Preliminary Feasibility Study and Strategic Plan

University of Connecticut

Depot Campus, Mansfield CT

March 31, 2012

The Connecticut Center for Advanced Technology, Inc[1] (CCAT) developed this Preliminary Feasibility Study and Strategic Plan for the University of Connecticut's (UConn) Depot Campus in cooperation with many members of UConn's faculty and staff. CCAT acknowledges the contributions of UConn's Office of Environmental Policy, the Center for Clean Energy Engineering, and Facilities Operations.

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[1] CCAT helps private and public entities to apply innovative tools and practices to increase efficiencies, improve workforce development and boost competitiveness. CCAT's Energy Initiative works to improve the economic competitiveness of the region by advancing community-supported solutions to reduce energy costs and increase reliability. As part of this goal, CCAT's Energy Initiative develops regional models for improved energy use, and helps to foster partnerships between industry, government and academia to promote renewable energy, hydrogen and fuel cell technology.

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Introduction

The University of Connecticut (UConn) has developed this plan in support of the "Green Depot Campus Initiative", to install, operate, and evaluate clean and renewable technologies. This initiative will facilitate technology transfer and collaborative research into green energy sources, smart storage, reduction of carbon dioxide (CO_2) and other greenhouse gases, and water management. One of the goals of the UConn Climate Change Action Plan is to integrate environmental principles into the student's learning experience. This initiative will also validate and demonstrate the integration of renewable generation systems that could exceed one megawatt (MW) of capacity, and would emulate a sustainable community.

The objective of the "Green Depot Campus Initiative" is to evaluate areas of the Depot Campus for self generation with alternative and sustainable energy sources. This Plan includes an assessment of electrical and thermal energy consumption for the UConn buildings at the Depot Campus; analysis of implementation targets for energy development; and the identification of funding for project development.

This plan provides a structure for the identification and assessment of renewable and advanced energy technologies at the Depot Campus. It is anticipated that the structure of this plan provides flexibility for updates as new/improved technologies and opportunities for development are presented. Furthermore, this Plan is consistent with the Preliminary Feasibility Study and Strategic Deployment Plan for Renewable and Sustainable Energy Projects, which evaluated potential deployment opportunities for renewable and sustainable energy technologies at UConn's Storrs campuses.

Executive Summary

The total electric consumption for the Depot Campus is approximately 4,500,000 kilowatt hours (kWh) per year. It is estimated that are the largest consumers of electricity at the Depot Campus are the Longley building, Merritt Hall, Thompson Hall, Storehouse Department of Residential Life (DRL), Brown, and the Center for Clean Energy Engineering (C2E2) buildings. These buildings consume approximately 48 percent of all electricity used at the Depot Campus. The analysis also revealed that the total thermal consumption, which is almost exclusively fueled by natural gas is approximately 32,239,000 cubic feet or 32 billion British Thermal Units (MMBtu). The buildings that are the largest consumers of natural gas and therefore thermal energy for heating/cooling and domestic hot water applications are: Longley Building, Thompson Hall, Storehouse-DRL, Merritt Hall, Carpenter Shop and C2E2. The buildings on the Depot Campus with the highest thermal energy intensity include: Norling, Hebron Cottage, the Garage/Fire House, Tolland Cottage, and Ashford Cottage. These buildings may provide the most favorable opportunities for conservation and advanced technologies for improved energy efficiency and reduction in greenhouse gas emissions.

One of the goals of the UConn Climate Change Action Plan is to integrate environmental principles into the student's learning experience. In addition, increased awareness of the University's commitment to environmental stewardship to minimize, to the extent practical, its impact on climate change by the students, staff, visitors, and the community is extremely important.

Based on the estimated electricity demand, actual thermal demand, calculated energy intensity, opportunities for education and academic research, building use, and building status, the buildings that provide favorable opportunities for integrating renewable and advanced energy technologies in support of the Green Depot Campus Initiative (as shown in Table 1) include Longley Building, C2E2, Brown, and Willow House. There are also a number of buildings at the Depot Campus that have emergency generators and may be able to use biodiesel, a renewable fuel, for electric generation.

Table 1- Summary of Potential Renewable Energy Applications at the Depot Campus

Technology	Example Locations	2010 Existing/Estimated Energy Consumption	Potential Renewable Energy Generation Capacity	Potential Renewable Energy Production	Potential Reductions of CO2 Emissions	Total First Cost ($) / Lifecycle CO2 Emissions Reductions ($/lb)
Fuel Cell	Center for Clean Energy Engineering (C2E2)	435,059 kWh/year	400 kW	3,250,000	860,000 lbs/year	$.33
Demonstration PV Site	Center for Clean Energy Engineering (C2E2) -	See Above	10 kW	11,520 kWh/year	10,575 lbs/year[2]	$.32
Ground Source Heat Pump	Longley Building	6,768 MMBtus	245 tons	5,414 MMBtu using 352,500 kWh to 396,600 kWh[3] 27,800 kWh to 33,800 kWh[4] displaced	307,345 lbs/year[2,5]	$.27 to $.30
Ground Source Heat Pump	Thompson Building	3,087 MMBtus	40 tons	1,017 MMBtu using 66,200 kWh to 74,500 kWh[6] 12,000 kWh to 18,000 kWh displaced[7]	60,875 lbs/year[5]	$.20 to $.24

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[2] ISO New England, "Electric Generator Air Emissions Report – Systems Planning Department," http://www.iso-ne.com/genrtion_resrcs/reports/emission/final_2009_emissions.pdf, 2009
[3] Based on displacing 5,414 MMBtus with a heat pump having a COP between 4.0 and 4.5
[4] Based on displacing 39,800 ton-hours of cooling with a heat pump between 4.0 and 4.5 COP
[5] EIA, "Voluntary Reporting of Greenhouse Gases Program Fuel Emission Coefficients," http://www.eia.gov/oiaf/1605/coefficients.html, January 31, 2011
[6] Based on displacing 1,017 MMBtus with a heat pump having a COP between 4.0 and 4.5
[7] Based on displacing 40,184 ton-hours of cooling with a heat pump having a COP between 4.0 and 4.5

Table 1- Summary of Potential Renewable Energy Applications at the Depot Campus – Continued

Technology	Example Locations	2010 Existing/Estimated Energy Consumption	Potential Renewable Energy Generation Capacity	Potential Renewable Energy Production	Potential Reductions of CO2 Emissions	Total First Cost ($) / Lifecycle CO2 Emissions Reductions ($/lb)
Wind Site	Longley Building - Demonstration	439,094 kWh/year	10 kW	5,305 kWh/year	4,933 lbs/year[8]	$.44
Demonstration Biofuels Site	Longley Building	N/A	150,000 GPY	150,000 GPY	16.12 lbs/gallon of B100[9]	$0 to $.02[10]
Demonstration Solar Thermal Site	Willow House	10 MMBtus	32 square feet	7 MMBtus/year	1024 lbs/year[11]	$.19
Biodiesel Electric Generation B100	Kennedy Building Surplus Warehouse Chaplin Cottage Ellington Cottage Willington Cottage Willimantic Cottage Merritt Hall Generator	6,275 GPY[12]	180 kW 80 kW 120 kW 100 kW 100 kW 100 kW 85 kW **765 KW**	76,500 kWh/year[13]	16.12 lbs/gallon of B100 biodiesel used[10]	$0 to $.02[14]

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[8] ISO New England, "Electric Generator Air Emissions Report – Systems Planning Department," http://www.iso-ne.com/genrtion_resrcs/reports/emission/final_2009_emissions.pdf, 2009

[9] Alternative PETROLEUM Technologies, "APT Fuels Clean Air at Port of Los Angeles," http://www.altpetrol.com/PDF/APT%20Bahrain%20-%20POLA%20present_201109a.pdf, Houlihan, Thomas, 2011

[10] Based on zero to thirty cents more per gallon for B100 as compared to #2 diesel

[11] EIA, "Voluntary Reporting of Greenhouse Gases Program Fuel Emission Coefficients," http://www.eia.gov/oiaf/1605/coefficients.html, January 31, 2011

[12] EIA, " Calculators for Energy Used in the United States," http://205.254.135.24/kids/energy.cfm?page=about_energy_conversion_calculator-basics, March 2012

[13] Assumes the generator sets are used for 100 hours per year to provide backup / community area reliability

[14] Based on zero to thirty cents more per gallon for B100 as compared to #2 diesel

Depot Campus History and Building Stock

"The Depot Campus at the University of Connecticut is located in Mansfield, Connecticut, a small town adjacent to Storrs, where the University's main campus is located. The Depot Campus was conveyed by the Connecticut Department of Public Works to UConn in July 1993, and consists of the property and buildings of the former Mansfield Training School. The Mansfield Training School, which was founded in 1909, served as a multi-functional facility providing housing, educational, and medical facilities for patients; housing and recreational facilities for employees; and a large agricultural complex providing food for the school as well as occupational training for the patients."[15]

According to the University of Connecticut Depot Campus Master Plan, completed by Symmes Maini & McKee Associates in 2009, the Depot Campus contains approximately 50 buildings, with approximately 714,000 gross square feet, including approximately 421,000 assignable square feet. The majority of the assignable square feet (57 percent) of all the buildings at the Depot Campus is occupied or leased, while approximately 43 percent consists of dead storage/vacant or storage.

[15] University of Connecticut Depot Campus Historic Evaluation, 2009

Figure I -Existing Building Status[16]

Use Type	Building Status (ASF)				
	Dead Storage/Vacant	Leased	Occupied	Storage	Grand Total
Academic			37,211	2,925	40,135
Administrative	3,000		24,379		27,379
Continuing Education			13,814		13,814
Facilities	11,115		28,035	52,809	91,958
Non-University Leased		41,067			41,067
University-Related Museum			5,132	18,354	23,486
University-Related Research		75,175	14,093		89,268
Subtotal	**14,115**	**116,242**	**122,664**	**74,087**	**327,108**
Unassigned	93,953				93,953
Grand Total	**108,068**	**116,242**	**122,664**	**74,087**	**421,061**

