FUEL CELL ECONOMIC DEVELOPMENT PLAN
HYDROGEN ROADMAP

APPENDIX

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Appendix A - Comparison of Distributed Energy Systems[1]

	Microturbines	Combustion Turbines	Reciprocating Engines	Photovoltaic Systems	Wind Systems
Commercially Available	Yes (Limited)	Yes	Yes	Yes	Yes
Size Range	25 – 500 kW	500 kW - 25 MW	5 kW – 7 MW	<1 kW -100 kW.	Several kW – 5 MW
Fuel	Natural gas, hydrogen, propane, diesel	Natural gas, liquid fuels	Natural gas, diesel, landfill gas, digester gas	Sunlight	Wind
Efficiency	20 – 30% (Recuperated)	20-45% (primarily size dependent)	25 – 45%	5-15%	20-40%
Other Features	Cogen (50 – 80°C water)	Cogen (steam)	Cogen (some models)	Commercially deployed, advanced PV films under development	Various types and sizes
Commercial Status	Small volume production, commercial prototypes now.	Widely Available	Products are widely available	-	Wind turbines are widely available
	Cost				
Capital Cost	$700-$1100/kW	$300-$1,000/kW	$300-$900/kW	$2,600-$7,000/kW	$800-$3,500/kW

[1]California Distributed Energy Resource Guide, The California Energy Commission, http://www.energy.ca.gov/distgen/equipment/equipment.html, UNEP Division of Technology, http://www.uneptie.org/energy/Act/re/fact_sheet/docs/pv.PDF

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Appendix B - 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^{0}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^{0}F	Distributed power	High efficiency Fuel flexibility/ Internal reforming High Temperature waste heat Solid electrolyte reduces corrosion & management problems

Appendix C - GZA Emissions Report – Evaluation of Air Emissions and Energy Benefits of Fuel Cells

September 14, 2007
File No. 05.0043915.00

Mr. Joel M. Rinebold
Director of Energy Program
Connecticut Center for Advanced Technology, Inc.
111 Founders Plaza, Suite 1002
East Hartford, CT 06108

Re: Evaluation of Air Emissions and Energy Benefits of Fuel Cells

Dear Mr. Rinebold:

GZA GeoEnvironmental, Inc. (GZA) has completed an assessment of the reductions in fuel consumption and reductions of air pollutant emissions that may result from the use of fuel cells to replace conventional fuel combustion equipment in the electric generation and transportation sectors. Based on information obtained through an extensive internet literature search and on engineering calculations, GZA first developed baseline data for current electric generating units in Connecticut, focusing on marginal and fossil fuel-fired generation. For the transportation sector, technical data on air emissions and fuel consumption were compiled for gasoline-powered passenger vehicles and for heavy diesel transit buses. Baseline fuel consumption and emissions data were also compiled for methane fuel cells (for the electricity generation sector) and for hydrogen fuel cells (for the transportation sector).

After compiling the baseline data for conventional electricity generation, transportation, and fuel cells, comparative analyses were performed to determine the emissions reductions and energy savings that could result by replacing conventional technology with fuel cell technology. The results of the analyses are summarized in the attached tables. Each table also includes detailed information on the source(s) of the baseline data, including any emissions and fuel efficiency calculation methodologies that were employed.

It must be noted that no attempt was made to evaluate or quantify air emissions or fuel consumption associated with the production of hydrogen for use in a hydrogen fuel cell. As such, it was assumed that emissions of nitrogen oxides (NO_x), sulfur dioxide (SO_2), and carbon dioxide (CO_2) from hydrogen fuel cells are zero. However, a brief qualitative summary of research performed by others with respect to societal life cycle costs of cars with alternative fuels and engines is presented.

Finally, a brief discussion of the health and environmental impacts associated with emissions of NO_x, SO_2 and CO_2 is also presented.

Baseline Data and Comparative Analyses

Table 1 compares emissions of NO_x, SO_2, and CO_2 from conventional marginal electricity generation and from conventional fossil fuel electricity generation with emissions from methane fuel cells. Average emissions for existing marginal generation in Connecticut were obtained from data recently published by ISO New England for calendar year 2005. For fossil fuel generation, GZA used 2004 data for all Connecticut generating facilities firing coal, oil, or natural gas as compiled in EPA's Emissions & Generation Resource Integrated Database (eGRID). Methane fuel cell emissions of NO_x and SO_2, which result from the hydrogen reforming process, were obtained from data published by Fuel Cell Energy, Inc. Because GZA's research identified a wide variation of CO_2 emissions associated with methane fuel cells, a range of CO_2 emissions has been presented. The results show that the replacement of marginal generating capacity with methane fuel cells could reduce emissions of NO_x by 0.70 lb/MWh, emissions of SO_2 by 0.83 lb/MWh, and emissions of CO_2 in the range of 89 - 597 lb/MWh. The average emissions reductions that could be realized by replacing any type of conventional fossil fuel electricity generation are even greater, with NO_x emissions reduced by 1.28 lb/MWh, SO_2 emissions reduced by 1.07 lb/MWh, and CO_2 emissions reduced by between 570 lb/MWh and 1,078 lb/MWh.

To provide more detail, Tables 2, 3, and 4 compare emissions from methane fuel cells with the emissions from conventional electricity generation that are associated with specific fossil fuels. For coal, Table 2 shows that the replacement of coal-fired electricity generation with methane fuel cells could reduce NO_x emissions by 2.53 lb/MWh, SO_2 emissions by 1.79 lb/MWh, and CO_2 emissions by between 1,016 lb/MWh and 1,524 lb/MWh. Similarly, for fuel oil, Table 3 shows that significant emissions reductions could also result from replacing conventional oil-fired generation with fuel cell technology. As shown, NO_x emissions could be reduced by 2.40 lb/MWh, SO_2 emissions by 4.12 lb/MWh, and CO_2 emissions by as much as 1,340 lb/MWh. Finally, Table 4 summarizes the possible emissions benefits of using fuel cells to replace conventional natural gas-fired electric generation in Connecticut. Although those benefits would not be as substantial as those estimated for "dirtier" fuels like coal and oil, Table 4 shows that those benefits could still be significant, with NO_x emissions reduced by 0.31 lb/MWh, SO_2 emissions reduced by 0.021 lb/MWh, and CO_2 emissions reduced by as much as 763 lb/MWh.

Next, Table 5 compares the fuel efficiencies associated with conventional marginal electricity generation and conventional fossil fuel generation in Connecticut with the fuel efficiency of methane fuel cells. The fuel efficiency of 8,140 Btu/kWh presented for conventional marginal generation is based on ISO New England's average marginal heat rate calculated for New England generating units for calendar year 2005. The overall average fuel efficiency of 11,431 Btu/kWh for conventional fossil fuel generation is

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calculated based on 2004 calendar year data from eGRID for all Connecticut generating facilities firing coal, oil, or natural gas. The fuel efficiency of 7,260 Btu/kWh for methane fuel cells was obtained from data published by Fuel Cell Energy, Inc. for three fuel cell models that they manufacture. In comparing these fuel efficiencies, it can be seen that the replacement of conventional electricity generation technology with methane fuel cells could result in significant energy savings, ranging from 880 Btu/kWh for marginal generation to 4,171 Btu/kWh for average fossil fuel generation.

Tables 6, 7, and 8 provide additional information in regard to the energy benefits of using methane fuel cells by comparing the energy efficiency of fuel cells with the fuel-specific energy efficiencies associated with conventional fossil fuel electric generation. As shown in these tables, the use of fuel cells could result in substantial energy savings, ranging from 4,609 Btu/kWh for the replacement of oil-fired generation, to 4,288 Btu/kWh for the replacement of coal-fired generation, to 3,976 Btu/kWh for the replacement of natural gas-fired generation.

The comparative analyses for emissions and fuel efficiency for the transportation sector are presented in Tables 9 and 10, respectively. In Table 9, emissions of NO_x and CO_2 from gasoline-powered passenger cars and gasoline-powered light trucks and emissions of NO_x from conventional diesel transit buses were obtained from EPA sources and from federal transportation statistics. Emissions of SO_2 from gasoline-powered passenger cars and light trucks and emissions of SO_2 and CO_2 from diesel transit buses were calculated using the procedures described in the table footnotes. Because NO_x, SO_2 and CO_2 emissions from hydrogen fuel cells are zero, the emissions benefits from the replacement of the existing passenger vehicle and diesel transit bus fleets with hydrogen fuel cell vehicles could be substantial. As Table 9 shows, NO_x emissions reductions of 0.95 grams/mile for passenger cars and 1.22 grams/mile for light trucks (including SUVs) could be realized. Similarly, the use of hydrogen fuel cell vehicles could reduce CO_2 emissions from passenger cars by 369 grams/mile and light trucks by 511 grams/mile. The unit emissions reductions that could occur by replacing conventional diesel transit buses with hydrogen fuel cell buses are even more significant, with potential NO_x emissions reductions of 12.50 grams/mile and potential CO_2 emissions reductions of 2,242.7 grams/mile. Although hydrogen fuel cell vehicles would also reduce SO_2 emissions, those benefits would be much more limited because of the recent implementation of federal regulations that severely limit the sulfur content of transportation fuels.

Finally, Table 10 presents a comparison of the fuel efficiencies of conventional gasoline-powered passenger vehicles and diesel transit buses with the fuel efficiencies of hydrogen fuel cell-powered vehicles. As presented in the table, the average fuel efficiencies (in Btu/mile) of the conventional vehicle types were calculated based on average fuel consumption data (in miles per gallon) reported by EPA and by the U.S. Department of Transportation. However, GZA's research on the energy efficiency of hydrogen fuel cell vehicles found recent data to be lacking. For hydrogen fuel cell passenger vehicles, GZA calculated a fuel efficiency based on the results of a vehicle simulation modeling analysis conducted by General Motors Corporation in 2001. For hydrogen fuel cell buses, the fuel

efficiency presented in Table 10 is based on a Ballard commercial prototype fuel cell bus. With these data, Table 10 shows that the replacement of conventionally-powered vehicles with hydrogen fuel cell vehicles could result in significant energy savings, ranging from 2,407.4 Btu/mile for a passenger car, to 4,505.1 Btu/mile for a light truck, to 16,264.2 Btu/mile for a transit bus.

Lifecycle Assessment of Cars with Alternative Fuels and Engines

The discussion above is somewhat limited in that it only addresses emissions and fuel efficiencies. It does not address total lifecycle costs to society. For more than a decade, the European Commission[2] (EC) has sponsored technological research that examines new and clean energy and environmental technologies and socio-economic research to provide the scientific basis for energy and environment-related policy decisions. The ExternE (External costs of Energy) model resulting from that research has proved to be a valuable evaluative tool for use in comparing different fuels and technologies for electricity generation and transportation. The externality components studied in the EC research include human health (mortality and morbidity), effects on building materials, crop yield, global warming, noise and impacts on ecosystems (acid deposition and eutrophication). The quantification of the externality comparison was expressed in unit costs (euros/kW-hr for electricity generation and euros/km-traveled for transportation). To date, the EC research has not conducted any significant studies on the use of fuel cell technology for either electricity generation or transportation.

Sorensen (2004)[3] has presented a lifecycle assessment (in part, based on ExternE) of a fuel cell car (Daimler-Chrysler) and has compared it to an internal combustion engine (ICE) Toyota Camry and a diesel Volkswagen Lupo. Environmental lifecycle impacts included car manufacture, fuel production, lifetime operation and decommissioning. Social lifecycle impacts included manufacture and decommissioning, maintenance, driving (e.g., accidents, noise, visual), road infrastructure, car infrastructure (e.g., maintenance and repair, law enforcement, insurance). Economic lifecycle impacts included car cost, fuel cost, service and maintenance and mobility needs (compared to availability of other modes of transportation). From a socio-environmental perspective, Sorensen's results demonstrate that the ICE car was 25% more costly than the fuel cell car. The economic analysis was heavily skewed towards the ICE car because of the current limited production associated with fuel cell vehicles.

Ogden, et. al. (2004)[4] studied the societal lifecycle costs (also based, in part, on ExternE) of ICE cars, hybrid electric (HE) cars and fuel cell (FC) cars. The basis for comparing the alternative engine/fuel options included vehicle first cost (assuming large-scale mass production), fuel costs, damage costs for emissions of air pollutants (AP) and greenhouse gases (GHG) calculated over the full fuel cycle and oil supply insecurity (OSI). The societal lifecycle costs (LCC) are summarized in Table 11.

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[2] European Commission, "External Costs – Research Results on Socio-Environmental Damages Due to Electricity and Transport", 2003
[3] Sorensen, B., Proceedings of the 15th World Hydrogen Energy Conference, 2004
[4] Ogden, Joan M., Robert H. Williams, Eric D. Larson, *Energy Policy,* 32 (1), 7-27, 2004

The hydrogen fuel cell car stands out as having the lowest externality costs (AP+GHG+OSI) of any option and, when mass produced, the lowest lifecycle cost (LCC).

Similar analyses of lifecycle costs associated with various electricity generation technologies (including fuel cells) were not reviewed for this report due to the lack of information on lifecycle costs related to electrical generation from fuel cells.

Air Pollutant Health and Environmental Impacts

This report discusses air emissions of NO_x, SO_2 and CO_2, as well as reductions of those emissions resulting from the increased use of fuel cell technology. It is instructive to understand why reductions of these pollutants are important to the people of Connecticut.

Nitrogen Oxides

Nitrogen oxides form when fuel is burned at high temperatures, as in a combustion process. The primary man-made sources of NO_x are motor vehicles, electric utilities, and other industrial, commercial, and residential sources that burn fuels. NO_x is one of the main ingredients involved in the formation of ground-level ozone, which can trigger serious respiratory problems. All of Connecticut has been designated as nonattainment for ozone. A reduction in statewide NO_x emissions is a key component of Connecticut's strategy to achieve attainment of the ozone ambient air quality standards.

Sulfur Dioxide

Sulfur oxide gases are formed when fuel containing sulfur, such as coal and oil, is burned, and when gasoline is extracted from oil or metals are extracted from ore. SO_2 dissolves in water vapor to form acid, and interacts with other gases and particles in the air to form sulfates and other products that can be harmful to people and their environment. SO_2 contributes to respiratory illness, particularly in children and the elderly, and aggravates existing heart and lung diseases. SO_2 contributes to the formation of acid rain, which damages trees, crops, historic buildings, and monuments and makes soils, lakes, and streams acidic. SO_2 also contributes to the formation of atmospheric particles that cause visibility impairment, most noticeably in national parks. Although Connecticut has been designated as being in attainment with respect to the SO_2 ambient air quality standards, SO_2 emissions contribute to the formation of aerosols, which exacerbate ambient concentrations of fine particulate matter ($PM_{2.5}$), for which a significant portion of Connecticut has been designated as nonattainment. Future reductions in SO_2 emissions will play a significant role in achieving the $PM_{2.5}$ ambient air quality standard.

Carbon Dioxide

Carbon dioxide is an important greenhouse gas because of its ability to absorb the infrared radiation that is emitted by the earth, and because of the length of time it stays in the earth's atmosphere. One of the major anthropogenic sources of CO2 is the combustion of fossil fuels. CO2 is currently at a globally averaged concentration of approximately 385 ppm by volume in the earth's atmosphere, although this varies both by location and time. Due to human activities such as the combustion of fossil fuels and deforestation, the concentration of atmospheric carbon dioxide has increased by about 35% since the beginning of the age of industrialization. Emissions of CO2 by human activities amount to about 30 billion tons per year. New environmental regulations are being implemented that will require significant reductions in CO2 emissions.

Thank you for the opportunity to assist you on this project to develop a "hydrogen roadmap" for Connecticut. Please contact us if you have any questions.

Very truly yours,

GZA GEOENVIRONMENTAL, INC.

Rick N. Soucy
Certified Consulting Meteorologist
Senior Project Manager

Mitchell Wurmbrand
Certified Consulting Meteorologist
Associate Principal

Table 1

Comparison of Emissions from Methane Fuel Cells with Emissions from Conventional Marginal Electricity Generation and Emissions from All Conventional Fossil Fuel Electricity Generation Air Pollutants: Nitrogen Oxides (NO_x), Sulfur Dioxide (SO_2), and Carbon Dioxide (CO_2)

Pollutant	Emissions from Existing Conventional Marginal Generation [a] (lb/MWh)	Emissions from All Existing Conventional Fossil Fuel Generation [b] (lb/MWh)	Emissions from Methane Fuel Cells [c] (lb/MWh)	Possible Emissions Reductions Resulting from Replacement of Conventional Marginal Generation with Fuel Cell Technology (lb/MWh)	Possible Emissions Reductions Resulting from Replacement of Conventional Fossil Fuel Generation with Fuel Cell Technology [f] (lb/MWh)
NO_x	0.72	1.30	0.02	0.70	1.28
SO_2	0.83	1.07	0.001	0.83	1.07
CO_2	1167	1648	570 [d] – 1078 [e]	89 – 597	570 – 1078

Notes:

[a] Average annual marginal emissions rate for Connecticut generating units. Data Source: *2005 New England Marginal Emission Rate Analysis* , ISO New England Inc., July 2007.

[b] Average annual emissions rates for all Connecticut generating units firing coal, oil, or natural gas for calendar year 2004. Data Source: EPA's *Emissions & Generation Resource Integrated Database (eGRID), Version 2.1.*

[c] Emissions data for NO_x and SO_2 obtained from Fuel Cell Energy, Inc. Data Source: Published technical specifications for Direct FuelCell® Model DFC300MA, DFC1500MA, and DFC3000 fuel cells.

[d] CO_2 emissions from a UTC Power PureCell™ System. Data Source: UTC Power presentation entitled *Energy Savings, Power Reliability, Environmental Stewardship,* presented at April 2007 meeting of the CTDEP's State Implementation Plan Revision Advisory Committee (SIPRAC).

[e] CO_2 emissions from a phosphoric acid fuel cell. Data Source: Figure 4 of Appendix B of *Model Regulations for the Output of Specified Air Emissons from Smaller-Scale Electric Generation Resources* , The Regulatory Assistance Project (RAP), October 15, 2002.

[f] Possible emissions reductions that would result if an average Connecticut fossil fuel-fired generating unit was replaced with fuel cell technology.

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Table 2

Comparison of Emissions from Methane Fuel Cells with Emissions from Conventional Coal-Fired Electricity Generation
Air Pollutants: Nitrogen Oxides (NO_x), Sulfur Dioxide (SO_2), and Carbon Dioxide (CO_2)

Pollutant	Emissions from Conventional Coal-Fired Generation [a] (lb/MWh)	Emissions from Methane Fuel Cells [b] (lb/MWh)	Possible Emissions Reductions Resulting from Replacement of Conventional Coal-Fired Generation with Fuel Cell Technology [e] (lb/MWh)
NO_x	2.55	0.02	2.53
SO_2	1.79	0.001	1.79
CO_2	2094	570 [c] – 1078 [d]	1016 – 1524

Notes:

[a] Average annual emissions rates for calendar year 2004 for all Connecticut generating units firing coal. Data Source: EPA's *Emissions & Generation Resource Integrated Database (eGRID), Version 2.1.*

[b] Emissions data for NO_x and SO_2 obtained from Fuel Cell Energy, Inc. Data Source: Published technical specifications for Direct FuelCell® Model DFC300MA, DFC1500MA, and DFC3000 fuel cells.

[c] CO_2 emissions from a UTC Power PureCell™ System. Data Source: UTC Power presentation entitled *Energy Savings, Power Reliability, Environmental Stewardship,* presented at April 2007 meeting of the CTDEP's State Implementation Plan Revision Advisory Committee (SIPRAC).

[d] CO_2 emissions from a phosphoric acid fuel cell. Data Source: Figure 4 of Appendix B of *Model Regulations for the Output of Specified Air Emissons from Smaller-Scale Electric Generation Resources* , The Regulatory Assistance Project (RAP), October 15, 2002.

[e] Possible emissions reductions that would result if an average Connecticut coal-fired generating unit was replaced with fuel cell technology.

Table 3

Comparison of Emissions from Methane Fuel Cells with Emissions from Conventional Oil-Fired Electricity Generation
Air Pollutants: Nitrogen Oxides (NO_x), Sulfur Dioxide (SO_2), and Carbon Dioxide (CO_2)

Pollutant	Emissions from Conventional Oil-Fired Generation [a] (lb/MWh)	Emissions from Methane Fuel Cells [b] (lb/MWh)	Possible Emissions Reductions Resulting from Replacement of Conventional Oil-Fired Generation with Fuel Cell Technology [e] (lb/MWh)
NO_x	2.42	0.02	2.40
SO_2	4.12	0.001	4.12
CO_2	1910	570 [c] – 1078 [d]	832 – 1340

Notes:

[a] Average annual emissions rates for calendar year 2004 for all Connecticut generating units firing oil. Data Source: EPA's *Emissions & Generation Resource Integrated Database (eGRID), Version 2.1.*

[b] Emissions data for NO_x and SO_2 obtained from Fuel Cell Energy, Inc. Data Source: Published technical specifications for Direct FuelCell® Model DFC300MA, DFC1500MA, and DFC3000 fuel cells.

[c] CO_2 emissions from a UTC Power PureCell™ System. Data Source: UTC Power presentation entitled *Energy Savings, Power Reliability, Environmental Stewardship,* presented at April 2007 meeting of the CTDEP's State Implementation Plan Revision Advisory Committee (SIPRAC).

[d] CO_2 emissions from a phosphoric acid fuel cell. Data Source: Figure 4 of Appendix B of *Model Regulations for the Output of Specified Air Emissons from Smaller-Scale Electric Generation Resources* , The Regulatory Assistance Project (RAP), October 15, 2002.

[e] Possible emissions reductions that would result if an average Connecticut oil-fired generating unit was replaced with fuel cell technology.

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Table 4

Comparison of Emissions from Methane Fuel Cells with Emissions from Conventional Natural Gas-Fired Electricity Generation
Air Pollutants: Nitrogen Oxides (NO_x), Sulfur Dioxide (SO_2), and Carbon Dioxide (CO_2)

Pollutant	Emissions from Conventional Natural Gas-Fired Generation [a] (lb/MWh)	Emissions from Methane Fuel Cells [b] (lb/MWh)	Possible Emissions Reductions Resulting from Replacement of Conventional Natural Gas-Fired Generation with Fuel Cell Technology [e] (lb/MWh)
NO_x	0.33	0.02	0.31
SO_2	0.022	0.001	0.021
CO_2	1333	570 [c] – 1078 [d]	255 – 763

Notes:

[a] Average annual emissions rates for calendar year 2004 for all Connecticut generating units firing natural gas. Data Source: EPA's *Emissions & Generation Resource Integrated Database (eGRID), Version 2.1.*

[b] Emissions data for NO_x and SO_2 obtained from Fuel Cell Energy, Inc. Data Source: Published technical specifications for Direct FuelCell® Model DFC300MA, DFC1500MA, and DFC3000 fuel cells.

[c] CO_2 emissions from a UTC Power PureCell™ System. Data Source: UTC Power presentation entitled *Energy Savings, Power Reliability, Environmental Stewardship,* presented at April 2007 meeting of the CTDEP's State Implementation Plan Revision Advisory Committee (SIPRAC).

[d] CO_2 emissions from a phosphoric acid fuel cell. Data Source: Figure 4 of Appendix B of *Model Regulations for the Output of Specified Air Emissons from Smaller-Scale Electric Generation Resources* , The Regulatory Assistance Project (RAP), October 15, 2002.

[e] Possible emissions reductions that would result if an average Connecticut natural gas-fired generating unit was replaced with fuel cell technology.

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Table 5

Comparison of Fuel Efficiency of Methane Fuel Cells with Fuel Efficiency of Conventional Marginal Electricity Generation and Fuel Efficiency of All Fossil Fuel Electricity Generation

Fuel Efficiency of Existing Conventional Marginal Generation [a] (Btu/kWh)	Fuel Efficiency of Existing Conventional Fossil Fuel Generation [b] (Btu/kWh)	Fuel Efficiency of Methane Fuel Cells [c] (Btu/kWh)	Possible Energy Savings Resulting from Replacement of Conventional Marginal Generation with Fuel Cell Technology (Btu/kWh)	Possible Energy Savings Resulting from Replacement of Conventional Fossil Fuel Generation with Fuel Cell Technology (Btu/kWh)
8,140	11,431	7,260	880	4,171

Notes:

[a] Calculated average annual marginal heat rate for New England generating units. Data Source: *2005 New England Marginal Emission Rate Analysis* , ISO New England, Inc., July 2007.

[b] Average fuel efficiency calculated for all Connecticut generating units firing coal, oil, or natural gas for calendar year 2004. Data Source: EPA's *Emissions & Generation Resource Integrated Database (eGRID), Version 2.1.*

[c] Data Source: Fuel Cell Energy, Inc. Published technical specifications for heat rate (LHV) of Direct FuelCell® Model DFC300MA, DFC1500MA, and DFC3000 fuel cells.

Table 6

Comparison of Fuel Efficiency of Methane Fuel Cells with Fuel Efficiency of Conventional Coal-Fired Electricity Generation

Fuel Efficiency of Conventional Coal-Fired Generation [a] (Btu/kWh)	Fuel Efficiency of Methane Fuel Cells [b] (Btu/kWh)	Possible Energy Savings Resulting from Replacement of Conventional Coal-Fired Generation with Fuel Cell Technology (Btu/kWh)
11,548	7,260	4,288

Notes:

[a] Average fuel efficiency for calendar year 2004 calculated for all Connecticut generating units firing coal. Data Source: EPA's *Emissions & Generation Resource Integrated Database (eGRID), Version 2.1.*

[b] Data Source: Fuel Cell Energy, Inc. Published technical specifications for heat rate (LHV) of Direct FuelCell® Model DFC300MA, DFC1500MA, and DFC3000 fuel cells.

Table 7

Comparison of Fuel Efficiency of Methane Fuel Cells with Fuel Efficiency of Conventional Oil-Fired Electricity Generation

Fuel Efficiency of Conventional Oil-Fired Generation [a] (Btu/kWh)	Fuel Efficiency of Methane Fuel Cells [b] (Btu/kWh)	Possible Energy Savings Resulting from Replacement of Conventional Oil-Fired Generation with Fuel Cell Technology (Btu/kWh)
11,869	7,260	4,609

Notes:

[a] Average fuel efficiency for calendar year 2004 calculated for all Connecticut generating units firing oil. Data Source: EPA's *Emissions & Generation Resource Integrated Database (eGRID), Version 2.1.*

[b] Data Source: Fuel Cell Energy, Inc. Published technical specifications for heat rate (LHV) of Direct FuelCell® Model DFC300MA, DFC1500MA, and DFC3000 fuel cells.

Table 8

Comparison of Fuel Efficiency of Methane Fuel Cells with Fuel Efficiency of Conventional Natural Gas-Fired Electricity Generation

Fuel Efficiency of Conventional Natural Gas-Fired Generation [a] (Btu/kWh)	Fuel Efficiency of Methane Fuel Cells [b] (Btu/kWh)	Possible Energy Savings Resulting from Replacement of Conventional Natural Gas-Fired Generation with Fuel Cell Technology (Btu/kWh)
11,236	7,260	3,976

Notes:

[a] Average fuel efficiency for calendar year 2004 calculated for all Connecticut generating units firing natural gas. Data Source: EPA's *Emissions & Generation Resource Integrated Database (eGRID), Version 2.1.*

[b] Data Source: Fuel Cell Energy, Inc. Published technical specifications for heat rate (LHV) of Direct FuelCell® Model DFC300MA, DFC1500MA, and DFC3000 fuel cells.

