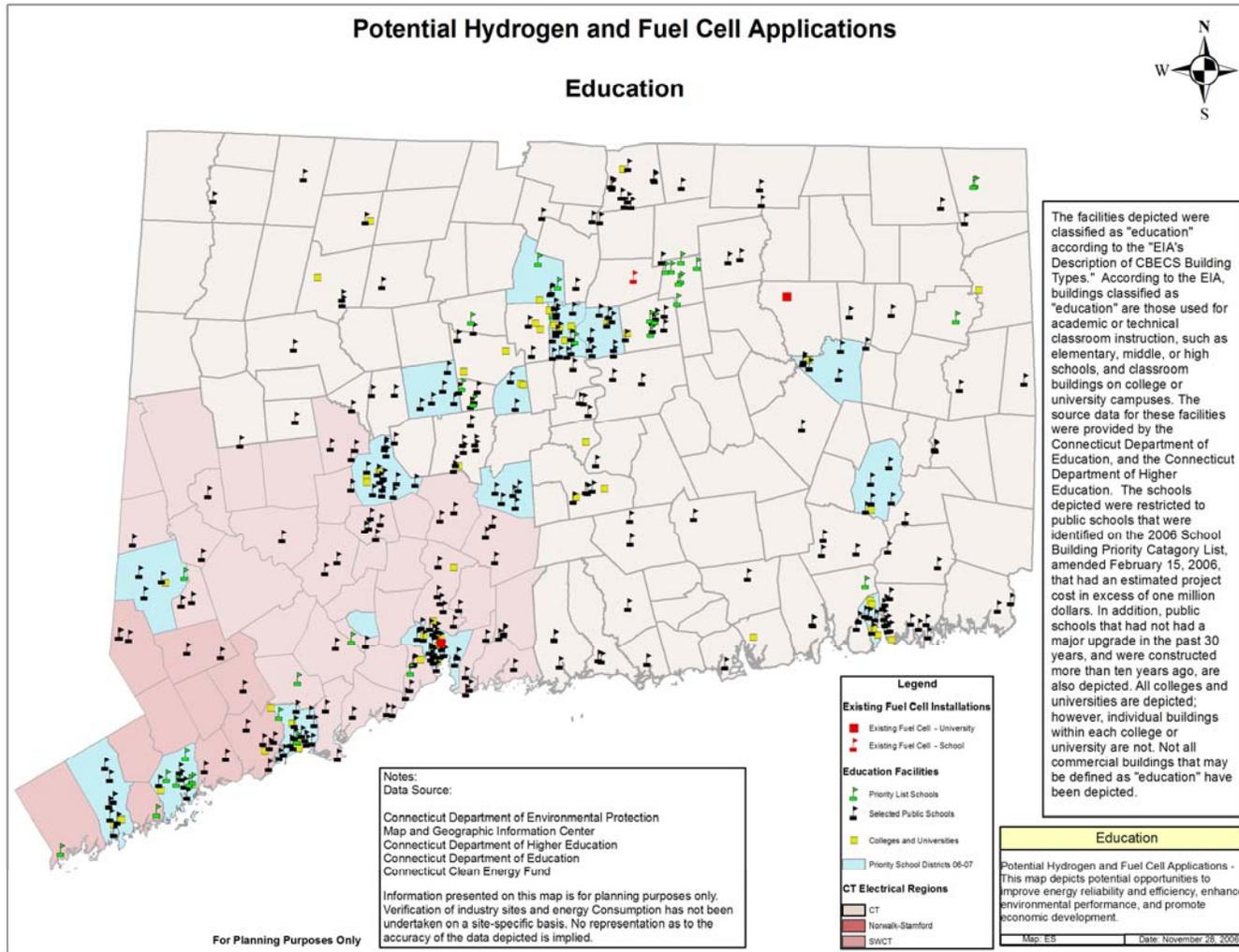
Appendix B - Figure 5: State Public Order and Safety