Building Status

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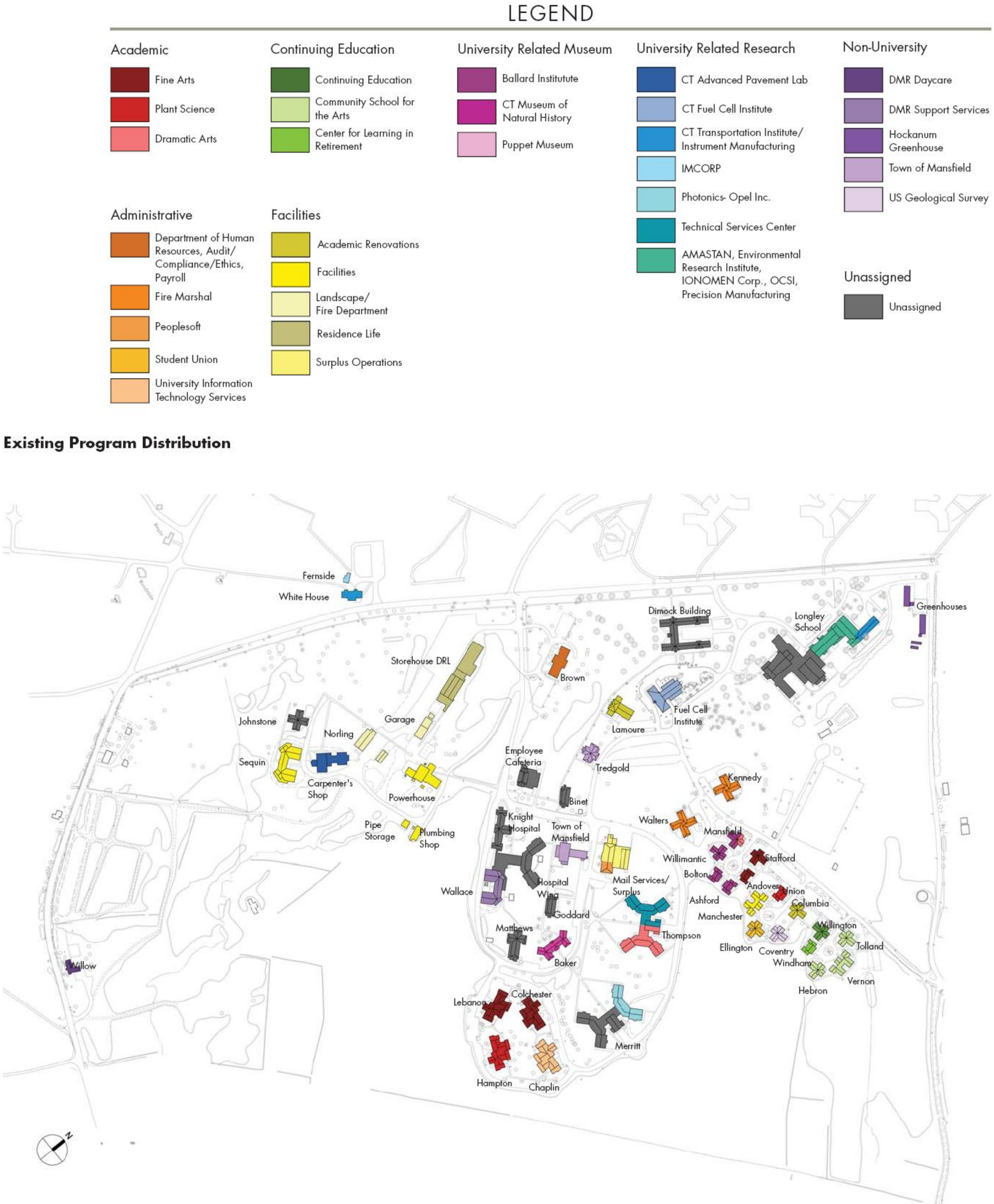
16 University of Connecticut Depot Campus Master Plan

Figure II-Existing Building Use[17]



[17] University of Connecticut Depot Campus Master Plan

Electric Assessment

Total electricity consumption at the Depot Campus was approximately 4,500,000 kWh/year based on an analysis of the fifteen-minute data provided by UConn for the Depot Campus for 2010. Peak demand for the 12 month billing period was 924 kW, with the peak demand occurring in September. A September peak most likely corresponds to the coincidence of peak occupancy levels during periods where there is a need for cooling. Figure III and Figure IV, show the Depot Campus's maximum and minimum electrical load at fifteen minute increments throughout the year. The figures indicate a significant spread between the maximum and minimum electric demand. Net metering rules allow excess electricity produced in one part of the day to be "banked" for use when electric consumption exceeds electric production. Excess electricity (kWh) produced during off-peak hours and returned to the grid is credited to the customer's account at retail rates, provided that the annual production doesn't exceed consumption (in this case, the renewable energy facility would receive compensation at the avoided wholesale cost of power). The Depot Campus electric load is served through a single utility service or master meter; however, the C2E2 and Brown buildings are submetered.

Figure III - Depot Campus Maximum and Minimum Electric Demand (kW)

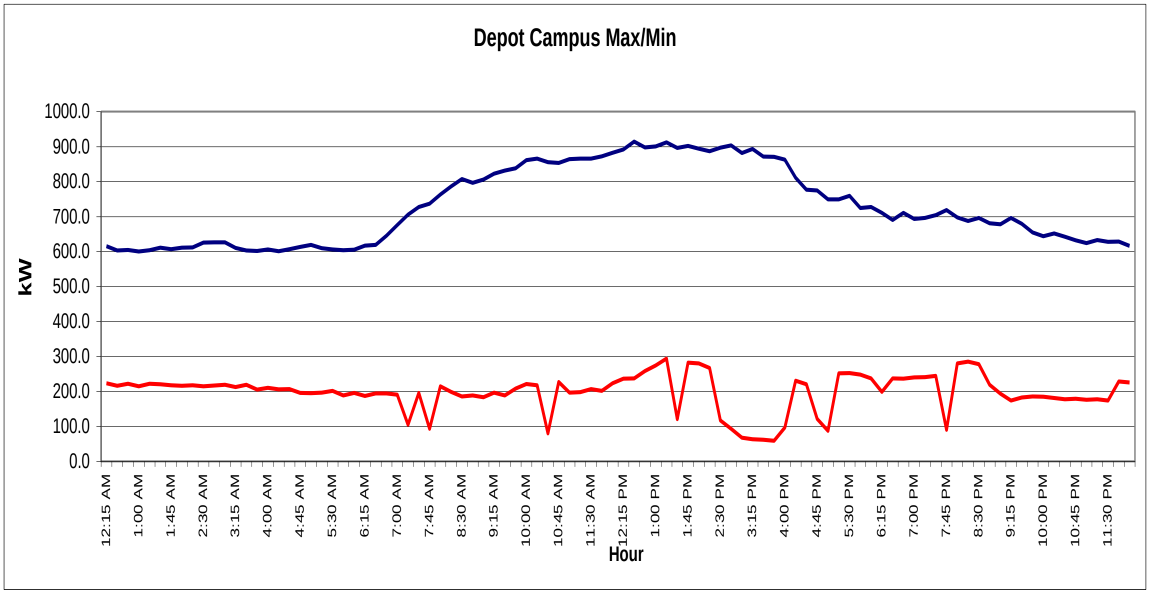
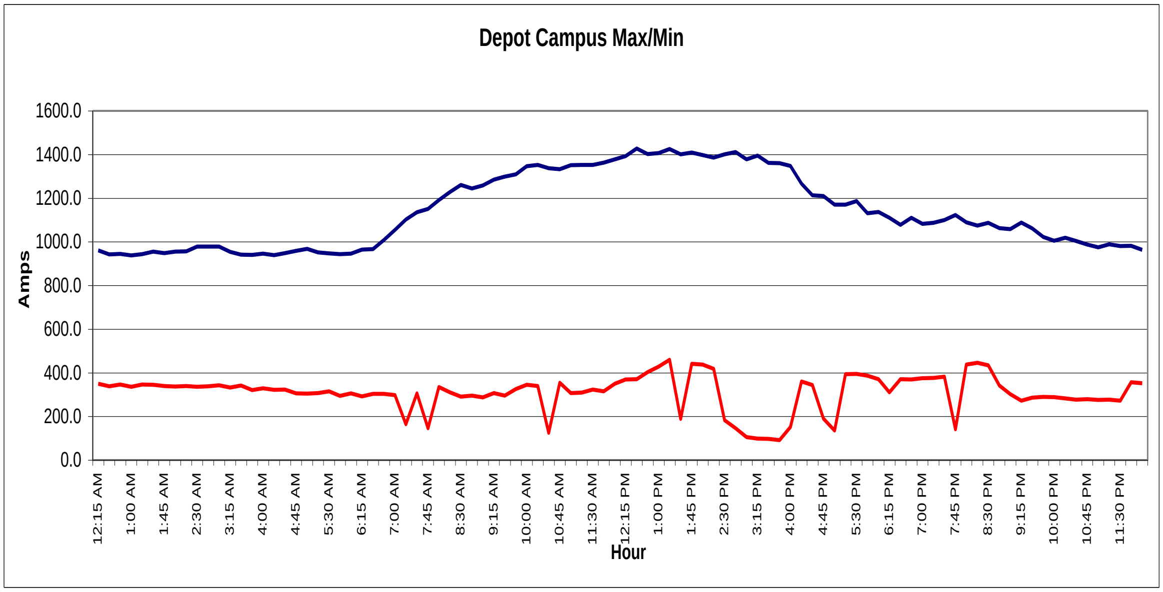


Figure IV - Depot Campus Maximum and Minimum Electric Demand (*Amps)*



Amps @ 480-V; 3-phase

The three largest energy end uses in educational facilities are: (1) lighting; (2) ventilation; and (3) cooling.[18] Electricity production from a renewable energy system, such as photovoltaics (PV), fuel cells, wind, and even biofuel derived fuel gensets could provide for these end uses, and others. The Depot Campus utilizes a master meter for all the buildings that are served by electricity. This provides an excellent opportunity to capitalize on the benefits of net metering. The disadvantage of a master meter is that each building does not have its own electricity meter, which makes it difficult to know the exact electric consumption for each building.

The Energy Information Administration (EIA) Commercial Building Energy Consumption Survey (CBECS) can be used to estimate the electric consumption for a particular building based on its use or "principal building activity" and square footage. There are fourteen categories for the "principal building activity" under the CBECS classification system. The categories that are applicable to the buildings at the Depot Campus, based on the University of Connecticut Depot Campus Master Plan that identifies the building status and current use for each of the buildings at the Depot Campus (see Figure I and Figure II), includes education, office, warehouse and storage, and vacant. As detailed in Table II below, the electricity consumption factors range from 2.4 kWh/square foot to 18.2 kWh / square foot:

Table II – CBECS Electricity Consumption Factors

Principal Building Activity	Per Square Foot (kWh)[19,20] (Zone 2)[21]
Education	**8**
Office	**18.2**
Warehouse and Storage	**9.6**
Vacant	**2.4**

As detailed in Table III and Table IV below, Longley, Merritt, Thompson, Storehouse DRL, Brown, and C2E2 are estimated to be the greatest consumers of electricity at the Depot Campus.

[18] Energy Information Administration, "Table E6. Electricity Consumption (kWh) Intensities by End Use for Non-Mall Buildings, 2003," http://www.eia.gov/emeu/cbecs/cbecs2003/detailed_tables_2003/2003set19/2003pdf/e06.pdf, September 2008

[19] Energy Information Administration, "2003 Commercial Buildings Energy Consumption Survey Table C20," http://www.eia.gov/emeu/cbecs/cbecs2003/detailed_tables_2003/2003set10/2003excel/c20.xls, December 2006

[20] Energy Information Administration, "2003 Commercial Buildings Energy Consumption Survey Table C14," http://www.eia.gov/emeu/cbecs/cbecs2003/detailed_tables_2003/2003set10/2003excel/c14.xls, December 2006

[21] All of Connecticut has been designated as Climate Zone 2; Less than 2,000 CDD and 5,500 – 7,000 HDD.