Table 9

Comparison of Emissions from Conventional Gasoline-Powered Passenger Vehicles and Diesel Transit Buses with Emissions from Hydrogen Fuel Cell Vehicles
Air Pollutants: Nitrogen Oxides (NO_x), Sulfur Dioxide (SO_2), and Carbon Dioxide (CO_2)

Pollutant	Emissions from Conventional Gasoline-Powered Passenger Cars (grams/mile)	Emissions from Conventional Gasoline-Powered Light Trucks (grams/mile)	Emissions from Conventional Diesel Transit Buses (grams/mile)	Emissions from Hydrogen Fuel Cells [h] (grams/mile)	Possible Emissions Reductions Resulting from Replacement of Conventional Gasoline-Powered Passenger Cars with Hydrogen Fuel Cell Vehicles (grams/mile)	Possible Emissions Reductions Resulting from Replacement of Conventional Gasoline-Powered Light Trucks with Hydrogen Fuel Cell Vehicles (grams/mile)	Possible Emissions Reductions Resulting from Replacement of Conventional Diesel Transit Buses with Hydrogen Fuel Cell Buses (grams/mile)
NO_x	0.95 [a]	1.22 [c]	12.50 [e]	0.0	0.95	1.22	12.50
SO_2	0.0070 [b]	0.0097 [d]	0.0214 [f]	0.0	0.0070	0.0097	0.0214
CO_2	369 [a]	511 [c]	2242.7 [g]	0.0	369	511	2242.7

Notes:

[a] Average emission factor for passenger cars on the road in July 2005 from EPA's MOBILE 6.2 emission factor model. Data Source: *Average Annual Emissions and Fuel Consumption for Gasoline-Fueled Passenger Cars and Light Trucks* , EPA Office of Transportation and Air Quality, EPA 420-F-05-022, August 2005.

[b] Average SO_2 emission rate calculated by mass balance assuming a maximum gasoline sulfur content of 30 ppm (per current regulations), a gasoline density of 6.17 lb/gal (from EPA's *Compilation of Air Pollutant Emission Factors* - AP-42), and an average fuel consumption of 24.0 mpg for passenger cars on the road in July 2005 (from *Average Annual Emissions and Fuel Consumption for Gasoline-Fueled Passenger Cars and Light Trucks* , EPA Office of Transportation and Air Quality, EPA 420-F-05-022, August 2005). See calculation below.

Emissions (grams/mile) = (6.17 lb gasoline/gal x 30 ppm S x 2 lb SO_2/lb S x 453.5924 g/lb) / (24.0 mile/gal)

[c] Average emission factor for light trucks on the road in July 2005 from EPA's MOBILE 6.2 emission factor model. Data Source: *Average Annual Emissions and Fuel Consumption for Gasoline-Fueled Passenger Cars and Light Trucks* , EPA Office of Transportation and Air Quality, EPA 420-F-05-022, August 2005.

[d] Average SO_2 emission rate calculated by mass balance assuming a maximum gasoline sulfur content of 30 ppm (per current regulations), a gasoline density of 6.17 lb/gal (from EPA's *Compilation of Air Pollutant Emission Factors* - AP-42), and an average fuel consumption of 17.3 mpg for light trucks on the road in July 2005 (from *Average Annual Emissions and Fuel Consumption for Gasoline-Fueled Passenger Cars and Light Trucks* , EPA Office of Transportation and Air Quality, EPA 420-F-05-022, August 2005). See calculation below.

Emissions (grams/mile) = (6.17 lb gasoline/gal x 30 ppm S x 2 lb SO_2/lb S x 453.5924 g/lb) / (17.3 mile/gal)

[e] Average NO_x emissions from all heavy-duty diesel vehicles for calendar year 2004. Data Source: *National Transportation Statistics - 2007* , U.S. Department of Transportation, Bureau of Transportation Statistics, Table 4-38.

[f] Average SO_2 emission rate calculated by mass balance assuming a maximum diesel sulfur content of 15 ppm (per current regulations), a diesel fuel density of 7.05 lb/gal (from EPA's *Compilation of Air Pollutant Emission Factors* - AP-42), and an average fuel consumption of 4.49 mpg for transit motor buses (2004 data from *National Transportation Statistics - 2007* , U.S. Department of Transportation, Bureau of Transportation Statistics, Table 4-24). See calculation below.

Emissions (grams/mile) = (7.05 lb diesel/gal x 15 ppm S x 2 lb SO_2/lb S x 453.5924 g/lb) / (4.49 mile/gal)

[g] Average CO_2 emission rate calculated assuming 22.2 lbs of CO_2 emitted from the combustion of one gallon of diesel fuel (Data Source: *Average Carbon Dioxide Emissions Resulting from Gasoline and Diesel Fuel,* EPA Office of Transportation and Air Quality, EPA 420-F-05-001, February 2005) and an average fuel consumption of 4.49 mpg for transit motor buses (2004 data from *National Transportation Statistics - 2007* , U.S. Department of Transportation, Bureau of Transportation Statistics, Table 4-24). See calculation below.

Emissions (grams/mile) = (22.2 lb CO_2/gal diesel x 453.5924 g/lb) / (4.49 mile/gal)

[h] Emissions from operation of a hydrogen fuel cell. Does not include emissions associated with hydrogen production.

Table 10

Comparison of
Fuel Efficiency of Conventional Gasoline-Powered Passenger Vehicles and Diesel Transit Buses and Fuel Efficiency of Hydrogen Fuel Cells

Average Fuel Efficiency of Conventional Gasoline-Powered Passenger Cars [a] (Btu/mile)	Average Fuel Efficiency of Conventional Gasoline-Powered Light Trucks [b] (Btu/mile)	Average Fuel Efficiency of Conventional Diesel Transit Buses [c] (Btu/mile)	Fuel Efficiency of Hydrogen Fuel Cell Passenger Vehicles [d] (Btu/mile)	Fuel Efficiency of Hydrogen Fuel Cell Transit Buses [e] (Btu/mile)	Possible Energy Savings Resulting from Replacement of Conventional Gasoline-Powered Passenger Cars with Hydrogen Fuel Cell Vehicles (Btu/mile)	Possible Energy Savings Resulting from Replacement of Conventional Gasoline-Powered Light Trucks with Hydrogen Fuel Cell Vehicles (Btu/mile)	Possible Energy Savings Resulting from Replacement of Conventional Diesel Transit Buses with Hydrogen Fuel Cell Buses (Btu/mile)
5416.7	7514.4	30,512.2	3009.3	14,248	2407.4	4505.1	16,264.2

Notes:

[a] Average fuel efficiency calculated based on a typical gasoline heating value of 130,000 Btu/gal (from EPA's Compilation of Air Pollutant Emission Factors - AP-42) and an average fuel consumption of 24.0 mpg for passenger cars on the road in July 2005. (Data Source: *Average Annual Emissions and Fuel Consumption for Gasoline-Fueled Passenger Cars and Light Trucks,* EPA Office of Transportation and Air Quality, EPA 420-F-05-022, August 2005). See calculation below.

Average Fuel Efficiency (Btu/mile) = 130,000 Btu/gal gasoline x (1 gal gasoline/24.0 miles)

[b] Average fuel efficiency calculated based on a typical gasoline heating value of 130,000 Btu/gal (from EPA's Compilation of Air Pollutant Emission Factors - AP-42) and an average fuel consumption of 17.3 mpg for light trucks on the road in July 2005. (Data Source: *Average Annual Emissions and Fuel Consumption for Gasoline-Fueled Passenger Cars and Light Trucks* , EPA Office of Transportation and Air Quality, EPA 420-F-05-022, August 2005). See calculation below.

Average Fuel Efficiency (Btu/mile) = 130,000 Btu/gal gasoline x (1 gal gasoline/17.3 miles)

[c] Average fuel efficiency calculated based on a typical diesel fuel heating value of 137,000 Btu/gal (from EPA's Compilation of Air Pollutant Emission Factors - AP-42) and an average fuel consumption of 4.49 mpg for transit motor buses (2004 data from *National Transportation Statistics - 2007* , U.S. Department of Transportation, Bureau of Transportation Statistics, Table 4-24). See calculation below.

Average Fuel Efficiency (Btu/mile) = 137,000 Btu/gal diesel x (1 gal diesel/4.49 miles)

[d] Fuel efficiency calculated based on the results of a vehicle simulation modeling analysis for a full-size pickup truck. The modeling analysis predicted a 50th percentile fuel economy of 43.2 mpg (gasoline-equivalent) for a hydrogen fuel cell-powered vehicle. Data Source: *Well-to-Wheel Energy Use and Greenhouse Gas Emissions of Advanced Fuel/Vehicle Systems, Part 2 - Tank-to-Wheel Energy Utilization for a North American Vehicle* , General Motors Corporation, June 2001. See calculation below.

Average Fuel Efficiency (Btu/mile) = 130,000 Btu/gal gasoline x (1 gal gasoline/43.2 miles)

[e] Fuel efficiency of a Ballard hydrogen PEM fuel cell bus (Phase 2 commercial prototype). Data Source: *Renewable Hydrogen for Transportation Study - Final Report* , L. Kron under contract with Wisconsin Energy Bureau, Wisconsin Department of Administration, January 1998.

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Table 11

Societal Lifecycle Costs for Automobiles with Alternative Fuel/Engine Options[(a)]

Alternative Fuel/Engine Options	Present Value of Air Pollutant (AP) Damage Costs	Present Value of Greenhouse Gas (GHG) Damage Costs	Present Value of Oil Supply Insecurity (OSI) Costs	Present Value of Lifetime Fuel Costs	Retail Cost of Drivetrain (including fuel storage)	Cost of Aluminum Intensive Frame	Total Societal Lifecycle Costs (LCC)
Internal Combustion Engine (ICE)	$2,640	$1,429	$2,654	$2,828	$2,837	$0	$12,388
Hybrid Electric (HE)	$1,097	$683	$1,235	$1,316	$4,179	$936	$9,446
Hydrogen (Natural Gas) Fuel Cells	$257	$479	$0	$2,169	$5,296	$936	$9,137

Notes:
[(a)]Data Source: Ogden, Joan M., Robert H. Williams, Eric D. Larson, *Energy Policy,* 32 (1), 7-27, 2004

Appendix D - Economic Impacts - Explanation of Methodology

The analysis conducted for the assessment of environmental impacts 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 which 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.

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.

The data used to estimate the economic impacts if the hydrogen and fuel cell industry were provided by the Connecticut Center for Advanced Technology.

Appendix E - Hydrogen and Fuel Cell Activities by U.S. Government, Other Countries and Other States

Activity by other Governments and Industry

Fuel cell and hydrogen infrastructure development is underway in Japan, China, Korea, India, the European Union and Australia. Government efforts in Japan and the European Union are well developed. Particularly in Japan and Europe, leading manufacturers of electrical equipment are involved with development of stationary fuel cells. In North America, the efforts of industry and government in Canada are significant with Canadian companies providing fuel cell power plants for a number of vehicle demonstrations in the U.S. Nearly every global manufacturer of vehicles is involved with development of fuel cell powered vehicles using hydrogen fuel. In addition, countries in Europe and Asia, Canada, Australia and the United States have significant activity by fuel cell and hydrogen infrastructure companies.

Efforts by other States

Connecticut companies dominated U.S. and world-wide fuel cell efforts through the 1980s. Beginning in the early 1990s, interest increased in fuel cells for vehicles. 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 countries has gained significant strength, eroding the relative position of Connecticut companies. Other efforts involved with supplying hydrogen to fuel cells have also accelerated, and Connecticut's position has been threatened.

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 and incentives for purchase and use. A comprehensive

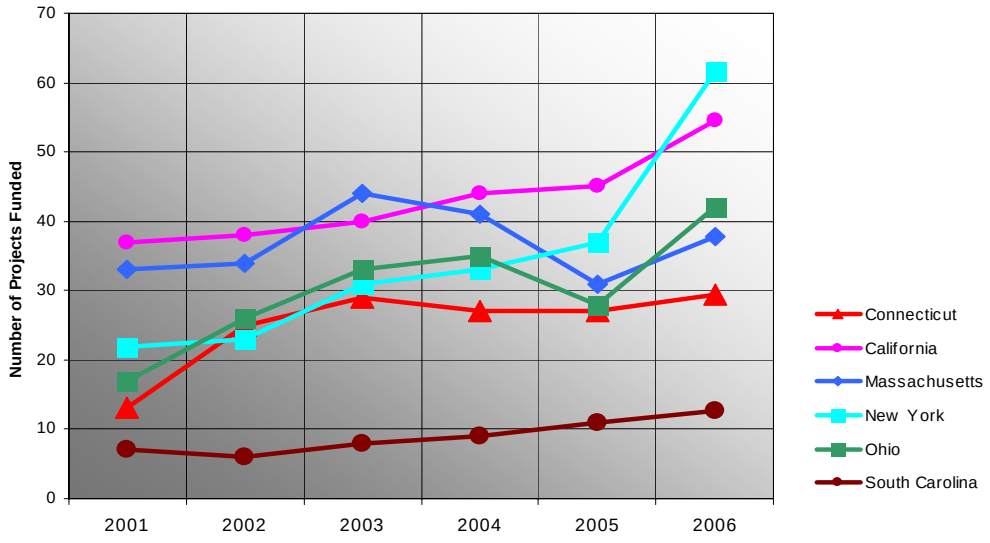
report on state activities that promote hydrogen and fuel cells was issued in July 2006 by the Breakthrough Technologies Institute Inc.[5]

Comparisons are made between Connecticut and eight states that have a significant fuel cell activity including: 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 have significant fuel cell research activities. The comparisons are on the basis of planning documents and partnerships (Table IV.4), research support (Table IV.5), assistance for stationary fuel cells (Table IV.6), and assistance for hydrogen fueled vehicles (Table IV.7) and hydrogen filling stations and stationary fuel cell installations. California leads the nation in hydrogen filling stations, followed by Michigan, and also leads in stationary fuel cell installations followed by New York and Connecticut. The position of California is believed to be associated with its market size and concern with clean energy while the positions of Michigan, New York and Connecticut are associated with manufacturing industry concentration. Both California and Michigan are involved with the U.S. DOE automobile demonstration program and California also has a significant position in the U.S. FTA bus demonstration program. On a per capita basis, Connecticut has a disproportionate share of stationary fuel cells reflecting state programs that promote use of these commercial technologies.

Figure A.2 provides information on federally funded projects for many of these same states.

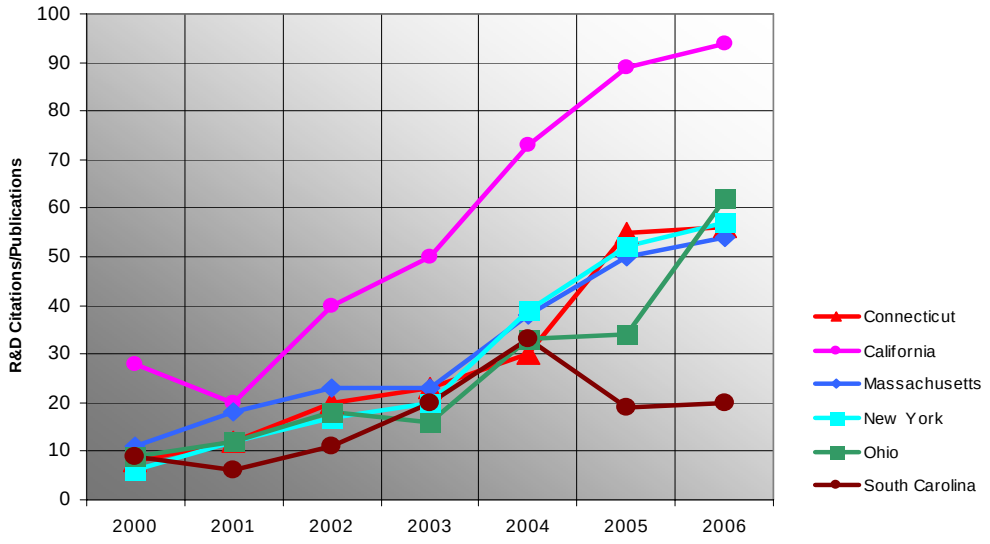
[5] "State Activities that Promote Fuel Cells and Hydrogen Infrastructure Development", July 2006, Breakthrough Technologies Institute

Figure A.2 Federally Funded Projects for Key States[6]



Figures A.3 and A.4 compare the states in terms of fuel cell R&D citations and patents assigned per year.

Figure A.3 R&D Citations for Key States[7]



[6] Connecticut Hydrogen and Fuel Cell Cluster, Benchmark Analysis (Draft), ICF International, September 26, 2007

[7] Connecticut Hydrogen and Fuel Cell Cluster, Benchmark Analysis (Draft), ICF International, September 26, 2007

Figure A.4 Fuel Cell Patents for Key States[8]

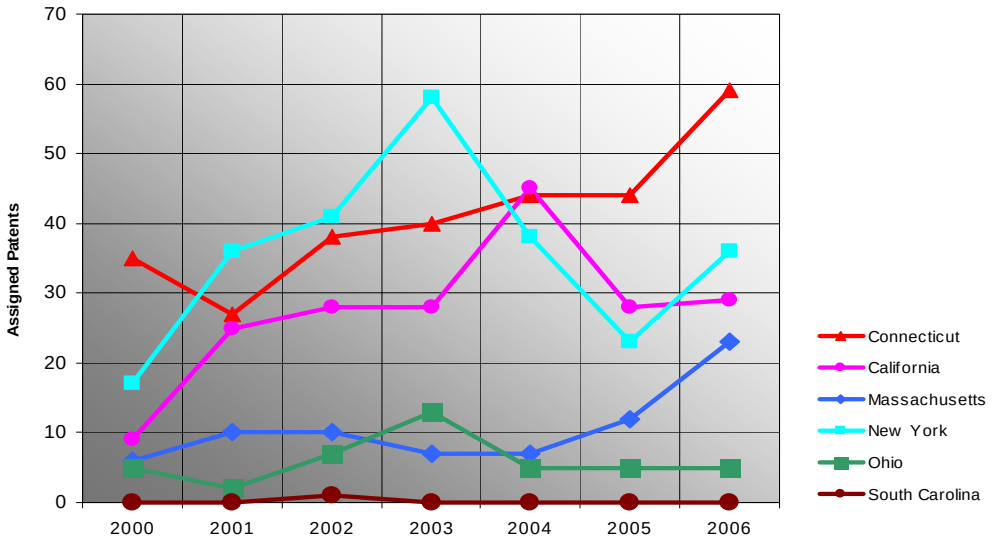
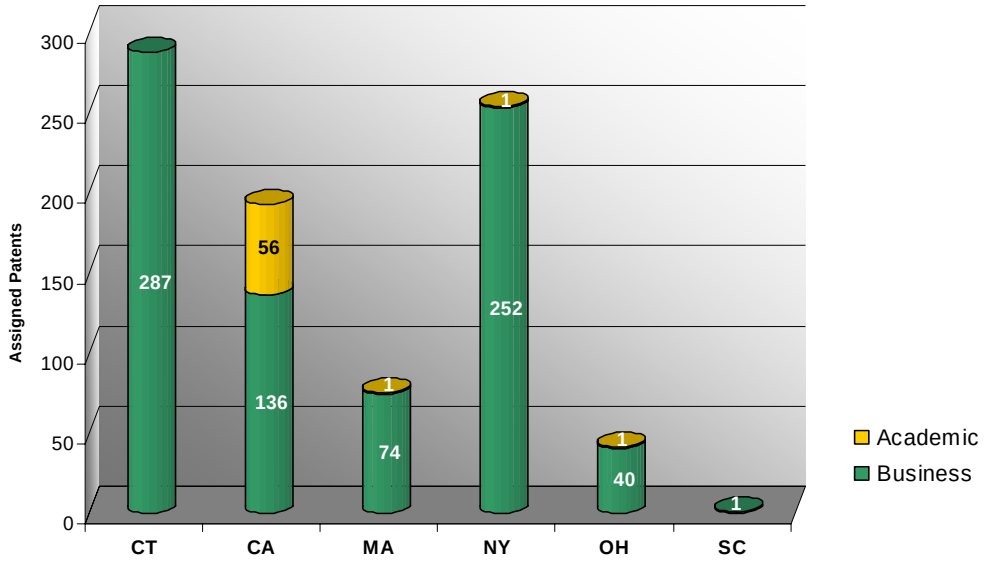


Figure A.5 depicts total number of fuel cell patents assigned within each state. Connecticut does not lead in R&D citations, but does lead in patents. These data show that Connecticut patents are all assigned to business while none are currently assigned to academia. This is consistent with other findings[9]which indicate Connecticut's academic efforts with regard to fuel cells are not as extensive as some of the other states and that Connecticut has a lower proportion of projects funded by the National Science Foundation. It has been demonstrated that, "Connecticut has "gaps" in innovation focused on codes and standards, storage, transportation, and consumer products."[10]

[8] Connecticut Hydrogen and Fuel Cell Cluster, Benchmark Analysis (Draft), ICF International, September 26, 2007
[9] Connecticut Hydrogen and Fuel Cell Cluster, Benchmark Analysis (Draft), ICF International, September 26, 2007
[10] Connecticut Hydrogen and Fuel Cell Cluster, Benchmark Analysis (Draft), ICF International, September 26, 2007

Figure A.5 Total Assigned Patents for Key States[11]



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, smaller-scale 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 in Massachusetts.[12] New York has major U.S. auto company fuel cell research and development including GM's efforts in the Rochester area (Ford and Daimler have purchased the automobile fuel cell business of Ballard Power Systems[13]) as well as leading companies in small proton exchange membrane power plants (Plug Power) and fuel cells for portable electronics (MTI Micro Fuel Cells). Massachusetts and New York would be logical candidates to join with Connecticut in regional activity for transportation fuel cell demonstration and deployment.

Tables IV.3.1, IV.3.2, and IV.3.3 identify manufacturing companies in 12 other states who are involved with fuel cells and/or hydrogen. Only one U.S. headquartered energy company,

[11] Connecticut Hydrogen and Fuel Cell Cluster, Benchmark Analysis (Draft), ICF International, September 26, 2007
[12] Tewksbury Advocate, November 17, 2005, reported by Fuel Cell Works
[13] "Ford, Daimler to buy auto-fuel cell unit" November 9, 2007, by Tyler Hamilton, Toronto Star, www.thestar.com

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.[14] The decision by Rolls-Royce has attracted interest from Japanese companies to locate/relocate in Ohio as well.[15] Table IV.3.1, IV.3.2, and IV.3.3 identify 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.

More information on individual states is provided below:

California

California is a major market whose environmental problems have made it a leader in reducing vehicle emissions and this leadership has now been extended to greenhouse gas reduction. California's efforts are being conducted as part of its Alternatives Fuels Plan.[16] Currently, California and Michigan have the largest efforts in demonstrating hydrogen vehicles with California's effort being much larger.

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[14] Akron Beacon, December 2, 2006 "Rolls-Royce fuels Ohio's tech plans," Paula Schleis
[15] Cleveland Plain Dealer, November 12, 2006
[16] State Alternative Fuels Plan, Committee Draft Report, CEC-600-2007-011-CTD, California Air Resources Board and California Energy Commission

The State of California has developed separate plans for stationary and transportation applications and has supported this activity through a program of grants and other financial incentives. Much of the activity has focused on the California Fuel Cell Partnership[17] which joined 34 vehicle, fuel cell and electrolysis manufacturers, energy companies, industrial gas companies, transit companies and state and federal agencies in an effort to demonstrate fuel cell vehicles. The partnership has 14 employees and a facility headquartered in West Sacramento which includes a hydrogen fueling station, service bays for vehicle maintenance, offices and a public gallery. The majority of the U.S. DOE auto demonstrations are taking place in California although Michigan, Florida and Washington D.C. also have participation.

In addition, Governor Schwarzenegger's California Hydrogen Highway Program would fund the development of 100 publicly accessible hydrogen fueling stations by 2010 at a cost of $65 million (50% funded by California). Incentives include $10,000 per hydrogen fueled vehicle (either fuel cell or internal combustion) targeting 2,000 vehicles to be placed on the road by 2010. The California Hydrogen Highway now spans 800 miles from Chula Vista near the border with Mexico to Arcata near the Oregon border.[18]

Other focused activities include stationary applications addressed by the California Stationary Fuel Cell Collaborative – an initiative sponsored by the California Air Resources Board and the National Fuel Cell Research Center. California sponsors many incentives for fuel cell purchase and advanced demonstration programs including the Emerging Renewables Rebate Program that provides incentives for the purchase of grid-connected renewable energy generating systems. The California Public Utilities Commission sponsors a Self-Generation Incentive Program to encourage residential and commercial electricity customers to install grid-tied renewables and clean distributed-generation systems. The South Coast Air Quality Management District (SCAQMD) sponsors the Air Quality Investment Program which funds projects that support emissions reductions. The Bay Area AQMD offers programs for clean

[17] The California Fuel Cell Partnership, http://www.cafcp.org/
[18] "California Hydrogen Highway Spans 800 Miles" by John Addison, April 24, 2007, CleantechBlog.com

vehicles, and the Sacramento AQMD Heavy Duty Low Emission Vehicle Incentive Program offers a variety of financial incentives to lower NOx emissions from heavy-duty vehicles.

The California Energy Commission's Public Interest Energy Research (PIER) program awards up to $62 million annually for research, technology development, demonstration, and technology commercialization, with perhaps 10% of these funds specifically focused on fuel cell activity. These projects target activities that will help improve the quality of life in California by bringing environmentally safe, affordable and reliable energy services and products to the marketplace. The PIER program achieves its goals by partnering with R&D organizations including individuals, businesses, utilities, and public or private research institutions. Funding efforts are split amongst the following initiatives:

- Buildings End-Use Energy Efficiency
- Climate Change Program
- Energy Innovations Small Grant Program
- Energy-Related Environmental Research
- Energy Systems Integration
- Environmentally-Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Natural Gas Research
- Renewable Energy Technologies
- Transportation Research

California also supports Energy Independence Now, which is a campaign to help transition California to a clean, renewable, hydrogen transportation economy as quickly as possible. This entity collaborates with companies, public agencies and consumers to identify and address the hurdles and make recommendations on timing, infrastructure siting, roll-out strategy, policy and regulatory options, incentives, financing options, public education, etc.

Florida

H2 Florida was initiated in 2003 by Florida's Energy Office to provide guidance on hydrogen activities in the state. In June 2006, Florida established a corporate tax credit to promote investment in hydrogen powered vehicles and fueling stations, and commercial stationary hydrogen fuel cells, among other technologies.

Seventy-five percent of all capital, operation and maintenance, and research and development costs incurred between July 1, 2006 and June 30, 2010 (up to $3 million per state fiscal year) for all taxpayers in connection with an investment in hydrogen-powered vehicles and fueling stations were covered by the credit. Also included in the credit were seventy-five percent of all capital, operation and maintenance, and research and development costs (up to $1.5 million per state fiscal year) for all taxpayers. This was limited to a maximum of $12,000 per fuel cell, over the same time frame, in connection with an investment in commercial stationary hydrogen fuel cells in the state. Florida further offers a $12.9 million matching grant program to support R&D, demonstration, and testing of hydrogen-related technologies.

