Renewable Energy Optimization Report for Naval Station Newport

A Study Prepared in Partnership with the Environmental Protection Agency for the RE-Powering America's Land Initiative: Siting Renewable Energy on Potentially Contaminated Land and Mine Sites

Robi Robichaud, Gail Mosey, and Dan Olis

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

Technical Report
NREL/TP-6A20-48852
February 2012

Contract No. DE-AC36-08GO28308

NATIONAL RENEWABLE ENERGY LABORATORY

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Prepared under Task No. WFD5.1000

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National Renewable Energy Laboratory
1617 Cole Boulevard
Golden, Colorado 80401
303-275-3000 • www.nrel.gov

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List of Acronyms

AD	anaerobic digestion
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BOS	balance of system
BTU	British thermal unit
CBECS	Commercial Building Energy Consumption Survey
CHP	combined heat and power
CO	carbon monoxide
CO_2	carbon dioxide
COE	cost of energy
COP	coefficient of performance
DAS	data acquisition system
DOE	U.S. Department of Energy
ECIP	Energy Conservation and Investment Program
EER	energy efficiency ratio
EPA	U.S. Environmental Protection Agency
EPAct 2005	Energy Policy Act of 2005
ESPC	energy savings performance contract
FAA	Federal Aviation Administration
FY	fiscal year
GHG	greenhouse gas
GHP	geothermal heat pump
GIS	geographic information systems
GSHP	ground source heat pump
GT	diurnal range
HDPE	high density polyethylene
HRSG	heat-recovery steam generator
HVAC	heating, ventilation, and air-conditioning
IESNA	Illuminating Engineering Society of North America
IGCC	integrated gasification and combined cycle
ITC	investment tax credit
LCC	life cycle cost
LFG	landfill gas
MBH	thousands of British thermal units per hour
MCFC	molten carbonate fuel cell
MCP	Measure-Correlate-Predict
MN	mean range
MSW	municipal solid waste
N_2O	nitrous oxide
NAVSTA	naval station

NFESC	Naval Facilities Engineering Service Center
NIST	National Institute of Standards and Technology
NMOC	non-methane organic compound
NOAA	National Oceanic and Atmospheric Administration
NO_x	nitrogen oxide
NPDES	National Pollutant Discharge Elimination System
NREL	National Renewable Energy Laboratory
O&M	operation and maintenance
PCB	polychlorinated biphenyl
PV	photovoltaics
PVC	polyvinyl chloride
R&D	research and development
RE	renewable energy
REO	Renewable Energy Optimization
ROI	return on investment
SODAR	sonic detection and ranging
SPB	simple payback
SVP	solar ventilation preheating
UESC	utility energy services contract
USDA	U.S. Department of Agriculture
VOC	volatile organic compound
VWSF	vertical wind shear factor
Wp	peak Watt
WRA	wind resource assessment

Executive Summary

In 2008, the U.S. Environmental Protection Agency (EPA) launched the RE-Powering America's Land initiative to encourage the development of renewable energy (RE) on potentially contaminated land and mine sites. As part of this effort, EPA is collaborating with the U.S. Department of Energy's (DOE's) National Renewable Energy Laboratory (NREL) to evaluate RE options at Naval Station (NAVSTA) Newport in Newport, Rhode Island.

NREL's Renewable Energy Optimization (REO) tool was utilized to identify RE technologies that present the best opportunity for life-cycle cost-effective implementation while also serving to reduce energy-related carbon dioxide emissions and increase the percentage of RE used at NAVSTA Newport. The technologies included in REO are daylighting, wind, solar ventilation preheating (SVP), solar water heating, photovoltaics (PV), solar thermal (heating and electric), and biomass (gasification and cogeneration). The optimal mix of RE technologies depends on several factors including RE resources; technology cost and performance; state, utility, and federal incentives; and economic parameters (discount and inflation rates). Each of these factors was considered in this analysis. Technologies not included in REO that were investigated separately per NAVSTA Newport request include biofuels from algae, tidal power, and ground source heat pumps (GSHP).

Improving overall energy efficiency is often the most cost-effective first step in implementing RE technologies. NAVSTA Newport has undertaken a number of energy efficiency audits and retrofits over the years and constructs new buildings with high efficiency goals. They desire to produce 25% of its base energy from life cycle cost (LCC) effective renewable sources. The base case of continuing to purchase electricity and natural gas has zero initial cost but high annual cost, while the RE solutions case has high initial cost but reduced annual cost and a reduced LCC. Based on NREL analysis, the REO results indicate that a RE solutions case combines wind turbines, SVP, solar water heating, and daylighting, which minimize the LCC of RE technologies at NAVSTA Newport. The results for the RE solutions case can be seen in Table ES-1.

Table ES-1. Sizes and Performance of Cost-Effective Renewable Energy Technologies under the RE Solutions Case

Technology	Size	Units	Electricity Offset	Percent Electricity Reduction	Fuel Offset	Percent Fuel Reduction	Annual Emission Reduction	25 - Year Emission Reduction
			kWh/yr	%	therms/yr	%	lbs CO_2/yr	lbs CO_2
Skylight/ Floor Area Ratio	1.4%	%	2,244,628	2.1%	-59,755	-1.2%	1,279,850	31,996,259
Wind Energy	9,000	kW	23,843,000	22.5%	-	-	21,019,315	525,482,875
Solar Vent Preheat	260,417	ft^2	-	-	468,632	9.5%	5,481,529	137,038,222
Solar Water Heating	138,409	ft^2	-	-	465,758	9.4%	5,447,912	136,197,801
PV	0	kW	-	-	-	-	-	-
Concentrating Solar Area	0	ft^2	-	-	-	-	-	-
Concentrating Solar Electric	0	kW	-	-	-	-	-	-
Biomass Gasifier Size	0	MBtu/hr	-	-	-	-	-	-
Biomass Gasifier Cogen Size	0	kW	-	-	-	-	-	-
Totals			**26,087,628**	**24.6%**	**874,635**	**17.7%**	**33,228,606**	**830,715,157**

Figure ES-1 compares the overall size and potential energy offset of each technology in the base case and the RE solutions case. Annual energy delivery of each technology is shown in equivalent energy of million British thermal units per year.

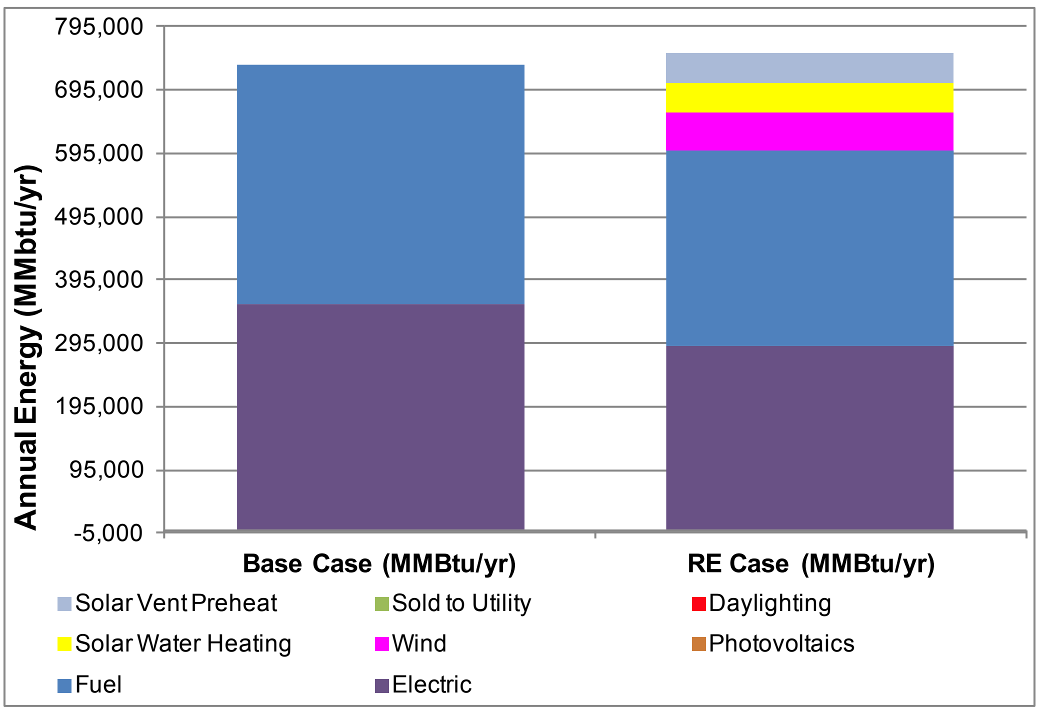

Figure ES-1. Energy delivery of each renewable energy technology per minimum life cycle cost

Table ES-2 provides a summary of the RE produced by these systems in equivalent kilowatt-hour terms; initial cost to implement the optimized RE solution with and without incentives; annual utility cost savings associated with those measures; and simple payback period with and without incentives. The REO analysis shows that the optimal solution reduces the 25-year cost of energy from around $418 million to $371 million, thereby saving about $47 million. An initial investment of around $44 million would be required to implement these technologies and would result in utility cost savings of about $4 million per year. This project has an 11.9% rate of return and an 11-year simple payback period. Implementing these measures would deliver roughly 21.3% of the site's energy use from renewables.

Table ES-2. Renewable Energy Cost and Savings Summary for the RE Solutions Case

Technology	Equivalent Energy Offset	Percent Energy Reduction	Initial Investment with Incentives	Annual Savings	Simple Payback	Initial Investment W/O Incentives	Simple Payback
	equiv kWh/yr	%	$	$/yr	yrs	$	yrs
Daylighting	2,244,628	0.9%	3,261,134	202,747	16.1	3,261,134	16.1
Wind Energy	23,843,000	9.5%	23,940,000	2,790,060	8.6	34,200,000	12.3
Solar Vent Preheat	13,730,918	5.5%	7,746,325	597,402	13.0	11,066,261	18.5
Solar Water Heating	13,646,709	5.4%	9,465,994	497,236	19.0	13,522,848	27.2
Totals	**53,465,255**	**21.3%**	**44,413,453**	**4,087,445**	**11**	**62,050,243**	**15**

Wind is the most cost-effective option at this site with paybacks 35% shorter than the next best option. Adding an additional 5.5 MW of wind, bringing the total to 14.5 MW, will enable the base to achieve its 25% RE goal.