Table III - Estimated Electric Demand for Selected Buildings[22]

Building Name	Estimated Gross Square Feet	Building Use Electricity Consumption Factor	Estimated Annual Electricity Consumption (kWh)	Percent of Total Electricity Consumption at the Depot Campus	
Longley (Occupied)	42,000	8	336,000	7.5 percent	9.8 percent
Longley (Storage)	42,956	2.4	103,094	2.3 percent	
Merritt (Occupied)	17,000	18.2	309,400	6.4 percent	7.3 percent
Merritt (Storage)	17,256	2.4	41,414	0. 9 percent	
Storehouse DRL	27,080	9.6	259,968	5.8 percent	
Thompson	33,824	8	270,592	6.0 percent	
Totals	**226,933**		**1,779,162**	39.1 percent	

Table IV - Electric Demand for C2E2 and Brown Buildings (March 2010 – March 2011)

Building Name	Estimated Gross Square Feet	Building Use Electricity Consumption Factor	Actual Annual Electricity Consumption (kWh)	Percent of Total Electricity Consumption at the Depot Campus
Brown	25,203	16.2 (Calculated)	407,059	9.0 percent
C2E2	21,614	20.1 (Calculated)	435,059	9.7 percent

Thermal Assessment

According to EIA, the two largest end uses of thermal energy in educational and office facilities are for space heating and domestic hot water applications.[23] Technologies such as fuel cells, solar thermal,

[22] Energy Information Administration, "Table E6. Electricity Consumption (kWh) Intensities by End Use for Non-Mall Buildings, 2003," http://www.eia.gov/emeu/cbecs/cbecs2003/detailed_tables_2003/2003set19/2003pdf/e06.pdf, September 2008

geothermal, and biofuel derived fuel generators can provide thermal energy for both of these end uses. As detailed in Table V below, Longley, Thompson, Storehouse DRL, Merritt, C2E2, and Carpenter Shop are the greatest consumers of natural gas and therefore thermal energy at the Depot Campus. Refer to Appendix III – Annual (2010) Natural Gas Consumption for Buildings at the Depot Campus for the list of buildings at the Depot Campus and their annual natural gas usage.

Table V - Buildings with the Largest Thermal Loads (2010 Natural Gas Consumption)

Building Name	Annual Thermal Consumption (CCF)	Percent of Total
Longley	67,680	21 percent
Thompson	30,870	9.6 percent
Storehouse-DRL	25,553	7.9 percent
Merritt	25,201	7.8 percent
C2E2	23,200	7.2 percent
Carpenter Shop	15,474	4.8 percent
Totals	187,978	58.3 percent

Evaluating buildings based on total natural gas consumption is useful in identifying potential targets for distributed generation; however, energy intensity, which is a measure of the energy consumed per area of building space used, can provide useful information to identify the best opportunities for improved energy efficiency through conservation and reduction in greenhouse gas emissions. As detailed in Table VI, the following buildings on the Depot Campus have the highest energy intensity: Norling, Hebron Cottage, the Garage/Fire House, Tolland Cottage, and Ashford Cottage.

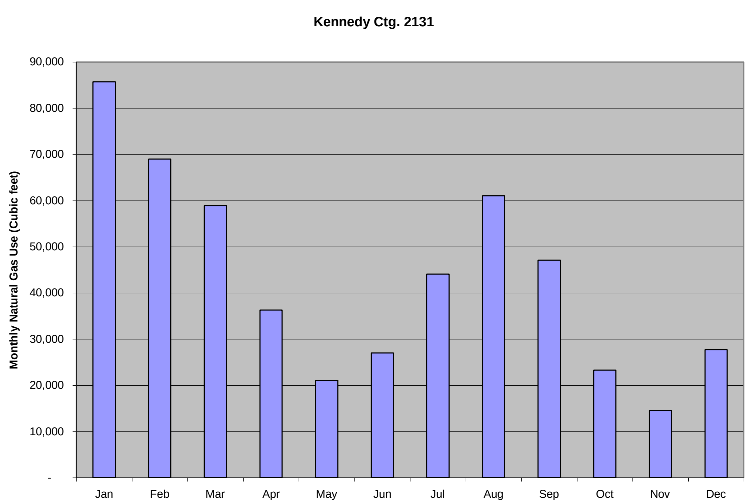
[23] Energy Information Authority, "Table E8. Natural Gas Consumption (cubic feet) and Energy Intensities by End Use for Non-Mail Buildings, 2003,"http://www.eia.gov/emeu/cbecs/cbecs2003/detailed_tables_2003/2003set19/2003pdf/e08.pdf, September 2008

Table VI - Buildings with the Highest Calculated Energy Intensity (Thermal)[24]

Building Name	Annual Thermal Consumption (CCF)	Area (Square Feet)	Energy Intensity (CCF/Square Feet)
Norling	10,683	5,204	2.05
Hebron Cottage	7,170	3,602	1.99
Garage/Fire House	6,933	4,172	1.66
Tolland Cottage	4,605	3,606	1.28
Ashford Cottage	329,900	2,630	1.25

One additional factor that may be used to identify potential targets for distributed generation includes energy utilization. The Kennedy Cottage has a natural gas demand profile which indicates that this building uses natural gas throughout the year at a level higher than other comparable buildings. The natural gas consumption for the Kennedy Cottage is primarily due to the natural gas fired furnace (385 cubic feet/hr) and the natural gas fired chillers (375 cubic feet/hr) which provide heating or cooling throughout the year. The annual natural gas usage for the Kennedy Cottage is depicted in Figure V, below.

Figure V – Annual Natural Gas Consumption for the Kennedy Cottage (2010)



[24] Based on Natural Gas Consumption for 2010.

Education and Awareness

One of the goals of the UConn Climate Change Action Plan is to integrate environmental principles into the student's learning experience. There are several buildings at the Depot Campus that may provide better opportunities to enhance education and promote awareness. Out of the 57 buildings classified at the Depot Campus, 25 have been classified as vacant or used for storage, 11 buildings are leased, and the remaining 21 are leased to non-university entities or used to support academic interests, facilities and administration. Those buildings that support academic interests at the Depot Campus, and are likely to be visited by students, faculty and other members of the public include Lebanon and Colchester (fine arts), Hampton (plant science) Thompson (dramatic arts); and university related research at C2E2, Longley, Merritt, and Thompson. Buildings that are visible from Route 44, include the Brown building, which is used by administration to support human resources, Longley, and Storehouse DRL.

Research and Academic Interests

The Office of Environmental Policy at UConn recently conducted a survey to assess the research interests of faculty at UConn. Results of this informal survey suggest that there is several opportunities to integrate faculty research interests and renewable/advanced energy technologies into plans for a "Green Campus Initiative" at the Depot campus, as detailed in Table VII below.

Table VII - Summary of Research and Academic Interests

Research Topic(s)	Particular Area(s) of Interest
Solar PV	• Integration of wind/solar with conventional power generation and microgrid applications • PV materials and devices, implementing nanotechnology in PV materials
Wind	• Integration of wind/solar with conventional power generation and microgrid applications
Biofuels/biomass	• Light-harvesting and electric potential generation by photosynthetic pigments and pigment-protein complexes • Making compounds in an environmentally benign way • Combustion characterization of biofuels and blending strategy with petroleum-derived fuels • Development of a gasification or methanation facility

Hydrogen/Fuel Cells *Advance Materials Processing, Fuel Cells*	• Hydrogen generation by high temperature bacteria • Long term stability, surface protection and corrosion • Cell stack materials, cost reduction, stack degradation mitigation and reliability related issues in micro tubular solid oxide fuel cell (SOFC) manufacturing.
Geothermal	• Increasing efficiency in geothermal heat exchange
Energy/Power conversion systems	• Renewable energy source integration • Demonstrate osmotic heat engine • Smart grid applications

Distributed Generation (DG) and Renewable Technologies

DG provides electricity at or near the facility where the electricity is consumed, as opposed to electricity generated at a remote site and transported through the electric grid via long distance transmission lines to the facility. DG resources are typically small-scale power generation technologies in the range of 3 to 10,000 kW.[25] DG can be sized to cover primary power needs for critical, average and peak electric loads, and serve as resources for standby power, peak shaving and grid support. By providing multiple sources of electric generation in a distributed manner, the electric supply system is decentralized, potentially resulting in greater security and reliability. There are many technological opportunities for renewable DG, including electric generators that operate on renewable fuels such as biodiesel, fuel cells, solar PV and solar thermal, geothermal, wind or biomass. Each of these technologies has different benefits in terms of installation, usage costs, best practices, fuel consumption and environmental impact. Furthermore, environmental and site differences are proposed to be taken into account when deciding upon the best technology for a facility. The best type of renewable technology for a facility(s) will vary by location, energy demands, site characteristics and other factors.

Electric

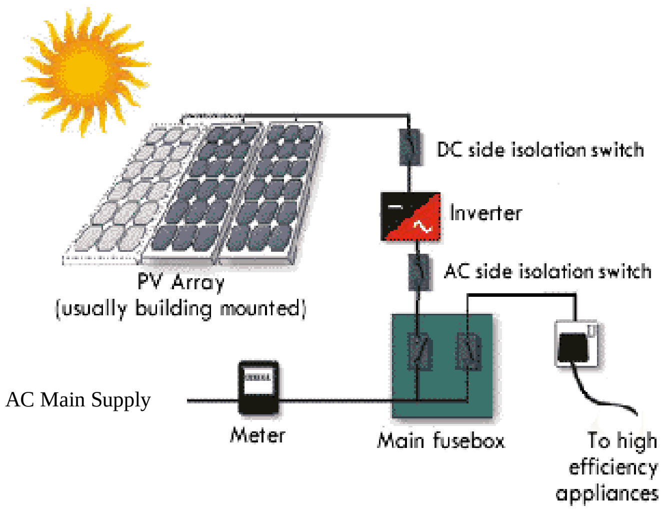
Solar Photovoltaic Power Systems (PV)

PV cells convert sunlight directly into electricity. There are now three generations of PV technologies available on the market. Traditional PV cells are flat plates made from silicon. Second generation PV cells, or "thin film" cells, are layers of semiconductors only a few micrometers thick. Third generation PV cells are made from a diverse set of materials, including solar inks using conventional printing press

[25] The California Energy Commission, "California Distributed Energy Resources Guide," http://www.energy.ca.gov/distgen/index.html, August 7, 2008

technologies, solar dyes, and conductive plastics.[26] Typically, traditional PV cells are more expensive per kW of installed capacity than 2nd or 3rd generation PV cells, but traditional PV cells have a higher efficiency.

Figure VI – Solar PV Schematic[27]



In general, photovoltaic power systems (PV) are technically feasible in Connecticut anywhere adequate electrical interconnections and a sound building roof exist. The Department of Energy National Renewable Energy Laboratory (NREL's) PV Watts model reports a value of 4.35 $kWh/M^2/day$ of incident solar radiation at Mansfield Connecticut. Typically, PV systems are engineered for the greatest average kWh output per year in order to maximize the amount of electrical energy that can be net metered. Consequently, yields are optimized when the PV panels are mounted such that they face due south on along an inclined plane. Other siting criteria to consider when evaluating potential buildings for the installation of PV systems include:

- Sites with sun exposure for 6-8 hours per day
- Building/structure capable of supporting renewable energy equipment without significant reinforcing
- Building/structure has flat roof or sufficient pitch and orientation to maximize solar potential
- Building/structure area sufficiently large to support renewable energy equipment
- Building/structure roof materials allow installation of renewable energy equipment and will not need to be replaced within the life of the renewable energy equipment
- Sites that have a daytime (peak) electric demand

[26] National Renewable Energy Laboratory, "Solar Photovoltaic Technology Basics," http://www.nrel.gov/learning/re_photovoltaics.html, March 21, 2012
[27] Solaryshop.com, "Solar Powered Electric," http://www.solarshop.com/solar-powered-electric.htm, March 2012

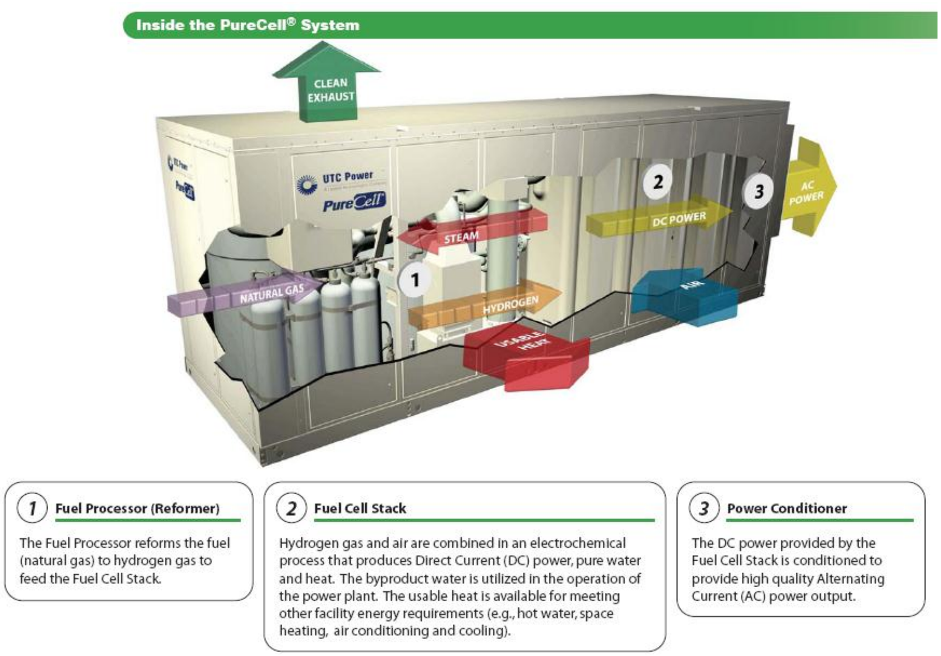
In situations where a building's remaining roof life and or structural integrity to support roof mounted systems is inadequate, ground mounted systems, walkway systems, or carport systems may be a possibility. Ground mounted systems are more accessible, but may be subject to vandalism or theft.