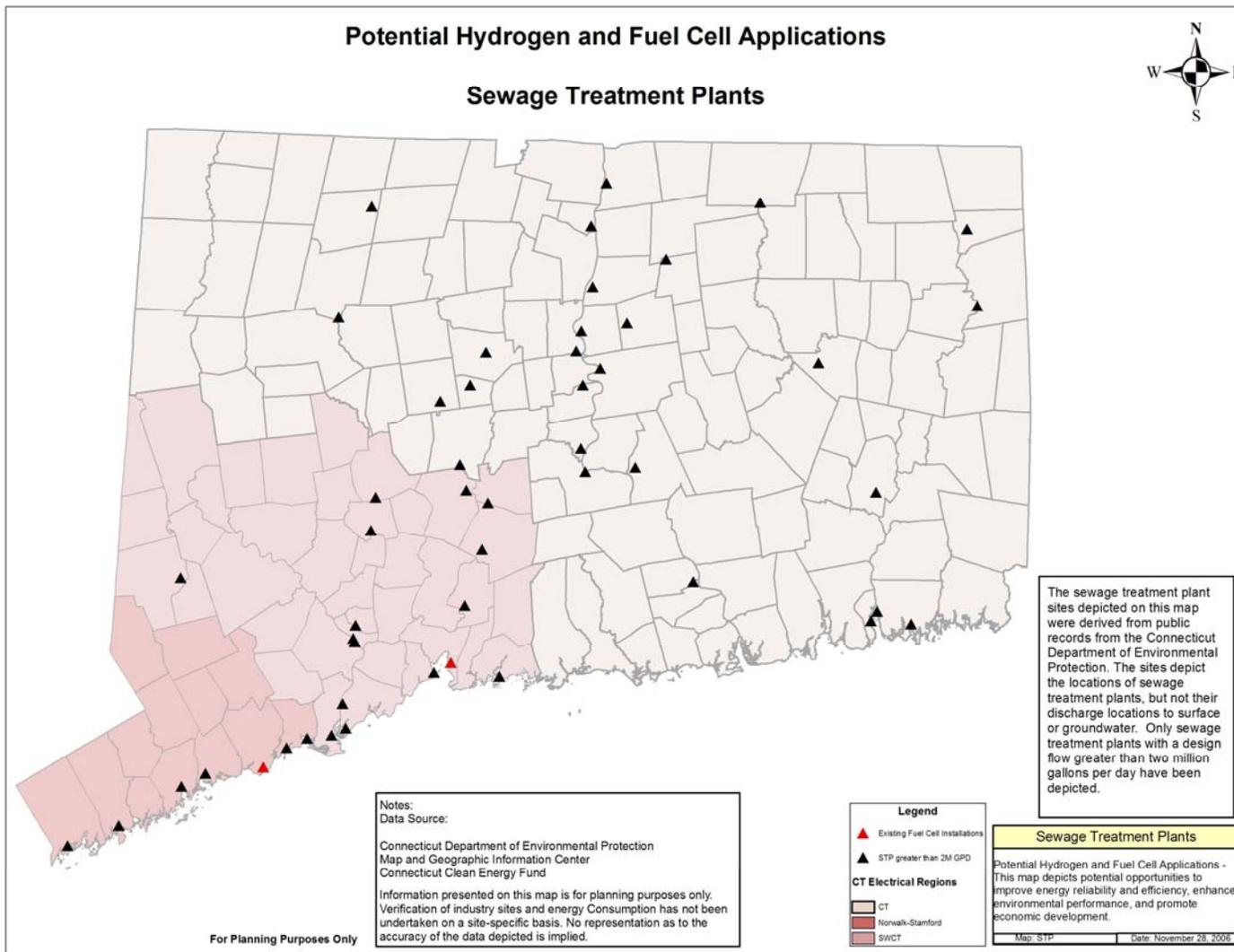
Appendix B - Figure 6: Lodging



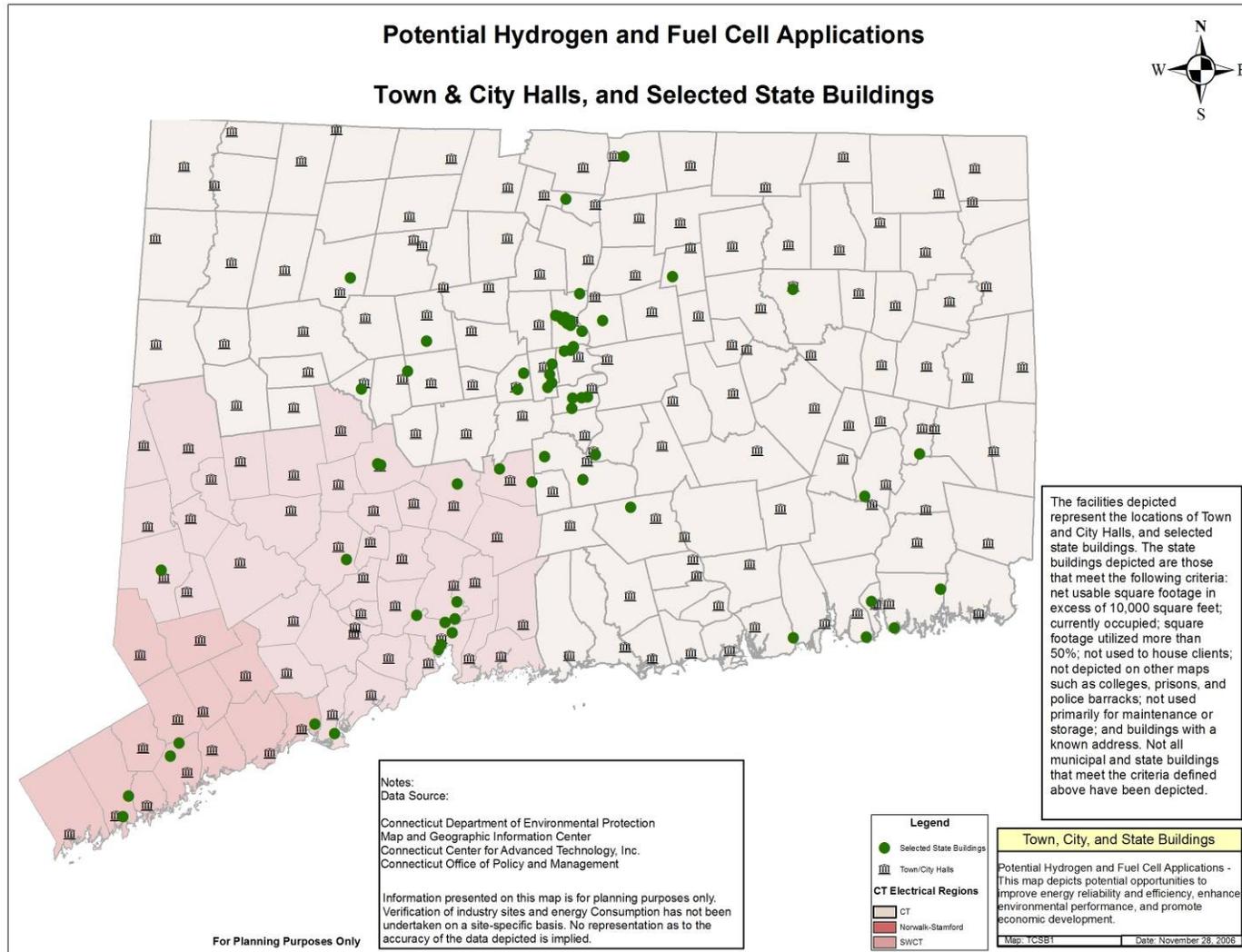