NAVSTA Newport asked that additional RE technologies be investigated, such as biofuels from algae, tidal power, and GSHPs. These technologies were considered and the findings are outlined in the report, but they were not analyzed with the REO tool as the modeling parameters are too broad (e.g., extent of resource and costing) to do meaningful analysis as done for the other technologies that have more established sizing algorithms and more consistent costing parameters.

The biofuels-from-algae technology is still in the early stages of development with optimization efforts focused on many aspects of improving yields, efficiencies, and viability by identifying better strains of algae, reducing water consumption while growing, and reducing energy consumption while drying/processing the algae into biofuel.

For two technologies, GSHP and tidal power, it is premature to make economic estimates based on limited knowledge of the extent of the renewable resource. Both require more site-specific investigation of the resource before reasonable economic projections and recommendations can be made. It is recommended that test bores be undertaken to better characterize the geothermal resource for potential GSHP applications. For tidal power, two studies are recommended, a bathymetrical study of potential turbines sites in Narragansett Bay and, if quality potential sites are identified, a tidal current flow analysis.

The wind resource data, collected at Coddington Point and Tank Farm #4, was used for a separate analysis of 9 MW utility-scale wind turbines at the site. These results were added into the REO analysis and are shown in detail in Appendix A.

Table of Contents

List of Figures

List of Tables

1 Introduction

In 2008, the U.S. Environmental Protection Agency (EPA) launched the RE-Powering America's Land initiative to encourage the development of renewable energy (RE) on potentially contaminated land and mine sites. EPA is encouraging RE development on current and formerly contaminated land and mine sites. This initiative identifies the RE potential of these sites and provides other useful resources for communities, developers, industry, state and local governments, or anyone interested in reusing these sites for RE development. As part of this effort, EPA is collaborating with the U.S. Department of Energy's (DOE's) National Renewable Energy Laboratory (NREL) to evaluate RE options at Naval Station (NAVSTA) Newport in Newport, Rhode Island.

There are approximately 11,000 sites and almost 15 million acres of potentially contaminated properties across the United States that are tracked by EPA that could be assessed for RE, energy efficiency, conservation, and innovative applications.[1] In addition, there are many other environmentally contaminated or impaired lands, mine sites, and mine-scarred lands under state enforcement. Furthermore, there may be opportunities to evaluate the feasibility for more sustainable cleanup practices, such as installing RE technologies to power cleanup systems. These systems can be included in plans for cleanup and longer-term land management activities using renewable or low-carbon fuels to power equipment and create more efficient new and existing cleanup systems.

NAVSTA Newport, established during the Civil War era, encompasses about 1,063 acres stretching 6–7 miles along the western shore of Aquidneck Island in the towns of Portsmouth, Rhode Island, and Middletown, Rhode Island, and the city of Newport, Rhode Island. The base footprint also includes the northern third of Gould Island in the town of Jamestown, Rhode Island.

EPA has been involved with NAVSTA Newport because there are multiple contaminated areas within the base that pose a threat to human health and the environment. The base was designated a superfund site on the National Priorities List in 1989.

NAVSTA Newport is committed to working toward reducing the base's dependency on fossil fuels, decreasing its carbon footprint, and implementing RE projects where feasible. EPA Region 1 and NAVSTA Newport have engaged NREL to investigate the RE options for the base.

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[1] U.S. Environmental Protection Agency (EPA). "RE-Powering America's Land: Siting Renewable Energy on Potentially Contaminated Land and Mine Sites." http://www.epa.gov/renewableenergyland/docs/repower_mapping_tools.pdf. Accessed October 27, 2011.

2 Background

EPA has long been interested in incorporating RE technologies to reduce energy costs and carbon emissions at EPA-tracked sites and in returning brownfields and superfund sites into productive use. RE technologies have historically presented more expensive options; however, recent advances have lowered upfront costs and increased performance of several RE technologies. EPA would like to enable property managers at contaminated sites to deploy the options that are cost effective. RE-Powering America's Land's objective is to promote the use of RE in the energy mix at contaminated sites. Additionally, there are significant financial incentives offered by utilities and state and federal governments encouraging site owners to consider incorporating RE technologies to their sites to offset purchased electricity or sell into the commercial electricity grid.

Federal legislation and mandates provide impetus for many federal entities, such as NAVSTA Newport, to take action. These include:

- The Energy Policy Act of 2005 (EPAct 2005) directs federal agencies to implement RE projects to reach specific RE goals. Section 203 of EPAct 2005 states that federal agencies cannot have less than 7.5% of their electricity consumption come from RE sources in fiscal year (FY) 2013 and thereafter. An important provision to note from this legislation is that federal agencies can receive double credit toward this goal for RE produced on site or on federal land and used at a federal facility.[2]
- Executive Order 13423 mandates that 50% of statutorily required RE comes from "new" sources since 1999.[3]
- Executive Order 13514 mandates targets for the reduction of greenhouse gases (GHGs) using various methods including increased use of RE from on-site projects.[4]

As an illustrative example, the task in front of many entities, such as NAVSTA Newport, is to determine whether it is more beneficial to install a 5,000 ft^2 solar hot water system with no incentive and a 12-year simple payback; a 25 kW PV system with a 30% rebate incentive and a 29-year simple payback; or a 1.5 MW wind turbine with a production incentive for third-party ownership that provides the owner with a $0.021/kWh tax credit for the first 10 years of operation.

This example illuminates some of the difficulties of evaluating the different RE technologies: they have different operating parameters and costs, they will be installed at locations with different RE resources, they will displace different energy types with different competing costs of energy, they will qualify for different incentives, and they

[2] Public Law 109-58, 109th Congress. "Energy Policy Act of 2005." http://doi.net/iepa/EnergyPolicyActof2005.pdf. Accessed September 30, 2011.
[3] U.S. EPA. "Executive Order 13423." http://www.epa.gov/greeningepa/practices/eo13423.htm. Accessed September 30, 2011.
[4] Federal Register. "Executive Order 13514." http://edocket.access.gpo.gov/2009/pdf/E9-24518.pdf. Accessed September 30, 2011.

will meet different objectives. There is no "one-size-fits-all" RE solution. Guiding the most effective allocation of project funds requires a complex analysis that considers all or most of these factors.

This report used the building energy load and cost data provided by NAVSTA Newport to derive the optimal mix of technologies and system sizes that yields lowest life cycle cost (LCC), which serves to maximize return on investment (ROI). These derived RE solutions considered multiple technologies in the energy mix and their relative contributions after iteratively re-sizing and re-optimizing the RE system sizes. The renewable energy optimization (REO) analysis estimates the size, LCCs, savings, rate of return, and simple payback period for each technology at the largest building locations to come up with an RE solution representing the optimal mix of technologies at NAVSTA Newport. This report identifies an RE "solutions case" that provides real savings over continuing business as usual case, or "base case," of energy use over the next 25 years.

Based on site, energy, and cost data provided by NAVSTA Newport, NREL conducted an optimization-based screening analysis of RE technologies for NAVSTA Newport. The objective of this analysis is to identify the economic feasibility of renewable technologies that could be considered at this site as it moves toward net-zero energy. Federal mandates for more RE in the energy mix used by federal agencies, coupled with financial incentives offered by utilities and state and federal governments, galvanize NAVSTA Newport to consider adding RE technologies to provide cost-effective electricity to the base. This study is a first-level screening intended to help NAVSTA Newport establish clear priorities in pursuing RE technologies. Additional analysis, including more detailed performance modeling and a building-specific (or site-specific for biomass, wind, tidal, or geothermal) assessment, is required prior to implementation of any technologies recommended in this report.

2.1 Study Objectives

The overall objective of this report is to provide energy, public works, buildings, and planning department personnel with objective information regarding multiple RE technology options for reducing the base-wide consumption of fossil-fuel-sourced electricity. REO allows for the designation of a screening criterion, and for this analysis, the REO screening criterion used was the ROI considering the LCCs over a 25-year project life to determine effective RE solutions and calculate the rate of return through a complex, multi-step analysis. The results of the analyses identify the best opportunities for cost-effective implementation of RE technologies at NAVSTA Newport.

2.2 Scope of Study

The analysis combines NAVSTA Newport site data with information from NREL's RE resource databases[5]; other databases from Platts, Inc. (avoided cost or wholesale electric power cost)[6]; and the Database of State Incentives for Renewable Energy (DSIRE)[7] to

[5] NREL. Geographical Information System (GIS) database of renewable energy resource information. http://www.nrel.gov/gis/. Accessed May 2010.
[6] Platts, http://www.platts.com/Home.aspx. Accessed May 2010.

estimate the installed cost (including the effects of incentives and tax depreciation), energy performance, cost savings, and LCC effectiveness of RE technologies.

EPA and NREL agreed to assess the following RE technologies using REO for this phase of the study:

- Daylighting
- Wind power
- Solar ventilation supply air preheating
- Biomass energy
- Solar water heating
- Photovoltaics (PV)
- Solar industrial process heat

NAVSTA Newport requested that additional RE technologies be investigated, such as biofuels from algae, tidal power, and GSHPs. These technologies were considered, and the findings are outlined in the report, but they were not analyzed with the REO tool as the modeling parameters are too broad (e.g., extent of resource and costing) to do meaningful analysis as done for the other technologies that have more established sizing algorithms and more consistent costing parameters. For example, without some site-specific resource information obtained by drilling test bore holes and completing a soil profile, it is not possible to obtain a reasonable estimate for a GSHP as the soil characteristics are a key variable for determining system size.