Project economics depend strongly on government support in the form of grants and/or tax credits (30 percent of project cost) and accelerated depreciation benefits (five year). The development model will depend strongly on the likelihood of attracting government funds for a project. Projects with relatively less grant funding may need to secure a third party developer in order to monetize potential tax credits and accelerated depreciation benefits.

Stationary Fuel Cells

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

Figure VII – Fuel Cell System[28]



Fuel cells can be used to provide electricity for vehicle, stationary and portable power applications. Stationary power is the most mature application for fuel cells. Stationary fuel cell units are used for

[28] UTC Power, "HOW A FUEL CELL WORKS – PureCell System," http://www.utcpower.com/files/DS0118_PureCell_HIW.pdf, December 6, 2008

backup power, power for remote locations, distributed generation for buildings, and co-generation (in which excess thermal energy from electricity generation is used for heat). In general, the thermal energy produced by fuel cells is suitable for space heating/cooling, domestic hot water, and process hot water applications.

While there are several types of fuel cells, there are currently three commercially available fuel cell technologies for stationary power applications: phosphoric acid, molten carbonate, and solid oxide. Phosphoric acid fuel cells are currently only available in 400 kW systems; molten carbonate fuel cells are currently available in 300 kW, 1,400 kW, and 2,800 kW systems; and solid oxide fuel cells are available in 100 kW and 200 kW systems. These base fuel cell units can be, and often are, combined for greater capacity and an increased economy of scale. Phosphoric acid and molten carbonate fuel cells that provide thermal energy can reach higher system efficiencies (≈90 percent) than electric only (solid oxide) fuel cells that have a system efficiency of approximately 52 percent. Nonetheless, the efficiency of solid oxide fuel cells is typically greater than distributed conventional electric generation technologies. Further, the thermal energy produced by phosphoric acid and molten carbonate fuel cells in combined heat and power mode must also be of the appropriate temperature and volume to meet the thermal energy requirements of the end user.

In general, there are no siting issues expected with a stationary fuel cell. A 400 kW fuel cell is approximately 29 feet long by 11 feet wide by 9 feet tall, and produces less than 60 dBA at 33 ft with full heat recovery. When siting a fuel cell, it would be advantageous to locate the fuel cell proximate to the building(s) that it will serve. Other siting criteria to consider when evaluating potential buildings for the installation of a fuel cell system include:

- Sites that are serviced by, or proximate to, natural gas or methane
- Sites that have a fairly constant electric demand throughout the day and year
- Sites with a substantial domestic hot water demand and/or significant cooling and heating loads.

Economic and technical modeling using monthly thermal data and electric consumption data from the Depot Campus fifteen-minute electric consumption data indicates that the fuel cell could provide approximately 72.8 percent of the Depot Campus's power and achieve a system efficiency of approximately 52 percent without the use of absorption chillers or thermal energy for biodiesel production. Project economics depend strongly on government support in the form of grants and/or tax credits (30 percent of project cost) and accelerated depreciation benefits (five year). Projects may need to secure a third party developer in order to monetize potential tax credits and accelerated depreciation benefits.

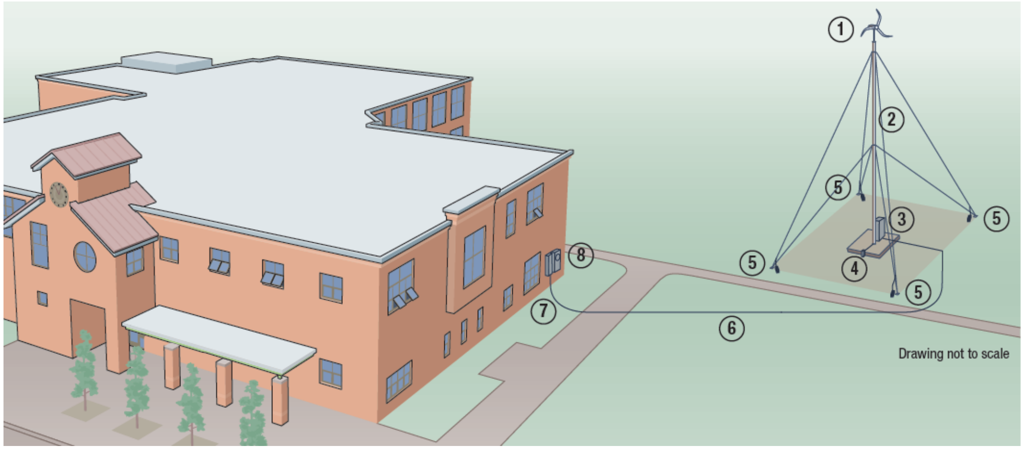
Small Scale Wind

All wind turbines function by capturing kinetic energy in the wind and turning it into mechanical power. Blades capture the wind over their swept area to turn a shaft, which connects to a generator to produce electricity.[29] Small wind systems typically range in size from 20 watts to 100 kW.[30]

In general, large scale wind energy systems (> 100 kW) may not feasible at the Depot Campus because wind speeds typically approximate Class 1 conditions. (12.5 mph or less at 50 meters).[31,32] The Clean Energy Finance and Investment Authority (CEFIA – formerly the Connecticut Clean Energy Fund) funded a Small Wind Turbine Demonstration Program to determine the broader feasibility of small wind systems in Connecticut.[33] In general, the economics of small wind energy systems at the Depot Campus may not be attractive without financial support because of the availability of adequate wind resources at hub heights less than 50 meters above ground level.

As depicted in Figure VIII, a tower-mounted horizontal axis turbine system typically consists of a wind turbine, a guyed or self supporting tower, foundations for the tower and guy wires, tower guy wires, electrical grounding, electrical power meter or interconnection point.

Figure VIII – Small Wind System[34]



[29] U.S. DOE EERE, "How Does a Wind Turbine Work?," http://www1.eere.energy.gov/wind/wind_animation.html, September 23, 2011

[30] U.S. DOE EERE, "Small Wind Electric Systems – A U.S. Consumer's Guide," http://www.nrel.gov/docs/fy07osti/42005.pdf, 2002

[31] NREL, "Wind Resources (50m) United States," http://www.nrel.gov/gis/images/map_wind_national_lo-res.jpg, December 12, 2008

[32] NREL, "Connecticut 50 m Wind Power," www.windpoweringamerica.gov/pdfs/wind_maps/ct_50m.pdf, February 6, 2007

[33]CEFIA, "Small Wind Turbine Demonstration Program – Program Overview," http://www.ctcleanenergy.com/YourBusinessorInstitution/SmallWindTurbineDemonstrationProgram/tabid/374/Default.aspx, March 2012

[34] NREL,"Wind for Schools Project Power System Brief - Wind Powering America Fact Sheet Series," http://www.windpoweringamerica.gov/pdfs/schools/project_system_brief.pdf, May 2009

Table VIII – System Components for a Typical Small Wind Power System[35]

1	**Wind Turbine**
2	**Guyed Tower**
3	**Tower/Turbine Base Fused Disconnect and Junction Box**
4	**Main Foundation for the Turbine and Tower**
5	**Tower Guy Wire Foundations and Electrical Grounding**
6	**Electrical Connection**
7	**Disconnect and Junction Box**
8	**Electrical Power Meter or Interconnection Point**

Aside from the presence of adequate wind resources, technical considerations for mounting wind turbine systems include ease of interconnection under various scenarios. Roof mounted systems may be the least costly because the electrical interconnections are more readily available. Moreover, roof mounted systems also have the advantage of not requiring the use of additional land area to site the turbine. Other siting criteria to consider when evaluating potential buildings/areas for the installation of a small wind turbine system include:

- Sites that provide unobstructed wind resources
- Building/structure capable of supporting renewable energy equipment without significant reinforcing

Biofuels

Biomass energy resources and biodiesel can both be considered for deployment at the Depot Campus. Biomass gasification involves the use of biomass as a feedstock, (forest, agricultural, and certain organic wood wastes), heat, and pressure in a controlled gasifier environment to make a hydrogen-rich fuel. This hydrogen rich fuel can then be used by various technologies to produce electricity and thermal energy. The use of biomass for solid-fuel boilers, which are designed to burn agriculture crop residues, such as corn stover or wheat straw, forest residues, etc. could also produce steam or hot water. The biomass

[35] NREL,"Wind for Schools Project Power System Brief - Wind Powering America Fact Sheet Series," http://www.windpoweringamerica.gov/pdfs/schools/project_system_brief.pdf, May 2009

steam can be used in a topping-cycle electrical generator to produce electricity first, then low-pressure steam or hot water for other thermal purposes with the turbine-generator exhaust steam.

Biodiesel is a renewable fuel that can be manufactured from new and used vegetable oils, animal fats, and recycled restaurant grease. Biodiesel's physical properties are similar to those of petroleum diesel, but it is a cleaner-burning alternative. The use of biodiesel can substantially reduce emissions of pollutants that impact air quality, and greenhouse gas emissions[36] Biodiesel can be produced using a variety of esterification technologies. The oils and fats are filtered and preprocessed to remove water and contaminants. If free fatty acids are present, they can be removed or transformed into biodiesel using special pretreatment technologies. The pretreated oils and fats are then mixed with an alcohol (usually methanol) and a catalyst (usually sodium hydroxide or potassium hydroxide). The oil molecules (triglycerides) are broken apart and reformed into methyl esters and glycerin, which are then separated from each other and purified.

The transesterification reaction, which results in biodiesel and glycerine from methanol, a catalyst, and a feedstock occurs at a relatively low temperature of between 113° F to 122° F. A thermal source at 140° F, which is the low grade thermal energy byproduct from a fuel cell, would be ideal because it would provide approximately 20° F thermal to promote heat transfer. A biodiesel reactor based on a continuous reaction would be well served to utilize the thermal output of a baseload fuel cell application.