Appendix B - Figure 7: Education



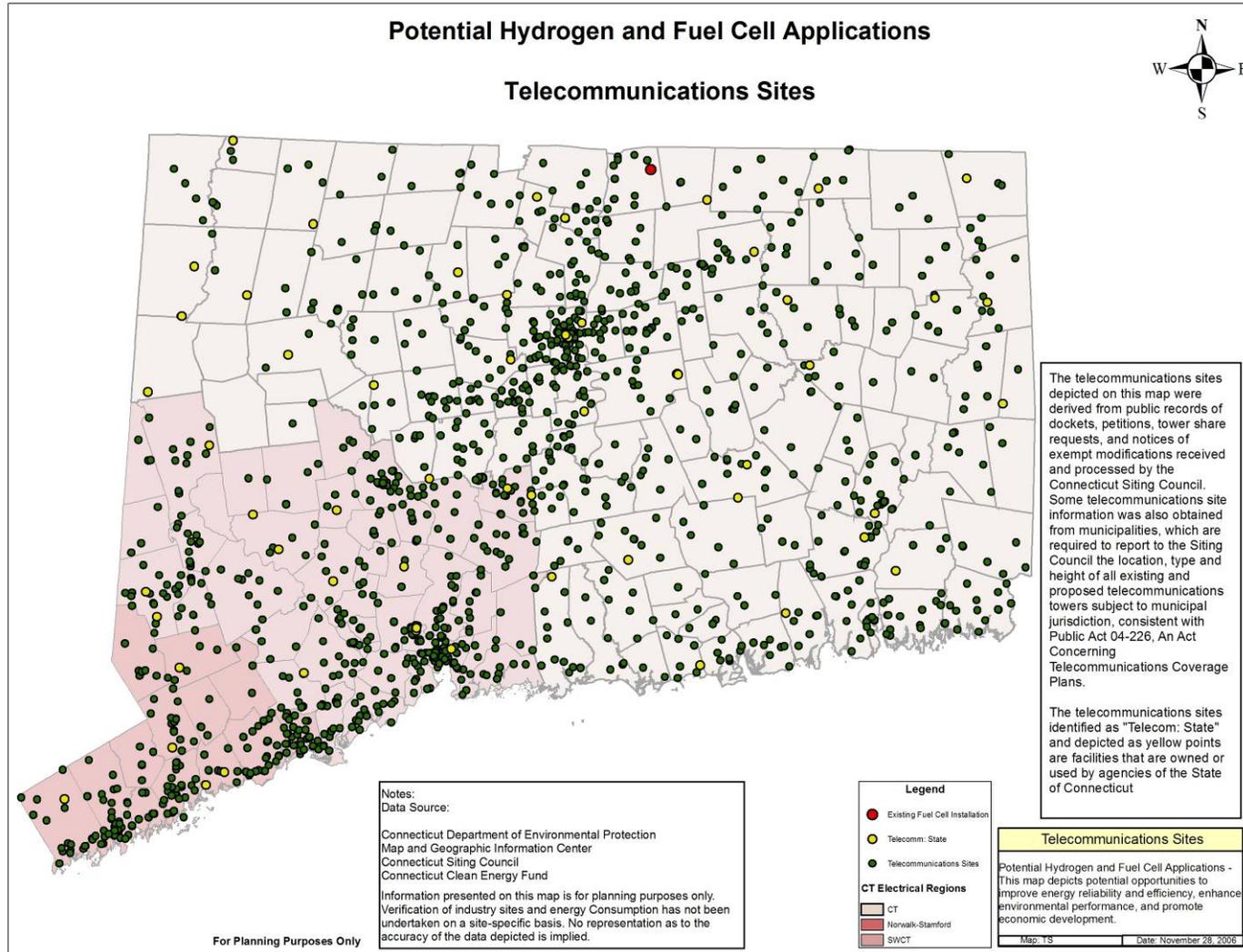
Appendix B - Figure 8: Sewage Treatment Plants