The wind resource data, collected at Coddington Point and Tank Farm #4, was used for a separate analysis of 9 MW utility-scale wind turbines at the site. These results were added into the REO analysis and are shown in detail in Appendix A.

Consistent with rates published by the National Institute of Standards and Technology (NIST) for federal analysis, NREL used a discount rate of 4.6% to represent the time-value of money. Other parameters used in the economic analysis (e.g., fuel escalation rate and general inflation rate) are based on the same publication: *Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis.*[8] NREL completed the analysis with and without tax-based incentives (tax credits) to provide guidance for the impact of the tax credits on technology viability. NREL assumed a typical corporate tax liability structure in the 35% tax bracket for estimating the effects of the business investment tax credit (ITC) and accelerated depreciation for scenarios when a third-party operator, financer, investor, or owner was considered.

[7] DSIRE. North Carolina State University. www.dsireusa.org. Accessed May 2010.
[8] DOE. *Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis*, Annual Supplement to Handbook 135 (ASHB 135), http://www1.eere.energy.gov/femp/information/download_blcc.html. Accessed May 2010.

3 Technology Characterizations

EPA and NREL assessed the RE technologies using REO for this study. Initial cost, efficiency, and operation and maintenance (O&M) cost for each of the RE technologies are characterized according to the cost and performance data reported in the *Power Technologies Energy Data Book*[9] and in *Renewable Energy Technology Characterizations.*[10] Other RE technologies were also examined, including biofuels from algae, tidal power, and geothermal energy. The characteristic cost and performance data from several sources are detailed in this report.

Each of the technologies is characterized briefly in this section. Resource and technology details can be found in Appendices A–E.

3.1 Daylighting

The term "daylighting" refers to consciously adding natural light to buildings to reduce the need for artificial light. A complete daylighting system consists of apertures (skylights, light shelves, and windows) to admit and distribute sunlight and a controller to modulate artificial light as needed to maintain the desired level of light for the building space. Electricity for lighting is reduced and no scheduled maintenance is required; however, skylights may increase roof maintenance. Figure 1 is a photograph of skylights in an application similar to the configuration modeled for this study. Daylighting was considered in the office and warehouse buildings of NAVSTA Newport. Utilization of daylighting can enhance both the quality of light and comfort for the people working in these buildings. It can also contribute to lowering overall cooling loads by reducing waste or by-product heat from electric lighting.

Figure 1. Daylighting in Hawaii

Photo by Scott Bly, NREL/PIX 07626

[9] NREL. *Power Technologies Energy Data Book,* Edition Four. http://www.nrel.gov/analysis/power_databook/. Accessed May 2010.
[10] DOE. *Renewable Energy Technology Characterizations.* EPRI Topical Report No. TR-109496. http://www1.eere.energy.gov/ba/pba/tech_characterizations.html. Accessed May 2010.

Table 1 lists the characteristics of daylighting technology used in this analysis. Daylighting was considered only in the office, utility, and warehouse spaces at NAVSTA Newport.

Table 1. Characteristics of Daylighting Technology

	Lighting Levels
Office	30 Fc
Warehouse	15 Fc
Utility	30 Fc
Skylight Transmittance Coefficient	0.7
Lightwell Transmittance Coefficient	0.8
Utilization Daylight Coefficient	0.55
Utilization Electric Light Coefficient	0.55
Luminous Efficacy Electric Light	75 Lumens/W
Roof U-value	0.1 Btu/hr/F
Skylight U-value	0.5 Btu/hr/F
Cooling Coefficient of Performance (COP)	3.5
Heating Efficiency Coefficient	0.8
Skylight Cost	$25/ft^2
Controls Cost	$0.25/ft^2 floor area

3.2 Wind Power

Uneven heating of the earth's surface creates wind energy. Variation in heating and factors such as surface orientation or slope, rate of reflectivity, absorptivity, and transmissivity also affect the wind resource. In addition, the wind resource can be affected (accelerated, decelerated, or made turbulent) by factors such as terrain, bodies of water, buildings, and vegetative cover. Wind power and energy and the results of the wind assessment are discussed in detail in Appendix A.

Wind is air with high kinetic energy that can be transformed into useful work via wind turbine blades and a generator. Overall, wind is a diffuse resource that can generate electricity cost effectively and competitively in regions with a good wind resource, high cost of electricity, or both.

3.2.1 Wind Characteristics

Winds vary with the season, time of day, and weather events. Analysis of wind data focuses on several critical aspects of the data—average annual wind speed, frequency distribution of the wind at various speeds, turbulence, vertical wind shear, and maximum gusts.

The wind speed at any given time determines the amount of power available in the wind. The power available in the wind is given by:

$$P = ½ * A * \rho * V^3$$

where

P = power of the wind [W]

A = windswept area of the rotor (blades) [m^2] = $\pi D^2/4 = \pi r^2$

ρ = density of the air [kg/m^3] (at sea level at 15°C)

V = velocity of the wind [m/s]

As shown, wind power is proportional to velocity cubed (V^3). This matters because if wind velocity is doubled, wind power increases by a factor of eight ($2^3 = 8$). Consequently, a small difference (e.g., increase) in average speed causes significant differences (e.g., increases) in energy production. Examining ways to increase the wind velocity at a particular site should be considered. Normally, the easiest way to accomplish this is to increase the height of the tower. The wind industry has been moving toward higher towers, and the industry norm has increased from 30 m to 80 m over the last 15–20 years.

The map of the national wind resource can be seen in Figure 2. Wind maps can give a visual approximation of the wind resource in an area but do not provide enough data for estimating annual electricity output at a particular site. On-site wind data collected for a period of 1–3 years is necessary to estimate wind turbine performance. This study used recently collected on-site wind data for its screening level production estimates and analysis.

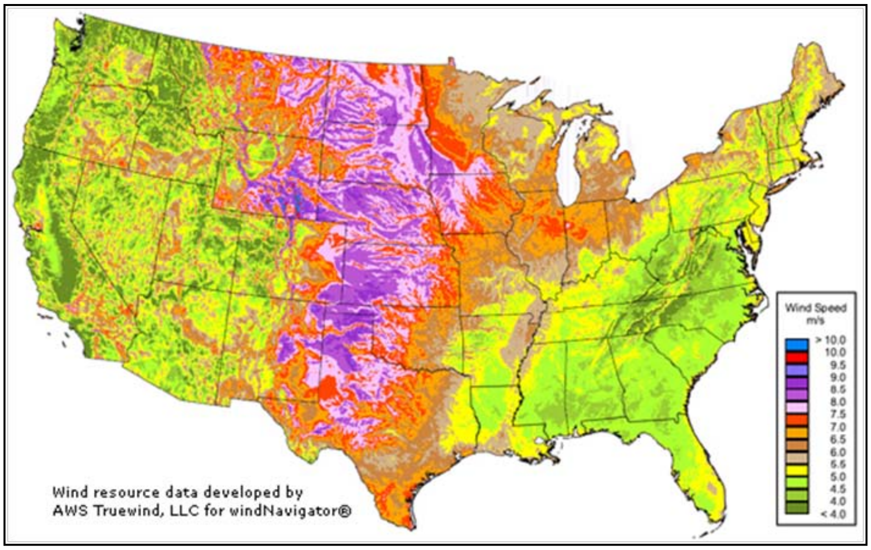

Figure 2. Map of U.S. wind resources

Credit: NREL, Wind Powering America

3.2.2 Wind Turbines

Wind turbines consist of rotating blades that convert the momentum of the wind to electric power. They have a number of moving parts and require regularly scheduled and unscheduled maintenance. Manufacturer warranties cover the first 2–5 years. Professional wind turbine maintenance contractors (aka windsmiths) are recommended after the warranty period. Figure 3 shows large wind turbines that may be considered for NAVSTA Newport.

Figure 3. Modern wind turbines

Photo by STG Inc., NREL/PIX 16797

Wind turbines, at less than wind farm scale, are typically cost effective where the average wind speed is high, where the competing energy costs are high, or a combination of both. Large wind farms of 100–500 MW have been driving the industry because of lower installed costs due largely to economies of scale and improved low wind speed turbine technology, which result in an overall lower cost of energy. No more than about 10 wind turbines would be considered for NAVSTA Newport due to land, permitting, and neighbor constraints. The small number of turbines and challenging construction sites would result in significantly higher installed costs than the wind farm industry norms.

In the United States, there have been about 35,600 MW of wind power installed with over 10,000 MW installed in 2009.[11] Turbines are available from as small as 250 W to as large as 5 MW. For the size of the wind plants considered here, large turbines in the range of 800 kW to 3,000 kW per turbine would be the optimal size. A 15 MW plant could consist of ten 1.5 MW turbines.

Table 2 lists the characteristics of wind technology typically used in REO analyses and shows the relation of cost to project size.

Table 2. Characteristics of Wind Power Technology

Tower Height	80 m
Wind Shear Exponent	0.115
Acres per MW	40–60 Ac/MW (for wind farms)
Capacity Factor	35%
Capital Cost	\$2,200/kW
O&M Cost	\$7.90/yr/kW
Power/Area	0.46 kW/m^2

[11] Wiser, R.; Bollinger, M. *2009 Wind Technologies Market Report*. Washington, D.C.: Department of Energy. http://www1.eere.energy.gov/windandhydro/pdfs/2009_wind_technologies_market_report.pdf. Accessed April 2011.

3.3 The Solar Resource

The solar resource available outside the earth's atmosphere is immense and always available. The solar radiation that gets filtered through the atmosphere with its accompanying clouds, moisture, and pollution is still enormous, though availability follows daily and seasonal patterns occasionally interrupted by weather events. The challenge in working with the solar resource for electricity generating applications is that the resource is relatively diffuse and unconcentrated.

For making electricity, only bands of the solar spectrum within the visible light wavelengths are utilized, and the objective for PV manufacturers is to utilize as much of that available energy as possible. For heating applications, whether for space (air) or materials (mass), the light energy is transformed into heat energy as it strikes a surface and is absorbed.