Siting criteria to consider when evaluating potential buildings/areas for the installation of a biodiesel production plant includes:

- Sites with access to both water and sewer service connections
- Sites at or near a source of biomass energy resources
- Truck access for the transport of the feedstock, production materials, finished product, or waste materials.
- Opportunity to use waste heat to reduce process costs

Biodiesel Fueled Electric Generation

The Depot Campus currently has approximately 700 kW of electric generating capacity, consisting of six emergency generators ranging in size from 80 to 180 kW each. As detailed in Table IX, these emergency

[36] U.S. DOE EERE, "VEHICLE TECHNOLOGIES PROGRAM – Biodiesel Basics," http://www.afdc.energy.gov/afdc/pdfs/47504.pdf, February 2011

generators are all fueled with diesel and have a fuel consumption rate ranging from 7.9 to 13.8 gallons per hour. However, these generators are between 15 and 30 years old, and may not be efficient or reliable, and may be subject to replacement with newer more efficient generation. There may also be an opportunity to selectively use B100 biodiesel in these generators during the summer to generate electricity for peak shaving and demand response applications. Since the fuel would be 100 percent biodiesel, output from the generators operated on 100 percent biodiesel would be classified as Class I renewable energy. However, changes to the operation of these emergency generators may require modification to their air permitting status, which would be addressed through the Connecticut Department of Energy and Environmental Protection.

Table IX - Electric Generating Capacity at the Depot Campus[37]

Description	Kennedy Building Generator	Surplus Warehouse Generator	Chaplin Cottage Generator	Ellington Cottage Generator	Willington Cottage Generator	Willimantic Cottage Generator	Merritt Hall Generator
Capacity	180 kW	80 kW	120 kW	100 kW	100 kW	100 kW	85 kW
Construction Date	1994	1994	1980	1985	1985	1985	Unknown
Maximum Rated Input Capacity (MMBtu/Hr	1.89	1.08	1.14	1.08	1.08	1.08	0.79
Fuel Type	diesel	diesel	diesel	diesel	diesel	diesel	diesel
Fuel Consumption Rate (GPH)	13.80	7.90	8.30	7.90	7.90	7.90	5.8
Actual Hours/year	75.8	68.5	80.4	54.8	56.5	56	75
Actual Annual Fuel Consumption Rate (Gallons)	1046	541	667	432	446	442	433

[37] Information obtained from the University of Connecticut air emissions inventory (2010).

Renewable energy systems typically have higher capital costs than conventional technologies, however, these systems can be more efficient, are much cleaner, and help to reduce the consumption of fossil fuels. As detailed in Table X below, fuel cells can provide electricity at 22.8 cents per kWh when all thermal energy from the fuel cell is used by the facility and natural gas supplied to the fuel cell costs $8/MMBtu. Under these cost conditions, the fuel cell provides electricity competitive with the grid. Photovoltaic (PV) and small wind power systems currently do not provide economically competitive power relative to the grid. Biodiesel powered generation would be used for peak shaving and/or demand response rather than base load generation. As such, a comparison is not readily made with other technologies.

Table X - Delivered Cost, Size, and Emissions for Renewable Energy Systems[38]

Technology	Size Range (kW)	Installed Cost ($/kW)	Efficiency (percent)	Delivered Cost of Energy[39] (¢/kWh)	Variable O&M ($/kWh)	Emissions (lb/kWh)	
						NO_x	CO_2
Fuel Cell	300+	≈$5,500 to $8,000	84-90 percent	22.8¢ to 34.88¢	0.01-0.05	0.000015	0.85
Solar Photovoltaics (PV)	Space dependent	≈$6,800	N/A	51.7¢ to 132¢	0.0182	0	0
Small Wind	20 watts – 100 kW	≈$5,430	N/A	138¢ to 231¢[40]	.09	0	0
Biodiesel (B100) Fueled Gensets	varies	Use of existing generators	31 percent (LHV)	N/A	3¢	0.000577	0.465084

Thermal Energy

Renewable and advanced energy technologies also exist to serve thermal applications. The two most common applications for providing thermal energy, and are considered renewable for the purpose of funding eligibility

[38] U.S. DOE EERE, "Federal Energy Management Program," http://www1.eere.energy.gov/femp/technologies/derchp_derbasics.html, February 3, 2012

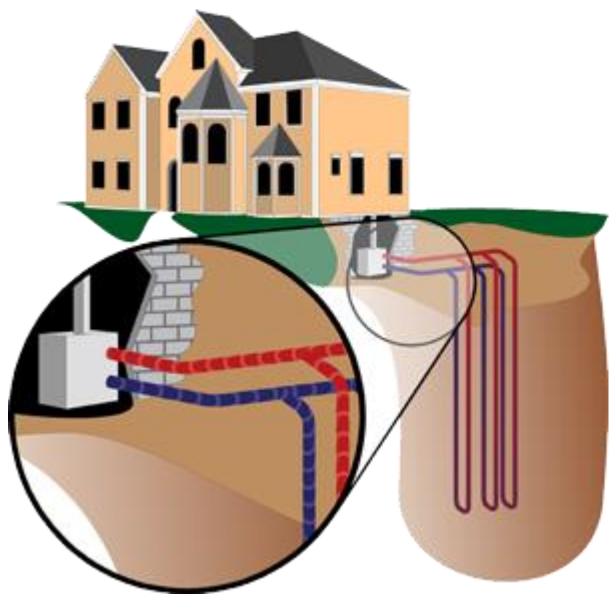
[39] The lower bounds of the delivered cost of energy includes: (1) federal investment tax credits, (2) accelerated depreciation, and (3) host site expectations for profitability as constrained by state performance incentives. The upper bounds assumes development without federal investment tax credits and accelerated depreciation (i.e. development on a non-profit basis) but assumes host site expectations for profitability remain unchanged.

[40] NREL, "In My Backyard," http://www.nrel.gov/eis/imby/, December 23, 2012

by the state of Connecticut, include solar thermal and geothermal technologies. Solar thermal technology use sunlight to capture thermal energy primarily for use in domestic hot water applications. Other applications include space heating and pool heating. Geothermal technology uses the relatively constant temperatures in the ground to provide heating during the winter, or to remove thermal energy during the summer for cooling. Other non-traditional advanced technologies that can also be used to provide cooling and shift the peak electric demand includes ice storage.

Ground Source Heat Pumps

Figure IX – Geothermal Heat Pump System[41]



Ground source heat pumps (GSHPs), also called geothermal heat pumps, are used for space heating and cooling as well as water heating. GSHPs utilize the naturally occurring thermal energy from the ground in order to provide heating and cooling to buildings.[42] Heat pump systems offer individual space temperature controls and work best for systems with multiple zones. Heat pump systems also fit well into systems with a dedicated outside air system (DOAS) with a conventional heat source because heat pumps do not provide a high enough temperature rise to accommodate directly heating outside air. The major components of a geothermal heat pump system include:

- Geothermal earth connection subsystem: Using the earth as the heat source and heat sink, this subsystem consists of a series of pipes for energy collection, which are commonly called a "loop." They carry a fluid used to connect the geothermal system's heat pump to the earth.

- Geothermal heat pump subsystem: An electric heat pump that exchanges heat between the fluid and the air that conditions the building.[43]

[41] Connecticut Clean Energy Fund, "Geothermal Heat Pump Incentive Program – Commercial," www.ctcleanenergy.com/YourBusinessorInstitution/GeothermalIncentiveProgramCommercial/tabid/521/Default.aspx, march 2012

[42] U.S. DOE EERE, "Geothermal Technologies Program," http://www1.eere.energy.gov/geothermal/heatpumps.html, February 16, 2012

[43] Geothermal systems typically also use a compressor with a refrigerant cycle and condenser that is cooled by the ground or ambient air temperatures.

- Geothermal heat distribution subsystem: An air-delivery system that delivers the conditioned air to the building

Water-source heat pump systems generally cannot be retrofit into existing systems unless it is a direct expansion system with a water-cooled condenser. However, use of existing wells may provide an opportunity for the supply of thermal energy without the added costs associated with well installation. At this time, commercial heat exchange products that extract thermal energy from existing well water infrastructure are not well developed, but this application may represent an opportunity for selected development using student resources.

Siting criteria to consider when evaluating potential buildings/areas for the installation of a GSHP includes:

- Sites that utilize boilers/furnaces to provide thermal energy
- Buildings that have significant cooling loads and are not served by the “chill” loop
- Sites with or near equipment used for absorption chilling
- Sites that have chilled water cooling (as this will allow the CHW piping system to be used for the GSHP loop)
- Sites that have cooling and heating loads during the winter

Solar Thermal

Solar thermal technology captures sunlight to make thermal energy for use in domestic hot water, space heating, or power generation applications.

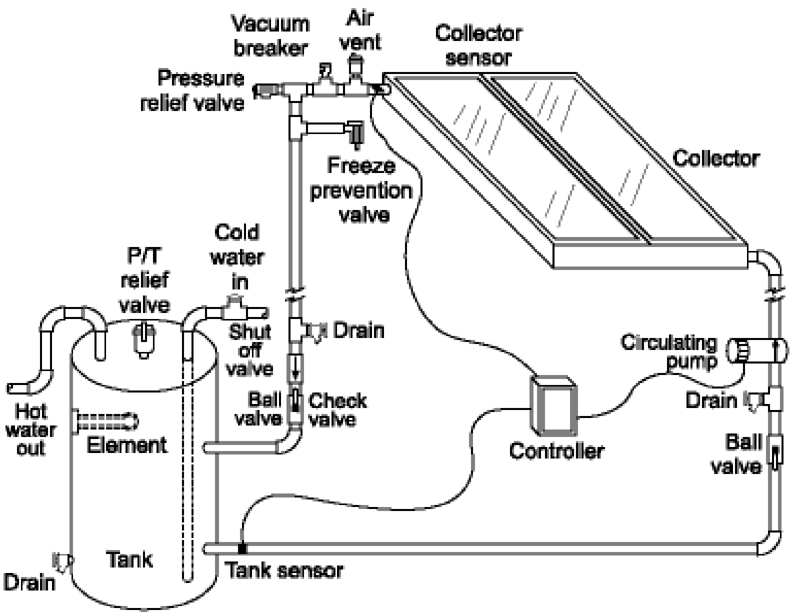
Solar thermal collectors are classified as low, medium, and high-temperature collectors:

- Low-temperature collectors provide low-grade heat (less than 110 degrees Fahrenheit), through either metallic or nonmetallic absorbers, and are used in such applications as swimming pool heating and low-grade water and space heating.

- Medium-temperature collectors provide medium-grade heat (usually 140 F to 180 F), either through glazed flat-plate collectors using air or liquid as the heat transfer instrument, or concentrator collectors and are mainly used for domestic hot water heating. Evacuated-tube collectors are also included in this category.

- High-temperature collectors are parabolic dish or trough collectors designed to operate at a temperature of 180 F or higher, and are primarily used by utilities and independent power producers to generate electricity for the grid.

Figure X – Solar Thermal System[44]



There are two types of solar thermal systems: active, which have circulating pumps and controls, and passive, which do not.

Passive solar water heating systems are typically less expensive than active systems, but are less efficient. However, passive systems can be more reliable and may last longer.

Roof mounted solar thermal systems are fixed mounted. As depicted in Figure X, solar thermal systems typically include one or more solar thermal collectors, which heats water, and a storage tank. The system produces savings by reducing the amount of fossil fuel that would be consumed to produce thermal energy (Btus) for water heating.