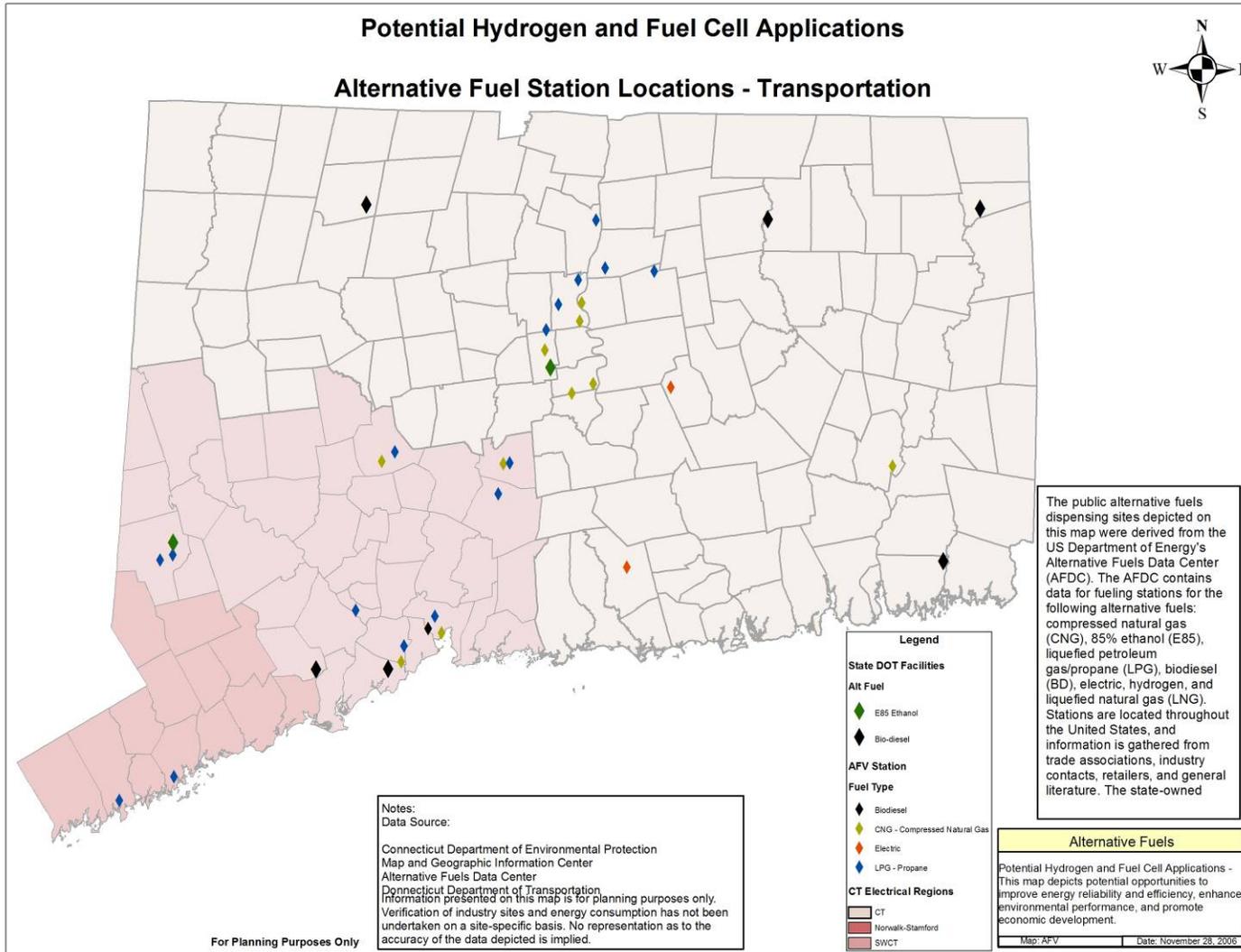
Appendix B - Figure 9: Town & City Halls, and Selected State Buildings