In the continental United States, the intensity of solar radiation during the middle 6–8 hours of the day is usually in the 500–1,000 W/m^2 range. A daily pattern of insolation intensity can be seen in Figure 4.

To facilitate climate comparison and predict system performance, the amount of solar radiation that falls on a collector throughout the day has been integrated to determine the area under the curve. The conventional level of intensity is 1,000 W/m^2 (1 kW/m^2), termed *peak sun-hours*. The solar resource at a site is often reported in sun-hours/day, which equates to kilowatt-hours per square meter per day. There have been extensive weather data collection efforts throughout the United States for a number of years and with a wide variety of data collectors, end users, and end uses in mind.

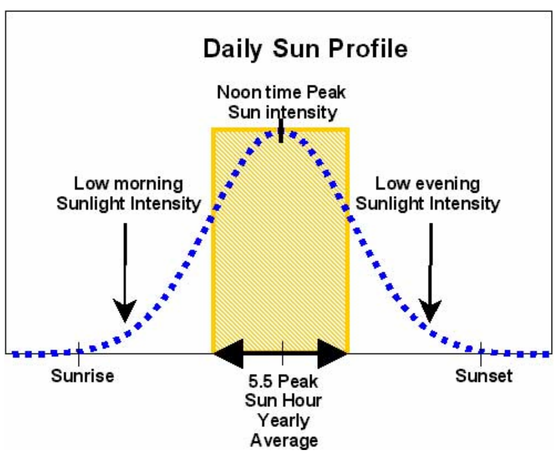

Figure 4. Annual daily insolation pattern integrated into a yearly average of sun hours per day

Illustration by Ameco Solar, Inc.

An important characteristic of the solar resource is determining what portion of the insolation is "direct" versus "diffuse" or "indirect." *Direct normal* is the term used to describe solar insolation (aka radiation) coming in perpendicular to the surface in question—normally either a horizontal surface or one tilted at the latitude angle. Diffuse insolation is that scattered by clouds, moisture, or dust in the atmosphere.

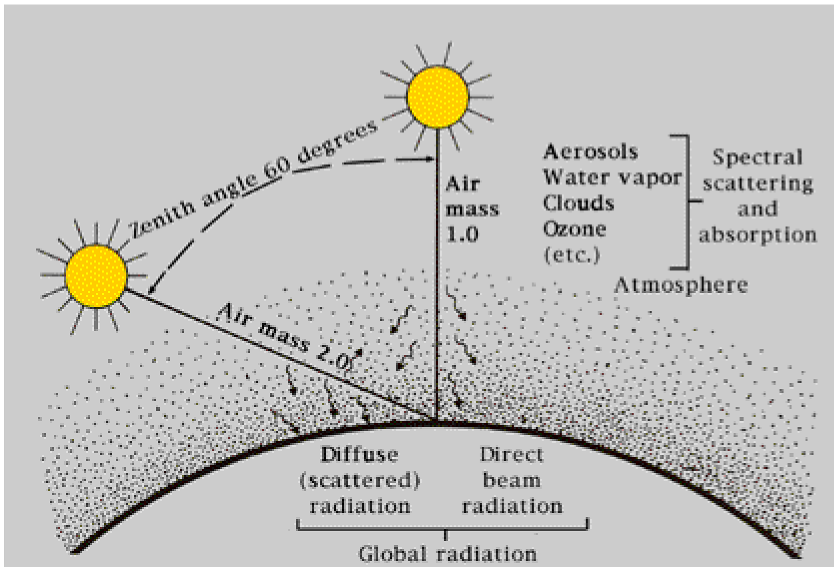

Figure 5. Atmospheric impacts on diffuse and direct beam insolation

The solar radiation resource data that was selected for resource analysis for NAVSTA Newport with particular solar technology applications in mind were chosen for four primary application purposes:

1. Solar hot water or PV systems that are most commonly operated at a fixed-tilt angle that corresponds to the local latitude
2. Transpired solar collectors that are most commonly added onto or affixed in front of vertical south-facing exterior walls
3. Horizontal roof-mounted PV systems that have gained popularity due to relative simple installation
4. Concentrated solar systems with single-axis tracking.

An advantage of solar compared to other renewable resources is that the variation of the solar resource from best-to-worst locations across the United States varies by roughly a factor of 2.4 to 1. This means that a solar project can be done essentially anywhere, though 2.4 times as many square meters (or feet) of PV or solar collector might be needed for a location with a low solar resource versus a location with a high solar resource. The key parameters for determining cost-effective applications will be highly influenced by other site-specific factors beyond solar resource alone such as incentives or construction labor rates.

3.4 Solar Ventilation Air Preheat

SVP is a very simple yet effective technology. SVP systems use the sun's heat to warm air before it is brought into a building's heating, ventilation, and air-conditioning (HVAC) system. Adding inexpensive hot air generated on cold sunny days to the supply air of an HVAC system can lower heating bills.

The system operates by the sun heating special siding (a metal sheathing perforated with small holes also known as a *transpired solar collector* or *solar wall*) that covers a portion of the south-facing exterior wall of a building. The sheathing leaves an 8–10 cm plenum between its outer surface and the building wall as shown in Figure 6 below. The sheathing has holes about 1 mm in diameter and about 9 mm apart to allow for effective collection of the heated air. The metal sheathing is usually painted black or another dark, light-absorbing color. The perimeter is sealed with flashing.

Solar radiation heats the metal sheathing and the air immediately adjacent to it (a thin film of air known as the *boundary layer*). The heated boundary layer air is drawn by a fan into the plenum through the small holes before it can mix with the ambient air. The warmed air is added to and mixed with ventilation air going into the building by the fan. This technology is only for preheating ventilation air; there is no recirculation to the inlet for reheating. For summer conditions when heated air is not needed in the building, a bypass damper on the face of the wall admits fresh outside air with no additional heating.

SVP systems are very low maintenance as there is only one moving part, the fan. Savings at each site depend on the solar resource, collector orientation, and the heating degree days for that site. Figure 6 illustrates how an SVP system works.

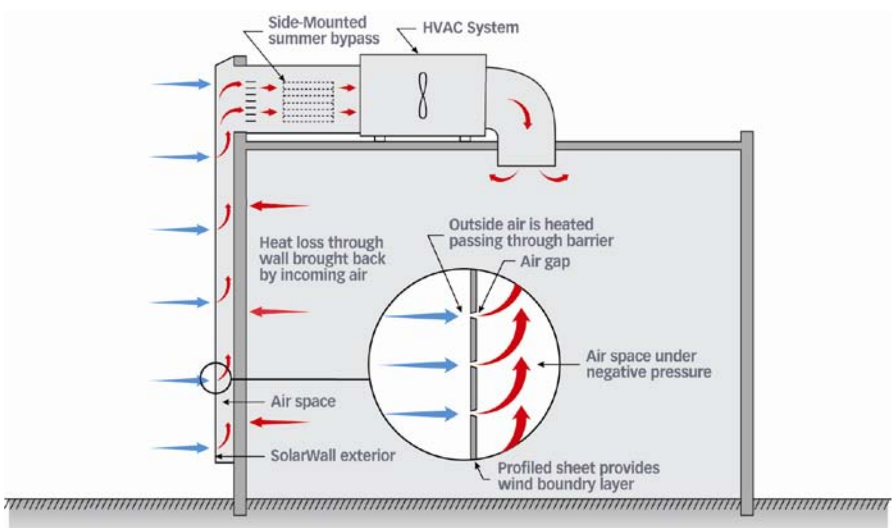

Figure 6. SVP system schematic

Illustration by Conserval Engineering, Inc.

SVP is generally cost effective in more northern latitudes that can use the heat throughout much of the year. A site with a heating season of four months or longer could consider this technology. An SVP system at the U.S. Bureau of Reclamation water treatment facility in Leadville, Colorado (Figure 7), cost $28,000 and saves $4,000 per year.[12]

Figure 7. SVP system in Leadville, Colorado

Photo by Thomas Bunelle, NREL/PIX 08357

Figure 8 shows the energy savings associated with utilizing SVP systems based on the distribution of solar resource across the country.

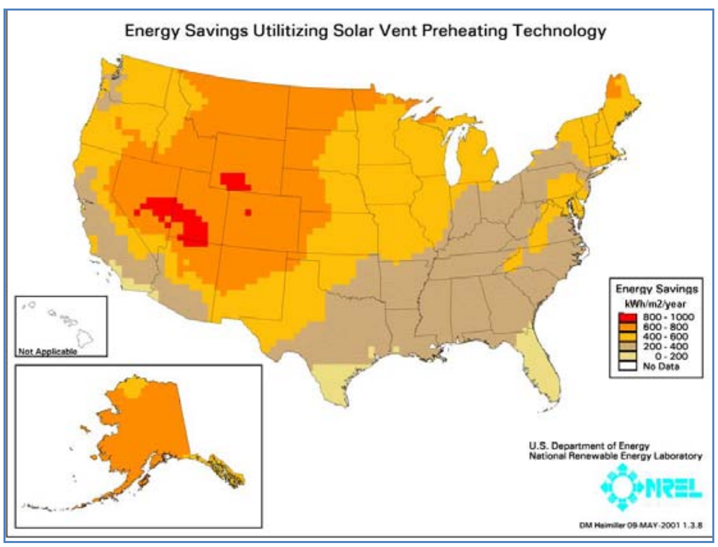

Figure 8. Map of SVP delivery (depending on both solar and heating requirements)

Due to the low cost of this simple technology (about $20/ft^2 installed) and its high efficiency, over 2 million ft^2 have been installed worldwide,[13] mostly in manufacturing

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[12] Walker, A. "Solar Air Heating." Presented at the Implementing Renewable Energy Projects Workshop, Washington DC, October 11-12, 2005.