Siting criteria to consider when evaluating potential buildings/areas for the installation of a solar thermal system includes:

- Sites with sun exposure for 6-8 hours per day
- Building/structure capable of supporting renewable energy equipment without significant reinforcing
- Building/structure has flat roof or sufficient pitch and orientation to maximize solar potential
- Building/structure area sufficiently large to support renewable energy equipment
- Building/structure roof materials allow installation of renewable energy equipment and will not need to be replaced within the life of the renewable energy equipment
- Sites that utilize oil-fired boilers/furnaces to provide thermal energy
- Sites with a substantial domestic hot water demand

[44] U.S. DOE, NREL, Sandia National Laboratories, "Solar Thermal Systems: Solar Heating R&D," http://www.nrel.gov/docs/gen/fy04/36831m.pdf, 2004

Under current conditions, solar thermal systems are best sized to function with existing thermal generation/storage infrastructure at a facility. Assuming a system efficiency of 40 percent, and proper system orientation, grid purchased natural gas costing approximately $14/MMBtu[45] and a grant of $550/MMBtu of useful thermal output (not to exceed 75 percent of system cost), systems costing approximately $1,600/M^2 have a simple payback of approximately 15 years. While not necessarily financially attractive relative to other investment opportunities, systems approximating these cost conditions can achieve a payback well within their useful life. Furthermore, solar thermal systems provide emissions reductions throughout the life of the system. Such reductions are dependent upon the thermal output of the solar thermal system and the resultant fuel that is displaced from the conventional thermal generation system.

Thermal Storage

Thermal storage technology uses renewable energy, waste heat, and off-peak power, usually during the evening, to produce thermal storage (such as ice) for cooling in order to reduce peak cooling loads. The thermal storage medium can include ice, eutectic salts, and low-temperature chilled water. Phase-change (freezing and thawing) materials provide the most storage capacity in ton-hours for the volume of storage. Low-temperature chilled water takes up more room, but has the advantage of being inexpensive and simple to use.

There are two general strategies that determine the size of the system: full storage and partial storage.

1. Full storage – the system is sized to ensure that enough ton-hours are stored to eliminate the need for mechanical refrigeration during the peak period. This removes the electrical load entirely from the peak electrical demand and should reduce peak electrical consumption costs.

2. Partial storage – the system is sized to provide a percentage of the peak load ton-hours. The existing conventional system will provide the remaining ton-hours during the peak period.

Thermal storage works best under the following conditions:

- The building is unoccupied for a significant part of the night. With the need to cool the spaces eliminated, the existing equipment can store all its available cooling energy.

- The existing equipment has the capability of operating at low evaporator temperatures.

- There is room and structural support for the storage containers.

[45] Accounts for combustion and distribution losses

Incentives

Federal Incentives

The federal government offers owners that install certain renewable energy technologies an energy tax credit per Section 1336 of the Energy Policy Act of 2005, which was extended through 2008 by Section 207 of the Tax Relief and Health Care Act of 2006 (H.R. 6111). The energy tax credit was extended again via the Emergency Economic Stabilization Act of 2008 (H.R. 1424), signed into law on October 3, 2008. The tax credits described below are for renewables placed into service on or before December 31, 2016. Under the Treasury's Grants in Lieu of Tax Credits program, tax credits may be taken as grants and vice versa.[46] Grants are outlined as follows:[47]

- Incentives for small wind turbines are equal to 30 percent of the basis of the property for small wind turbines. Eligible small wind property includes wind turbines up to 100 kW in capacity.
- Incentives for qualified facilities are equal to 30 percent of the basis of the property for qualified facilities that produce electricity. Qualified facilities include wind energy facilities, closed-loop biomass facilities, open-loop biomass facilities, geothermal energy facilities, landfill gas facilities, trash facilities, qualified hydropower facilities, and marine and hydrokinetic renewable energy facilities.
- Incentives for geothermal heat pumps are equal to 10 percent of the basis of the property for geothermal heat pumps.
- Incentives for combined heat and power (CHP) are equal to 10 percent of the basis of the property for CHP. Eligible CHP property generally includes systems up to 50 MW in capacity that exceed 60 percent energy efficiency, subject to certain limitations and reductions for large systems. The efficiency requirement does not apply to CHP systems that use biomass for at least 90 percent of the system's energy source, but the incentive may be reduced for less-efficient systems.
- Incentives are equal to 30 percent of the basis of the property for solar energy. Eligible solar-energy property includes equipment that uses solar energy to generate electricity, to heat or cool (or provide hot water for use in) a structure, or to provide solar process heat. Passive solar systems and solar pool-heating systems are not eligible. Hybrid solar-lighting systems, which use solar energy to illuminate the inside of a structure using fiber-optic distributed sunlight, are eligible.

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[46] U.S. Department of Treasury, "1603 Program: Payments for Specified Energy Property in Lieu of Tax Credits," http://www.treasury.gov/initiatives/recovery/Pages/1603.aspx, January 18, 2012

[47] Dsireusa.org, "U.S. Department of Treasury – Renewable Energy Grants," http://www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=US53F&re=1&ee=1, November 29, 2011

- Incentives for fuel cells are equal to 30 percent of the basis of the property for fuel cells. The incentive for fuel cells is capped at $1,500 per 0.5 kilowatt (kW) in capacity. Eligible property includes fuel cells with a minimum capacity of 0.5 kW that have an electricity-only generation efficiency of 30 percent or higher.

State Incentives

In addition to exemptions from sales and use tax for selected technologies made available through legislation (see Appendix II on state incentives), the State of Connecticut has incentives to encourage the development of renewable energy and energy efficiency projects. On July 1, 2011, the State of Connecticut enacted Public Act 11-80: An Act Concerning the Establishment of the Department of Energy and Environmental Protection and Planning for Connecticut's Energy Future. This Public Act contains many provisions that may impact the development and use of energy throughout the State (See Appendix I). The Public Act created CEFIA and the Connecticut Department of Energy and Environmental Protection (DEEP). These two state entities will administer programs that may provide incentives to promote the development and use of renewable energy technologies. It is unclear how the existing programs (see Appendix I) administered by the state will change or if existing financial resources will be reallocated. In addition, funding and incentives available through the American Recovery and Reinvestment Act of 2009 (ARRA) and administered by the state, significantly increased financial resources for the development of energy projects across the nation.

CEFIA can potentially assist with the provision of grants to help finance certain renewable energy installations. DEEP can also potentially assist with incentives for the development of renewable energy facilities through the approval of long term contracts for LRECS (low emissions renewable energy credits) and ZRECS (zero emissions renewable energy credits), which would provide revenue for the production of renewable energy. CEFIA programs are funded by a surcharge on electric utility customers, based on the amount of electricity a customer uses, and through ARRA funds. The long term contracts would be established through the local electric service provider and funded through the electric rate base. Funding is expected to be available for zero emissions and low emissions renewable energy technologies. The specific details of the new LREC and ZREC funding mechanisms have yet to be released.

The Connecticut Public Utilities Regulatory Authority (PURA)(formerly the Department of Utility Control) provides key low interest financing for customer owned distributed energy resources in the State of Connecticut. The energy efficiency programs administered by the electric and natural gas utilities, and regulated by the PURA, provide incentives for energy efficient commercial new construction and retrofit programs. In addition, the PURA has a significant amount of incentive money available through its Energy

Efficiency Partners program for technologies that reduce peak demand. The PURA currently offers grants for $950/ton of installed capacity for direct-expansion ice based thermal storage systems through its Energy Efficiency Partners program.[48] For more information regarding available incentives offered through the PURA, see Appendix II.

The State of Connecticut also supports a Biodiesel Production and Distribution Grant Program, which provides funding to qualified Connecticut biodiesel producers for the production of biodiesel. Funds are administered by CCAT with funding provided by the Department of Economic and Community Development from December 1, 2007 to January 31, 2012. The Program was developed in order to increase economic growth opportunities for Connecticut's clean energy sector and promote a greater use of biodiesel; advance technological innovation in biodiesel; increase public confidence, support and awareness for biodiesel; support the development of biodiesel production and distribution equipment and facilities; and reduce dependence on fossil fuel consumption, and greenhouse gas emissions. The current grant for qualified biodiesel producers is ten cents per gallon of biodiesel (B100) produced.

Implementation Targets

As discussed above, there are several renewable and advanced energy technologies that may be appropriate at one or more buildings at the Depot Campus. Several buildings, identified as being high energy users, have been selected as examples for the integration of renewable and advanced energy technologies at the Depot Campus, as follows:

Center for Clean Energy Engineering (C2E2) - Fuel Cell

The Center for Clean Energy Engineering (C2E2) operates as a multidisciplinary research, education and outreach center focusing on sustainable energy engineering. The main building consists of both laboratory and office/meeting space. While the Depot Campus is master metered, C2E2 is submetered and therefore it was possible to assess electric demand and use based on 15-minute interval data. The actual annual electric demand from March 9, 2010 through March 8, 2011 was 435,059 kWh, with minimum and maximum values for this period of 18 kW and 121 kW, respectively. The main bus of the C2E2 building electrical service distribution panel is rated for 1,000 Amps and the main disconnect switch is rated for 1,200 Amps. The peak Amps output of a 400 kW fuel cell is approximately 589 Amps (at 480 Volts; 3-phase). A 400 kW fuel cell is estimated to generate approximately 3.3 million kWh per year. The

[48] CT Department of Public Utility Control, "$ViewByTechnologyView," http://www.dpuc.state.ct.us/dpucelectricefficiencypartners.nsf/f2ac2226676a8cd885257625004eb8be?OpenView, March 2012

electrical output from a 400 kW fuel cell would greatly exceed the electrical requirement for C2E2, but as discussed previously, since the Depot Campus is master metered and since state policy allows for net metering, all of the electricity produced is expected to be consumed by users at the Depot Campus.

Natural gas consumption for heating for C2E2 ranges from a monthly minimum of approximately 10 MMBtu during the summer to a monthly maximum of approximately 620 MMBtu during the winter, with an annual demand of 2,320 MMBtu. The thermal input (natural gas) for a 400 kW fuel cell operating at a capacity factor of 95 percent would have a natural gas demand of approximately 31,500 MMBtu per year, and a thermal output of approximately12,800 MMBtu. The building heating system is not compatible with a direct interface connection to the fuel cell thermal output. In order to use the fuel cell thermal output for building heat at C2E2 a hot water heating distribution system will need to be designed and retrofit into the packaged rooftop units as well as the heating and ventilating units. This will require the installation of all the pumps, pipes, insulation, hot water coils, and control equipment necessary to convert the direct-fired natural gas heating equipment to air-handling units that heat the building with indirect-fired hot water coils. However, the fuel cell thermal output could be used to provide the heat source for heat pump equipment during the winter, or if water-source heat pumps are added to the high-bay areas for summer cooling.

Thermal energy from a 400 kW fuel cell at C2E2 could also be utilized by the Longley building and/or the Brown building. Overall, the Longley building, located approximately 700 feet north of C2E2, represents the largest building on campus, with correspondingly the greatest thermal energy consumption. The peak heating load for the Longley building is greater than the heat recovery output of a 400 kW fuel cell. In terms of system integration, an engineering walkthrough revealed that there is a higher-temperature hot water heat system for radiators that can use the “high grade” heat recovery from a fuel cell at 250° F through a heat exchanger. There is also lower-temperature hot water radiant heat system that can use the remaining “low grade heat recovery at 140° F through a heat exchanger. There is no central cooling at this building, which may make it difficult to use an absorption chiller during the summer to utilize the heat recovery from the fuel cell. However, the gymnasium, which is currently being used for storage, could be used for biodiesel production, thereby using the unused heat recovery from the fuel cell during the winter, and all of the heat during the summer. This is discussed in greater detail below.