The Florida Hydrogen Initiative[19] has been funded by U.S. DOE and funds projects in infrastructure development, technology demonstrations, and applied technology research & development.

Florida has two[20] hydrogen fueling stations to date and a fleet of 8 hydrogen fueled shuttle buses with internal combustion engines at the Orlando airport and plans an additional hydrogen fueling station.[21]

[19] The Florida Hydrogen Initiative, www.h2florida.org
[20] Hydrogen Fueling Stations Worldwide, http://www.h2stations.org/, December 2007
[21] "Nations First Hydrogen Bus Station Opens in Orlando", May 23, 2007, WESH-TV

Massachusetts

The Massachusetts Hydrogen Association[22] states there are 60 companies with fuel cell or hydrogen business in Massachusetts with a total of 1,500 employees[23] and has a number of fuel cell companies with product objectives including:

- Acumentrix and ZTek in solid oxide fuel cells
- Lillliputian Systems in small portable fuel cells
- Nuvera in PEM fuel cells for stationary and vehicle applications
- Protonex in PEM fuel cells for portable power, including military applications

Massachusetts also has a number of companies involved with fuel cell research including:

- Analytic Power
- Electrochem
- Giner Electrochemical Systems, LLC

A number of academic institutions in Massachusetts are involved with fuel cells including Worcester Polytechnic Institute and the University of Massachusetts at Amherst, which only recently announced a major award from the National Science Foundation to the "Fueling the Future Chemical Bonding Center" for fuel cell development.[24]

The Massachusetts Renewable Energy Trust[25] is a division of the Massachusetts Technology Collaborative which is funded through a ratepayer charge. Funding is available for fuel cells through its Commercial, Industrial, and Institutional Initiative. Massachusetts further offers residents who have applied for or hold an alternative energy or energy conservation system patent a break on state taxes providing the patent meets certain predetermined criteria.

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[22] The Massachusetts Hydrogen Coalition, http://www.massh2.org, November 2007
[23] http://www.fuelcellsworks.com/Supppage6729.html, November 28, 2007
[24] The Boston Globe, November 27, 2007
[25] The Massachusetts Renewable Energy Trust, http://www.mtpc.org/, November 2007

Additional funds are allocated through an array of debt, equity and grant programs to assist in the development and deployment of clean energy technology. Six million dollars has been allocated over three years to fund distributed renewable energy projects used by commercial, industrial, and institutional facilities. Up to $25 million will be provided in the form of rebates and production incentives to electric power generators that meet or exceed minimum requirements for producing electricity using renewable resources.

Michigan

As home to the U.S. auto industry and many suppliers, Michigan has a large stake in hydrogen and fuel cell vehicles. It is second to California in terms of participation in U.S. DOE fuel cell demonstrations and conducts work on fuel cells and hydrogen as part of a broad program on alternative energy.

Michigan has developed a $3 million Hydrogen Technology Park just outside of Detroit in Southfield to demonstrate an integrated hydrogen energy system. The U.S. Department of Energy and DTE Energy have been active in this major initiative. In addition, the NextEnergy Center in Detroit houses a hydrogen fueling system, a research program, and a hydrogen generation test bed. NextEnergy[26] is a nonprofit which was founded to advance alternative energy technology in Michigan through portable power generation, renewable fuels and hydrogen production for use within commercial and military applications.

New York

New York has been aggressive in pursuit of clean energy and alternative fuels and has many compressed natural gas stations and buses. It is also home to several fuel cell development activities involving a significant number of employees: General Motors vehicle fuel cell efforts are centered near Rochester. Near Schenectady, Plug Power is a significant manufacturer of small fuel cells for back-up and primary power and is developing home fuelers which generate hydrogen from natural gas in conjunction with Honda. MTI, another

[26] NextEnergy, http://www.nextenergy.org

company near Schenectady, is developing portable fuel cells. Praxair, which is headquartered in Connecticut, has hydrogen and engineering facilities in New York.

The New York State Energy Research and Development Authority (NYSERDA) sponsors research, development and demonstration including alternative fuels and both stationary and vehicle fuel cells and hydrogen.[27]

New York has developed a number of initiatives that focus on the development and use of renewable energy resources. Up to $50 million in tax credits over five years have been provided to offset 30 percent of the capitalized costs for corporate and residential "green buildings", which includes buildings that install clean energy technologies. An annual $19 million has been allocated for demonstration projects that involve emerging alternative energy technologies including fuel cells. This fund is supported by a systems benefit charge. A 280 acre Saratoga Technology Energy Park is being created by NYSERDA to promote clean energy technology industry.

Ohio

Like Michigan, Ohio has many companies involved in the supply chain for vehicles and its efforts on fuel cells and hydrogen are driven by economic development considerations as well as a research foundation associated with programs at Case-Western Reserve University, NASA and Air Force research facilities.

Ohio has launched a major initiative focused on becoming a national leader in the manufacture of fuel cell systems, components, and balance of plant equipment by maintaining selective research excellence, sustaining leadership in focused developments, creating a supportive business investment climate, and demonstrating leadership in public policies related to fuel cell education, research, development, demonstration and usage.

[27] NYSERDA, http://www.nyserda.org/default.asp

In this regard, Ohio has established a means of university R&D/collaboration through the Wright Fuel Cell Group, other research universities, federal laboratories, technology transfer teams, and the Edison Welding Institute.

Ohio has provided over $63 million in state support since 2003 – further leveraging private and federal funds. They have provided financial support through the Third Frontier Fuel Cell Initiative[28], a $1.1 billion overall program covering a range of technology projects, and plan to provide over $11 million for fuel cell development in 2008 and 2009. (It is projected that funds will total approximately $200 million from 2006-2011). This program is open to any Ohio-based organization and funds projects ranging from $250,000 to $1 million. These projects must also involve at least one Ohio-based organization operating in a collaborative mode and the program anticipates a cost share of 1:2.

Ohio has an active fuel cell coalition[29] which holds conferences, promotes economic development and advocates on the part of the industry in Ohio, which includes fuel cell companies such as HydroGen LLC, Rolls Royce Fuel Cell Systems U.S. Inc., SOFCo, UltraCell and major suppliers such as Graftech, NexTech Materials, Inc. and others.

Pennsylvania

Pennsylvania has strength in fuel cells and hydrogen through location of Air Products, an industrial gas company active in hydrogen; Siemens-Westinghouse, a company active in solid oxide fuel cells; Franklin Fuel Cells, another solid oxide fuel cell company; a fuel cell test center at Concurrent Technologies Corporation; and university research at Pennsylvania State University.

[28] The Third Frontier Project, http://www.thirdfrontier.com/, December 2007
[29] Ohio Fuel Cell Coalition, http://www.fuelcellsohio.org

South Carolina

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. South Carolina's alternative fuels program includes: hydrogen efforts associated with its government sponsored research at the Savannah River National Laboratory, university research and a goal of attracting manufacturing associated with fuel cells and hydrogen to the state. The South Carolina Hydrogen and Fuel Cell Alliance is an industry advocacy group which among other objectives is focused on building the fuel cell and hydrogen industry in the state.[30]

South Carolina has been developing broad-based hydrogen capabilities for many years – primarily centered around three leading research groups: Savannah River National Laboratory (SRNL), the University of South Carolina (USC), and Clemson University. These entities have established a track record of attracting nearly $30M/year in federal funding for hydrogen-related funding, although nearly 90% of these funds have been focused on SRNL's defense-related activities. The State of South Carolina has sponsored selected R&D activities primarily centered around economic development initiatives – some of which focus on the development of hydrogen technologies. One of the hydrogen research centers that has been funded at USC derives a portion of its funding from State lottery revenues. Other initiatives have focused on the construction of buildings and other infrastructure that benefit hydrogen research. One example is the Center for Hydrogen Research in Aiken, South Carolina which was organized to promote collaborative research, development, testing, and commercialization of hydrogen-related technologies. This facility was constructed with $10 million in financial assistance from Aiken County and the region's Economic Development Partnership is responsible for operations, commercialization activities and marketing. USC secured a package of state, federal and private funding to build the $32

[30] South Carolina Hydrogen and Fuel Cell Alliance, http://www.schydrogen.org

million Horizon Center, which is a two-building complex devoted to research and development of the next generation of energy technologies.

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

State	Company	Product(s)/Technology(ies)	Application(s)	Status
MA.				
	Acumentrics Corporation www.acumentrics.com	Solid Oxide Fuel Cells	Small natural gas or propane fueled power generation	5 kW demonstrations
	Analytic Power www.analytic-power.com/	Proton Exchange Membrane and Solid Oxide Fuel Cells	Research and development for clients	Continuing research and development activity
	Electrochem, Inc. www.fuelcell.com	Proton Exchange Membrane Fuel Cells	Small fuel cell components. Contract research	Components available, research activity underway
	Giner, Inc. and Giner Electrochemical Systems, LLC www.ginerinc.com	Proton Exchange Membrane Fuel Cells and Electrolysis Systems	Research and development for clients	Continuing research and development activity
	Nuvera www.nuvera.com	PEM Fuel Cells and Hydrogen Generation from Natural Gas and Petroleum	Back-up power, Auto power, bus power Rail power	Demonstrations
	Protonex Technology Corporation www.protonex.com	Proton Exchange Membrane Fuel Cells	Portable applications	Demonstrations
	ZTEK www.ztekcorporation.com	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
New York				
	BAE Systems www.na.baesystems.com	Drive System Integration	Bus OEMs	Demonstration Hybrid bus drives
	Corning www.corning.com	Solid Oxide Fuel Cell Stacks	OEMs	Research and development
	ENrG Inc www.enrg-inc.com	Solid Oxide Fuel Cell Components	OEMs	Research and development
	General Electric www.ge.com/research	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 www.gm.com/company/gmability/adv_tech/400_fcv/index.html	PEM fuel cells	Automobiles, military, stationary	In demonstration vehicles
	MTI Micro Fuel Cells Inc www.mtimicrofuelcells.com	Direct Methanol Fuel Cell (DMFC)	Portable electronics—commercial and military	Prototype delivered for customer evaluation Fuel distribution partnership
	Plug Power http://www.plugpower.com	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
CA				
	Chevron Corporation www.chevron.com	Hydrogen Fuel	Vehicles	Demonstrations
	ISE Corporation www.isecorp.com	Integrated drive systems for hybrid and fuel cell buses	Buses	Demonstrations
	Jadoo Power www.Jadoopower.com	Hydrogen-fueled fuel cell power plants for portable applications	Military, first responders, telecommunications	Demonstrations, products available for sale
	Polyfuel www.polyfuel.com	Hydrocarbon Membranes for Direct Methanol and Proton Exchange Membrane Fuel Cells	OEMs	Demonstrations
CO				
	Versa Power Systems www.versa-power.com Note: Partial Ownership by FuelCell Energy of CT	Solid Oxide Fuel Cells	Auxiliary power units, combined cycle power plants	Research and development
DE				
	DuPont www.dupont.com	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 www.gore.com	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. www.ion-power.com	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

MI				
	Delphi www.delphi.com	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 www.daimlerchrysler.com	Fuel Cell Automobiles	Automobiles, buses	Demonstration
	Eaton Corp www.eaton.com	Fuel Cell Ancillary Components	OEMs	Demonstration
	Energy Conversion Devices Inc. www.ovonic.com	Hydrogen Energy Storage and Hydrogen Fuel Dispensers	Automobiles, vehicle fueling stations	Demonstrations
	Ford Motor Company www.ford.com	Fuel Cell Automobiles	Automobiles	Demonstration
	General Motors Corporation www.gm.com	Fuel Cell Automobiles	Automobiles	Demonstration
MN				
	3M www.mmm.com	Membrane Electrode Assemblies for Proton Exchange Membrane Fuel Cells	OEMs	Demonstrations
NJ				
	Millennium Cell Inc. www.millenniumcell.com	Hydrogen Storage in Chemical Hydrides for Portable fuel cell products	OEMs	Demonstration, relationships with fuel cell companies
OH				
	Dana Corporation www.dana.com	Fuel Cell Stack and Balance of plant components	Fuel cell OEMs	Supplier of components to vehicle industry and others
	GrafTech International www.graftech.com	Graphite Electrodes and Other Fuel Cell graphite parts	Fuel cell OEMs	Supplier of commercial graphite products
	Nextech Materials, Ltd. www.nextechmaterials.com	Solid Oxide Fuel Cell Materials and Fuel Processing Catalysts	Fuel cell and fuel processors	Supplier to OEMs
	Rolls-Royce Fuel Cell Systems (US) Inc. www.rolls-royce.com	Solid Oxide Fuel Cells	Megawatt fuel cell-turbine combined cycle power plants	Research and development
	SOFCO-EES Holdings, LLC www.sofco-efs.com	Solid Oxide Fuel Cells and Fuel Processors	Stationary and vehicle auxiliary power	Laboratory demonstrations
	UltraCell Corporation www.ultracellpower.com (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

OR				
	Idatech www.idatech.com	Small Fuel Cell Power Plants up to 15 kW for portable power applications operating on hydrogen or hydrocarbon fuels	Military, commercial, residential applications	Demonstrations
PA				
	Air Products www.airproducts.com	Global Industrial Gas Company	Hydrogen fueling stations for vehicles	Demonstrations in U.S. and Europe
	Franklin Fuel Cells www.franklinfuelcells.com	Solid Oxide Fuel Cells	Range of power from kilowatts to hundreds of kilowatts	Research and development
	Siemens (US Fuel Cell Activity) www.siemens.com	Solid Oxide Fuel Cells	Fuel cells and fuel cell-turbine combined cycle power plants	A number of demonstrations
UT				
	Ceramatec Inc. www.ceramatec.com	Solid Oxide Fuel Cells	Research and development	Advanced technology materials for fuel cell and other applications.
VA				
	H2 Gen Innovations Inc. www.h2gen.com	Natural gas to hydrogen generators	Industrial hydrogen and hydrogen for vehicles	Commercial products
WA				
	Hydrogen Power Inc. www.hydrogenpowerinc.com	Hydrogen Storage based on reaction of water and aluminum	Military and commercial portable power, vehicles	Demonstration
	Relion www.Relion-inc.com	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

State	Planning	Partnerships
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
Connecticut	**Hydrogen and Fuel Cell Planning Effort Begins (2006)**	**Connecticut Hydrogen and Fuel Cell Coalition (2005)** **Cluster Formation (2007)**

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

State	Research and Development Centers	State Funding for research and Development
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	--
Connecticut	**Connecticut Global Fuel Cell Center**	**Connecticut Innovations, Inc.** **Connecticut Clean Energy Fund** **New Energy Technology Grants**

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										
Connecticut	**Yes**	**Yes**	**Yes**			**Yes, State Facilities**		**Yes**	**Yes**	**Yes**

Table IV.7 - State Assistance for Hydrogen Fueled Vehicles

State	Hydrogen Infrastructure Support	AFV Sales Rqmt	Government Purchase of AFV	ZEV Bus Purchase Requirement	Vehicle/Fuel Purchase Incentive	HOV/Parking Incentives for AFV	Manufact'r Incentives	Demonstrations
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								
Connecticut			**Yes**		**Yes**			

Appendix F - Fuel Cell Supply Chain Analysis

Executive Summary

The Connecticut Center for Manufacturing Supply Chain Integration (CMSCI) in support of the Connecticut Center for Advanced Technology (CCAT) Energy Initiative, conducted an analysis as part of the Fuel Cell Economic Development Plan Hydrogen Roadmap. Objectives of the analysis are:

- Identify current suppliers in the fuel cell supply chain. This list will be used to improve the exchange of information among suppliers and facilitate strategic planning activities for a fuel cell industry cluster.
- Identify how investment in key market segments of the fuel cell supply chain will benefit the state with jobs and economic value.

The fuel cell market is a growing industry emerging in the global economy. Fuel cells represent a path to a more efficient, renewable source of power that would allow the world to decrease its dependency on a depleting oil reserve. However, the manufacturing of fuel cells is currently very expensive which prevents the industry from being competitive with other energy applications. These high costs are partially associated with a supply chain that is weak and spread out over large geographical areas. Original equipment manufacturers (OEMs) and suppliers must improve their productivity in order to become more competitive. The supply chain must strengthen and become more cohesive in order to drive down cost. Economies of scale alone will not make fuel cells more cost-effective.

Conclusions drawn from the analysis are:

- There are over 40 companies identified in the current Connecticut fuel cell supply chain. These companies are provided in Table 1.1.
- There are over 150 Connecticut companies that have the capability to be part of the fuel cell supply chain. These companies are provided in Table 1.2
- Investment in the following will assist the fuel cell supply chain to be more competitive and profitable, and thus benefit the state by creating new jobs and contributing to the state economy:
    - Innovation programs
    - Lean manufacturing/six sigma programs
    - Design for Manufacture/Assembly (DFM/A) programs
    - Make/buy analysis programs
    - Developing a local fuel cell supply chain
    - Tooling for sub-tier suppliers

Introduction

CMSCI interviewed three fuel cell OEMs in Connecticut - GenCell of Southbury, UTC Power of South Windsor, and FuelCell Energy of Danbury. With information obtained from these companies, CMSCI documented the "current state" of fuel cell manufacturing in Connecticut. This "current state" identifies opportunities for supply chain development and thus allowed CMSCI to project a "future state" of fuel cell manufacturing in Connecticut. The analysis includes recommendations for suppliers, OEMs, or the state, that in our opinion, are required to strengthen and grow the fuel cell industry in Connecticut

The "current state" of the fuel cell supply chain can be best explained as one of low volume production and high costs. Manufacturers currently perform certain processes in-house that could be outsourced. These processes are kept in-house because of intellectual property issues and the inefficiencies and high cost associated with managing and producing a small number of parts elsewhere. High labor costs and start-up capital investment required by outside suppliers also add to the difficulty of outsourcing. Certain materials and sub-assemblies associated with manufacturing fuel cells are currently of such unique specifications and tolerances that the number of available suppliers is limited and thus, forces the OEMs, in many cases, to look outside Connecticut. The current practice of assembling, testing and shipping a complete fuel cell plant one manufacturing facility to its installation location is expensive. Depending on the size of the plant and the labor costs in the region of the installation site, shipping fully tested subassemblies is an attractive alternative. Other power generating stations (fossil fuel generating stations) assemble and test at the installation location.

The "future state" of a fuel cell supply chain should have OEMs performing critical and proprietary manufacturing processes in-house and outsource other processes to suppliers inside the state, or at least in New England. This will allow OEMs to concentrate on core competencies; what they do best and to leverage the strong manufacturing base in the region. For instance, there are over 150 aerospace and defense suppliers within the state of Connecticut that are capable of working with precision tolerances and exotic materials. Many of these suppliers are aggressively reducing cost via lean manufacturing methods. With the development of a Connecticut fuel cell supply chain, and the operational efficiencies that will invariably come with this development, the overall cost of manufacturing fuel cells in the state will be reduced. Lower costs should lead to increased sales and production, thus decreasing costs further and allowing for expansion and creation of jobs.

This analysis documents the detailed issues of the "current state" while visualizing the ideal "future state" and brings forth recommendations for bridging the gap. In order for fuel cells to become more competitive, the goal must become a reality.

Current State

Anatomy of a Fuel Cell

The following is a simple representation of the major components of a turn-key fuel cell plant:

Fuel Cell Plant

Balance of Plant (BOP)

- Structural Components
- Power Conditioners
- Heat Exchangers
- Fuel Processors
- Water Systems
- Air Systems
- Control Systems

Stack

- Plates
- Other Components (Repeat and Non-Repeat)
- Membranes or Electrolyte Storage Means
- Seals

Manufacturing a Fuel Cell

The following is a table of the typical materials, manufacturing processes, and manufactured components involved in the manufacturing of a fuel cell:

Materials	**Manufacturing Processes**	**Manufactured Components**
Platinum	Metal forming	Heat exchangers
Aluminum Clad Metal	Machining	Valves
Stainless Steel	Welding	Controllers
Nickel	Plating	Pipes/Tubing
Plastics	Coating	Connectors
Adhesives	X-Ray Inspection	Cathodes/Anodes
Ceramics	Heat Treating	Instrumentation
Insulation	Degreasing	Catalysts
Structural Steel	Casting	Insulation
Carbon	Int. Molding	Wiring
Graphite	Composites	Gaskets
Jepson		

What do Connecticut OEMs currently do?

- Manufacture
- Repair
- Refurbish
- Test
- Assemble
- Install
- Maintain and Monitor

What do Connecticut OEMs currently make?

- Turn-key fuel cell plants
- Fuel cell stacks
- Fuel cell plates
- BOP equipment

Life expectancy of a fuel cell plant

The magnitude of the fuel cell spare part business is based on the life expectancy of the three major categories of parts in a fuel cell:

- 80,000 hrs for "low temperature" stack technology
- 20yrs for "high temperature" technology Balance of Plant (BOP) parts
- 3yrs for "high temperature" technology parts –stacks/plates

The fuel cell industry in Connecticut faces numerous challenges:

- High labor costs – difficult for Connecticut OEMs to compete with OEMs in low cost regions and drives Connecticut OEMs to look for suppliers in low cost regions
- Expensive materials – affects all OEMs, not just in CT
- Logistics – manufacturing, testing, assembling, shipping and installation of large complex system
- Manufacturing volume is low and demand is intermittent, therefore difficult to get suppliers to invest in capital and tooling
- OEMs doing too much in-house fabrication:
    - To protect intellectual property (this is ok)
    - Because they cannot get suppliers to meet their specifications (this is NOT ok)
- Large system integration of hundreds of parts and components. Many of these parts have unique specifications, high tolerances and are made of specialized materials
- High shipping costs of parts/components and sub-assemblies to Connecticut for processing and assembly

- Very poor mechanical design practice (DF_x)

The fuel cell industry has come up with very few solutions for these challenges:

- Some OEMs are implementing semi-automated processes in an attempt to address the labor cost issue
- Hire experienced (non-chemical) engineers

Future State

- Overall cost of fuel cells will be competitive with fossil fuel generating stations.
- Higher manufacturing volumes will make it more attractive for suppliers to invest in machines and tooling to a degree
- Innovation and Design for Manufacture/Assembly (DFM/A) will be applied to improve material selection and parts manufacturing, lowering cost by improving producibility
- OEMs will focus on core competencies and outsource everything else
- Local supply chain will be available for outsourcing of specific materials, parts and sub-assemblies
- Increased number of pre-tested sub-assemblies ready for system integration will be delivered to installation site – modular design
- Lead-time for delivery will be reduced by greater than 50% due to condensing the fuel cell supply chain and applying lean techniques

Recommendations

To bridge the gap between the current state and the future state:

- Initiate innovation projects to find less costly materials, parts and assemblies – some OEMs have started doing such projects
    - The Connecticut Small Business Innovation Research (SBIR) Program is one source available to initiate innovation
- Implement lean manufacturing/six sigma techniques to increase competitiveness at OEMs and suppliers
    - Aerospace and Defense Initiative (ADI) – grant money currently available
    - Manufacturing Initiative (MI) – similar grant money pending
- Initiate DFM/A principles to increase production efficiency and decrease unit cost
    - Eligible for ADI reimbursement
- Instruct and facilitate OEM make/buy analysis
    - CMSCI can help
- Assist OEMs to develop local supply chain to manufacture outsourced parts and assemblies
    - CMSCI can help identify candidate suppliers for:
        - Wire harnesses, sheet metal, piping, valves, machined components, etc.

- Create financial incentives (tax abatements, grants, low cost loans, etc) for:
    - Tooling for sub-tier suppliers
    - Programs similar to ADI in other states in the region -- work through other state Manufacturing Extension Partnerships (MEP) to develop these programs

Summary

The following matrix shows a summary of our findings:

Current State	**Future State**	**Bridge**
Overall cost of fuel cell is expensive	Overall cost of fuel cells will be competitive with fossil fuel generating stations	Initiate innovation projects (SBIR) and implement lean techniques (ADI, MI)
Too much in-house fabrication at OEMS	OEMs will focus on core competencies and outsource everything else	Instruct and facilitate OEM make/buy analysis
Large system integration contains numerous parts of unique specifications and exotic materials	Local supply chain will be available for outsource of specific materials	Assist OEMs to develop local supply chain by identifying "low hanging fruit"
Expensive materials effecting OEMs	Improving producibility and lower cost of materials	Initiate DFM/A principles and innovation
Logistics of manufacturing, testing, assembling, shipping, and installing of a large complex system	Increased number of pre-test sub-assemblies ready for system integration will be delivered to install site	Use DFM/A principles for the definition of sub-assemblies
Low manufacturing volumes makes it difficult to get suppliers to invest	With increased manufacturing volumes, it will make investment more attractive to suppliers	Create state incentives to encourage investment in required processes
High lead times due to lack of concentrated supply chain	Decreased lead times by greater than 50%	Apply lean techniques and take advantage of a strengthened supply chain

- Significant cost in fuel cell systems is driven by poor design practice and R&D mindset even when addressing product design with presumed hundreds and/or thousands of unit production runs.
- Drive system, component, part level *simplification*

Appendix

The following tables identify Connecticut companies that are 1) currently in the fuel cell supply chain and 2) companies that could be considered for the fuel cell supply chain based on their manufacturing capabilities. Companies that are involved in the ADI program are working on continuous improvement projects and are identified with an *.

Summary of the following tables:

- Over 40 companies identified in the Connecticut fuel cell supply chain
- Over 150 companies that have the capability to be part of the fuel cell supply chain
- Over 20 companies implementing lean techniques demonstrating continuous improvement

Table 1.1
Connecticut Companies in the Current Fuel Cell Supply Chain

Company Name	Type of Supplier
Accu-Rite Tool & Mfg Co Inc	Component Supplier
AccuStandard Inc	Material Supplier
Adchem Inc*	Material Supplier
Aerogel Composite	Material Supplier
Atlantic Fabricating	Material Supplier
Atlantic Ventilating	Component Supplier
Avālence LLC	Fuel and Infrastructure
Becon	Component Supplier
Brand Nu Labs	Material Supplier
Dexmet Corporation	Material Supplier
Digatron/Firing-Circuits	Component Supplier
Druck Inc	Component Supplier
Fabtron	Material Supplier
Fibercote Industries	Material Supplier
Forrest Machine	Material Supplier
Gems	Component Supplier
GenCell	Component Supplier
Habco Inc*	Fuel and Infrastructure
Henkel Loctite	Material Supplier
Horst Engineering	Component Supplier
IMS Inc	Material Supplier
Inframat	Material Supplier
Jet Process Corp	Material Supplier
Jones Metal	Material Supplier
Leppert Nutmeg	Component Supplier
Litton Systems	Material Supplier
Lynn Welding	Material Supplier
Mott Corporation	Component Supplier
Oxford Performance Materials Inc	Component Supplier
Parker Hannifan	Component Supplier
Pegasus Triumph Mfg. Inc	Component Supplier
Plainville Electroplating	Material Supplier

Praxair	Fuel and Infrastructure
Precision Combustion Inc	Component Supplier
ProFlow	Component Supplier
PTFE Industries	Material Supplier
Rogers Corporation	Material Supplier
Southington Tool & Mfg. Corp	Component Supplier
T & T Automation	Component Supplier
Tech Circuits	Component Supplier
The Claremont Sales Corporation*	Material Supplier
Treadwell	Component Supplier
Trueline Corp	Component Supplier
US Nanocorp	Material Supplier
Whitcraft Corp*	Material Supplier

* These companies participate in the ADI program..