[13] Conserval, Inc. http://solarwall.com/en/home.php. Accessed October 20, 2011.

plants in the Northeast and Canada. Buildings such as high bay automotive shops (due to the need for high ventilation rates) are very good candidates for SVP systems.

The size of an SVP system is determined by the optimization, but there are some constraints, as noted in Appendix B.

Table 3 lists the initial and annual costs associated with SVP technology characterization. Table 4 lists the ventilation rates required for each type of space at NAVSTA Newport. Often the size is limited by the available south wall area, which was estimated from the NAVSTA Newport data provided.

Table 3. Initial Cost of Components of SVP Technology

Material Cost	$14/ft^2
Installation Cost	$14/ft^2
Ductwork	$4/ft^2
Other	$4/ft^2
Total Installed Cost	$36/ft^2
O&M Cost	$0

Table 4. Ventilation Rates Used in the Analysis[14]

	Warehouse	Office	Lab	Residence	Other
Ventilation Rate (cfm/ft^2)	0.02	0.14	1.00	0.00	0.34

[14] ANSI/ASHRAE. Standard 62.1-2007. Ventilation for Acceptable Indoor Air Quality. Atlanta, GA: American Society of Heating, Refrigerating, and Air-Conditioning Engineers. www.ashrae.org/pressroom/detail/16298. Accessed May 2009

3.5 Solar Water Heating

Solar water heating systems use the sun to heat water that is stored in tanks for later use. Solar collectors provide the heat, heat exchangers heat potable water, and pumps circulate the fluid. Such systems also contain expansion tanks, pressure relief valves, flush and fill valves, and controls. Typical solar water heating systems, as shown in Figure **Error! Reference source not found.**9, are sized to provide 40%–70% of water heating requirements. The conventional water heating system is used as a back-up to the solar system.

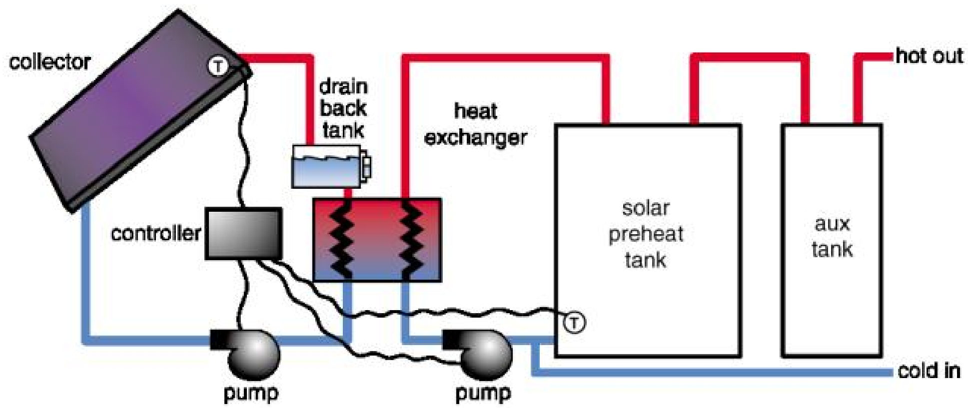

Figure 9. Solar hot water heating system schematic

Illustration by Jim Leyshon, NREL

A roof-mounted solar hot water system designed to meet the hot water load for showers and laundry at the Chickasaw National Recreation Area in Oklahoma can be seen in Figure 10.

Figure 10. Solar water heating system at Chickasaw National Recreation Area, Oklahoma

Photo by Andy Walker, NREL

There are three types of solar water heating collectors: unglazed plastic collectors for low temperature applications; glazed, insulated flat plate collectors for mid-temperature hot water; and evacuated tube collectors with reflectors for high temperature applications.

3.5.1 Unglazed Plastic Collectors for Low Temperature Applications

Typical solar water heating systems provide 40%–70% of water-heating requirements. Typical solar pool-heating systems use unglazed polymer collectors that provide 50%–100% of swimming pool heating requirements. The low temperature requirements of swimming pools enable the systems to meet a high fraction of the load. Typical systems generate 1,600 therms, or 46,000 kWh, of energy per year and cost $0.30–$0.50/W (of peak capacity).

3.5.2 Glazed, Insulated Flat Plate Collectors for Mid-Temperature Hot Water

Typical flat plate collectors deliver about 900 kWh/m^2/yr and cost $1–$2/W, or $0.08/kWh. The system delivers heat (Btus), not electricity. The units were converted to electrical units for comparative purposes only. The energy costs of solar thermal systems have declined by more than 50% due to technology improvements.

3.5.3 Evacuated Tube Collectors with Reflectors for High Temperature Applications

Parabolic trough collectors with evacuated tubes cost about $1/W and deliver about 900 kWh/m^2/yr.[15]

Water heating load (gallons per day) is estimated according to the statistics available[16] and is listed in Table 5. System sizing equations can be found in Appendix C.

Table 5. Water Heating Load and Characteristics

Hot Water as a Fraction of Total Building Energy	
Office	0.089506
Education	0.219420
Healthcare	0.262063
Lodging	0.403771
Public Assembly	0.153914
Food Service	0.112016

[15] For a full listing of certified systems, please visit the Florida Solar Energy Center at http://www.fsec.ucf.edu/en/certification-testing/STsystems/ratings/index.htm#DHWRatings.
[16] DOE Office of Building Technologies. "2008 Building Energy Databook." http://buildingsdatabook.eren.doe.gov/. Accessed May 2010.

Food Sales	0.042623
Warehouse	0.052219
Other	0.088850
Average of All	0.152486
Solar Domestic Water Heater (SDWH) Efficiency	0.4
System Cost per Square Foot of Collector	$73/ft^2
O&M Cost	0.005% of initial cost
Auxiliary Efficiency	0.8

Source: DOE/OBT Energy Databook[17]

3.6 Photovoltaics

PVs are panels that convert sunlight directly into electricity. Fixed-axis PV has no moving parts and little required maintenance, make no noise, and emit no pollution (see Figure 11). Solar cells are fabricated from thin semi-conductor wafers with an electric field applied to the cell to make one side positive and one side negative. When the sun's light strikes the solar cell, electrons are knocked loose from one side of the wafer and are conducted from one side of the solar cell to the other with an embedded conductor wire. This movement of electrons along the conductor wire is an electric current, or electricity, which is collected and used to power any electrical device.

Figure 11. Solar electric PV system

Photo by Jamie Keller, NREL/PIX 19697

[17] DOE Office of Building Technologies. "2008 Building Energy Databook." http://buildingsdatabook.eren.doe.gov/. Accessed May 2010.

Over the past two decades, significant improvements have been made in the efficiency of PV materials, and manufacturing costs have been driven down, yet PV is still more expensive than conventional grid electricity, and, in the United States, PV's cost effectiveness is dependent to a large degree on the local, state, or utility incentive programs coupled with tax-based incentives.

The cost of PV-generated electricity has dropped 15- to 20-fold in the last 40 years, and grid-connected PV systems currently sell for about $5–$8/Wp (peak Watt), resulting in energy produced in the $0.20–$0.32/kWh range, including support structures and power conditioning equipment. Complete system cost is reported at $8,500/kW.[18] PV modules themselves are highly reliable and last 20 years or longer.

The PV cost function used in the analysis can be seen in Appendix D. Though the "Initial Cost" shown in Table 6 is at $8,500/kW, it should be noted that this price is for very small systems. For an optimization analysis range of approximately 100–10,000 kW, the installed cost range is $4,300–$5,000/kW. In this analysis, we represent cost as a function of size as $6.7637 multiplied by the system size in kilowatts raised to an exponent of –0.0615. O&M costs are reported at $0.006/kWh as produced in *Factors Associated with Photovoltaic System Costs.*[19]

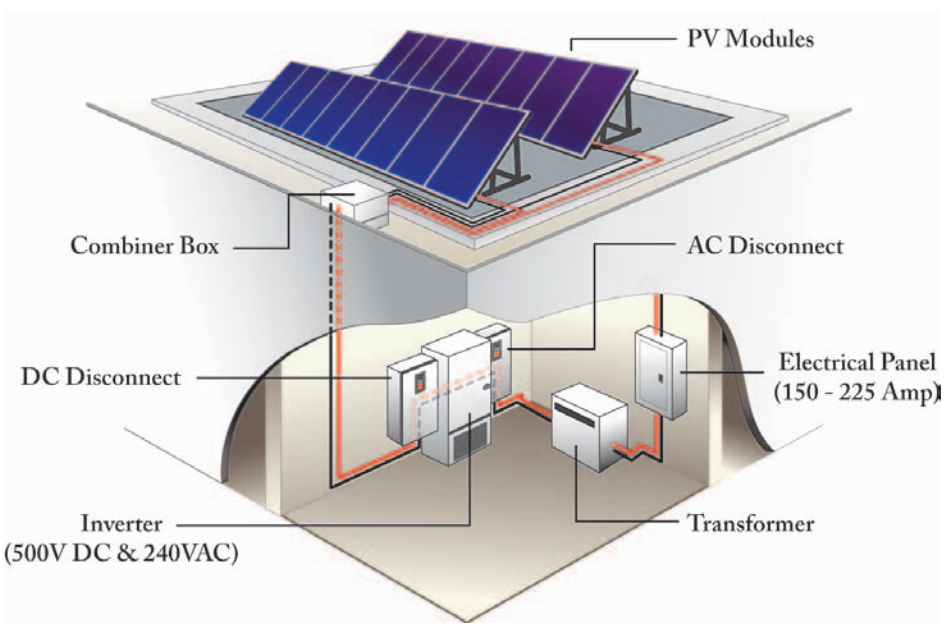

Figure 12. PV system schematic

Illustration by Jim Leyshon, NREL

[18] RS Means Green Building Project Planning and Cost Estimating, 2010. http://www.rsmeans.com/bookstore/detail.asp?sku=67338A, Accessed March 2011.
[19] Mortensen, J. *Factors Associated with Photovoltaic System Costs.* NREL/TP-620-29649. Golden, CO: NREL, June 2001.