The thermal energy from a 400 kW fuel cell at C2E2 could also be utilized by the Brown building, located approximately 500 feet southwest of C2E2. The Brown building has a shell-and-tube heat exchanger that converts steam to hot water for a perimeter baseboard heating system. Hot water from the fuel cell could be piped to the Brown building and connected to the existing hot water baseboard heating system for use during the heating season. Utilization of the thermal energy from a 400 kW fuel cell for heating, cooling and biodiesel production would improve system efficiency and significantly improve project economics providing a greater return on investment.

Center for Clean Energy Engineering (C2E2) - Demonstration PV Site

C2E2 was examined for multiple technology applications, including the development of a PV power system for the following reasons: the main entrance to the facility faces almost due magnetic south with an inclined roof along the south-facing plane; the site is expected to have sun exposure for 6-8 hours per day; the building is visited by students, faculty, staff, and visitors; the building has a daytime (peak) electric demand, and there is adequate space and capacity in the building’s MDP to interconnect with the PV system’s output. However, no structural analysis of the building was undertaken as part of this study.

Based on the building’s roof area, a 10 kW PV system could be installed at C2E2. A 10 kW PV system located at the Depot Campus is expected to generate approximately 11,520 kWh per year, or 11.52 MWh which represents approximately 2.6 percent of the annual electric demand for C2E2.

A 10 kW PV system is anticipated to cost $68,000, based on the average cost ($6.80/kw) of PV systems installed through CEFIA’s Onsite DG Program last year. Actual project costs may be higher or lower. CCAT also assumed an operations and maintenance cost of 1.82 cents per kWh in the modeling process. Actual maintenance may be higher or lower, depending on factors such as the weather and labor costs. Maintenance for PV systems is generally minimal because of the absence of moving parts; however, inspection of the system and components should be performed monthly to ensure system performance.

Utilization of all tax credits and accelerated depreciation benefits associated with the potential PV system project would significantly improve project economics providing a greater return on investment. A 10 kW PV project could achieve a positive cash flow for all years if a fifteen year finance period is selected to match the grant payment period (at $.385/kWh) of the ZREC program at an avoided electricity cost of 13.20 cents per kWh (a total energy value of $.517/kWh). The project would have an eight year payback, an internal rate of return of 9.42 percent, and a NPV of $6,449 (assumes an installed cost of $6.80 per watt, and a seven percent discount rate). Similar economics would apply to other buildings at the Depot Campus.

Longley Building - Ground Source Heat Pump

Longley Building is currently cooled by multiple window air conditioners. Window air conditioners are usually the least efficient type of mechanical cooling equipment, and are not easily controlled. Often, window air conditioners over-cool a space and are routinely left operating when the space is unoccupied, such as at night and/or over weekends, etc. The installation of a water-source heat pump system connected to a ground-source heat sink/source could be used to replace the existing window air conditioners. The area around the Longley Building appears to favor wells rather than a horizontal field; however, a detailed investigation is needed to determine the installation specifics. A single well might support up to 1,750 square feet of cooling, which could cool the same area as approximately six or seven window air conditioners and provide anywhere from three to six different zone controls for greater space temperature accuracy and automated controls.

A ground source heat pump could also be used to replace the existing hot water heating equipment in the spaces that are retrofit. The existing low-temperature hot water radiant heating system could be used as a supplemental backup heat source to minimize initial costs. When, and if, the need for supplemental heat is verified and quantified, a more efficient condensing boiler system can be installed.

Thompson Building - Ground Source Heat Pump

Thompson building has a central chilled water system that may be suitable for conversion to a ground-source heat pump system. The chilled water piping from the chillers to the chilled water coils in the air-handling units may also be able to serve as the heat pump loop between the ground-coupled heat source/sink and new water-source heat pumps air-handlers inside the building. Thompson building is currently served by two natural gas fired hot water heaters, a dual fuel boiler (natural gas and oil), and a 40-ton chiller. The GSHP system may be able to provide 41 percent of the building heating requirement at a considerable savings over supplying the heat from the boiler. The GSHP system will also be able to provide 100 percent of the chilled water cooling capacity at a reduced cost of 30 to 50 percent of the existing cooling system.

To replace the existing cooling system with a GSHP would require the following:

- Replace the existing chilled water air handling unit with a water-source heat pump (WSHP) air handling unit.
- Install the ground-coupling system. Space limitations would indicate that a well system would be the best option.

- Connect the existing chilled water pumps to the new GSHP well system.

Assuming a 600-foot deep well will support two tons, the replacement of the existing 40-ton chiller would require twenty wells spaced at least fifteen feet apart. Therefore, the well field would require a space of approximately 60 feet by 75 feet. Assuming that the GSHP system will displace 41 percent of the heating requirement and will match the existing 40-tons of cooling, the cost of the system is estimated to cost approximately $400,000[49]. The cost of a geothermal system will depend on whether the system will require drilling vertically deep wells, use existing wells, or use loops in a horizontal fashion below ground. The cost of drilling wells also will vary depending on the terrain, depth, and other local factors.[50]

Longley Building - Demonstration Wind Site

The Longley Building is estimated to have a high electricity demand; is located at a relatively high elevation in the northern corner of the Depot Campus where available wind resources are expected to be unobstructed by significant vegetation or other structures; and provides good visibility along Route 44.

An assessment of the wind resources at the Depot Campus indicates that the monthly average wind speed is generally less than 12 MPH at hub heights less than 50 meters above ground level; however, a 10 kW system is still expected to produce 5,305 kWh per year. According to the United States Department of Energy: Energy Efficiency and Renewable Energy agency, small wind turbines have a capital and installation cost of approximately $5,430 per kW of installed capacity.[51]

The results of CCAT's financial modeling indicate that a 10 kW small wind system installed at the Depot Campus would not achieve a financial payback within the projected life of the system. The primary driver behind this is the initial cost of the system and the lack of sufficient wind resources in the area. However, with a capital grant of $23,000, a 10 kW small wind system could achieve a four year financial payback, an internal rate of return of 11 percent, and a net present value of $4,621 over the twenty five year life of the system; the financial modeling also assumed an installed cost of $5.43 per watt, a ZREC of $0.385/kWh for fifteen years, a discount rate of seven percent, and that all applicable tax credits and accelerated depreciation benefits were monetized.

[49] Clean Energy Finance and Investment Authority, Geothermal Heat Pump Incentive Program - Commercial http://www.ctcleanenergy.com/YourBusinessorInstitution/GeothermalIncentiveProgramCommercial/tabid/521/Default.aspx, March 2, 2012

[50] The University of Alabama, Geo-Heat Center, Oregon Institute of Technology "Cost Containment for Ground-Source Heat Pumps," http://geoheat.oit.edu/pdf/tp72.pdf, Kavanaugh, Steve; Gilbreath, Christopher, December 1995

[51] U.S. DOE EERE, "Small Wind Electric Systems – A U.S. Consumer's Guide," http://www.nrel.gov/docs/fy07osti/42005.pdf, 2002

As a demonstration project, a small, roof-mounted wind turbine is technically feasible since it will be easier to connect electrically; however, project economics are not favorable without significant grant funding. Similar economics for small scale systems would apply to other buildings at the Depot Campus.

Longley Building - Demonstration Biofuels Site

As discussed previously, one method for utilizing the thermal energy produced by a fuel cell at the Depot Campus involves the development of a biodiesel production facility. Interest from UConn faculty has been raised in developing a biodiesel production facility with a capacity to produce approximately 150,000 gallons per year. It is estimated that the biodiesel production operation could absorb over 1,000 MMbtus of thermal energy from a fuel cell, which would equate to approximately 14 percent of the thermal energy output from a 400 kW phosphoric acid fuel cell. A fuel cell installed at C2E2 or the Longley Building could provide the thermal energy to support a biodiesel production facility.

Facility requirements for a biodiesel production facility with a boiler plate capacity rate of 150,000 gallons per year would require an approximately 1,500 square feet of indoor space with a concrete floor, optimally being 50 feet long by 30 feet wide by 12 feet high in order to observe best safety practices.[52] Outdoor space requirements for methanol storage as well as the mixing unit to mix methanol and the potassium hydroxide catalyst together would be approximately 20 feet long by 10 feet wide by 12 feet high. In terms of utility service access, the facility would require 208 volt 3-phase power at 100 Amps[53] in addition to normal hot and cold running water at about 200 gallons per day. Other facility requirements would include a 2,500 gallon oil storage tank and a 2,500 gallon biodiesel output storage tank will be required. In addition, a loading dock is preferred but not necessary.[54]

An engineering walkthrough of Longley Building revealed that the Longley Building's central boiler is the largest boiler in the Depot Campus and the existing burner is rated for natural gas and # 2 fuel oil; however, this boiler currently uses natural gas only. An inspection of the Longley Building indicates that a portion of Longley, formerly used as a gymnasium and currently used for storage, has the space to accommodate the proposed biodiesel production facility. The building has access to both water and sewer service connections, is serviced or is proximate to natural gas; and has truck access for the transport of the finished product and for receiving waste vegetable oil or virgin vegetable oil feed stocks, methanol, and catalyst inputs. Outdoor space can accommodate the methanol storage and mixing unit. In terms of utility

[52] Currently, Professor Parnas of the Chemical Engineering Department has a 10,000 gallon per year biodiesel production facility located at the Center for Environmental Science and Engineering and is in favor of moving this operation to the Longley building

[53] Professor Parnas has indicated that a specification of 120 amps may be desired

[54] Personal communications with Dr. Richard Parnas, UConn.

service, the main switch in the MDP is rated at 600 Amps; 120/208 Volts, which would be adequate to meet the biodiesel production facility requirement for 208 volt 3-phase power at 100 Amps.

Willow House - Demonstration Solar Thermal Site

The Willow House Day Care is recommended for consideration of a solar thermal system because there is an inclined roof facing south-east above the existing DHW heater. In addition, the DHW use in a daycare center is expected to be greater than in an office or academic facility. The Willow House is visited almost daily by parents and care givers that utilize the building and services. Moreover, the location of Willow House provides good visibility along Route 32.

Based on the estimated DHW demands for the building, a 32 square-foot collector panel can potentially provide approximately 70 percent of the DHW heating requirements. The installation of a small tank in series with the existing DHW heater in the boiler will provide a convenient heat exchanger to preheat the DHW before it goes to the oil-fired heater. The thermal output from the proposed collectors was calculated to be approximately 7.0 MMBtu. Assuming fuel oil costs of $3.50 per gallon, the estimated fuel cost savings is expected to be approximately $177 per year.

Solar thermal systems, including capital and installation costs, are expected to cost between $100 per square foot (SqFt) and $200 per SqFt. Assuming an installed cost of $150 per SqFt, the 32 SqFt solar thermal system is estimated to cost approximately $4,800. Assuming an incentive from the CCEF Solar Thermal Program in the amount of $3,600 or $514/MMBtu (75 percent of the system cost), it is expected that the simple payback for the proposed solar thermal system would be approximately 7 years.

CONCLUSION

The Depot Campus at UConn is a unique setting of facilities and buildings that provides many opportunities to incorporate renewable and advanced energy technologies for improved energy management. Sites at the Depot Campus have been identified as examples for the development of renewable energy technologies, or for the development and use of renewable energy resources by conventional technologies. There are potentially many other sites on the Depot Campus that could utilize renewable and advanced energy technologies, such as small distributed PV systems. This plan identifies criteria for each renewable energy technology that can be used in the assessment of other potential locations. Based on the development of renewable energy technologies identified in this plan and the use of biodiesel in existing conventional generators, it would be possible to achieve the goal of the Green Depot Campus Initiative to validate and demonstrate a one megawatt (MW) system. Further, because of the master electrical meter at the Depot Campus and the distributed nature of the renewable energy technologies identified, utilizing smart grid technology, such as adaptive fuel switching and energy storage, could assist in utility load leveling.