Table 1.2
Connecticut Companies with Potential to Participate in the Fuel Cell Supply Chain

Company Names	**Products Supplied**
A E Aubin Co.	Metals, Alloys, Stainless Steel
A & D Components, Inc	Assemblies and Kits
Able Coil and Electronics Co,. Inc	Actuators; Cables, Wires, and Connectors; Electronic Components
Able Wire Co	Cables, Wires, and Connectors
Acceleron	Assemblies and Kits
Accurate Threaded Products	Fasteners, Nuts, Bolts, Washers, Shims
Ace Technical Plastics	Rubber and Plastic Components
Admill Machine Co LLC	Assemblies and Kits
ADP Rivet	Fasteners, Nuts, Bolts, Washers, Shims
Advanced Aerospace Corp.	Assemblies and Kits
Aerodyne Alloys	Metals, Alloys, Stainless Steel
AeroSpace Coating Systems, Inc	Coatings, Finishes, and Sealants
AEROSWISS	Fasteners, Nuts, Bolts, Washers, Shims
Aerotech Fasteners, Inc	Fasteners, Nuts, Bolts, Washers, Shims
AGC Inc	Composites; Metals, Alloys, Stainless Steel; Rubber and Plastics Components
Aircraft Welding and Mfg	Rubber and Plastic Components
AIW-Alton	Metals, Alloys, Stainless Steel
Alden O Sherman Co. Inc.	Assemblies and Kits
Algonquin Parts Incorporated	Assemblies and Kits
Alinabal	Fasteners, Nuts, Bolts, Washers, Shims
Allied Metal Finishing	Coatings, Finishes, and Sealants
Alloy Specialties Inc.	Assemblies and Kits
Alpha Q Inc	Assemblies and Kits
Alpine Electronic Component Co.	Electronic Components
AMCO Precision Tools Inc.	Assemblies and Kits
Anamet Inc.	Metals, Alloys, Stainless Steel

Anodic, Inc	Coatings, Finishes, and Sealants
Applied Engineering Products Inc*	Cables, Wires, and Connectors; Electronic Components
Armoloy of Connecticut Inc.	Coatings, Finishes, and Sealants
Arrow Electronics	Electronic Components
Associated Spring, Barnes	Fasteners, Nuts, Bolts, Washers, Shims
Atlantic Inertial Systems (BAE)*	Assemblies and Kits
Balding Precision	Metals, Alloys, Stainless Steel
Baumer Electric Ltd.	Electronic Components
BDK Machine Co.	Assemblies and Kits; Fasteners, Nuts, Bolts, Washers, Shims; Metals, Alloys, Stainless Steel
Bechert Brothers Manufacturing Co.	Fasteners, Nuts, Bolts, Washers, Shims
Beckson Industrial Products Inc.	Tubing and Tubing Assemblies; Valves
Beta Shim Co.	Fasteners, Nuts, Bolts, Washers, Shims
Birken Mfg. Co.	Assemblies and Kits
Bland Company	Fasteners, Nuts, Bolts, Washers, Shims
Bodine Assembly and Test Systems	Assemblies and Kits
BodyCote Thermal Processing	Coatings, Finishes, and Sealants
Budney Overhaul and Repair LTD	Assemblies and Kits
C V Tool Company Inc.	Metals, Alloys, Stainless Steel
CAM Group	Assemblies and Kits
Cambridge Specialty	Assemblies and Kits
Capewell Components*	Assemblies and Kits
CBS Manufacturing Co.	Assemblies and Kits
Collins Pipe and Supply	Assemblies and Kits; Valves
Colonial HanDee Spring*	Fasteners, Nuts, Bolts, Washers, Shims
Compair Inc.	Assemblies and Kits
Component Engineers	Tubing and Tubing Assemblies
Connecticut Aircraft Products	Fasteners, Nuts, Bolts, Washers, Shims
Connecticut Spring and Stamping	Electronic Components
Connecticut Stamping and Bending	Tubing and Tubing Assemblies; Valves
Consolidated Ind	Electronic Components; Metals, Alloys, Stainless Steel
Constitution Cable Products	Cables, Wires, and Connectors
Cook and Chick Co.	Metals, Alloys, Stainless Steel
Cooper Crouse-Hinds	Electronic Components
Copper and Brass Sales	Metals, Alloys, Stainless Steel
Crane Co	Tubing and Tubing Assemblies; Valves
CRC Chrome Corp	Coatings, Finishes, and Sealants
Crompton Corp	Coatings, Finishes, and Sealants
Curtis Products,, LLC	Fasteners, Nuts, Bolts, Washers, Shims
Cyro Industries	Rubber and Plastic Components
Deburr Co.	Coatings, Finishes, and Sealants; Composites
Deburring Laboratories	Coatings, Finishes, and Sealants; Composites
Delcegno Threading	Valves
Dell Manufacturing Co.	Assemblies and Kits
Delta Industries*	Assemblies and Kits

Devon Precision Industries Inc	Fasteners, Nuts, Bolts, Washers, Shims
Doncasters Inc.	Metals, Alloys, Stainless Steel
Donwell Co, The	Coatings, Finishes, and Sealants
DRS Fermont	Assemblies and Kits; Electronic Components
Dymax Corp	Adhesives
Dynamic Metals	Metals, Alloys, Stainless Steel
Dynatech International Co.	Assemblies and Kits
Eastern Connector Specialty Corporation	Electronic Components
EDAC	Tubing and Tubing Assemblies; Valves
Electro-Flex Heat, Inc.	Assemblies and Kits
Electro-Methods Inc.	Electronic Components
Electronic Connection Corp	Cables, Wires, and Connectors
Emhart Technologies	Fasteners, Nuts, Bolts, Washers, Shims
Engelhard Corporation (BASF)*	Coatings, Finishes, and Sealants; Electronic Components
Engine Alliance	Electronic Components
Esteem Mfg	Composites; Electronic Components; Metals, Alloys, Stainless Steel; Rubber and Plastic Components
Farmington Engineering	Tubing and Tubing Assemblies; Valves
Fenn Technologies	Assemblies and Kits
FilmX Technologies*	Coatings, Finishes, and Sealants
Flanagan Brothers Inc.	Assemblies and Kits
Foster*	Coatings, Finishes, and Sealants; Composites
Gar Electroforming	Coatings, Finishes, and Sealants
General Cable	Electronic Components
Global Armour LLC	Assemblies and Kits
GROS-ITE Industries	Assemblies and Kits
HAR Conn Chrome Inc.	Coatings, Finishes, and Sealants
Harco Laboritories Inc.*	Assemblies and Kits
Hexcel Corporation	Composites
Hi-Speed Machine Products	Fasteners, Nuts, Bolts, Washers, Shims
Hoffman Engineering	Electronic Components
Honeywell	Assemblies and Kits
Hottec, Inc.	Adhesives
House of Metals	Cables, Wires, and Connectors; Metals, Alloys, Stainless Steel; Tubing and Tubing Assemblies
Howmet Castings Corporate Machining	Coatings, Finishes, and Sealants
Integra Cast Inc*	Metals, Alloys, Stainless Steel
Integrity Manufacturing LLC	Assemblies and Kits
Integro	Rubber and Plastic Components
J.R. Merritt Controls Inc.	Electronic Components
James Ippolito	Assemblies and Kits
Jobin Machine Inc.	Assemblies and Kits
Jonal Laboratories	Rubber and Plastic Components
Kamatics*	Fasteners, Nuts, Bolts, Washers, Shims; Metals, Alloys, Stainless Steel; Rubber

	and Plastic Components
Kapco Valter	Tubing and Tubing Assemblies; Valves
Kimchuk	Electronic Components
Leading Edge Concepts Inc.	Assemblies and Kits
Lee Co.	Assemblies and Kits; Valves
Lex Products Corporation*	Electronic Components
Light Metals Coloring Co., Inc	Coatings, Finishes, and Sealants
Loos and Company Inc.	Assemblies and Kits; Cables, Wires, and Connectors; Electronic Components
Lord Kinematics	Metals, Alloys, Stainless Steel; Rubber and Plastics Components
Magellan Aerospace	Assemblies and Kits
Mark Eyelet Inc.	Electronic Components
Marlborough Plastics	Rubber and Plastic Components
McMellon Brothers Inc	Fasteners, Nuts, Bolts, Washers, Shims
Meriden Electronics Corporation	Electronic Components
Metal Finishing Technologies	Coatings, Finishes, and Sealants; Fasteners, Nuts, Bolts, Washers, Shims
Metal Management Aerospace	Metals, Alloys, Stainless Steel
Metalizing Services	Coatings, Finishes, and Sealants
Metallon, Inc	Cables, Wires, and Connectors; Electronic Components
Metalurgical Processing Inc.	Coatings, Finishes, and Sealants
Microboard, Inc*	Electronic Components
Microwave and Video Systems Inc.	Electronic Components
Moeller Instrument Co. Inc.	Electronic Components
MPI Corporation	Assemblies and Kits
Newberry Industries, Inc	Assemblies and Kits
Newhart Plastics Inc.	Rubber and Plastic Components
Nexus Inc.	Electronic Components
Nielsen Hardware	Assemblies and Kits
Nordex Inc.	Electronic Components
Norse, Inc	Fasteners, Nuts, Bolts, Washers, Shims
North East Fasteners Corp.	Fasteners, Nuts, Bolts, Washers, Shims
Northern States Metals Corp	Metals, Alloys, Stainless Steel
OFS	Electronic Components
Orange Research Inc	Assemblies and Kits; Electronic Components; Valves
Overhaul Support Services	Assemblies and Kits
Oxley, Inc	Electronic Components
Paneloc Corporation	Fasteners, Nuts, Bolts, Washers, Shims
Paramount Machine Co. Inc.	Assemblies and Kits
Patten EA Company	Tubing and Tubing Assemblies
Peter Paul Electronics*	Electronic Components; Valves
PIC Design	Assemblies and Kits; Fasteners, Nuts, Bolts, Washers, Shims
Pierce Aluminum	Metals, Alloys, Stainless Steel
Plasti-Coat Corp.	Coatings, Finishes, and Sealants; Metals, Alloys, Stainless Steel
Plastonics, Inc	Coatings, Finishes, and Sealants

Polamer Precision Inc.	Assemblies and Kits
Polycast Technology	Rubber and Plastic Components
Polymer Engineering	Adhesives
Precision Electronic Assembly	Electronic Components
Prestige Industrial Finishing	Coatings, Finishes, and Sealants
Projects Inc.	Fasteners, Nuts, Bolts, Washers, Shims
Prototype and Plastic Mold Co.	Rubber and Plastic Components
PTI Industries, Inc	Coatings, Finishes, and Sealants
Purdy Corporation	Assemblies and Kits
Pye and Hogan LLC	Assemblies and Kits
Quality Deburring	Coatings, Finishes, and Sealants
Ram Technologies	Assemblies and Kits
Reliable Mfg	Assemblies and Kits; Electronic Components
Rich Plastic Products Inc.	Rubber and Plastic Components
Richard Manufacturing Co.	Assemblies and Kits
RJ Enterprises	Metals, Alloys, Stainless Steel
Rockbestos-Surprenant Cable*	Electronic Components
Romco Contractors	Metals, Alloys, Stainless Steel
Rostra Vernatherm*	Actuator Suppliers; Assemblies and Kits; Electronic Components; Valves
Rotair Industries Inc	Assemblies and Kits
RTG - Thermal Spray Coatings	Coatings, Finishes, and Sealants
Saf Industries	Tubing and Tubing Assemblies; Valves
Safe-T-Tank Corp.	Rubber and Plastic Components
Scott's Metal Finishing	Coatings, Finishes, and Sealants
Sermatech Klock	Assemblies and Kits; Electronic Components
Sibley Co.	Electronic Components
Sifco Industries Inc.	Coatings, Finishes, and Sealants
Skillcraft Machine Tool Co.	Assemblies and Kits
Soldream Inc	Assemblies and Kits
Sorge Industries Inc.	Metals, Alloys, Stainless Steel
Specialty Cable Corp	Cables, Wires, and Connectors
United Avionics	Cables, Wires, and Connectors
VDO Control Systems	Cables, Wires, and Connectors

* These companies participate in the ADI program.

Appendix G - Connecticut Distributed Generation Incentive Programs

Table 1 – Summary of Connecticut Distributed Generation Incentive Programs

Incentive Program	Effect on Economics	Limitations	Value
"Net Metering"	Values excess power exported to utility at avoided wholesale cost	Up to 2,000 kW	Exported energy valued at retail rate unless net energy is exported to the utility network in which case, the net energy exported is valued at the avoided whole-sale cost. Demand charges still apply
Back-up power charges	Eliminates a portion of demand charge if fuel cell outage occurs entirely in off-peak periods	Only for off-peak outages	Avoids back-up demand charges for some outages
Renewable Energy Certificates	Credit for environmental benefit of power delivered	Maximum is 5.5 cents per kWh based on penalty for failure to meet Renewable Portfolio Standards	Value determined by market. Has varied from $10 - $50 per megawatt hour (1 - 5 cents per kWh)
Distributed Generation Incentives through Connecticut Clean Energy Fund (CCEF)	Capital cost subsidy and subsidy for kWh delivered in Southwest Connecticut	Up to $4,700 per kW, Additional 1.5 cents per kWh in Southwest Connecticut. $4 million limit for an installation over its life cycle	Depends on CCEF evaluation of site specific factors, including use of fuel cell heat. Amount of incentive will likely be less than $4,500 per kW
Distributed Generation Incentive through Department of Utility Control (DPUC)	Capital cost subsidy	Only available if facility does not qualify for CCEF incentive; limited to congestion charge avoidance	$200 - $500 per kW depending on site- specific factors
Forward Capacity Market through ISO-New England	Monthly credit for power capacity	Fixed schedule through 2010, then defined by auction, 1 - 5 year contract	Currently $3.10 per kW per month. Depends on need, ISO-NE decision
Federal Income tax credit	Tax credit	Up to 30% of project cost or $1,000 per kW, whichever is less. Efficiency must be 30% or higher.	Depends on legislation to extend beyond December 2008. Applies only to facilities owned by profit-making entities.

Economic and Market Analysis for Fuel Cell Development
A Case for Connecticut

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September 10, 2007

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Economic and Market Analysis for Fuel Cell Development: A Case for Connecticut

I. INTRODUCTION

A. OBJECTIVE

This study was undertaken to assist The Connecticut Center for Advanced Technology (CCAT), Inc. in the following ways: 1. Validate from current research sources existing and future markets for hydrogen and fuel cell technologies including stationary, portable, transportation and research and development, 2. Analyze the potential investment opportunities to best encourage economic development through increased production, reduction in overall cost, job creation and any other direct, indirect or otherwise induced benefits from hydrogen and fuel cell development, 3. Present a practical and hopefully usable public financing model for the State of Connecticut for strategic investment of public resources in Connecticut's hydrogen and fuel cell industry.

B. METHODOLOGY

This report is a result of numerous interviews with Connecticut experts in academics, government and industry who are on the forefront of new cutting edge technology, research, development and manufacturing of hydrogen and fuel cell products and services. From these interviews and from recent research studies and reports listed in the reference section, conclusions were made in current and future prospects for Connecticut's hydrogen and fuel cell industry. Economic forecasts made are based upon these future prospects.

In advance, the following disclaimer is made. Forecasts are just that, forecasts, and are little more than a best guess. While any forecast is a guess, the conclusions are based upon what was found to be the majority opinion from experts in the field. While the research and advice came from the experts in the field, the economic development forecast is unique to this and other studies by CCAT.

C. OVERVIEW

Technological developments in energy and transportation have transformed nearly every aspect of our lives. We live in a world today where not a moment passes that nearly everything we do uses more and more energy. Economies of scale in the production of all new technologies are tremendous. We have seen the consumer sales prices of everything from airplane tickets to cell phones and flat-panel TVs start at prices designed for the very, very rich, far beyond the reach of most of us, but with investment, increased sales and the economics of scale of industry prices, fell exponentially. International round-trip airfares once surpassed one's monthly income and now it is often less than a week's pay. Cell phones that once cost thousands are offered free with a contract to use service. Flat panel TVs just 10 years ago seemed out of reach at $10-$20,000 per unit while now one can buy a 32" flat-panel HDTV for under $1,000. Other technologies like diesel locomotives while cleaner, with less of a logistical burden and operated with less maintenance than coal locomotives, still took 50 years or so to replace them. Jet engines while providing great benefits over reciprocating engines, also took years to replace in many commercial airliners. Fuel cells and hydrogen equipment are subject to economies of scale in manufacturing like other technologies.

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D. WHY HYDROGEN?

Hydrogen can be the ideal answer. Hydrogen is clean because it contains no carbon, no sulfur or soot, and hydrogen allows for lean combustion and very low NOx emissions, and hydrogen can be used to power machines, like fuel cells that are extremely quiet and efficient, and every year its production cost declines. Hydrogen, however, is not a fuel but an energy carrier. Hydrogen can be produced from renewable and non-renewable energy sources. To produce hydrogen one currently incurs many of the problems with hydrocarbon fuels. When producing hydrogen from non-renewables like natural gas or more importantly from coal, the well to wheels efficiency is often no better than legacy approaches, particularly in regard to global warming gases. While producing hydrogen from renewable energy sources is virtually pollution free, production from non-renewables can produce pollutants. Hydrogen can be the ideal energy carrier if it can be produced in an environmental friendly way. The solution, therefore, is not only in using hydrogen as the energy carrier but finding new and innovative ways to produce it.

E. WHY CONNECTICUT?

Connecticut has one of the world's largest hydrogen and fuel cell industrial bases. Based upon research on numbers of employees employed around the world in the hydrogen and fuel cell industries, one can say 13% of the resources in this industry are in Connecticut. Connecticut is posed to become the "silicon valley" of hydrogen energy but not unlike any other technology, the industry needs public investment. Examples abound. Few would be driving a private automobile without the billions of public dollars spent on roads and highways. Trains would still be on the drawing board if government did not assist in securing rail lines. Airports were built to support air travel, and government organized and issued the licenses that make cell phone service possible. Fuel cells are no different. The question is how can government help to jump-start this new industry and help guide it to maturity and technological efficiency. Most understand hydrogen to be the clean, quiet, energy source of the future but how can hydrogen and fuel cells become economically feasible while the industry matures?

II. ECONOMIC AND MARKET ANALYSIS

This report identifies existing and future markets for hydrogen and fuel cell technologies for stationary power, portable power, the transportation market, and research and development.

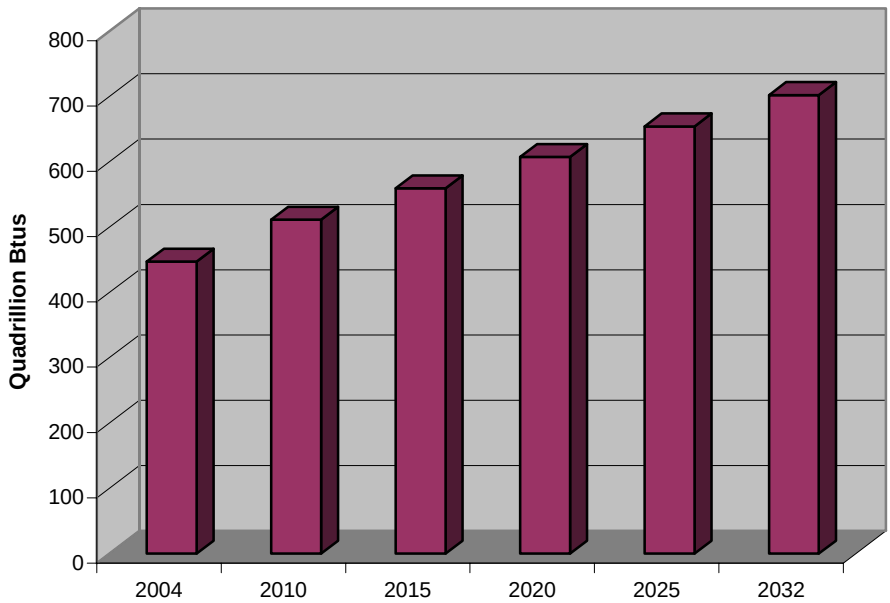
A. STATIONARY

1. National and World Market

The market for electric generation is among the richest industrial markets in the world. In the world of investing, economic growth is measured in the industrial, utility and transportation averages on Wall Street. While electric generation is key in the industrial sector, electric generation is the basis of the utility sector and a small but critically important portion of transportation runs on electricity. Electric power is a key catalyst behind nearly all modern economic growth. Not only is global electric consumption, " . . . projected to increase by

57% from 2004 to 2030," (see Figure I) but also, renewable energy generation (see Figure II), according to the Energy Information Administration (EIA). The EIA also stated that between 7-8% of all electric power is produced through renewable energy, and many project that to rise rapidly in the near future increasing by about 66% from 2004-2030 (see Figure II) (13). While today most renewable energy is hydropower, many feel the future rests with using more and more renewables. Hydrogen is effective in distributed stationary power generation

Figure I: World Energy Consumption

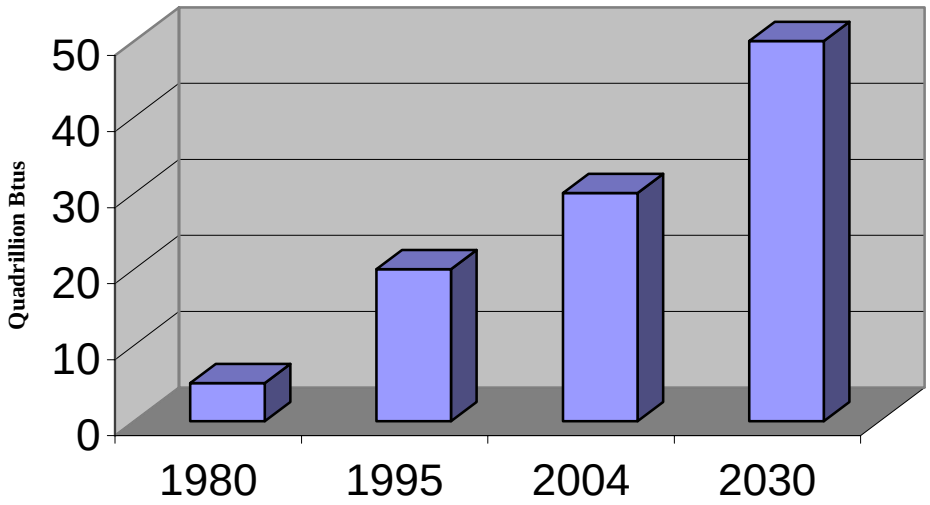


Source: Energy Information Administration International Energy Outlook 2007

(25).

Note: Figure 1 charts worldwide energy consumption from any available source.

Figure II: Worldwide Renewable Energy Consumption



Source: Energy Information Administration International Energy Outlook 2007

Note: Figure II depicts global renewable energy consumption from all available sources.

Forecasts indicate that the trend toward distributed energy including fuel cells is increasing. The so called "grid" is and will for a very long time remain the primary source of electricity but distributed generation is on the forefront of technological development and deployment, and appears to offer the best opportunity to use renewable energy sources.

Some of the reasons appear to be quite clear: 1. Distributed generation provides a powerful backup or primary system where reliability is essential as with hospitals, and necessary public services as with police stations and prisons, 2. Distributed generation embraces newer technologies, in many cases, such as hydrogen and fuel cell technology that can virtually eliminate green house emissions, 3. Distributed generation can be deployed in relatively small stations that take up very little land and thereby make power generation possible in constrained areas such as inner cities, 4. No or reduced use of transmission or distribution lines are required which use significant amounts of scarce land resources especially in urban areas, and 5. Distributed generation utilizes the heat produced in electric generation to provide a more efficient use of scarce resources. The growth of distributed power increased steadily, eight fold, from 1990 to 2005 (25).

2. Connecticut Market

Many firms have and will continue to eye the Connecticut market as the source needed to grow their fuel cell businesses throughout the U.S. and the rest of the world. Connecticut state government has a unique opportunity to provide the seed money necessary to not only jump-start the industry but begin the process of developing a long term, mature, labor-intensive industry.

Connecticut is uniquely positioned to benefit from stationary fuel cell deployment. While it is impossible to estimate exactly where the market will go, it is known that government and private firms will invest where firms sense profit and government perceives societal benefits. Studies referenced at the end of this paper show numerous accounts of private investment and government spending in support of hydrogen and the fuel cell industry (2, 3, 8, 10, 11, 12, 21, 23 and 25). An explosion in private and public investment in the fuel cell industry underscores what research has indicated, a growing hydrogen industry serving our growing energy needs in an environmental friendly way.

Connecticut has an extensive set of incentives for renewable energy, including: 1. Property tax exemptions, 2. Sales tax exemptions, 3. State grant programs, 4. State loan programs, 5. State rebate programs, and 6. Alternative fuel and vehicle incentives (10, 20).

Distributed generation with fuel cells today only accounts for about 1/10th of 1% of world energy output with less than 1,000 operating fuel cells worldwide (2). If fuel cells and hydrogen generation accounted for around 7-8% of new power, it could generate about $30 billion in sales worldwide and about $4 billion are sales per year for Connecticut alone (2, 13). (Potential income based upon Connecticut currently having about 13% of the fuel cell workforce and two of the largest manufacturers of fuel cells in the world (UTC Power and FuelCell Energy, Inc. (2, 13)).

If Connecticut companies capture the majority of the business and fuel cell production continues on its current growth path, Connecticut companies could benefit over the next 5-10 years with over $20-$30 billion in new business (estimates based on EIA estimates of world production) (2, 13).

Connecticut would benefit in many ways from hydrogen and fuel cell distributed electric power generation. According to the ISO-New England, Connecticut summer peak electric demand is projected to grow from 7,320 MW in 2007 to 8,475 by 2016. This 1,150 MW projected growth from 2007 to 2016 may likely materialize even with successful conservation.[31] Distributive generation could not only help fill this void but also help meet Connecticut legislative requirements for renewable electric power. Connecticut legislation requires that in ten years, "on and after January 1, 2018, not less than seventeen percent of the total output or services of any such supplier or distribution company shall be generated from Class I renewable energy sources and an additional three per cent of the total output or services shall be from Class I or Class II renewable energy sources".[32] Consequently, the State of Connecticut has required that in ten years approximately 780 MWs of Class I electric generating capacity would need to be developed in order to satisfy the requirements on the legislation, based on a capacity factor of 93%. This would mean that on average, additional Class I capacity of at least 78 MW per year over the next ten years would need to be developed.

[31] Connecticut Siting Council, Draft Report: Review of the Ten-Year Forecast of Connecticut Electric Loads and Resources; June 6, 2007.
[32] Connecticut General Assembly, Public Act 07-242.

It is extremely unlikely, based on the availability of renewable resources and the efficiency of existing technologies, that solar, thermal, photovoltaic, wind, biomass, small hydroelectric, tidal energy, wave energy, and ocean thermal energy alone could not accomplish the legislative goals without at least an additional 40 MW of fuel cell capacity per year over the next ten years. Electric and thermal energy would be exceptionally beneficial in southwest Connecticut where concentrated generation in limited land areas with little or no pollution is needed.