About 79 MW of PV were installed in the United States in 2000, and 878 MW of PV were installed in 2010, indicating the growth of this industry.[20] Annual market growth for PV has been about 25% as a result of reduced prices, government incentives, and successful global marketing. A growth rate of over 100% due to the ITC made available through the Treasury Cash Grant program occurred in 2010.[21] There is concern that when this program expires (December 2011) there will be a significant impact on the PV market and prices. Current leading PV companies in the United States total 104 MW of rated power production manufactured per year.[22]Almost two-thirds of U.S.-manufactured PV is exported.

Hundreds of applications are cost effective for off-grid needs. Viability of on-grid PV can be determined by the level of incentives, the solar resource, and the competing cost of electricity. However, the fastest growing market segment is currently grid-connected PV, such as roof-mounted arrays on homes and commercial buildings in the United States. California is subsidizing PV systems because it is considered cost effective to reduce their dependence on natural gas, especially for peak daytime loads for air conditioning, which matches PV output.[23]

The solar resource across the country can be seen in Figure 13. The results shown are for a flat plate collector tilted at the latitude angle.

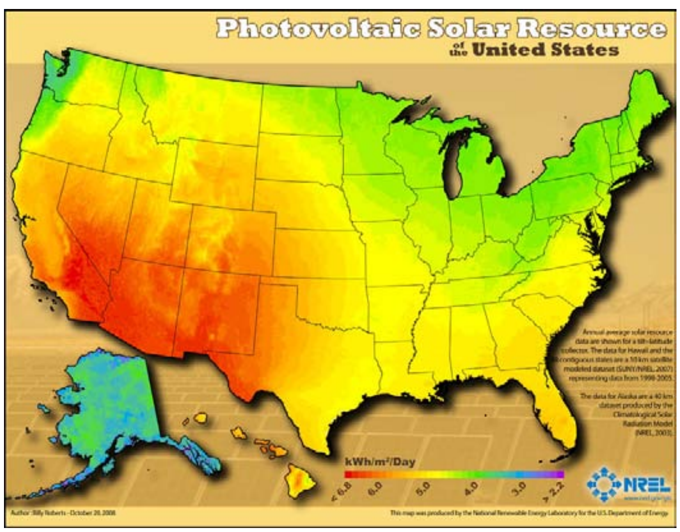

Figure 13. Solar resource across the United States

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[20] SEIA. "U.S. Solar Market Insight™, 2010 Year in Review, Executive Summary." http://www.seia.org/galleries/pdf/SMI-YIR-2010-ES.pdf. Accessed March 2011.
[21] SEIA. "U.S. Solar Market Insight, 2010 Year in Review, Executive Summary." http://www.seia.org/galleries/pdf/SMI-YIR-2010-ES.pdf. Accessed March 2011.
[22] PG&E. "SGIP - Available Funding and Program Statistics." http://www.pge.com/mybusiness/energysavingsrebates/selfgenerationincentive/availablefundingandprogramstatistics.shtml. Accessed May 2009.
[23] DOE. *Renewable Energy Technology Characterizations.* EPRI Topical Report No. TR-109496. http://www1.eere.energy.gov/ba/pba/tech_characterizations.html. Accessed May 2010.

PV system sizing details can be found in Appendix D. Key sizing and cost variables are listed in Table 6.

Table 6. Characteristics of PV Technology

Source	Characteristic	Metric
Initial Cost	$8,500/kW	RS Means Green Building Project Planning and Cost Estimating, 2010; NREL Data from Project Bids
O&M Cost	$0.006/kWh	Renewable Energy Technology Characterizations, EPRI TR-109496, 1997.C185
Balance-of-System Efficiency	0.77	PVWatts documentation www.nrel.gov
Acres per MW	6.5 Ac/MW	

3.7 Solar Industrial Process Heat and Solar Thermal Electric

Solar industrial process heat systems have parabolic trough solar collectors that focus the sun's rays onto a pipe running through a glass cover pipe down the focal line of the trough. Motors and controls track the sun for maximum gain from east to west in a north-south oriented trough. The concentrating collectors require direct sun with minimal clouds, moisture, or dust. The desert southwest, which has many clear sunny days every year, is considered the most viable region for these concentrating systems.

A key parameter in establishing the extent of the suitability of the solar resource for a concentrating system is the "clearness index" (aka clear sky insolation clearness index). The clearness index, often denoted by K_T, is the ratio of the horizontal radiation incident on a surface on the ground relative to the radiation incident on a surface in space with no atmospheric attenuation, clouds, pollution, rain, or volcanic ash. It describes the fraction of the insolation just outside the atmosphere that actually reaches the surface of the earth.

The annual clearness index, K_T, for Providence, Rhode Island, is 0.50.[24] In Tucumcari, New Mexico, it is 0.62,[25] representing a 24% increase in "clearness" of the atmosphere. The increased clearness in the atmospheric conditions in Tucumcari makes it a better candidate for concentrating solar collectors than Providence.

Since the system has moving parts, it requires preventative and unscheduled maintenance. Figure 14 shows a solar thermal system of the size and type considered for NAVSTA Newport. In order to displace natural gas (to get to net zero), on-site thermal storage is required. Additional equipment to consider with a thermal storage system may include a fluid tank, tubes in sand, or tubes in concrete.

[24] The Solar Radiation Data Manual for Buildings, NREL. http://rredc.nrel.gov/solar/old_data/nsrdb/1961-1990/bluebook/data/14765.SBF. Accessed September 30, 2011.
[25] The Solar Radiation Data Manual for Buildings, NREL. http://rredc.nrel.gov/solar/old_data/nsrdb/1961-1990/bluebook/data/23048.SBF. Accessed September 30, 2011.

Figure 14. Solar industrial process heat system

Photo by Ed Hancock, NREL

Table 7. Characteristics of Solar Industrial Process Heat Technology

Characteristic	Metric
Solar Thermal Cost	$60/ft^2
O&M Cost	$0.127/therm/yr
Coefficient of Efficiency	0.33
Cost of Thermal Storage	$1,465/therm
Hours Per Day of Solar Collection	6 hrs/day
Cogen Cost	$1,650/kW
Cogen Efficiency	0.2
Boiler Capacity Factor	0.85
Coefficient of Heat Exchanger Effectiveness	0.7
Federal Production Tax Credit	$0.01/kWh

Energy savings consist of savings in natural gas and electricity. Natural gas savings are limited to the minimum of:

1. Base case natural gas use
2. RE heat generating capacity.

Electric savings are limited to the minimum of electric peak, then RE generation above that is treated as wholesale power to the utility. Electric savings are limited to:

1. The minimum cogeneration size (kW)
2. Heat generating capacity of the plant times heat-to-electric cogeneration efficiency.

Thermal energy as a by-product of electric generation is added back into the gas savings but multiplied by a heat exchanger effectiveness. System sizing equations can be found in Appendix E.

3.8 Biomass Energy

Biomass energy is fuel, heat, or electricity produced from organic materials such as plants, agricultural residues, forestry by-products, and municipal or industrial wastes. Biomass has its energy stored within the chemical structure of the organic substance itself. Solid or liquid biomass feedstocks from surrounding areas can be acquired, sometimes at low cost, and converted to heat or electricity for buildings. Much of the plant-based biomass resource is already in a form that is readily transportable and dispatchable, with no energy transformation necessary; although ensuring the fuel has the required moisture content is often critical. There are costs associated with moisture removal/regulation, storage, and transport. Maintaining the energy quality (i.e., moisture content) of the fuel may require some environmental control and consideration for a shelf life that is not indefinite.

This analysis considered several available technologies to convert biomass feedstocks into heat and electricity. These include direct combustion, gasification, and liquefaction of solid biomass and anaerobic digestion of liquid biomass.

Combustion of solid biomass can be used to generate steam or used in a topping cycle for steam cogeneration of heat and power at a facility. For the latter, some of the heat output of the boiler may be converted to electricity by a steam turbine in a cogeneration topping cycle. Combustion of dry biomass feedstocks, such as wood mill waste available in the area, was also analyzed. Dry sources of waste from the NAVSTA Newport site may also be considered if the site were to include an inventory of waste streams, such as waste pallets or tree trimmings. Given the level of vegetation viewed across the base during the site visit, the site is not considered a sustainable source of vegetative biomass. Further investigation of the waste stream is needed to determine if there is enough daily waste generated to be viable.

Gasification of solid biomass produces a fuel gas by heating the feed material in a vessel, sometimes with the additional oxygen and/or water (Figure 15). The fuel gas, aka syngas, can be used directly in combustion for a boiler or stored for dispatchable use.

In wet feedstocks, decomposition reactions take place that produce a mixture of hydrogen and carbon monoxide, along with water, methane, and carbon dioxide. Anaerobic digestion of wet feedstocks is considered in this analysis to produce methane gas. Wet waste streams include confined animal waste from surrounding areas.

Unlike the other RE technologies considered in this report, on-site use of biomass resources involves atmospheric emissions, solid waste residues (ash), and possible water-borne wastes. It may be expected, however, that emissions from a gasification operation would be no worse than those of a direct-burn operation.