Appendix I – Summary of Public Act 11-80[55]

On July 1, 2011, Governor Dannel P. Malloy signed into law Public Act 11-80 - An Act Concerning the Establishment of the Department of Energy and Environmental Protection and Planning for Connecticut's Energy Future. The legislation creates the Department of Energy and Environmental Protection (DEEP) by merging the Connecticut Departments of Environmental Protection (DEP) and Public Utility Control (DPUC). In addition, the legislation provides for the following energy-related planning and oversight responsibilities:

- renames the Public Utility Control Authority the Public Utilities Regulatory Authority (PURA)
- creates a quasi-public authority (the Clean Energy Finance and Investment Authority) to administer the Clean Energy Fund, rather than Connecticut Innovations, Inc.;
- requires the Clean Energy Finance and Investment Authority to establish a program to promote residential photovoltaic systems under which participants can choose to receive an up-front payment or a payment tied to the power the systems produce;
- expands the resources that can go into the Clean Energy Fund to include private capital and revenues reallocated to the fund by the legislature and expands the types of projects the fund can support to include electric and natural gas vehicle infrastructure, electricity storage, and the financing of energy efficiency;
- establishes three-year pilot programs to develop combined heat and power and anaerobic digester projects and provides $ 2 million annually for each of the programs;
- establishes a program that requires electric companies to enter into long-term contracts to buy renewable energy credits (RECs) from zero-emission generators (e. g. , solar, wind, hydro) and establishes a similar program for low-emission technologies;
- requires DEEP to develop a plan to reduce energy use in state buildings by at least 10 percent by 2013 and another 10percent by 2018; and
- explicitly authorizes state agencies and municipalities to enter into energy saving performance contracts.

[55] Connecticut Office of Legislative Research, "OLR Bill Analysis SB 1243," http://www.cga.ct.gov/2011/BA/2011SB-01243-R01-BA.htm, March 2012

Appendix II – State Incentives[56]

Funding Source: Clean Finance and Investment Authority (CEFIA)
Program Title: On-Site Renewable Distributed Generation (OSDG) Program
Applicable Energies/Technologies: Solar PV, Wind, Fuel Cell, Landfill gas, Waste heat recovery – power generation, Low emission advance biomass conversion, Hydropower meeting the standard of the Low-Impact Hydropower Institute
Summary: CEFIA is currently offering OSDG grants through an RFP format. The OSDG Best of Class, Public Buildings and Affordable Housing RFP will be offered to bridge the time until the launch of the Zero-Emission and Low-Emission Renewable Energy Certificate (REC) programs become available to the market and to prepare the market for the transition from a grant-based program model to a REC-based program model.
Restrictions: Solar PV- No maximum, but incentive is based on a maximum of 250 kW (AC)
Timing: The competitive, solar photovoltaic (PV) only RFP will close at 5:00 p.m. EST on December 30, 2011. The rolling submission, other technologies RFP will close at 5:00 pm. EST on March 30, 2012**.**
Maximum Size: N/A
Requirements: Projects will be evaluated on four major criteria: • PV Project Economics • Technology Appropriateness ("Deployment of the Technology") • Feasibility and Probability of Completion • Societal Benefits (such as in-state job creation, dissemination efforts, project diversity)
Rebate amount: Incentive amounts are calculated based on the project specifics, but the maximum incentive is $3.60/Watt (PTC) for systems 100 kW (AC) and smaller and $3.30/Watt (PTC) for systems greater than 100 kW up to 250 kW.
For further information, please visit: http://www.ctcleanenergy.com **Source:** CEFIA, "Supporting On-Site Generation Projects at Commercial and Government Facilities", "http://www.ctcleanenergy.com/YourBusinessorInstitution/OnSiteRenewableDG/OSDGRequestforProposals/tabid/594/Default.aspx, December, 2011 DSIRE. "CEFIA – On-Site Renewable DG Program", December, 2011

[56] State incentive programs may change based on several factors, including the provisions of Connecticut Public Act 11-80, and the availability of funding.

Funding Source: Property-Assessed Clean Energy (PACE) financing
Program Title: Local Option – Sustainable Energy Program
Applicable Energies/Technologies: Solar Water Heat, Solar Space Heat, Photovoltaics, Wind, Geothermal Heat Pumps, Locally determined
Summary: Property-Assessed Clean Energy (PACE) financing effectively allows property owners to borrow money from the local government to pay for energy improvements. The amount borrowed is typically repaid via a special assessment on the property over a period of years. Connecticut has authorized local governments to establish such programs. The law does not specify which energy upgrades or renewable energy systems will be eligible for financing - that will be determined locally. The law does require energy audits and/or renewable energy feasibility analysis be performed to determine which upgrades would be eligible for financing. Municipalities may make these programs available to property owners (residential and non-residential) and they may work with other localities or third-party administrators to implement programs.
Restrictions: Locally determined
Timing: Locally determined
Maximum Funding: Locally determined
Requirements: Locally determined
Rebate amount: Locally determined
For further information, please visit: http://www.cga.ct.gov/2011/ACT/PA/2011PA-00080-R00SB-01243-PA.htm **Sources:** DSIRE. "Local Option – Sustainable Energy Program", http://www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=CT90F&re=1&ee=1, December, 2011

Funding Source: Department of Revenue Services
Program Title: Sales Tax Incentive
Applicable Energies/Technologies: Solar Water Heat, Solar Space Heat, Photovoltaic, Geothermal Heat Pumps, Other Distributed Generation Technologies, Geothermal Direct-Use
Summary: Recently enacted legislation exempts from Connecticut sales and use taxes any sales of solar energy electricity generating systems, passive or active solar water or space heating systems, and geothermal resource systems. This legislation also exempts from the sales and use tax equipment related to the systems mentioned above and sales of services relating to the installation of the systems. The legislation also adds an exemption for sales of ice storage systems used for cooling by a utility ratepayer who is billed by the utility on a time-of-service metering basis. Additionally, this exemption includes equipment related to ice storage systems and sales of services related to the installation of the systems.
Restrictions: Sales occurring before July 1, 2007.
Timing: The exemption has no expiration date.
Maximum Size: **NA**
Requirements: See "2007 Legislation Granting a Connecticut Sales and Use Tax Exemption for Sales of Solar Heating System, Solar Electricity Generating Systems, and Ice Storage Cooling System" http://www.ct.gov/drs/cwp/view.asp?A=1514&Q=385310
Rebate amount: ► 100 percent exemption
For further information, please visit: http://www.ct.gov/drs/cwp/view.asp?A=1514&Q=385310 **Sources:** State Of Connecticut Department Of Revenue Services. "SN2007(7)", December, 2011 DSIRE. "Sales and Use Tax Exemption for Solar and Geothermal Systems", December, 2011

Funding Source: Connecticut Energy Efficiency Fund (CEEF)
Program Title: Energy Conscious Blueprint Program
Applicable Energies/Technologies: Efficient technologies incorporating Geothermal Heat Pumps
Summary: Custom and prescriptive rebates are available to increase the energy efficiency of non-residential new construction and major renovation projects. The rebates will vary by square footage, capacity and incremental cost. Customer must apply for this program before any construction starts. In addition to these rebates, the Energy Conscious Blueprint Program has a grant component that covers larger capital projects. Participating organizations maintain complete control over the project. For qualifying projects, these financial incentives can cover up to 100 percent of the incremental cost.
Restrictions: Projects signed proceeding 1/1/2009 are not eligible
Timing: NA
Maximum Size: NA
Requirements: See "Energy Conscious Blueprint" http://www.uinet.com/wps/wcm/connect/c53b610040d5787ca3febbd2ce51850f/Final+C0008+ECB+Sheet+Rev+02.09.pdf?MOD=AJPERES&CACHEID=c53b610040d5787ca3febbd2ce51850f
Rebate amount: ► Ground Source Heat Pumps - $50 - $150/ton
For further information, please visit: http://www.ctenergyinfo.com/dpuc_energy_conscious_blueprint.htm **Source:** DSIRE. "Energy Efficiency Fund (Electric) – Commercial New Construction Rebate Program", April 1, 2011

Funding Source: Public Utilities Regulatory Authority (PURA) (Formerly the Connecticut Department of Public Utility Control)
Program Title: Connecticut Electric Efficiency Partner Program (EEP)
Applicable Energies/Technologies: Direct digital control / Building automation control system, Ice based thermal storage (direct expansion), Gas Chiller, Solar assisted air conditioning, HVACR Duty Cycle Optimization controller technology.
Summary: The primary intension of this program is to reduce demand for electricity, particularly peak-demand, based on the use of demand-side technology. The EEP program is to support enhanced demand-side management technologies that conserve electricity and reduce electric distribution customers' electric demand in the state, specifically, peak electric demand. Under the program, PURA approves Electric Partners, the companies that implement the program, and Partner Technologies, energy efficient technologies that generally do not qualify for incentives under the programs funded by the CEEF.
Restrictions: Participants must either be a customer of an electric distribution company, or be providing technology or technology consultancy to a customer of the Connecticut Light and Power Company or The United Illuminating Company. Customers of municipal electric companies are not eligible for grants.
Timing: NA
Maximum Size: ► Direct digital control / building automation – NA ► Ice based thermal storage – 10 tons ► Gas Chiller – NA ► Solar assisted air conditioning – NA ► HVACR Duty Cycle Optimization – NA
Requirements: See "DPUC Review of The Connecticut Electric Efficiency Partner Program Docket # 07-06-59"
Rebate amount: ► Direct digital control / building automation – $165/kW ► Ice based thermal storage – $950/ton ► Gas Chiller – $300/ton ► Solar assisted air conditioning – $318/ton ► HVACR Duty Cycle Optimization – $46/ton
For further information, please visit: http://www.ctenergyinfo.com/dpuc_energy_efficiency_partners.htm http://www.ct.gov/pura/cwp/view.asp?a=3355&q=417158 **Source:** Department Of Public Utility Control. "Electrical Efficiency Partner Program", April 1, 2011

Appendix III – Annual (2010) Natural Gas Consumption for Buildings at the Depot Campus

Name	2010 Annual Total (Cubic Feet)
Brown Bldg. 2106	905,800
Longley Bldg. 1125	6,768,000
Stafford Ctg. 2160	346,200
Mansfield Ctg. 2138	291,600
Willimantic Ctg. 2174	334,300
Andover Ctg. 2100	152,200
Bolton Ctg. 2105	227,100
Ashford Ctg. 2101	329,900
Thomson Hall 2166	3,087,000
Merritt Hall 2141	2,520,100
Chaplin Ctg. 2108	635,700
Colchester Ctg. 2110	658,300
Lebanon Ctg. 2135	702,700
Hampton Ctg. 2124	638,000
Columbia Ctg. 2111	322,800
Union Ctg. 2169	205,200
Coventry Ctg. 2112	326,600
Manchester Ctg. 2137	121,300
Ellington Ctg. 2114	-
Tolland Ctg. 2167	460,500
Willington Ctg. 2175	395,200
Windham Ctg. 2177	311,400
Vernon Ctg. 2170	594,700
Hebron Ctg. 2125	717,000
Fuel Cell Ctr. 2198	2,320,000
Surplus Whuse. 2134	1,189,200
Hampt2-Grnhs 2124	845,500
Garage/Fire Huse 2119	693,300
Carpenter Shop 2107	1,547,400
Kennedy Ctg. 2131	515,700
Thomson Hall 2166	452,400
Norling Bldg. 2142	1,068,300
Storehouse-DRL 2163	2,555,300
Total	**32,238,700**