3. Connecticut Employment in the Fuel Cell and Hydrogen Industry

The best indicator of a market for stationary hydrogen fuel cells is the level of private investment. Private investors only invest when they perceive the potential for earnings, according to Jonathan Berk and Peter Demarzo (39, page 178) and Connecticut manufacturers, with hundreds of millions in investment in hydrogen fuel cells, see potential (7).

It is estimated that approximately 13% of global fuel cell manufacturing resources (labor and capital) resides in Connecticut. The key players in the Connecticut fuel cell and hydrogen industry include Avālence LLC in Milford, Fuel Cell Energy, Inc. in Danbury and Torrington, GenCell Corp. in Southbury, Infinity Fuel Cell and Hydrogen, Inc. in Suffield, Distributed Energy Systems in Wallingford, and UTC Power in South Windsor. These manufacturers together now employ nearly 930 people according to the Connecticut Hydrogen-Fuel Cell Coalition in 2007 (7). These companies all see a future market for their products and services.

4. Making Stationary Fuel Cell Capital Cost Effective

Proprietary industry estimates reported the cost of capital to produce electric distributed energy in 1997 to be around $20,000 per kW; however, that has dropped to an estimated $3,200 per kW today (14). This seems to suggest that as more and more fuel cells are deployed, capital costs will continue to decline for distributed generation. Proprietary studies project most of the distributed energy market will be in the range of 1 to 2 MW or less because most buildings require distributed generation with a capacity less than 500 kW. Estimates range from $2,000/kW or less for units with ratings from 200 kW to 2.5 MW out to 2008 and beyond (Note; numbers based on interviews with leading researchers by the investigator). When fuel cell unit production increases to over 1,000 MW in annual Connecticut volume, estimates bring the production cost per kW down as low in a goal of $400 per kW in the DOE National Energy Technology Laboratory for solid oxide fuel cells in the future (see these estimated at the following website: www.netl.doe.gov/technologies/coalpower/fuelcells/seca.html). Furthermore, the US Department of Energy has long-term goals that are even lower (see 31 for testimony by DOE researchers estimating goals even lower per kW).

Research studies reviewed (see reference section) state that current fuel cell capital costs greatly exceed the cost of competing generating technologies. While it is difficult, at the very least, to calculate exactly what the traditional capital equipment costs are, it is even more difficult to estimate future capital costs of fuel cells and hydrogen generation equipment. Recently (***New York Times***, July 10, 2007) in an article by Mathew Wald it was stated that " .

. . standard industry metric, dollars per kilowatt capacity (is) in a huge range from $2,000 to $3,000 (per kW)." (38) Other studies, including those presented in 2007 to the US Department of Energy, estimate the costs of conventional distributed energy capital costs around $1,400 per kW today. If the capital to produce energy in traditional distributed electric generating equipment is about $1,400 per kW today, and researchers estimate the capital cost of fuel cells to be about $3,200 per kW, it would require approximately $1,800 in credits for fuel cells to compete with traditional electric generation based solely on initial capital costs. The Fuel Cell Financing Initiative (Baker and Adamson, ***Fuel Cell Today,*** 2 November 2005, p. 10) offers the suggestion of a $1,000/ kW as an offset. This study recommends an $800.00/kW offset as Connecticut power companies have the ability to get $1,000 per kW of more in additional production credits in current and future projected subsidy programs (see chart below) (20, 10).

Incentive Program	**Effect on Economics**	**Limitations**	**Value**
"Net Metering"	Values excess power exported to utility at avoided wholesale cost	Up to 2,000 kW	Exported energy valued at retail rate unless net energy is exported to the utility network in which case, the net energy exported is valued at the avoided whole sale cost. Demand charges still apply
Back up power charges	Eliminates demand charge if fuel cell outage occurs in Off-peak Periods	Only for off-peak outages	Avoids back up demand charges for some outages
Renewable Energy Certificates	Credit for environmental benefit of power delivered	Maximum is 5.5 cents per kWh based on penalty for failure to meet Renewable Portfolio Standards	Value determined by market. Has varied from $10 - $50 per megawatt hour (1 - 5 cents per kWh)
Distributed Generation Incentives through Connecticut Clean Energy Fund (CCEF)	Capital cost subsidy and subsidy for kWh delivered in Southwest Connecticut	Up to $4,700 per kW. Additional 1.5 cents per kWh in Southwest Connecticut. $4 million limit for an installation over its life cycle	Depends on CCEF evaluation of site-specific factors, including use of fuel cell heat. Amount of incentive will likely be less than $4500 per kW
Distributed Generation Incentive through DPUC	Capital cost subsidy	Only available if facility does not qualify for CCEF incentive. Limited to congestion charge avoidance	$200 - $500 per kW depending on site specific factors
Forward Capacity Market through ISO-New England	Monthly credit for power capacity	Fixed schedule through 2010, then defined by auction, 1 - 5 year contract	Currently $3.10 per kW per month. Depends on need, ISO-NE decision
Federal Income tax credit	Tax credit	Up to 30 percent of project cost or $1,000 per kW. Which ever is less? Efficiency must be 30% or higher.	Depends on legislation to extend beyond December 2008. Applies only to facilities owned by profit making entities.

Reference #20 and see http://www.ctcase.org/summaries/execum_railfuelcells_web.pdf

If $800.00 per kW was made available as a direct or production grant for a maximum of 40 MW per year in new production, the State would have to invest $32 million per year or $320 million over 10 years. (NOTE: It is estimated that on average at least 40 MW of renewable generation would be needed to comply with the Connecticut Renewable Portfolio Standards) (5). $800.00/kW or $32 million in direct or production grants for 40 MW would drive the industry to produce the most efficient level of output with current manufacturing techniques. With a constant infusion of $32 million each year, industry will become more efficient and benefit from economies of scale and average costs over time will fall per kW. Declines in unit costs will encourage industry to not only produce the needed 40 MW but also begin to produce more units in the succeeding years. For example, the industry may produce 42 MW in year two, 44 MW in year three, and over time make fuel cell manufacturing more and more cost effective. This action will not only drive Connecticut investment but also stimulate the whole market so that OEM will be encouraged to expand and invest.

Beyond the elimination of greenhouse gases and the benefit of silent and relatively small physical plants, the following direct economic benefit would flow to Connecticut. First, the current source of traditional electric generating equipment is outside the State of Connecticut. Connecticut now has a significant share of manufacturers to supply all the hydrogen generating equipment and fuel cells to the suppliers of distributed energy. The economic impact of spending $32 million in Connecticut investment dollars on $32 million of capital goods in Connecticut would drive economic growth alone even if there were no other benefits. Public investment normally is spent on services, which generally, have only one round of benefits. Capital spending, on the other hand, would have more than one round of benefits as investment leads to economic growth, including a gain in employment. The total spending on new equipment would include the $32 million from state investment; $40 million ($1,000 x 40 MW) in production credits and grants, and the manufacturers themselves would be spending the balance or $56 million (the same cost as traditional capital) for the new capital. All in all, the total capital outlay per year would be $128 million ($3,200/kW x 40 MW), most of which would be spent in Connecticut rather than in other states and countries. Traditionally about 26% of all industrial costs are attributed to labor (figure calculated from annual reports of the Fortune 500). At that rate about 554 direct new jobs would be created with a return based on salaries estimated to be $33.28 Million (calculated by multiplying .26 times total investment of 128 million per year from all sources, see Figure 5), which is more than the State investment. Furthermore, since these salaries would potentially be spent in Connecticut, they would create 2.31 times more jobs (based on conventional economic theory of multipliers from industrial employment) or 1,280 new permanent jobs. Even more jobs would be created when the industry began growing to meet the demands of new workers and industries.

Figure 5 (attached)

Note: Figure 5 shows spending on direct employment in the State, and capital and business investment in the State would be many times greater than State investment. This graph does not include any employment multipliers that would show even greater Connecticut job and business investment growth.

If this investment encouraged not only the subsidized production but also additional production that could be sold on the open market at a profit, the benefits would be much greater. If industry, over 10 years, can cut their costs to $2,000 per kW, and sell not only the 400 MW but also an additional 400 MW in the open market, $416 million would be generated in salaries and wages and $1.6 billion in capital outlays in Connecticut over the next ten years.

Figure 6 (attached)

Note: Figure 6 builds upon Figure 5 and depicts how investment by the State can lead toward innovation and market expansion in the industry that would drive economic growth and job creation even further.

Furthermore, the State's investment would be in people and manufacturing facilities, which drive economic growth. Any capital project, very conservatively, would more than double its economic impact on the State. This does not even take into account the benefits from improvements in manufacturing, and the savings in health care from a cleaner environment, as well as the jobs and income from the many years of purchases of spares and fuels to keep the plants going.

5. Producing Electric Power in Cost Effective Ways

While estimates of retail charges per kWh vary widely, it is an industry standard to accept the retail price per kWh in Connecticut to be somewhere between 15-20 cents. While today per kWh fuel cell power costs about 20 cent per kWh, increased production, reduction in maintenance costs, restack engineering and improved manufacturing costs, and reductions in capital and installation costs could cut the cost per kWh in half (31). Some researchers predict the cost of producing electricity from hydrogen to be about 6 cents per kWh over the next 5-10 years. That means a future with clean, quiet, reliable and cost effective electricity at prices even lower than we are paying now. The key appears to be to encourage the industry to mature, grow and begin enjoying the economies of scale other industries have in the past (14).

Beyond the kWh cost of retail electric power, which all of us must pay, other benefits can be measured using established and objective metrics to show other cost benefits to society in general and Connecticut in particular. In a report sponsored by industry, including some Connecticut manufacturers, to the California Air Resources Board in June 2007, the following was reported (25): fuel cells, as a renewable form of electric generation, have benefits they quantified as a benefit per kW hour consumed by the public. Because hydrogen is clean, there are health benefits in (see ***Build Up of Fuel Cell Value in California***, 2007)(25):

1. reduced disease and health care costs,

2. reduced CO2 emissions and other harmful green house gases,
3. new jobs,
4. less water usage,
5. the impacts of reduced societal dependence on fossil fuels as a hedge,
6. support and cost reduction of the overall electric grid,
7. avoidance of traditional fuel and generation costs,
8. avoided traditional generation transmission cost,
9. increased reliability, and
10. avoided maintenance and fixed operation costs,

all of which, were quantified. All in all, the savings in reductions or offsets in these specific externalities were estimated at between 6.6 cents per kWh to 19.6 cents per kWh when electricity is produced with fuel cells. The conclusion being, even if the cost of producing electricity with fuel cells is higher, the societal benefits will more than offset any increased price.

Even though it is at best difficult to estimate how the development of a mature hydrogen and fuel cell industry can lead to much, much more development. By looking at Figure I, one can easily see that the global market is in the trillions of US dollars. If Connecticut industries are able to reduce costs and begin implementing cost effective manufacturing procedures, the benefit could amount to 10s of billions of dollars worth of future business and with it thousands and thousands of new jobs.

Conclusion

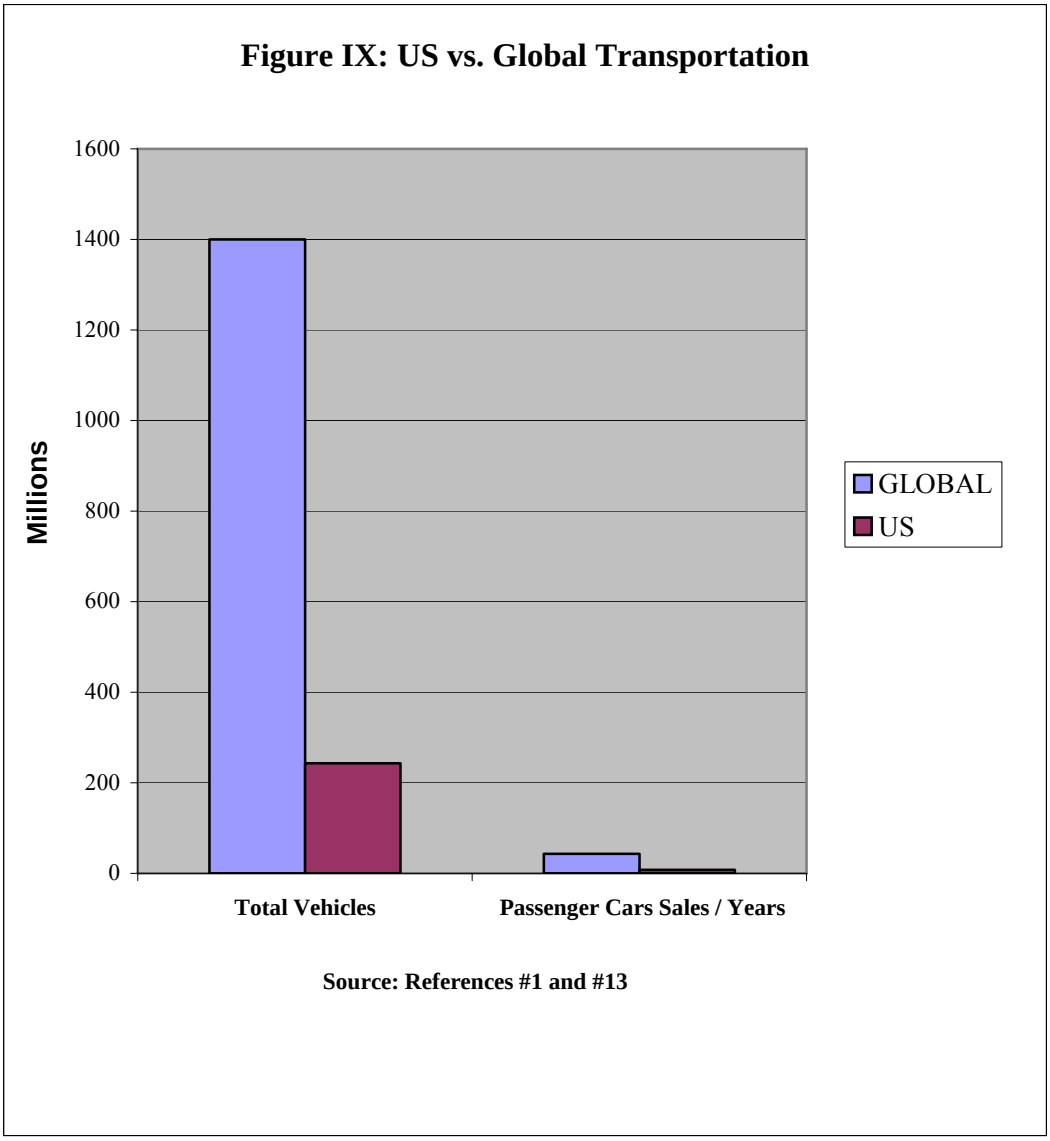
An investment by the State of Connecticut for capital or production grants to assist in the development and deployment of at least 40 MW of fuel cell capacity through existing hydrogen fuel cell technology in each of the next ten years, a total of $320 million (see Public Funding Model for Direct and Indirect Benefits)

.

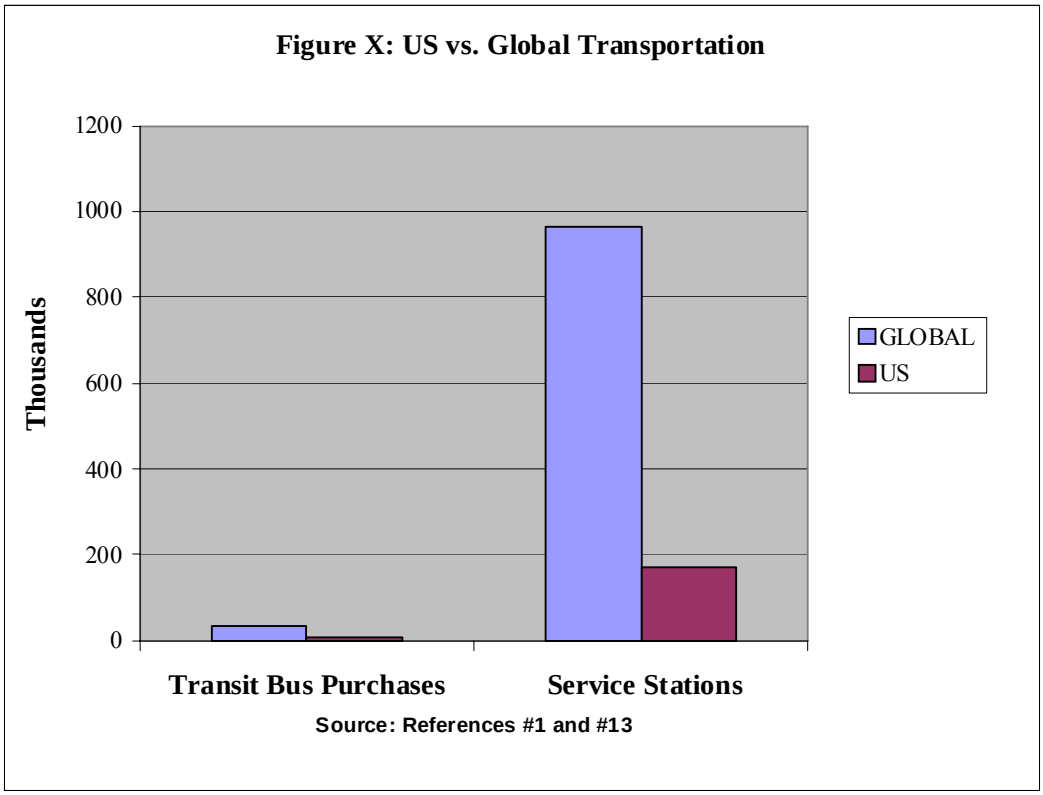
B. TRANSPORTATION

1. National Market

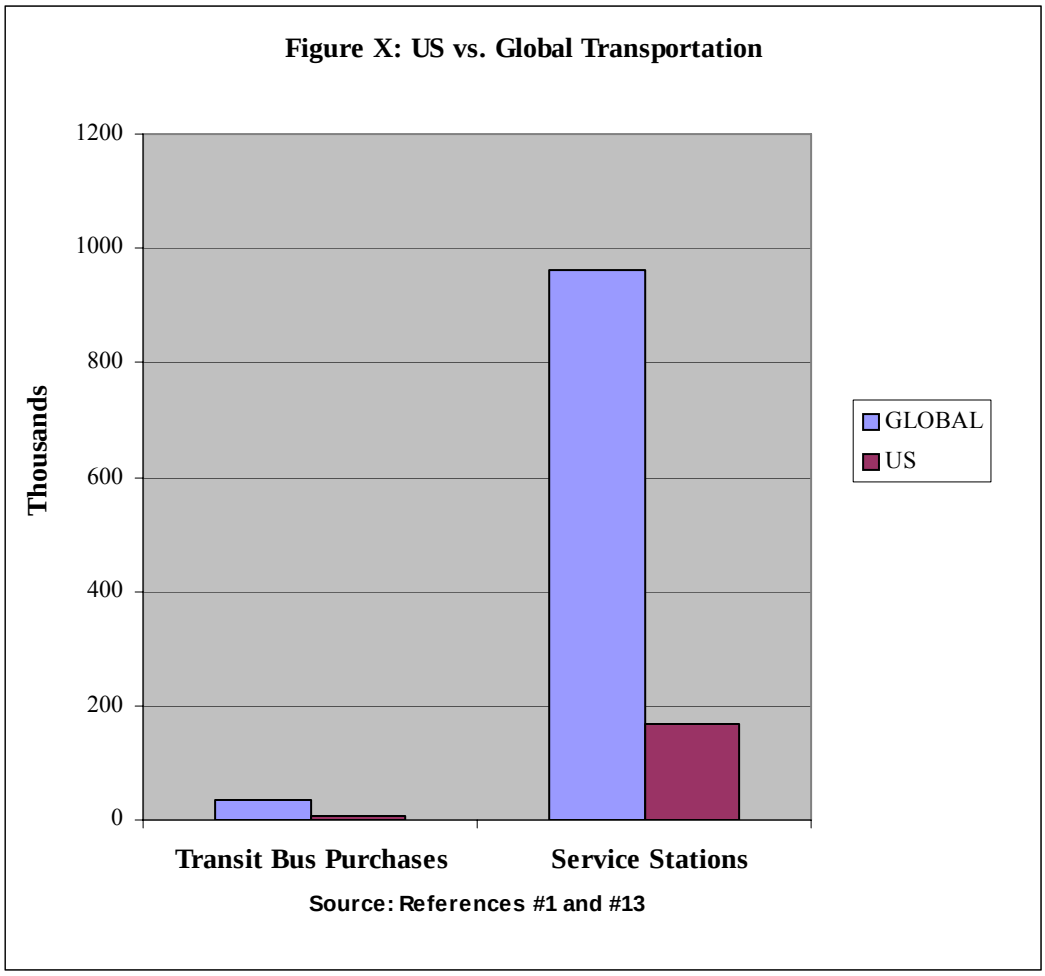
The national market in transportation is tremendous. Figures IX and X (1, 13) below show how massive the US market is but surprisingly only a small fraction of the global market. Not only is the market huge but also its dependence on foreign oil is excessive. Today the US imports more than 55% of the oil it consumes and if the US economy continues on the same trend line, oil consumption in the US should increase by more than 68% by 2025. Furthermore, a full 2/3rds of the approximately 20 million barrels of oil we use in the US each day is used for transportation. Our oil thirsty economy not only supports economic growth elsewhere but has been a major contributor to global pollution. Reducing our dependence on oil and improving environmental performance is a goal of our national and state government (1, 13).



In the United States today over 243 million vehicles are in use and worldwide about 1.4 billion (1, 13). The vehicles operating in the US include over 7.5 million new cars, 6.37 million trucks, 81 thousand buses of which 6,000 are new and to support all this we have in the US today about 169,000 service stations (1, 13).



Few will disagree with the proposition of substituting oil with a clean energy source such as hydrogen. While it is difficult at best to estimate the exact potential of hydrogen and fuel cell technology on the transportation industry, estimates abound from experts. One of the most interesting is by Barbara Sisson who suggests 10% of all transit bus purchases will be powered by hydrogen by 2010 (33). Shell Oil projects 50% of new automobile purchases to be fuel cell cars (all types of fuel cell applications including hybrids) by 2040 (4, p.25 #34). Many experts find these forecasts overly optimistic with only 5% of new car purchases by 2050 (20). Even if these and other studies are only half right, the market for fuel cells for transportation will be tremendous with a potential of billions for the citizens of Connecticut(21).



2. Connecticut Market

Connecticut has over 3 million vehicles in operation today (21, p.31). Automobiles make up a full 2/3rds of Connecticut vehicles in operation and the Connecticut vehicles are about 1.3% of the total US market. Connecticut Transit has a total of approximately 650 buses in operation across the state (21, Table 4-1).

Connecticut has a global leadership position in hydrogen and fuel cell research, development and manufacturing. UTC Power owns the technology for fuel cells for transit vehicles and automobiles. The current cost of a hydrogen-fueled fuel cell powered automobile, by all estimates, is well beyond a million dollars per unit even under the best of current manufacturing conditions based upon interviews with current engineers. The market potential, however, in fuel cell powered buses is quite different. The power plant for an automobile can only move a few passengers at a time but currently a fuel cell powered bus can carry 45 passengers (see www.chfcc.org/FuelCellBus/busspecs.asp). The power plant for hydrogen-fueled fuel cell buses is manufactured in Connecticut, but no diesel buses are currently manufactured in the State. Estimates by the Connecticut Department of Transportation suggest about 10% of the fleet or about 60 buses will be replaced each year (21).

As hydrogen-fueled fuel cell powered buses and automobiles become more available, there will be a related growth in hydrogen fueling stations and hydrogen operation and maintenance operations within Connecticut.

3. Making Hydrogen-Fueled Fuel Cell Buses Capital Cost Effective

Connecticut's bus transit systems receive a subsidy from the federal government equal to about 80% of the cost of a diesel-powered bus, according to experts at UTC Power. Figures published by the Connecticut Department of Transportation and from Connecticut industries suggest the current retail price of a diesel bus is about $250,000.00. At an 80% subsidy, the net cost to the transit system would be only $50,000 each. A hydrogen-fueled fuel cell bus, when produced in quantities of over 300 buses, has been estimated by Connecticut industries to cost about $750,000 to $1,000,000 each.

Added to the cost of each bus must be the additional life cycle costs beyond the cost of purchasing the new bus, including the cost of operation, maintenance and fuel for a traditional diesel bus including purchase price. Over its operational life, the life cycle cost of a traditional diesel bus has been estimated at about $1,045,000.00 per unit. All of the buses, and most, if not all parts, come from manufacturers outside the state. When one combines the purchase price of the hydrogen-fueled fuel cell powered bus together with life operation, maintenance and fuel, the total life cycle cost is estimated to be $1.607 million per bus or $562,000.00 more than the traditional diesel bus.

Externalities, related to cost, however must also be considered. Since the bus is a public good providing a public service, funding of a public good has effects on the costs of other public goods and services funded by the State. First of all, the hydrogen-fueled fuel cell powered bus is virtually pollution free, noise free, can be manufactured in Connecticut, and would be supplied a fuel that can also be produced in Connecticut. The cost of the hydrogen bus over its life cycle is $1.607 million, the federal subsidy would be $200,000, and the reduction in noise, pollution and improved health is estimated to be about $476 million over the life of the bus (Note: figures based on financial statistics were provided by interviews with experts in Connecticut). Other benefits for Connecticut include increased jobs from manufacturing the buses or bus components in Connecticut (28% of the cost of the hydrogen bus would be Connecticut labor) is estimated to be about $210,000, and increased jobs from producing and buying hydrogen fuel in the state (28% of the cost of fuel over the life of the bus) is estimated to be approximately $70,000. **The gross cost then for the hydrogen-fueled fuel cell powered bus over its lifetime would be $651,000.**

The diesel bus would cost $1,045,000 over its life cycle and the federal subsidy would be $200,000. **The gross cost of the diesel bus over its lifetime would be $845,000.**

When one takes into account not only capital costs but public good externalities and includes the impact of jobs in the state, the hydrogen bus has the advantage. To encourage this economic advantage the State should provide capital grants of $500,000.00 per bus to assist the State's transit authorities in its initial purchases. If 10% of all replacement buses were hydrogen-fueled fuel cell powered buses, it would cost $3 million per year over 10 years to build a fleet of 60 hydrogen buses or a total of $30 million. If each bus generated $280,000 in

new salaries, the 10-year production of 60 hydrogen buses would create $16.8 million in new Connecticut salaries. The benefits in job creation and elimination of externalities would far outweigh the expenditure by the State. The main externality would become the foundation of a vibrant hydrogen based industry in the state.

4. Deployment of the Hydrogen Bus [1]

Because hydrogen-fueled fuel cell powered buses have unique requirements such as hydrogen refueling infrastructure and bus maintenance, bus operation should be centralized. Like any other newer technology, from the first steamships to the most recent jet liner or hybrid car use, begin with limited, specialized customers. Everyone in Connecticut will benefit from clean, quiet transportation but to make it a financial success, it should be deployed first where it is needed most, in the most congested residential areas of the state such as central and southwest Connecticut and be deployed in HOV lanes during commuting times to maximize ridership and revenue potential. Like all new technologies' deployments, they could become more widespread over time and appeal to everyone.