Figure 15. Biomass-fueled gasifier and boiler

Photo by Bob Bender, NREL/PIX 13534

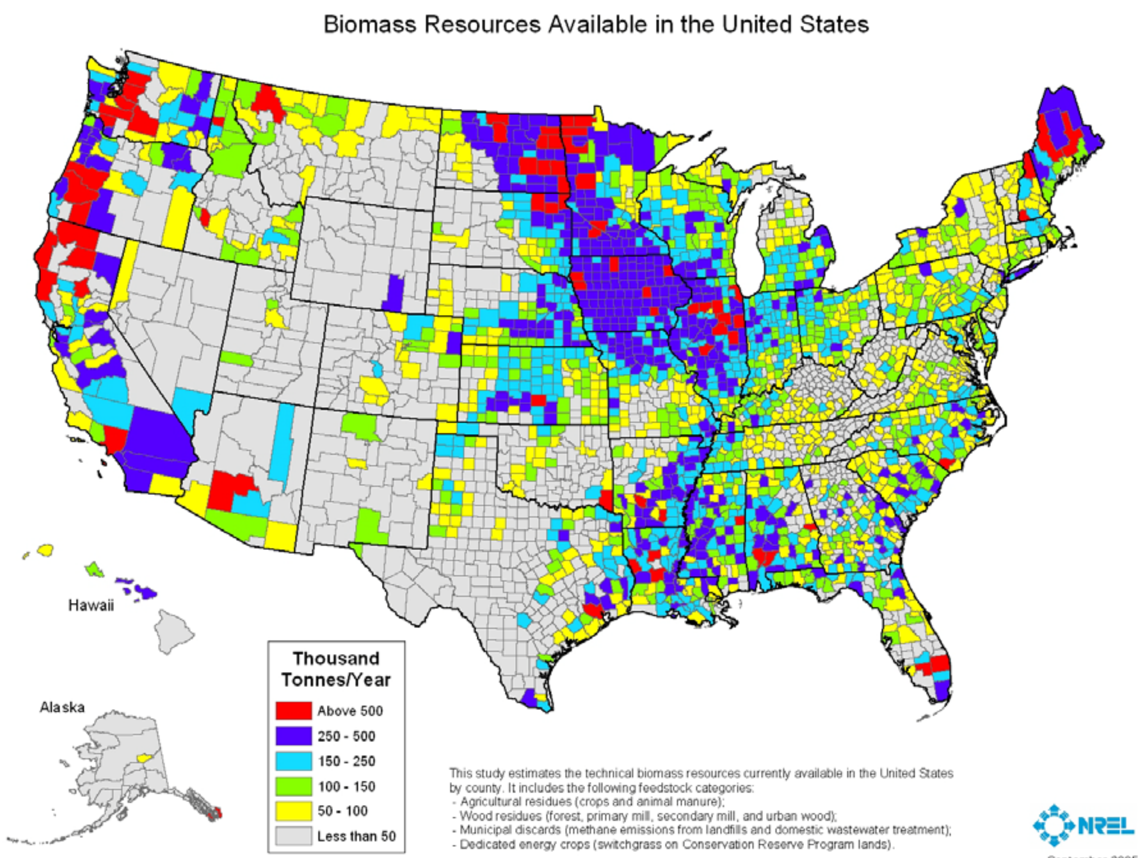

Figure 16. Biomass resources in the United States by tonnage

3.8.1 Biomass Resource Data

Biomass fuel resources available at NAVSTA Newport were taken from existing databases. No on-site biomass data was provided. Biomass resources considered are detailed in Appendix F. Figure 16 provides a visual context for the biomass resources available across the country on a county-by-county basis.

3.8.2 Technology Characteristics of Biomass Energy Conversion Configurations

The emerging biomass energy sector is focusing on increasing the conversion efficiency of solid biomass-based fuels compared to the standard boiler and steam-cycle configuration. While further research and development (R&D) is needed to increase reliability, reduce maintenance costs, and reduce capital costs, these new biomass conversion approaches are already penetrating the biomass energy sector in a number of countries. The details of these conversion technologies and system configurations can be found in Appendix F.

3.9 Biofuels from Algae

NAVSTA Newport requested an investigation of the potential for using their existing tanks on various tank farms for the production of biofuels processed using algae.

Conventional U.S.-based liquid biofuel production, primarily corn-grain ethanol and soybean biodiesel, have been in use for a number of years. There are known impacts regarding GHGs, use of fertilizers, water consumption, and fossil fuels used for production and transport. The production of biofuels from algae is a relatively new area in the fuel development field. Experiments in the laboratory have yielded results that merit further investigation.

Advantages of this type of microalgae production include the ability to utilize nutrient-laden wastewater streams reducing or negating the need for fertilizers and the higher yields per land than conventional soybean production. However, some studies have suggested that harvesting microalgae is energy intensive and may require significant chemical inputs to achieve effective separation.[26] Yields improve significantly with heterotrophic (i.e., sugar-grown) algae.

Overall, biofuels from algae are viewed as having a reasonable potential as a fuel supply, but it is dependent upon several independent factors such as continued technology development, energy and environmental policy, and relative cost of competing fuels.

To help frame potential yields, an estimate from an NREL biologist, Dr. Al Darzins, for a moderately producing sugar-grown algae (20 gm/m^2/day) that has an oil content of 15%

[26] Williams, P.R.D.; Inman, D.; Aden, A.; Heath, G.A. "Environmental and Sustainability Factors Associated With Next-Generation Biofuels in the U.S.: What Do We Really Know?" http://pubs.acs.org/doi/full/10.1021/es900250d?prevSearch=&searchHistoryKey=&cookieSet=1. Accessed May 31, 2011.

can be expected to produce about 75–95 L/yr (about 20–25 gal/yr) of algal oil using a 93 m^2 (about 1,000 ft^2) pond.[27]

Using this biofuel production range, based on estimated dimensions taken during the site visit, a single tank at NAVSTA Newport might have a diameter of approximately 30–45 m (100–150 ft) with a resultant area of approximately 700–1,700 m^2 (8,000–18,000 ft^2). Using the production figures above, annual output from a single tank might be in the 160–450 gal/yr range. Depending on the competing cost of fuel (roughly $3–$5/gal), the value of the biofuel that could be produced from a single tank would fall between $500/yr and $2,300/yr. There are not reliable estimates for the infrastructure costs to produce that level of annual economic value, but the likely development costs would dwarf the benefit range.

Regarding the technology itself and the production of oil, there are a host of issues still to be studied further, including feedstock optimization, fuel quality standardization, reduction of energy consumption for drying, waste stream disposal, overall sustainability, and net GHG displacement.

Transportation fuels generally have a higher value than heating or power generation fuels due to their high energy content and ease of transport. When algal fuels become more cost competitive and commercially available, it is likely that an initial (possibly primary) use will be for transportation. However, many aspects of this technology are still years to decades away from being commercial.

In terms of NAVSTA Newport hosting a microalgae plant, there are many factors to evaluate. The technology is not considered a mature technology at this point. A project would require hiring staff dedicated to algae production (with algae and fermentation experience to start). There would need to be a dedicated fermentation facility with carefully monitored and controlled growing conditions—pH, temperature, dissolved oxygen, and mixtures, for example. There would also need to be a significant downstream infrastructure to harvest the cells, extract the oil, convert the oil to fuel, process residues, and monitor fermentation rates. Given these constraints, this sort of homegrown biofuel experiment at NAVSTA Newport is not likely to be cost effective.

3.10 Tidal Power

Tidal power was not included in the original REO analysis. NAVSTA Newport requested an investigation into the potential for utilizing marine-based hydro-generation (aka tidal power), so it was investigated separately. Given NAVSTA Newport's location right on the Narragansett Bay, where tidal flows are seen every day, this RE resource is the most abundant, though not necessarily the most economic, renewable resource.

Tidal power was one of the earliest forms of RE harnessed by mankind. The Spanish, French, and British built tidal storage ponds behind dams filled by incoming tides

[27] Darzins, A. Email. NREL, Golden, CO, 4 June 2010.
Jarvis, E. Email. NREL, Golden, CO, 23 June 2010.

through sluice gates during rising tides.[28] The trapped water was used to power a water wheel to mill grain. Tide mills were used in the United States and Great Britain in the 17th–19th centuries for milling flour, sawing lumber, manufacturing paper and cotton, and grinding pepper and gunpowder.[29] This method relied on the use of "barrages" to capture the water at high tide. These gave way to steam-powered mills through the Industrial Revolution. The environmental impact of these barrages is high and, consequently, will not be considered further in this report.

Tidal power has several advantages over other forms of RE but also has challenges in its availability and implementation. Though tidal power has been deployed successfully for mechanical power applications for centuries, the use of tidal currents for generating electricity is still a relatively new technology. Tidal power is non-polluting, reliable, and predictable. At a given location, the magnitude of the resource can be defined with reasonable certainty and the oscillations defined with precision. There are two primary factors of interest in the tide—the periodic volume of water available and the tidal current (or speed) of that water. Details of the resource and power conversion equations can be found in Appendix G.

The area of interest for tidal power for NAVSTA Newport is the channel between Conanicut and Aquidneck Islands. The channel varies in width between approximately 0.5 and 2.5 miles near NAVSTA Newport, as shown in Figure 17.

[28] Hagerman, G.; Polagye, B. "Methodology for Estimating Tidal Current Energy Resources and Power Production by Tidal In-Stream Energy Conversion (TISEC) Devices," EPRI, 2006.
[29] Elling Tide Mill. http://www.culture24.org.uk/am35881. Accessed September 2010.