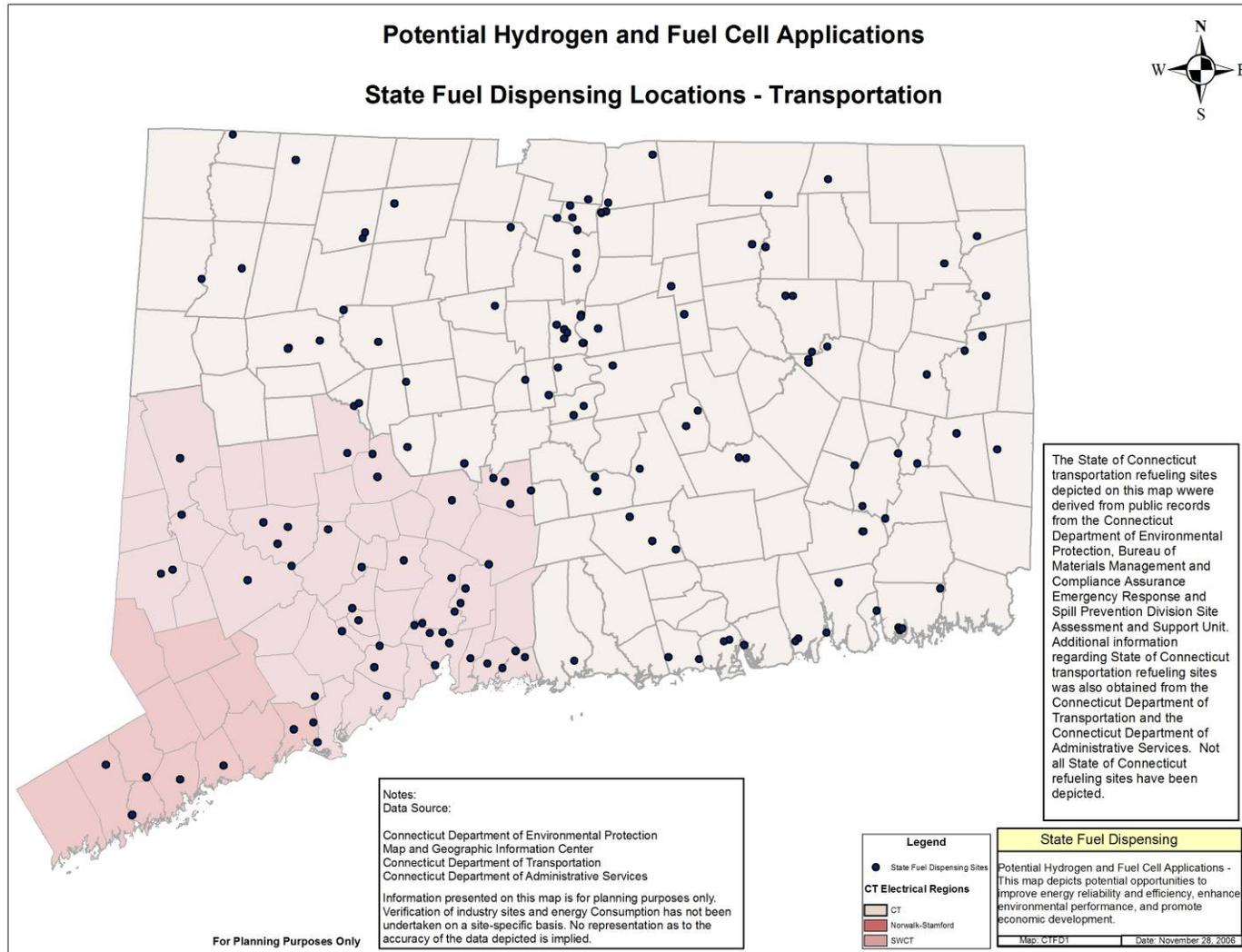
Appendix B - Figure 10: Telecommunications Sites