The benefits to Connecticut would not only be reduced pollution, reduced traffic congestion, faster and quieter and more reliable transportation but a significant hedge against our national dependence on oil.

Conclusion

An investment by the State of Connecticut to assist the Connecticut Department of Transportation and transit districts in the State in purchasing 60 hydrogen-fueled fuel cell buses over the next ten years. The cost to the State would be $30 million (see Public Funding Model for Direct and Indirect Benefits).

1. The planned deployment of the hydrogen bus should be coordinated with what is going on in the Transportation Subcommittee headed up by Joe King. He has developed this scenario:

Step 1--now through 2010 with the recent order for 4 buses to be delivered in 2009 and Lee Grannis's bus, which is now under construction, there will be 6 fuel cell powered buses in CT, which are already funded by the Federal Government. **Existing fueling station at UTC**

Step 2--gets us to 2012, which is the FTA goal for meeting commercialization criteria--10 to 30 buses during period 2010 through 2012. **2 or 3 additional fueling stations of high capacity plus a few of lower capacity**

Step 3 Initial commercial deployment--aggregated purchases of 100 units by Connecticut, MA and NY over this period--one could assume the period goes from 2013 to 2018--CT should take a disproportionate share because of its OEM interest. Population total for these states is 29 million and CT is 12%. I suggest CT share be 30% or 30 buses. **Maybe 10 fueling stations**

Step 4 Commercial Deployment--CT should buy at least 6 to 12 hydrogen buses per year as its share of the 500 to be purchased nationwide. **30 stations by say 2020 and 200 in another 20 to 30 years.**

C. PORTABLE

1. National Market

Portable fuel cells have been reported in numerous studies to not only have a growing market but one that will continue to grow for many years to come. Widespread use of laptop computers, cell phones, iPods® and dozens of other mobile devices has created a large demand for portable power. Nickel based batteries or Li-ion batteries cannot alone satisfy current demand for energy density. Studies at the University of Connecticut (22) report a growth in energy requirements for portable power to jump about 20% per year and generate an average of $10 billion in sales (22). Larger and larger levels of energy output are continually being demanded. Not only is the demand for density and output in fuel cells increasing but consumers also want lighter fuel cells that are easier to recharge.

"The development of fuel cells is already a global industry. The greatest concentration of development is to be found in the United States, Canada, and Germany with the major contributors being UTC Fuel Cells and Ballard Power Systems," according to Trent Molter at the UCONN School of Engineering (22). Molter went on to say, "A prime example of how fuel cells can help revolutionize future technology can be found . . . a new military technology called Objective Force Warrior (OFW) . . . using fuel cells as a primary energy source." Other military uses include military vehicle power plants as well as mobile power generation (26).

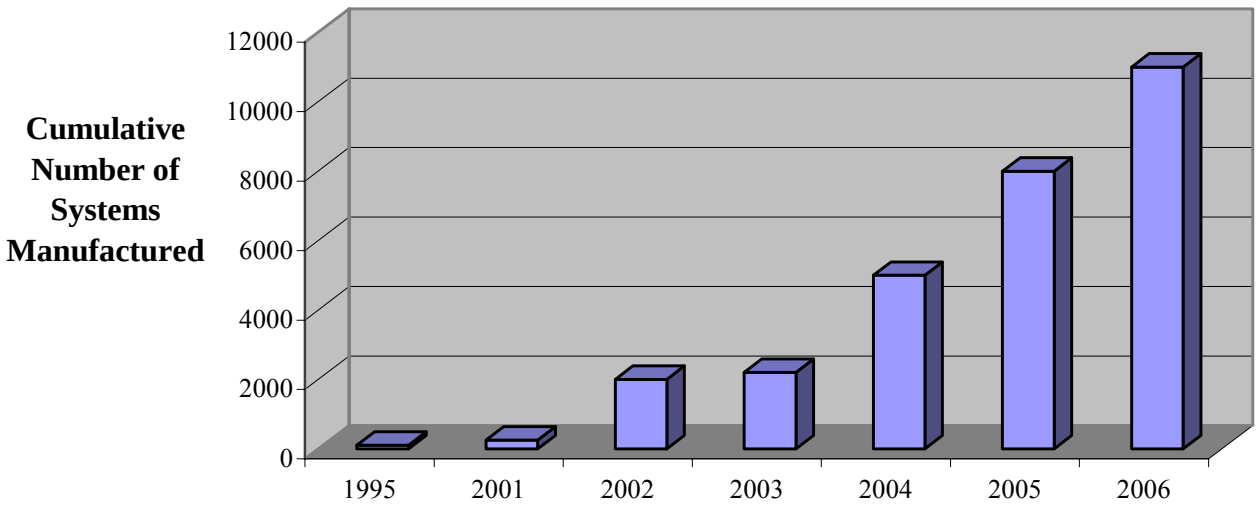
2. Connecticut Market

While significant research is underway in both universities like UCONN and private companies in Connecticut like UTC Power (see 27 for an exhaustive study of the portable market), Connecticut is not currently a major player in the manufacture of portable fuel cells. Estimation based on interviews of existing employers shows few people are currently employed in this industry in the state but the potential is great for increased job growth with the advent of newer technologies

3. Making New Portable Fuel Cell Technology Cost Effective

No specific manufacturing opportunity was found for the State of Connecticut to support advanced manufacture of portable fuel cells, and research and development dollars are needed to expand this market. Because of the types and kinds of new portable fuel cells (see Figure XI) and their application number in the thousands, money would be best spent on competitive bids for state research dollars.

Figure XI: Types of Portable Systems Manufactured Worldwide



Source: Reference #9, Page 4

Conclusion:
Investment by the State of Connecticut of $1 million to fund competitive research in portable fuel cell manufacturing in Connecticut (see Public Funding Model for Direct and Indirect Benefits).

D. RESEARCH AND DEVELOPMENT

1. National Research Dollars

At a recent DOE Hydrogen Program meeting (30, 31) in May of 2007 research dollars were being made available to push toward the goal of lower and lower capital costs from current capital cost range of $3,000 to $4,000/kW in Polymer Electrode Membranes (PEM) fuel cells, Membrane Electrode Assemblies (MEAs) and Stacks. DOE estimates with a 30% minimum applicant cost share, three awards or a total of $6 million will be available for projects lasting 3-4 years. For Novel MEA manufacturing with an applicant's cost share of 20%, DOE estimates funding of $8 million for up to two awards lasting 3-4 years or longer. For rapid MEA conditioning with an applicant's cost share of 30%, DOE estimates funding of $7 million for two awards lasting 3-4 years. For process modeling for fuel cell stacks with an applicant's cost share of 20%, DOE estimates funding up to $5 million for up to three awards lasting 2-3 years. For process and device for cost effective testing of stacks with an applicant's cost share of 30%, DOE estimates funding of $12 million for up to three awards for projects lasting 3-4 years. DOE wants to encourage on-board hydrogen storage systems improvements and manufacturing technologies to reduce the cost of high-pressure composite conformable tanks with an applicant's cost share of 30%. DOE estimates offering up to $10 million for up to two awards for such projects lasting 3-5 years. Hydrogen Freedom Car Initiative has DOE funding of over $100 million for 2007 alone (28, 29, 33). Even though

this effort is well received in the research community, funding for a national effort by these few grants is nowhere near enough (see table below).

TOPIC	Industry Cost Share %	DOE Funding (up to)	Number of Awards (up to)
1. Alternative Electrode Deposition Processes	30%	$6 Million	3
2. Novel MEA Manufacturing	20%	$8 Million	2
3. Rapid MEA Conditioning	30%	$7 Million	2
4. Process Modeling for Fuel Stacks	20%	$5 Million	3
5. Process and Device for Cost Effective Testing of Fuel Stacks	30%	$12 Million	3
6. Reducing the Cost of High Pressure Composite Conformable Tanks	30%	$10 Million	2
	Total	$48 Million	
	Freedom Car	$100 Million	

Source: Reference # 30.

States also have extensive R and D programs underway. Like California, Connecticut and New Jersey, many other states hope to encourage the ultimate manufacturing and employment in their state. While federal funding is available as the chart above shows, only a total of 15 grants for R and D will be made through the DOE.

2. Connecticut Research and Development

At the University of Connecticut significant research and development is underway at the Connecticut Global Fuel Cell Center. Between 1995 and 2006 Connecticut Innovations together with the State helped leverage the State's $65 million capital contribution into $133 million invested in Connecticut companies and technological initiatives in many areas including fuel cells and hydrogen (8, p. 3).

3. Large Hydrogen Electrolizer

One of the greatest challenges is producing hydrogen in large enough quantities in diverse locations to support many dispersed hydrogen fuel cell generators. These could be in cars, buses or possibly distributed stationary energy generators. A recent study by Moulthrop et al. in 2007 reports the need for larger commercialized PEM based hydrogen generators for energy and industrial applications (23). This paper presented at the National Hydrogen Association describes the markets and pathways for getting a much larger (100 to 500 kg/day) electrolizer of hydrogen. This is further supported in research reported by DOE (12). The industry appears to have the ability to produce 100 kg per day, but to fuel forklifts, buses, light duty vehicles and more than a few cars per day a larger electrolizer is needed (11).

Estimates are that a large electrolizer of 500 kg per day at 90% capacity could support 4 cents per kWh of power (11).

Conclusion

An investment by the state of Connecticut of $960,000 to $1,440,000 for research and development funding would be used to leverage federal R&D investment valued at approximately $4.8 million (assumption based upon Federal research dollars of $48 million available at 20-30% cost share. If Connecticut gets 10% of the grants or $4.8 million, then the cost share would be between $960,000 (20%) and $1,440,000 (30%). (See Public Funding Model for Direct and Indirect Benefits)

III. SUMMARY

Based on extensive research and the review of the most current literature the following advice is offered to assist Connecticut in the economic development of the new and emerging hydrogen and fuel cell businesses.

A. The Most Appropriate Level of Public Investment (cost) and the Potential Return on Investment (benefit):

(1) Stationary –

Cost --$800/kW in capital grants for up to 40MW of additional new production of electric power from stationary distributed hydrogen fuel cells in each of the next 10 years. Total grant $32,000,000 per year for 10 years.

Direct Benefits -- $128 million in new capital spending in Connecticut per year, an initial estimated 554 new jobs in Connecticut paying an estimated $33.28 million in salaries. They also include a significant reduction in greenhouse gases, greater dependability and reduction in noise as well as meeting the state mandates on renewables. Indirect Benefits follow in Public Funding Model.

(2) Transportation –

Cost -- $500,000 per hydrogen fuel cell bus delivered for up to 6 buses per year in each of the next 10 years or a total of 60. This would replace 1 out of 10 replacement buses and cost $3,000,000 in each of the next 10 years or a total of $30,000,000.

Direct Benefits – An investment of $60 million in buses of which about $16,800,000 in new Connecticut salaries and wages or about 336 new jobs which would last for 10 years. More jobs would be added if profitable sales begin to grow. A reduction in the public cost including externalities from $845,000.00 to $651,000.00 or a savings of $194,000 per bus over the buses' life cycle including all estimated externalities, maintenance, operation fuel and capital cost. Other Indirect Benefits to follow in Public Financing Model.

(3) Portable –

Cost -- $1,000,000 in research grants with a 30% cost share to develop and deploy in Connecticut portable fuel cells with current and future technologies. Develop procedures and guidelines on what and who get funded from among literally thousands of possibilities.

Direct Benefit – $1,300,000 spent in research and development to further both economic and environmental state goals to become the world's leader in fuel cell technology. Indirect benefits to follow in Public Financing Model.

(4) Research and Development –

Cost -- $960,000 to $1,440,000 in State grants with a 20% to 30% cost share to provide cost sharing to get up to 10% of available Federal grants equal to $4.6 million.

Benefit-- $4.6 million in direct benefits plus Indirect Benefits to follow in Public Finance Model.

IV. CONCLUSION

Literally hundreds of researchers around the world have lent their expertise to give advice on how states can support the emerging fuel cell business in stationary, transportation and in making portable power. Nearly everyone is in agreement that like any other new technology, the assistance of government is necessary to get progress.

The state of Connecticut is in a unique position to support its great concentration of government, academic, and commercial interests in this field, which estimates say include some 13% of world resources. Connecticut is in the position to nurture this industry and possibly become the "silicon valley" of the fuel cell world. Connecticut could become a leader in quiet, clean, efficient energy and lead the way to reduce our dependence on foreign crude oil. This report recommends a conservative amount of investment to advance each of the primary fuel cell areas. With distributed hydrogen and electric generation, more and more hydrogen powered buses and with more numerous potential fueling stations, Connecticut may begin to have the infrastructure for this industry to grow.

All experts seem to agree that what it will take to make this industry self-sustaining over the next 10-20 years is the ability to produce hydrogen and fuel cells at a capacity and with lower costs to sustain its success against competitive forces. At the moment dirty, environmentally unsound energy sources are much less expensive but with increased capacity most agree that fuel cells will not only outperform traditional power sources but also do it at a less expensive price.

This study offered the most appropriate level of public investment given what resources and technologies are available. It makes a prediction that if these relatively modest investments are made, the hydrogen economy in Connecticut may begin to mature and become poised for long-term growth. This industry offers great potential for not only near- term but also long-term job growth throughout the state.

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Figure 5

State Direct Grants for Hydrogen Fuel Cells
Versus Total Capital Spending in Connecticut over 10 Years

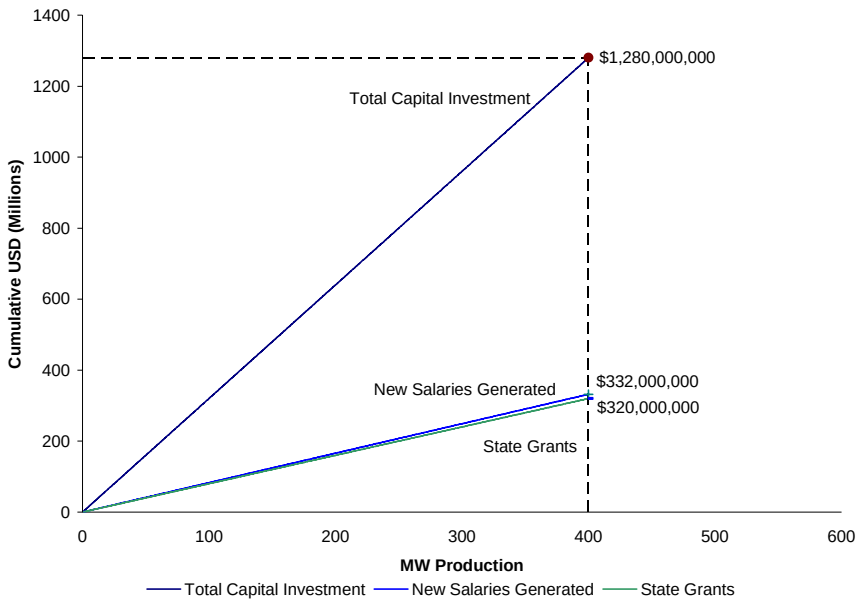
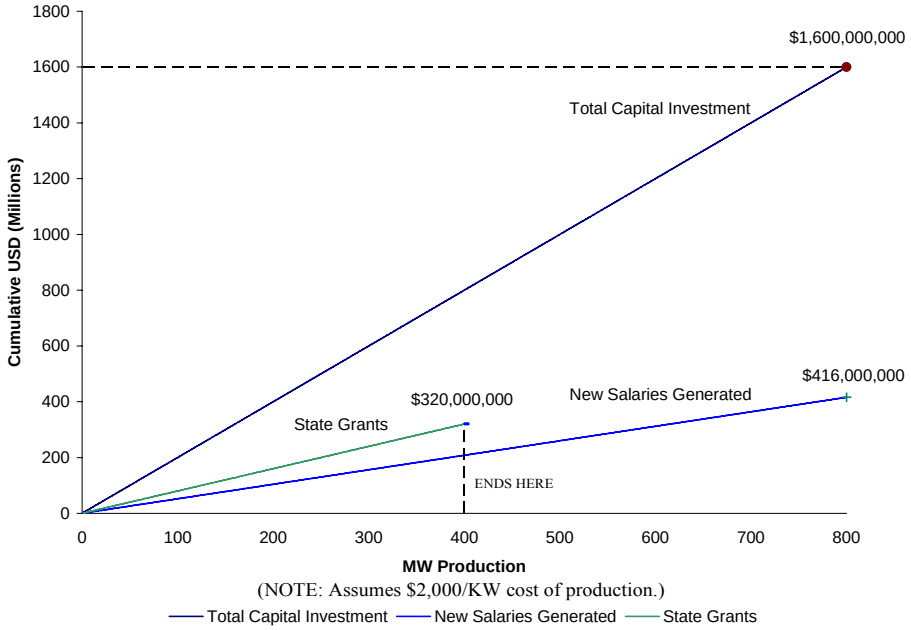


Figure 6

State Direct Grants for Hydrogen Fuel Cells
Versus Total Capital Spending in Connecticut over 10 Years



(NOTE: Assumes $2,000/KW cost of production.)

Appendix I - High Value Opportunities for Fuel Cell & Hydrogen Applications

As an exercise to identify the technical potential and strategic targets for Connecticut, Connecticut Center for Advanced Technology (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 sulfer dioxide (SO_2), nitrogen oxides (NOx), and volatile organic compounds (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 Energy Information Administration's (EIA) 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.[33] These commercial buildings with potentially high electricity consumption may have high and potentially advantageous load factors for the favorable application of combined heat and power (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.[34] The Connecticut State Department of Education reports that there are approximately 383[35] 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.[36] In addition, there are 50 colleges and universities in Connecticut, including 22 public institutions and 28 private institutions.[37] There is currently a fuel cell installed at the South

[33]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
[34] Energy Information Administration, Description of CBECS Building Types; http://www.eia.doe.gov/emeu/cbecs/building_types.html
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[37] Connecticut Department of Higher Education, "Fall 2006 College and University Headcount in Connecticut", November 2006; http://www.ctdhe.org/info/pdfs/2006/2006Enrollment.pdf

Windsor High School and Yale University.[38] The fuel cells installed at the Connecticut Global Fuel Cell Center at the University of Connecticut (Storrs) are primarily laboratory sized units for testing and evaluation.[39] (See Appendix I - 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.[40] There are over 3,000 businesses in Connecticut that may be engaged in the retail sale of food,[41] including 817 food stores that have obtained a grocery store beer permit for the retail sale of beer.[42] 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 I - 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

[38] Connecticut Clean Energy Fund
[39] Connecticut Global Fuel Cell Center
[40] Energy Information Administration, Description of CBECS Building Types; http://www.eia.doe.gov/emeu/cbecs/building_types.html
[41] Proprietary market data
[42] Connecticut Department of Consumer Protection, Liquor Control Division

were powered by current fuel cell technology, approximately 12 units could be deployed for a total capacity of between 2.4 and 3 MW.

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.[43] There are over 6,400 businesses in Connecticut that may be classified as food service establishments.[44] 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 I - 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 impatient care, including hospitals and inpatient rehabilitation facilities, but not including convalescent homes and skilled nursing facilities.[45] CCAT has identified approximately 99 inpatient healthcare facilities in Connecticut.[46]

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[43] Energy Information Administration, Description of CBECS Building Types; http://www.eia.doe.gov/emeu/cbecs/building_types.html
[44] Proprietary market data
[45] Energy Information Administration, Description of CBECS Building Types; http://www.eia.doe.gov/emeu/cbecs/building_types.html
[46] Connecticut Department of Public Health, Facilities Licensing & Investigations Section

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 I - Figure 4: Inpatient Healthcare)

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.[47] There are approximately 690 businesses in Connecticut that may be classified as lodging establishments.[48] 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.[49] There are currently no fuel cells installed at lodging establishments in Connecticut. (See Appendix I - 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

[47] Energy Information Administration, Description of CBECS Building Types; http://www.eia.doe.gov/emeu/cbecs/building_types.html
[48] Proprietary market data
[49] Connecticut Department of Public Health, Facilities Licensing & Investigations Section

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 that may be classified as public order and safety.[50] 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.[51] There are currently no fuel cells installed at pubic order and safety facilities in Connecticut.[52] (Appendix I - 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

[50] Proprietary market data
[51] 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
[52] Connecticut Clean Energy Fund

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.[53]

Appendix I 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)[54]	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
Total:		**1,997**		**139**	**53 - 67**

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.[55] Energy intensive industries with high electricity consumption have also been identified as potential locations for on-site generation

[53] EIA, "Electricity Generation Capability", 1999 CBECS; http://www.eia.doe.gov/emeu/cbecs/pba99/comparegener.html
[54] EIA, CBECS: Table 14. Electricity Consumption and Expenditures for Non-Mall Buildings, 2003
[55] EIA, http://www.eia.doe.gov/emeu/mecs/iab/index5e.html

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 intensive industry sites that are included in these seven industry classifications in Connecticut.[56] (See Appendix I - 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.[57] (See Appendix I - 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.

[56] Connecticut Clean Energy Fund
[57] UTC Press Release March 20, 2002; http://www.utc.com/press/releases/2002-03-20.htm

Telecommunications Facilities with Potential for Onsite Generation

There are approximately 1,475 wireless telecommunications sites in Connecticut.[58] CCAT has identified 59 wireless telecommunications sites owned or operated by the State of 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.[59] (See Appendix I - 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.[60] 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

[58] Connecticut Siting Council
[59] Connecticut Clean Energy Fund
[60] Connecticut Department of Environmental Protection

treatment plants in Fairfield and New Haven, Connecticut. (See Appendix I - 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. 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

There are approximately 1,500 retail transportation fuel stations in Connecticut.[61] 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.[62] There are no publicly accessible transportation fueling stations in Connecticut that provide hydrogen for alternative fuel vehicles. However, UTC power in South Windsor Connecticut has developed hydrogen refueling infrastructure to fuel the hydrogen powered fuel cell bus that is operated by CTTRANSIT. (See Appendix I - Figure 11: Alternative Fuel Station Locations)

State Fuel Dispensing Stations

There are approximately 150 fuel dispensing stations operated by the State,[63] including 70 operated by the Connecticut Department of Transportation.[64] In addition, the Connecticut

[61] Connecticut Department of Consumer Protection, Food and Standards Division
[62] Alternative Fuels Data Center; http://www.eere.energy.gov/afdc/infrastructure/locator.html
[63] Connecticut Department of Environmental Protection, Bureau of Materials Management and Compliance Assurance Emergency Response and Spill Prevention Division Site Assessment and Support Unit

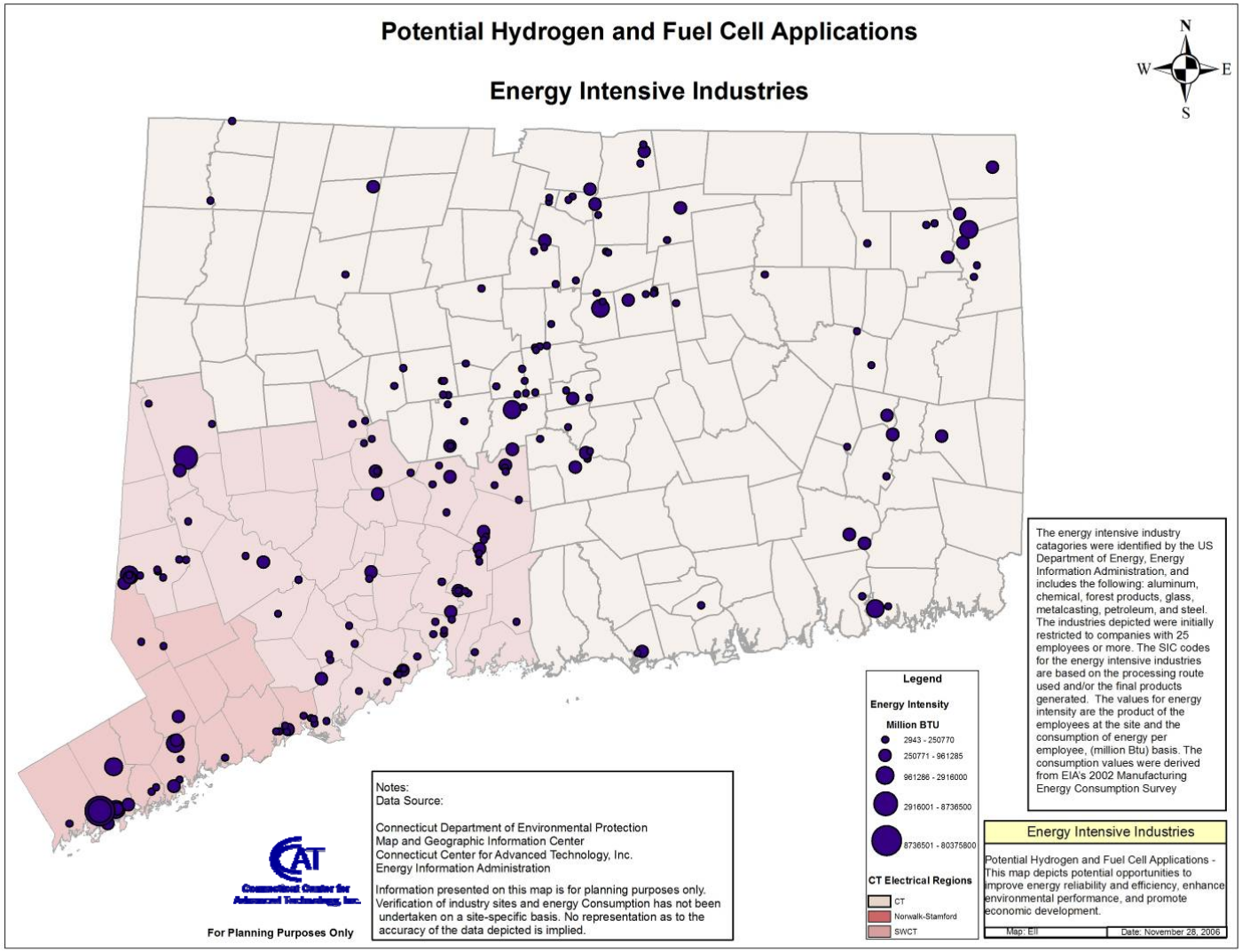
Department of Transportation operates eight sites that provide alternative fuels, including six sites that dispense bio-diesel and two sites that dispense E85 – Ethanol.[65] (See Appendix I - Figure 12: State Fuel Dispensing Locations)

Fleet Vehicle and Transit District Locations

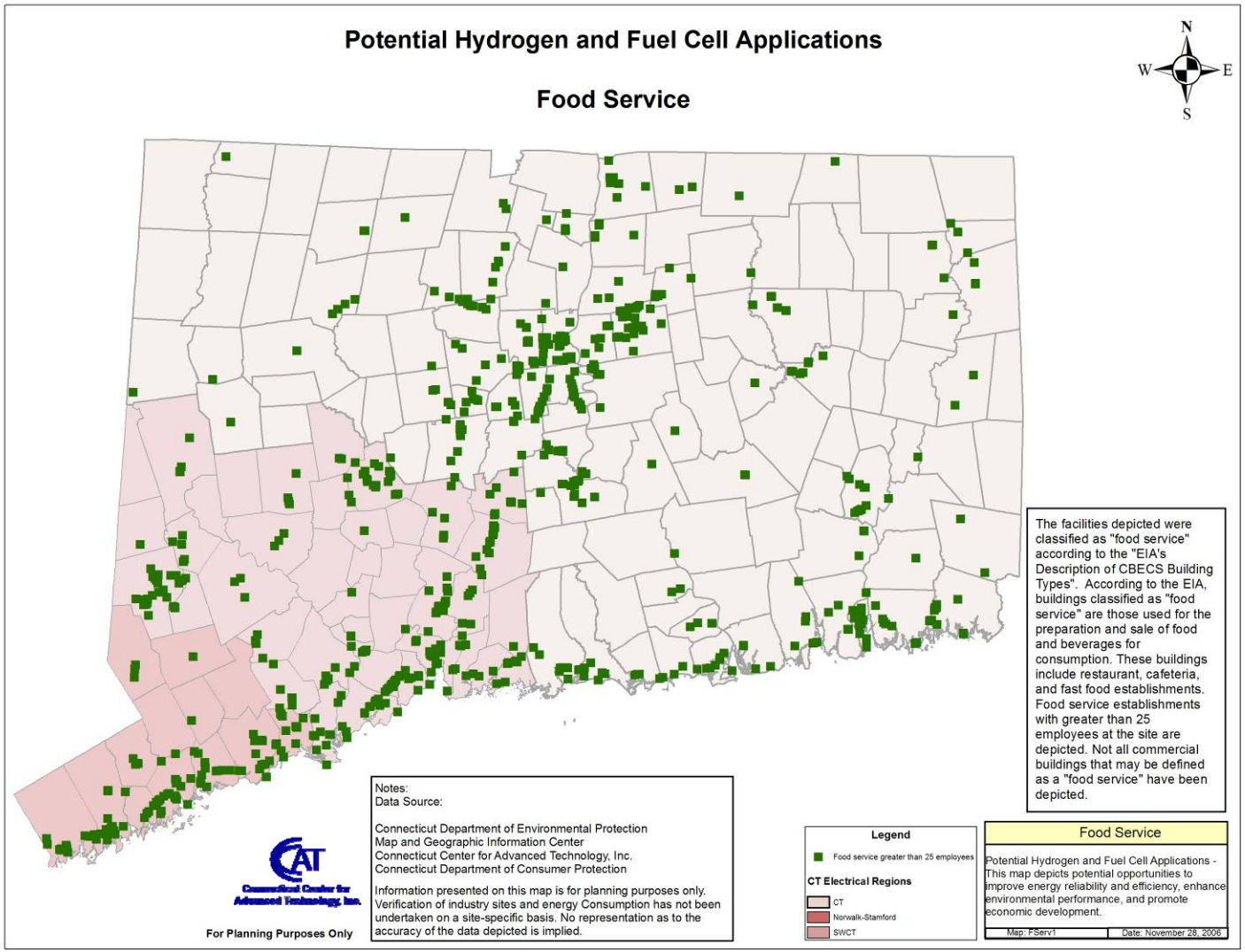
There are approximately 237 locations of vehicle fleets, which have more than 100 vehicles classified as non-leasing and 13 transit districts in Connecticut that provide local, coordinated public transportation in the area they serve. The Connecticut Department of Transportation operates CTTRANSIT, the state owned bus service and the largest transit operation in Connecticut. CTTRANSIT Hartford operates a hydrogen powered fuel cell bus in the Hartford area. These transit and fleet vehicle locations could be served by hydrogen or hydrogen mixture refueling stations located near Connecticut's major highways. The potential hydrogen refueling stations in/near Hartford and Hamden would support existing and planned fuel cell and hydrogen powered bus projects. (See Appendix I - Figure 13: Transit Districts and Fleet Vehicle Location

[64] CASE Report – "Preparing for the Hydrogen Economy: Transportation", June 2006, p. 34
[65] Connecticut Department of Transportation, Fuel Station Listing, October 26, 2006

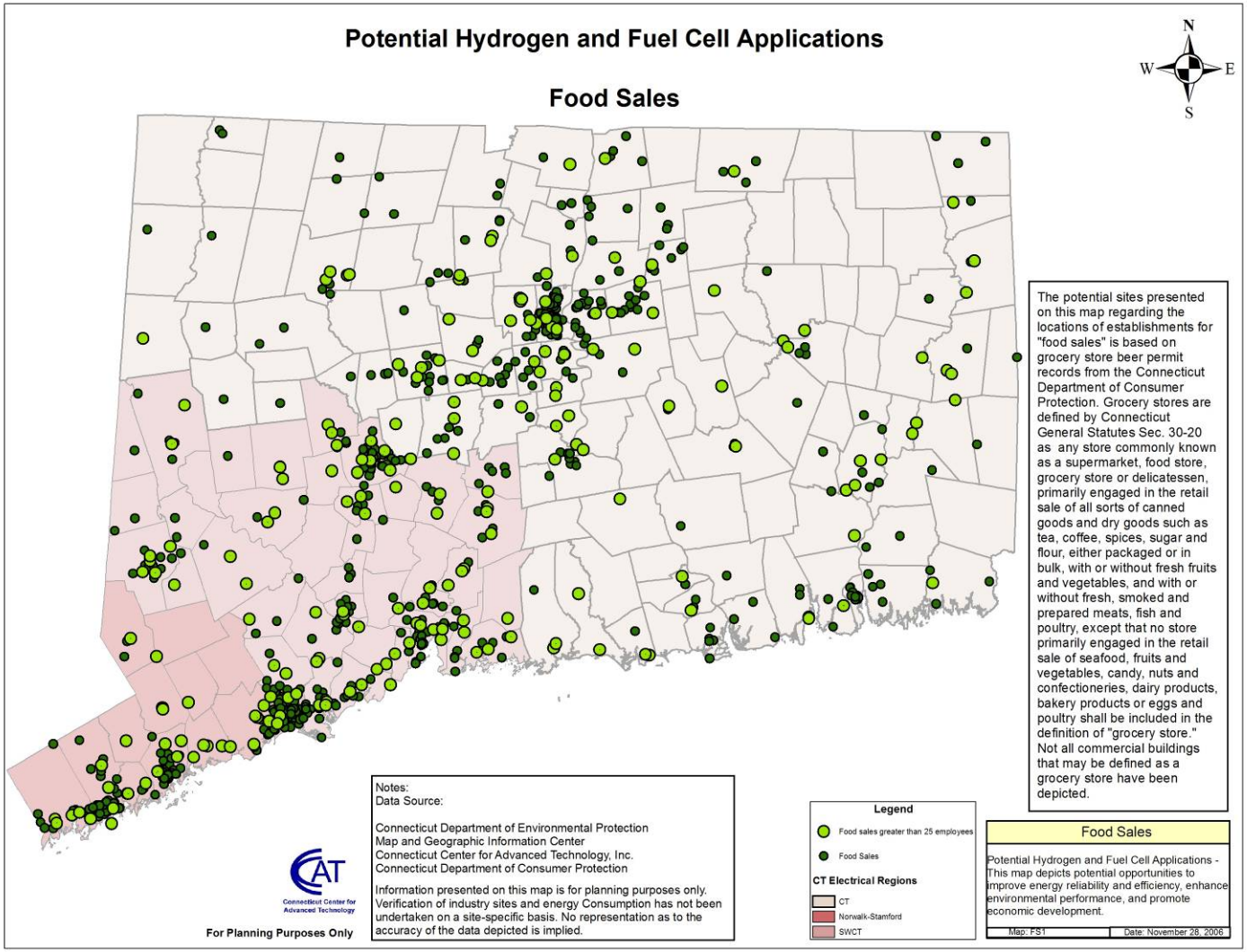
Appendix I - Figure 1: Energy Intensive Industries



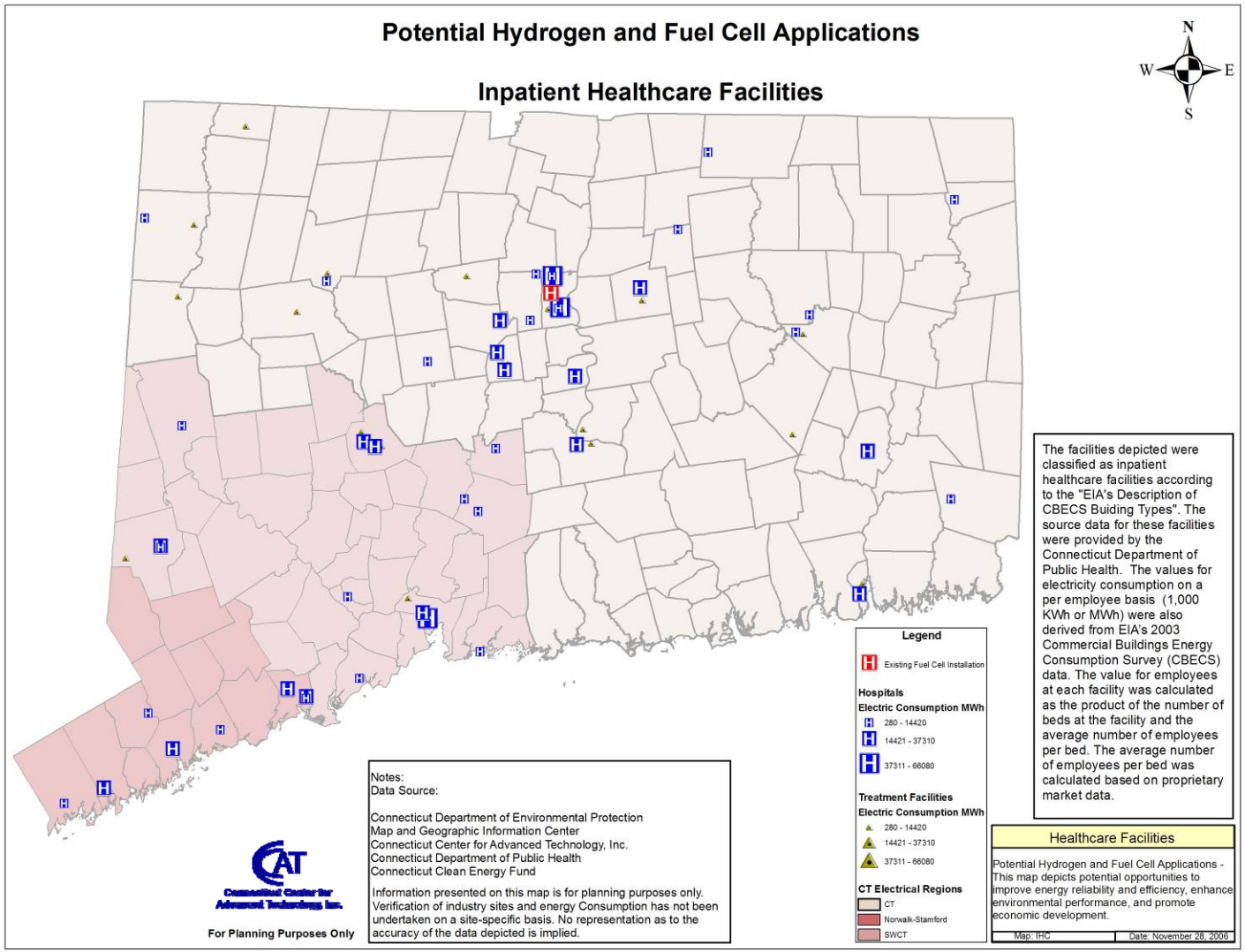
Appendix I - Figure 2: Food Service



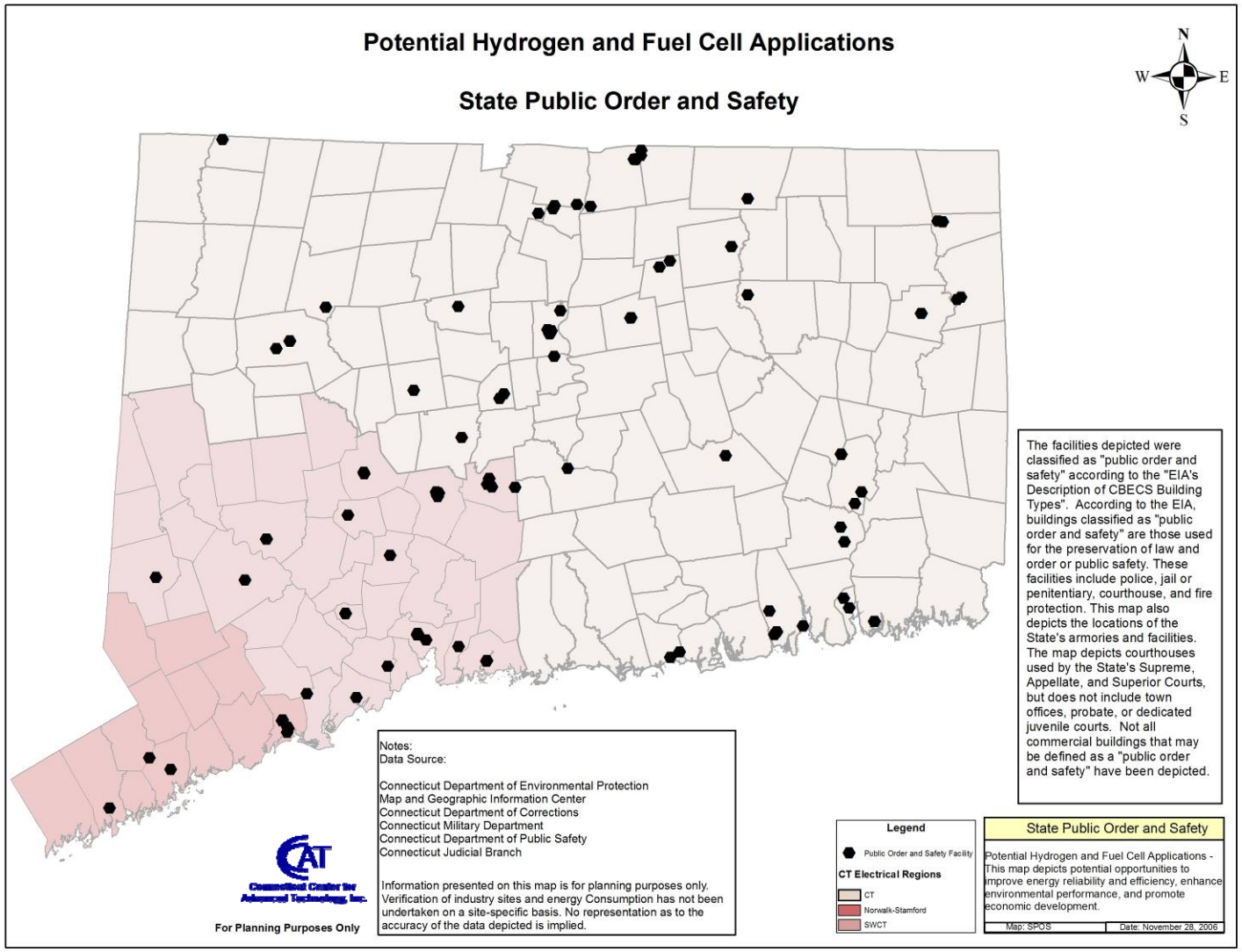
Appendix I - Figure 3: Food Sales



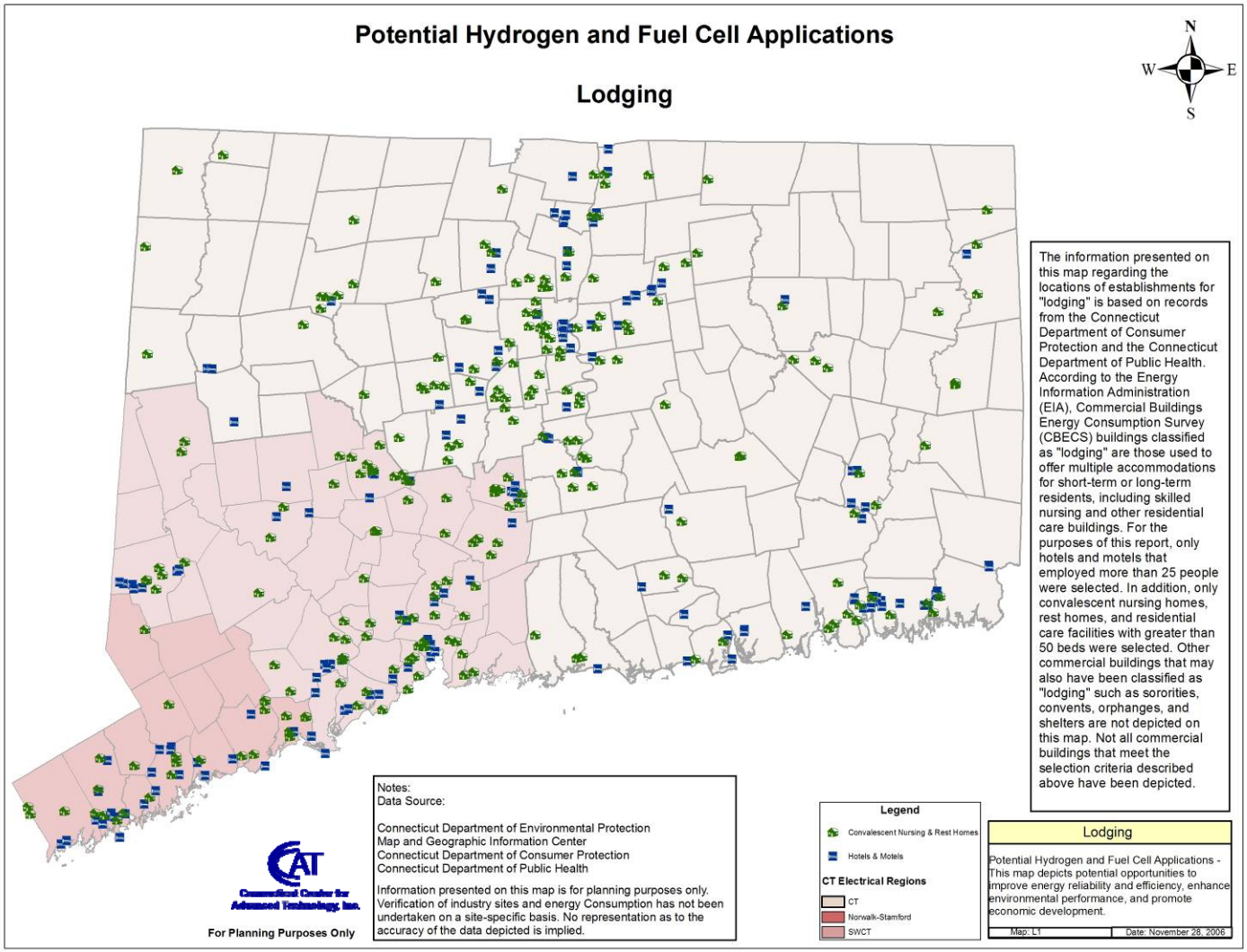
Appendix I - Figure 4: Inpatient Healthcare



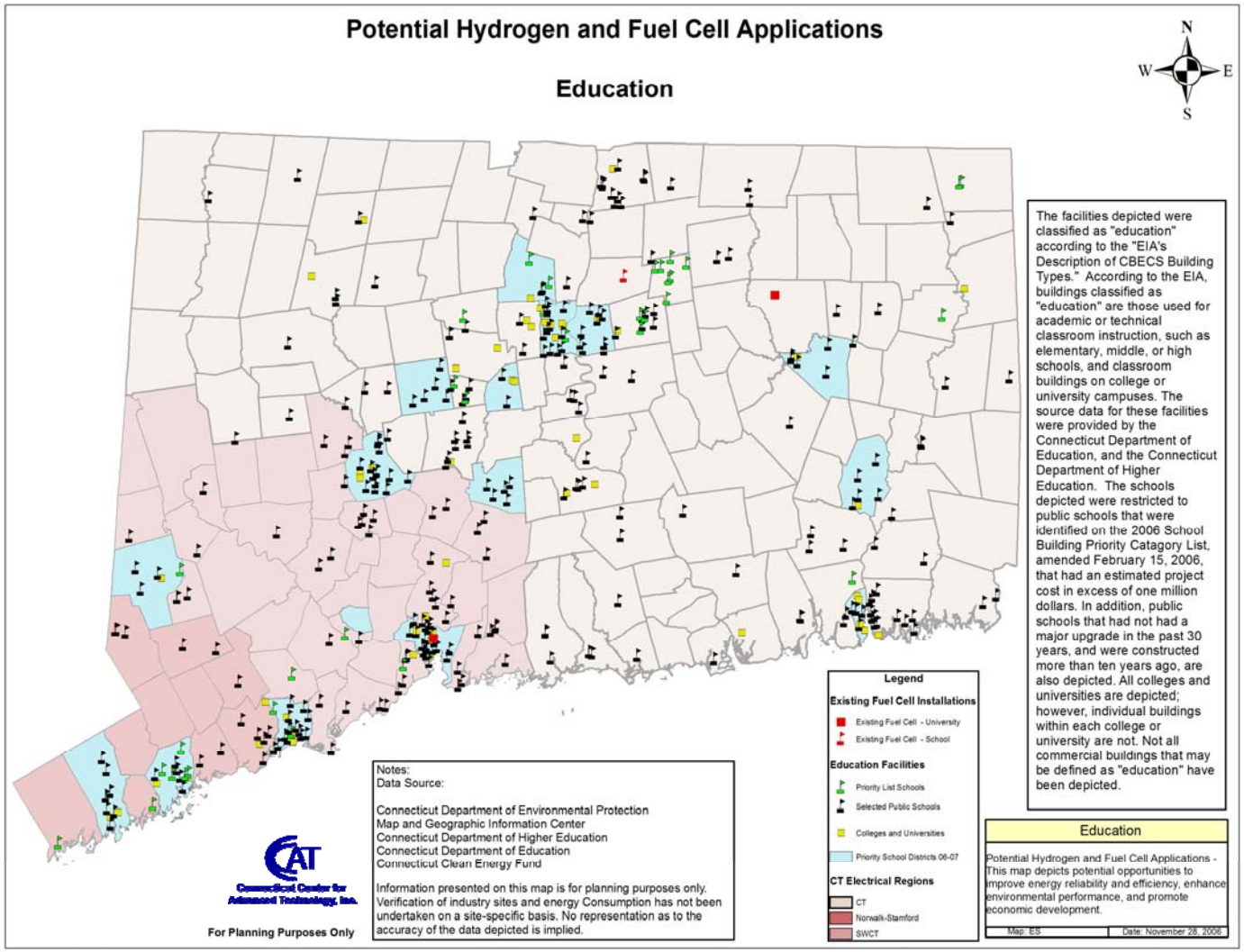
Appendix I - Figure 5: State Public Order and Safety