Appendix B - Figure 11: Alternative Fuel Station Locations



Appendix B - Figure 12: State Fuel Dispensing Locations



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### Appendix C: Comparison of Fuel Cell Technologies

Fuel Cell Type	Electrolyte	Operating Temperature	Applications	Advantages
Polymer Electrolyte membrane (PEM)	Solid organic polymer poly-perfluorosulfonic acid	60-100°C 140-212°F	Distributed power Portable power Transportation	Solid electrolyte reduces corrosion & management problems  Low temperature  Quick start-up  High power density
Alkaline (AFC)	Aqueous solution of potassium hydroxide soaked in a matrix	90-100°C 194-212°F	Space Underwater	Cathode reaction faster in alkaline electrolyte so high performance
Phosphoric Acid (PAFC)	Liquid phosphoric acid soaked in a matrix	175-200°C 347-392°F	Distributed power Transportation	Up to 85% efficiency in cogeneration of electricity and heat  Can use fuel gas with carbon monoxide
Molten Carbonate (MCFC)	Liquid solution of lithium, sodium, and/or potassium carbonates, soaked in a matrix	600-1000°C 1112-1832°F	Distributed power	High efficiency  Fuel flexibility  Internal reforming  High temperature waste heat
Solid Oxide (SOFC)	Solid zirconium oxide to which a small amount of yttria is added	600-1000°C 1112-1832°F	Distributed power	High efficiency  Fuel flexibility/ Internal reforming  High Temperature waste heat  Solid electrolyte reduces corrosion & management problems

**Appendix D: Acronyms**

AC - Alternating Current

AFC - Alkaline Fuel Cell

ASME - American Society of Mechanical Engineers

CASE - Connecticut Academy of Science and Engineering

CCAT – Connecticut Center for Advanced Technology, Inc.

CCEF - Connecticut Clean Energy Fund

CGFCC - Connecticut Global Fuel Cell Center

CGS - Connecticut General Statutes

DECD - Department of Economic and Community Development

DEP - Connecticut Department of Environmental Protection

DMFC - Direct Methanol Fuel Cell

DPUC - Department of Public Utility Control

DOE - Department of Energy

DOT - Department of Transportation

EIA - Energy Information Administration

EPA - Environmental Protection Agency

FCV - Fuel Cell Vehicle

FMCC - Federally Mandated Congestion Charges

GHG - Greenhouse Gas

ISO-NE - ISO New England, Inc.

kWh - Kilowatt Hours

LHV - Lower Heating Value

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MCFC - Molten Carbonate Fuel Cell

MEA - Membrane/Electrode Assembly

MW - Megawatts

NAAQS - National Ambient Air Quality Standards

OECD - Organization for Economic Cooperation and Development

PAFC - Phosphoric Acid Fuel Cell

PEM - Polymer Electrolyte Membrane / Proton Exchange Membrane

PEMFC - Polymer Electrolyte Membrane Fuel Cell

R&D - Research & Development

RGGI - Regional Greenhouse Gas Initiative

RPS - Renewable Portfolio Standards

SCR - Selective Catalytic Reduction

SOFC - Solid Oxide Fuel Cell

T&D - Transmission and Distribution

UConn - University of Connecticut

U.S. - United States

WADE - World Alliance for Decentralized Energy