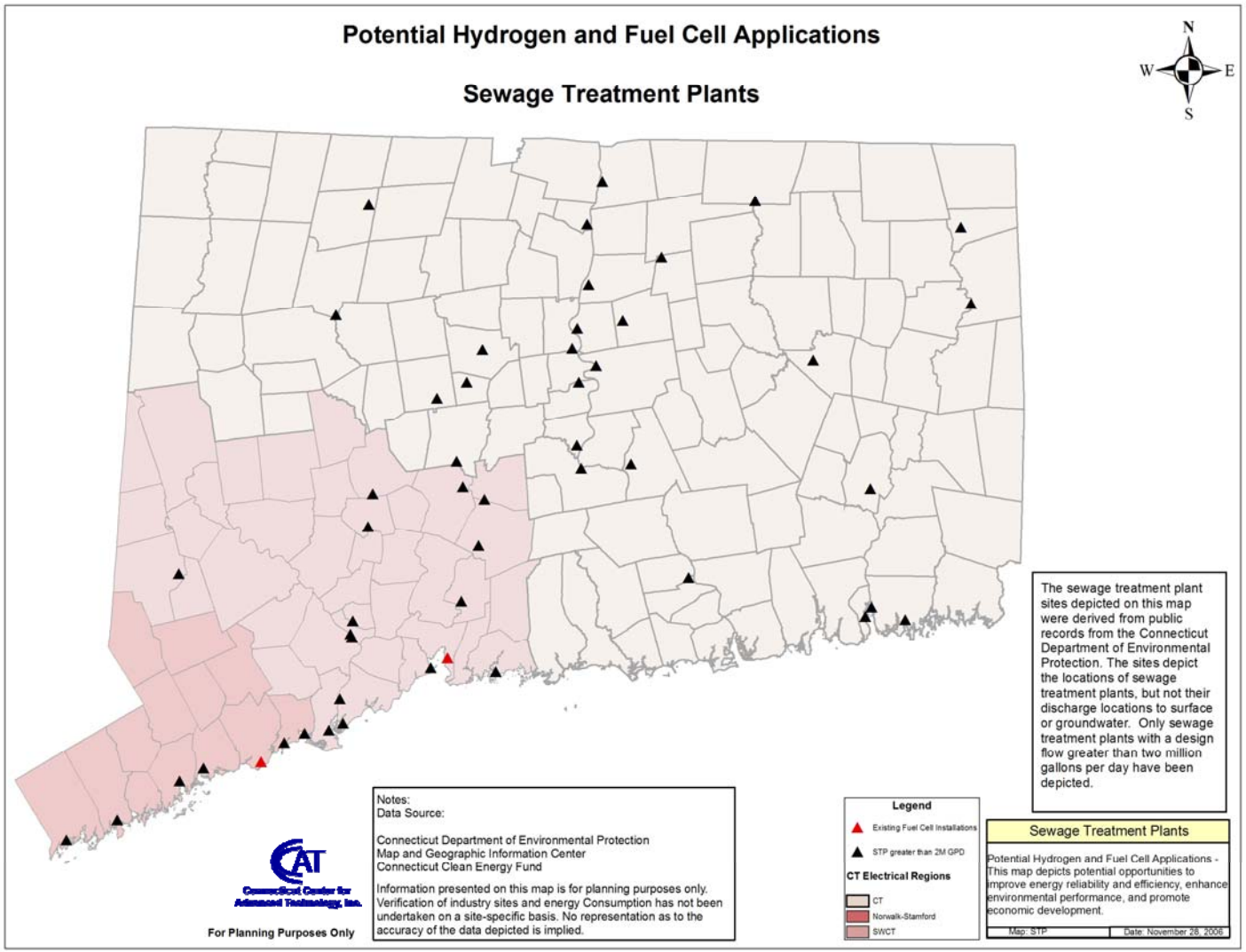
Appendix I - Figure 6: Lodging



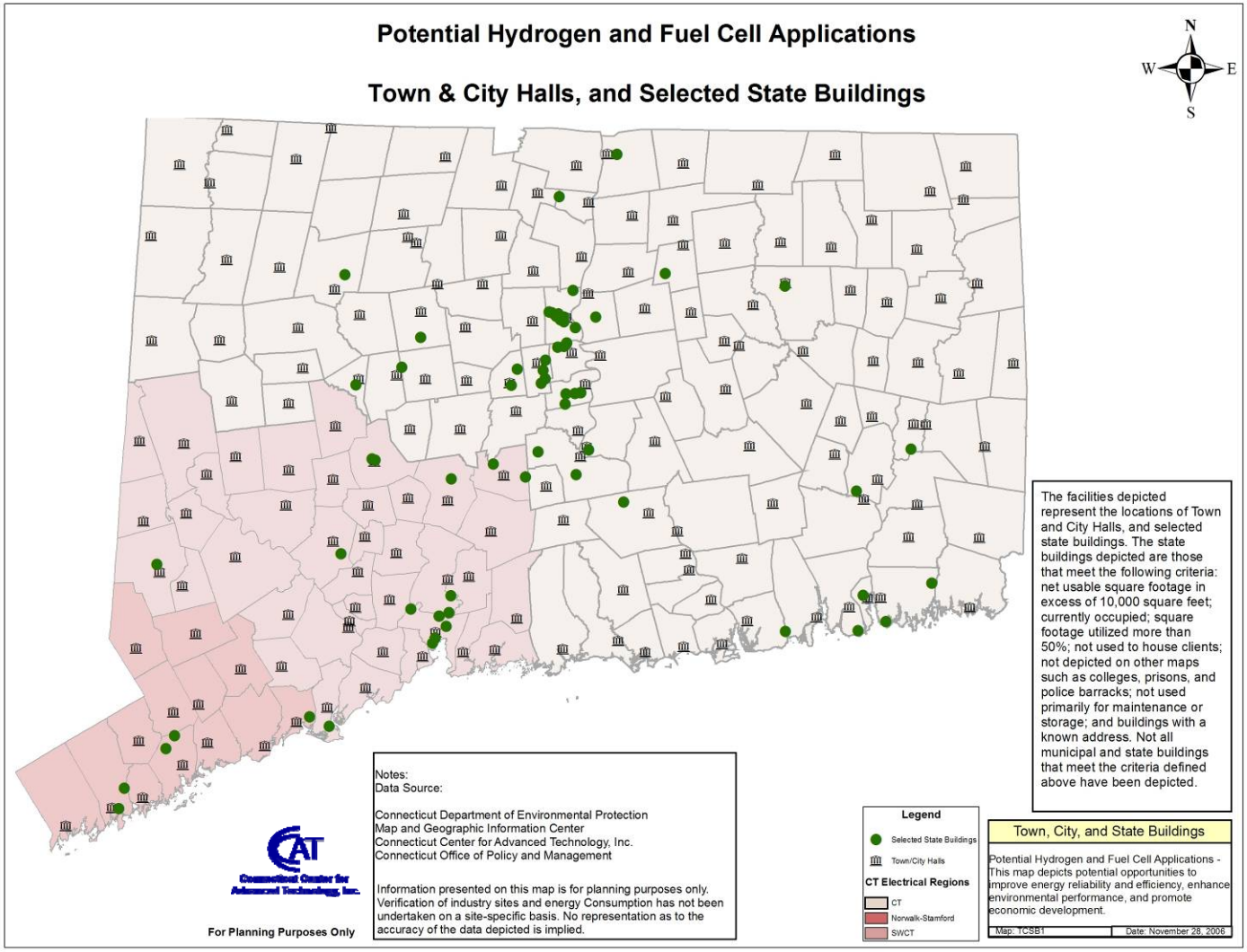
Appendix I - Figure 7: Education



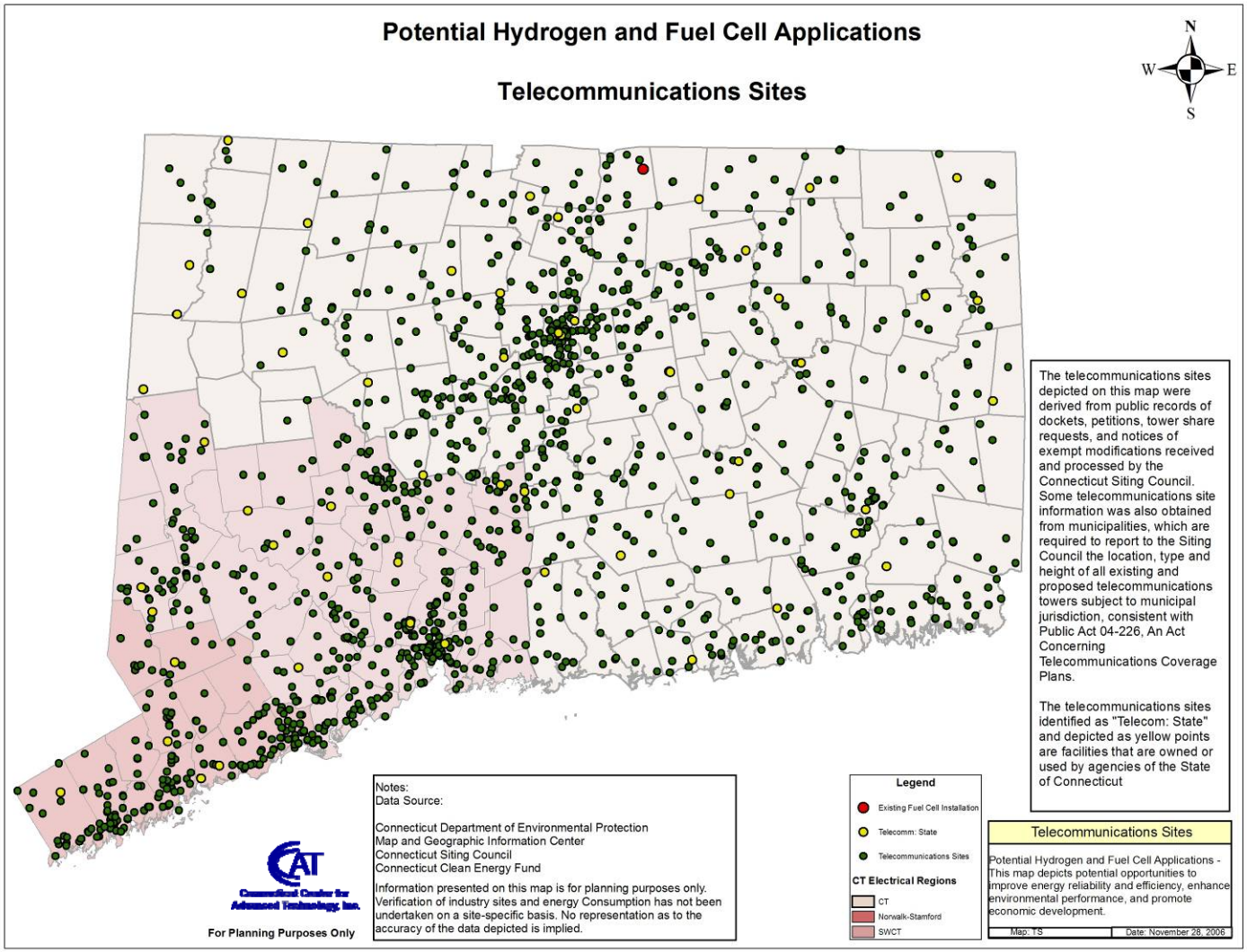
Appendix I - Figure 8: Sewage Treatment Plants



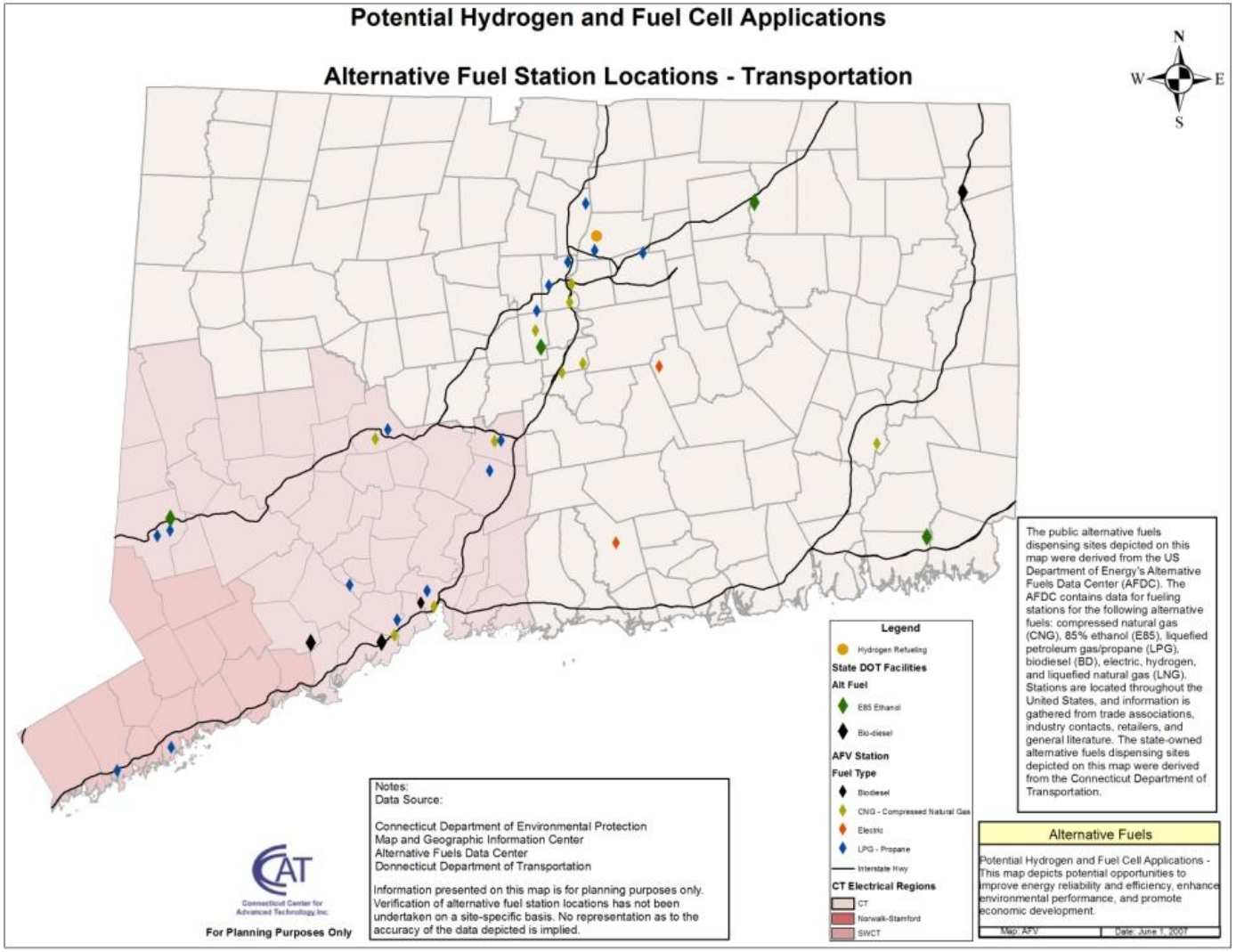
Appendix I - Figure 9: Town & City Halls, and Selected State Buildings



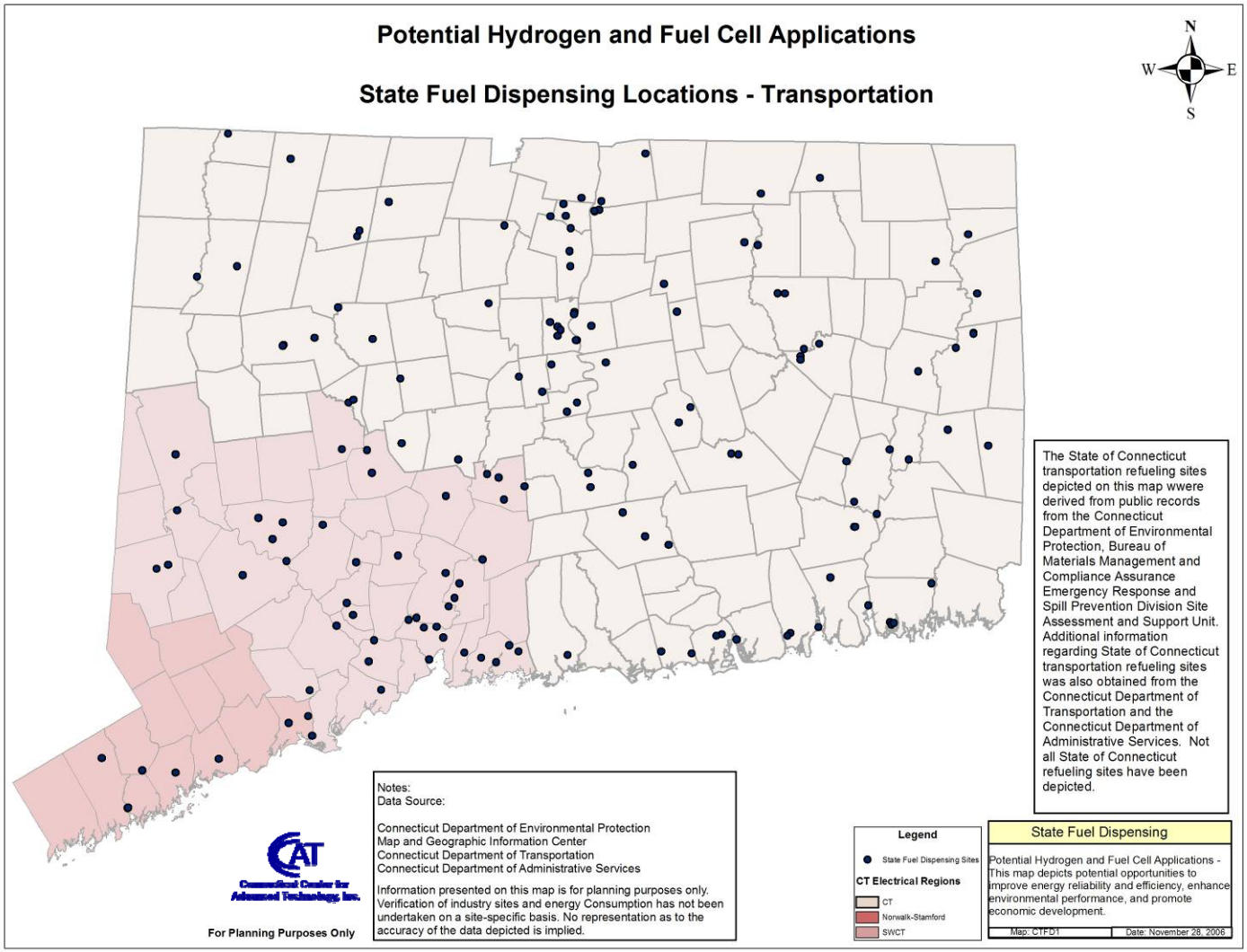
Appendix I - Figure 10: Telecommunications Sites



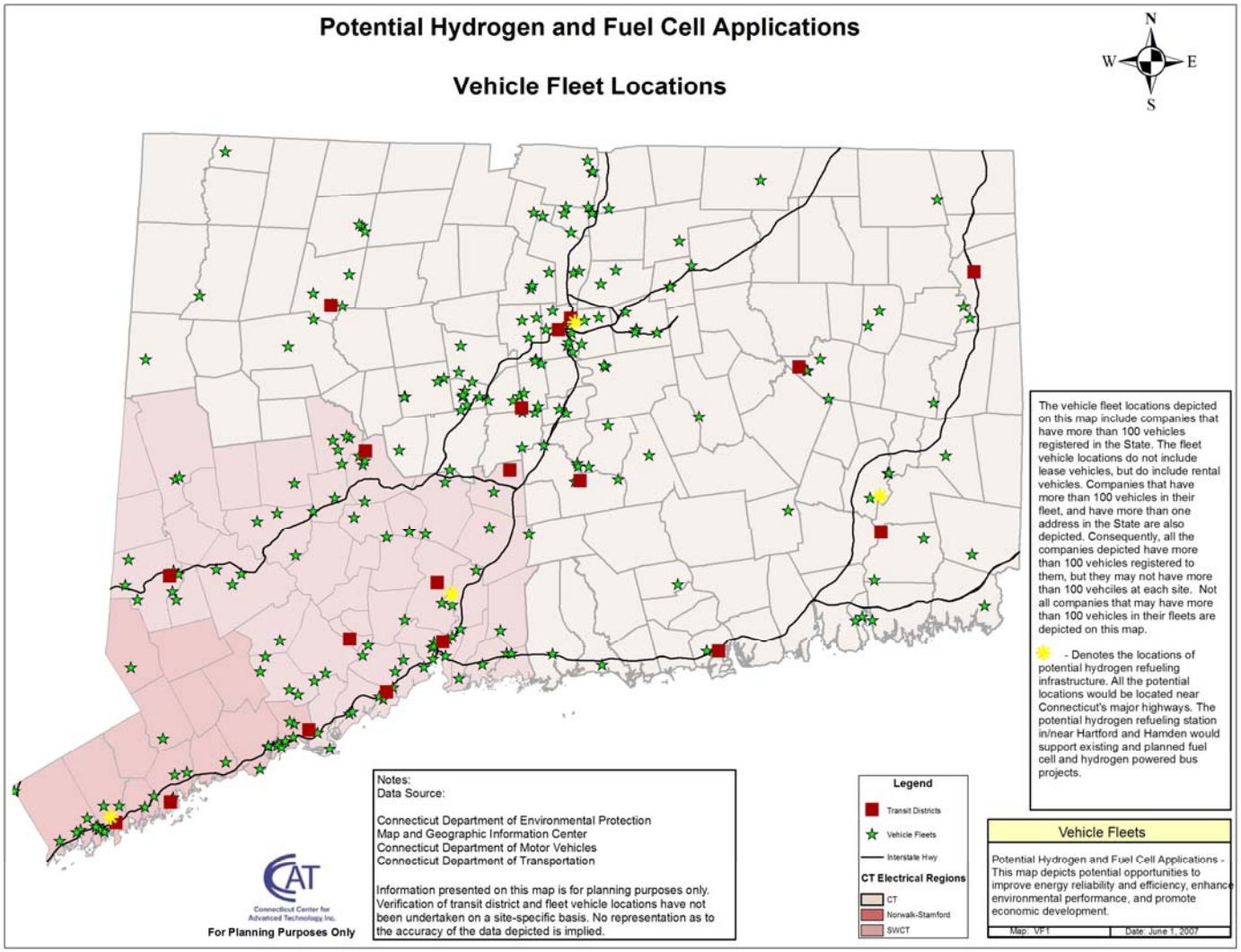
Appendix I - Figure 11: Alternative Fuel Station Locations



Appendix I - Figure 12: State Fuel Dispensing Locations



Appendix I - Figure 13: Transit Districts and Fleet Vehicle Locations



Prepared for:

Connecticut Center for Advanced Technology, Inc.

Proposal for Marketing Communications Plan

November 1, 2007

CONNECTICUT HYDROGEN AND FUEL CELL INDUSTRY MARKETING COMMUNICATIONS PLAN

FINAL

Introduction

The following strategic marketing communications plan addresses a variety of issues including background information about the hydrogen and fuel cell industry in the local and regional geographic area, the market environment regarding the current level of awareness of hydrogen and fuel cell technology, and tactical recommendations that can be implemented to promote awareness about the state's hydrogen and fuel cell technology and its benefits in order to facilitate building a competitive industry in Connecticut.

Background

Driven by economic development motivators and more specifically job creation within the state, Connecticut business leaders formed the Connecticut Hydrogen-Fuel Cell Coalition under the leadership of the Connecticut Center for Advanced Technology, Inc. (CCAT). This Coalition works to promote Connecticut's hydrogen and fuel cell industry, and to advance the development, manufacture and deployment of fuel cell and hydrogen technologies and associated fueling systems. The Coalition is comprised of representatives from Connecticut's fuel cell and hydrogen companies (OEMs and suppliers), workforce and education organizations, state government and other stakeholders, including CCAT and the Connecticut Clean Energy Fund. The group's assists Connecticut fuel cell and related companies to continue to grow and will ultimately help establish Connecticut as the leader of the hydrogen and fuel cell industry.

Situation Analysis

Connecticut is one of many states that are in the process of or have completed a hydrogen fuel cell roadmap. Some of these states (Ohio, California, South Carolina, New York, Massachusetts, New Jersey, and Rhode Island) were closely examined to determine the maturity of their hydrogen and fuel cell industries and to identify successful efforts that Connecticut could adopt. Generally, as expected, the more funding that the state allocates towards the development of their hydrogen and fuel cell industry, the more advanced their programs and infrastructure seem to be. For example, states such as California and Ohio have clearly defined hydrogen fuel cell coalitions and programs, whereas Rhode Island and South Carolina, with smaller amounts of funding, seem to be less advanced in the program development areas. Stakeholders have also set up a hydrogen and fuel cell cluster to demonstrate the importance of this industry to state policy makers and business leaders. In terms of focused, comprehensive marketing communications programs and materials, only a select few states have traditional marketing materials such as brochures, trade show and conference displays, and annual reports. Many of the initiatives have websites that appear to be the main source for information and promotions.

As part of this planning process, preliminary research was conducted among a small sample of 150 business decision makers, stakeholders and investors to determine their overall current perceptions of and attitudes towards hydrogen and fuel cell technology, and related perceptions of Connecticut. Feedback identified marketing communication vehicles that might effectively reach the target audience, including primarily the Internet, direct mail and local, state or federal government sources. Results showed that Connecticut has a unique opportunity to position the state as an industry leader in the development and implementation of hydrogen and fuel cell technology. Overall respondents were very familiar and had a favorable assessment of the technology, albeit with some concern relative to cost and reliability. In terms of their impression of Connecticut, most perceived the state to be innovative and forward thinking with a skilled workforce and resources to support the technology infrastructure. The most notable barrier to marketing appears to be that targets do not perceive a "need" for information relative to hydrogen and fuel cell technology. Some key findings included:

- Nine of ten (90.7%) respondents were either very familiar (61.6%) or somewhat familiar (29.1%) with hydrogen fuel cell technology.
- Stakeholders were more likely to be familiar with hydrogen fuel cell technology than other respondents.
- Business decision makers were more likely to report knowing a "great deal" about hydrogen fuel cell technology.
- Cost and reliability of supply were the most important factors among the targeted audience when they consider hydrogen fuel cell technology.
- One-third (33.1%) of all respondents perceived the State of Connecticut as "a pioneer in the development and application of hydrogen fuel cell generation for global use."

**Note: Further research will provide more in-depth analysis among a larger audience.*

Objectives

The communications goal stated by the Coalition is to create public awareness with industry, academia, and government regarding the benefits and uses of fuel cell and hydrogen technologies. The recommended objectives of this plan are as follows:

- Educate key target audiences about the benefits of hydrogen and fuel cell technology
- Increase awareness about hydrogen and fuel cell technology among target audiences
- Promote the extensive capabilities of Connecticut's hydrogen and fuel cell companies and organizations
- Position Connecticut as a leader in the industry
- Support Connecticut's Hydrogen-Fuel Cell Coalition, its members and the general industry cluster in their overall initiatives
- Demonstrate the need for increased state support

Strategies

The following strategies provide direction for the tactical implementation in order to meet the communications objectives:

- Demonstrate the viability and reliability of hydrogen and fuel cell technology
- Highlight successful, fully operating hydrogen and fuel cell companies
- Address the issue of high cost by providing a cost/benefit analysis including economic and environmental values
- Identify areas for public access to information on hydrogen and fuel cell technology
- Engage business leaders and decision makers in discussions about hydrogen and fuel cell technology through energy forums and conferences

Target Audiences

In addition to a broad outreach to the general public and media, recommended marketing efforts target three primary audiences, extending beyond state borders to the global level.

- *Businesses/Organizations, i.e., potential customers (decision makers, C-level executives, and facility/operation managers)*

  Local, national and international companies, including high-energy users, manufacturers and those committed to corporate responsibility
  Local municipalities, including transportation departments
  Transportation/fleet organizations
  Utilities, energy generating/power plants
  Schools and universities
  Hospitals
  Real estate developers

- *Stakeholders (policy makers, executives, business liaisons, communication contacts)*

  Federal and state government agencies, including DOT, DEP, DOE, Homeland Security, executive and legislative branches
  Environmental organizations, green advocate groups
  Hydrogen and fuel cell industry companies (OEMs and suppliers) in and out of state
  Information outlets, including academia, libraries, professional associations, business assistance organizations

- *Investors*

Messaging

Clear, concise messaging about the strengths of Connecticut's hydrogen and fuel cell industry and the benefits of the technology will be incorporated consistently across tactics to reach specific targets.

- *Businesses/Organizations*
  "Hydrogen and fuel cell technology provides safe, reliable and valuable alternative energy. Connect to Connecticut's industry suppliers and resources for innovative options."

- *Stakeholders*
  "Connecticut is a leader in hydrogen and fuel cell technology. Connect to Connecticut's fuel cell Coalition for a network of resources, knowledge, skilled workforce and innovation."

- *Investors*
  "Invest in Connecticut's hydrogen and fuel cell companies and technology. Connect to Connecticut for innovative partnerships, thriving enterprise creation, and forward-thinking research and development. "

**Note: Although general consumers are an important target audience, marketing to them would be cost prohibitive, therefore we will rely on the "spill over" effect from the outreach we implement for the other target audiences mentioned above.*

Tactics

The recommended tactics will be implemented over a 2-3 year time period in order to provide an effective opportunity to shift awareness levels and perceptions, and to establish a long-term, consistent brand message and image of Connecticut's hydrogen and fuel cell industry and technology. The tactics will target specific key audiences, as well as more broadly to the general public and media.

Trade Show, Conferences, Seminars

Identify and attend/sponsor key events that target identified audiences
Supplement efforts by coordinating local outreach in surrounding areas

Special Events, Promotion

Coordinate opportunities to promote industry successes and to reach targets with marketing messages, information/giveaways, e.g. Kickoff campaign event, ribbon cuttings, bus road shows, car demonstrations, Science Center exhibit, Hydrogen Day, sporting events – ESPN/NASCAR, legislative events

Public Relations

Develop a series of press releases, op-eds, feature stories, by line articles, case studies and on air interviews that highlight the successes to targeted media outlets.
Identify celebrity spokesperson(s) to represent the Connecticut brand.

Advertising

Develop creative campaign (including tagline) to promote messaging across select media outlets (i.e. radio, cable TV, transit vehicles, magazines, trade publications – e.g. NPR, Fuel Cell Today, NY Times)

Collateral

Create brochures, posters, signage with consistent theme/messaging/style

Direct and eDirect Mail

Develop pieces (e.g. enewsletters) to target audiences – pre/post events, trade shows on an ongoing basis

Website portal

Create a home site with information about the industry, to be promoted across all tactics to all audiences

Promote web links from stakeholder organizations

**Note: Partnerships with local/state government resources and information outlets to promote the above tactics will maximize the budget as well as the impact of the marketing reach.*

Research

In order to gauge the impact of this marketing communications plan, more formal/in-depth research should be conducted prior to the implementation phase to establish a benchmark. A series of statewide focus groups, along with a national/international telemarketing survey, will provide more specific measures of the current perceptions of hydrogen and fuel cell technology and Connecticut's related industry among identified audiences. At the close of the first 12-month marketing communications program, another series of focus groups and surveys should be conducted to gauge the increase in awareness levels among key targets.

Deliverables

The recommended plan will accomplish a series of deliverables related to the plan objectives including:

- Raise awareness levels about Connecticut hydrogen and fuel cell companies and their product/service offerings
- Raise level of knowledge of hydrogen and fuel cell technology and company capabilities
- Increase in media exposure through number of placements
- Help to increase state support for the Fuel Cell cluster through federal, state and regional venues including policy initiatives
- Assist efforts to increase number of fuel cell installations and jobs created

Budget

To implement the proposed plan over a 2-3 year period, a multi-year budget of $1.5 million ($500,000 per year) is recommended.