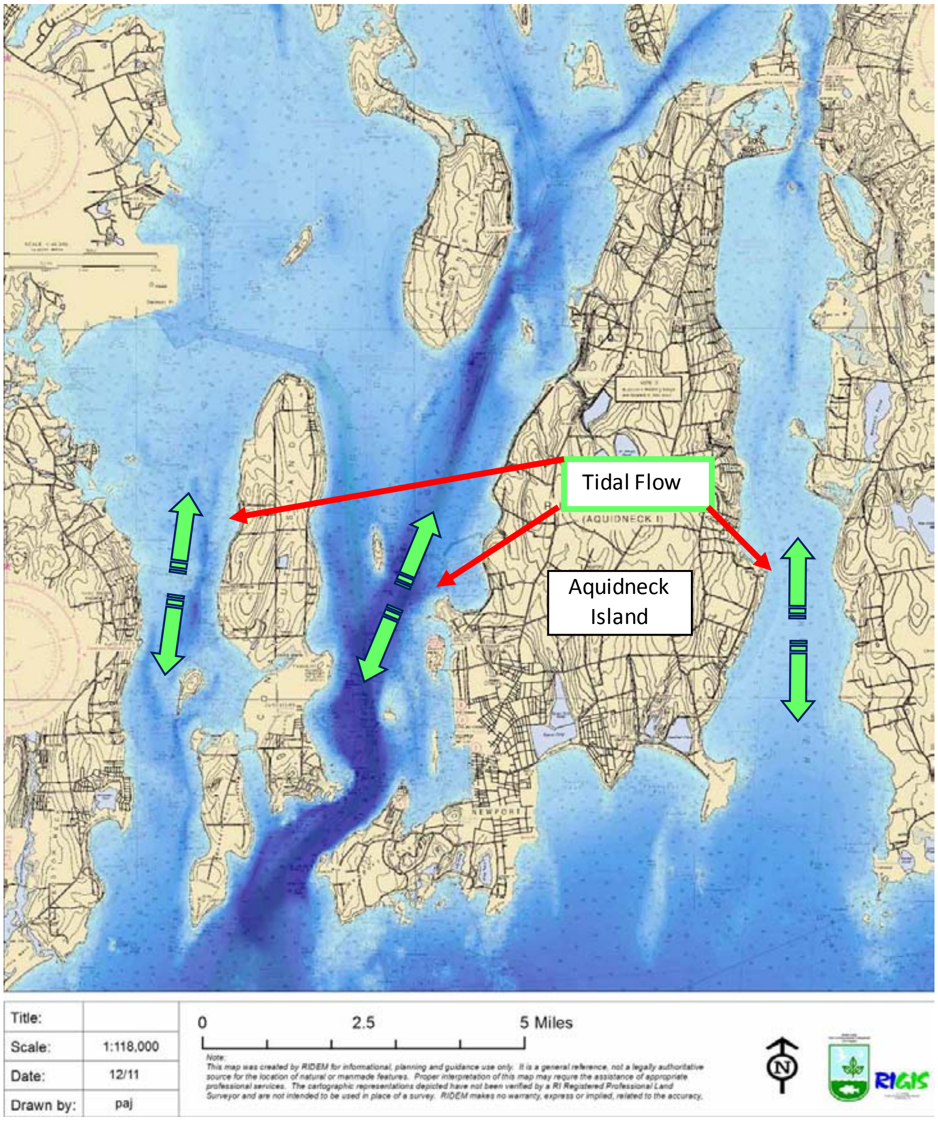

Figure 17. Aquidneck Island in Narragansett Bay

Illustration by Paul *Jordan, Rhode Island Department of Environmental Management*

3.10.1 Tidal Power Technologies

Tidal current electricity conversion is still a relatively new technology. Ideas, approaches, energy capture, and generator designs are still being developed and tested. There are a number of turbine technologies that have been deployed and, similar to wind turbines of a couple generations ago, there are both vertical and horizontal axis turbines being investigated and developed. Over time, the most reliable turbines with reasonable energy conversion efficiencies will emerge. More experience in the field, with analyses of failure modes and documenting of O&M, are necessary to bring this industry to a more commercially mature stage.

Jurisdiction over the land underwater and NAVSTA Newport's ability to place hydro-turbines there is a new area of permitting to explore. Permits would be required from

Rhode Island Coastal Resource Management Council and the Rhode Island Department of Environmental Management.[30] It is expected that it might take some time to receive the necessary permits, so beginning the process well in advance of an impending developable project is recommended.

The tidal currents in the Narragansett Bay, as a whole, do not appear adequate at this time for cost-effective power generation with current technologies given the cost of competing electricity. However, there may be individual locations on the bay floor that have accelerated tidal current speeds and could merit further investigation with a bathymetric study. Increased tidal current speeds may prove viable. Over time, as conversion technologies improve, there could be technologies well-suited to the level of resource NAVSTA Newport has available.

Figure 18. Tidal power turbines

Photo by Marine Current Turbines Ltd.

3.11 Ground Source Heat Pumps

NAVSTA Newport requested an investigation into the potential for utilizing GSHP and geothermal heat pump (GHP) systems to provide heating and cooling to buildings using the earth's thermal energy as both a thermal energy source and sink.

In the United States alone, over 50,000 GSHP units are sold each year, with a majority of these for residential applications. It is estimated that a half million units are installed,

[30] "Overview of Water Planning Authority in Rhode Island." RI Water Resources Board. http://www.water.ri.gov/wapacmeetings/waterrights/regauthdiagrams.pdf. Accessed July 2011.

with 85% closed-loop earth connections (46% vertical and 38% horizontal) and 15% open-loop systems (groundwater).[31]

Geothermal energy can be used to make electricity—but that requires geothermal heat sources of 200–600°F (93–315°C). There is not that kind of geothermal resource available in Rhode Island. GSHP (term will be used to cover both GSHP and GHP generically, unless specific identification merits delineation) were not included in the REO analysis but investigated separately.

To understand the advantages of using the geothermal resource, it might be best to look first at the framework that it will be used in. Heat pumps are an energy efficient HVAC equipment option that can be used as an energy saving alternative to conventional HVAC boilers, furnaces, and air conditioners. Heat pumps use electricity to move heat from a cool space to a warm space, making the cool space cooler and the warm space warmer. The most common type of heat pump is an air-to-air or air-source heat pump.

GHPs operate at higher efficiencies than air-source heat pumps (under most operating conditions) because they start with a higher temperature source in winter (in the example, 52ºF ground temperature versus 15ºF air temperature) and a lower temperature "sink" in summer (for example, 60ºF ground versus 95ºF air). They use anywhere from 25%–50% less energy than a conventional heating and cooling system.[32]

3.11.1 Geothermal Resource Characteristics

The earth provides a continuous RE resource that can be tapped to meet all or most of building heating and cooling loads, and in some cases, even hot water loads. GSHP systems take advantage of the temperature differential between the earth's surface temperature and building loads versus the earth's nearly constant temperature at some distance under the surface. Within 4–8 m of the earth's surface, ground temperatures remain very stable despite the large fluctuations the earth's surface undergoes due to the change of seasons in many regions of the United States. In the winter, this underground temperature is warmer than the air above it, and during the summer, it is cooler than the air above. A GSHP system exchanges heat with the steady temperature of the earth to meet building loads. In the winter, the heat pump removes heat from the ground and delivers it into the building. In the summer, the heat pump removes heat from the building and delivers it to the ground. GSHPs can offer a cost-effective technology solution to utilizing the heat of the earth to meet building loads. Overall, system performance and economics are improved at locations that have both a heating load and cooling load, such as NAVSTA Newport.

If a water source is available, it should be evaluated as an option as it can enhance the performance of a system in several ways. Water has a considerably higher heat capacity at 4.186 Kj/(Kg °K) than any of the soil types shown in Table 8, so it can store heat and

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[31] RETScreen International. "Clean Energy Project Analysis: RETSCREEN® Engineering & Cases Textbook." Clean Energy Support Center. www.retscreen.net. Accessed September 30, 2011.
[32] NAHB Research Center. "Types of Equipment -Heating and Cooling." http://www.toolbase.org/PDF/DesignGuides/MDL_8_MechanicalSystems.pdf. Accessed September 30, 2011.

transfer it better than the soils. Water's heat capacity is even higher than granite. Though some of water's other properties are lower than those of the various soil types, water's high heat capacity make it a useful ground loop thermal source. Also, in water source systems, after the water has completed its thermal exchange in the building, it is returned to the water source and all of its heat is removed, not just the partial heat removal that occurs through a heat exchanger in the ground source systems.

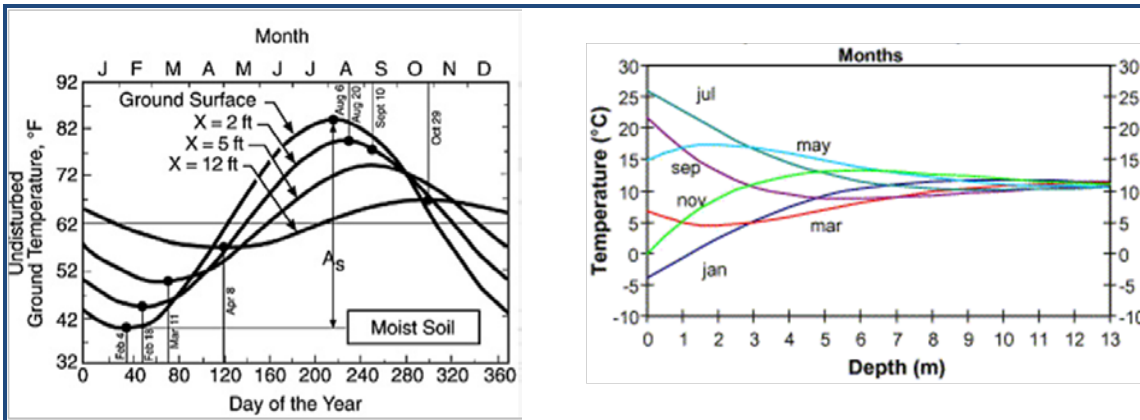
The soil characteristic profile is a key component of any initial screening for GSHP applications. The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) recommends site investigations and sample boreholes to objectively evaluate the type of geo-exchange system best suited to a site.

Table 8. Soil Types Defined in the GSHP Model[33]

Soil Type	Conductivity W/(m·°C)	Diffusivity m^2/s	Density kg/m^3	Heat Capacity kJ/(kg°C)
Light Soil – Damp (Loose sand, silt)	0.9	5.16e-7	1,600	1.05
Light Soil – Dry (Loose sand, silt)	0.3	2.84e-7	1,400	0.84
Heavy Soil – Damp (Clay, compacted sand, loam)	1.3	6.45e-7	2,100	0.96
Heavy Soil – Dry (Clay, compacted sand, loam)	0.9	5.16e-7	2,000	0.84
Light Rock (Limestone)	2.4	1.03e-6	2,800	0.84
Heavy Rock (Granite)	3.5	1.29e-6	3,200	0.84
Permafrost – Light	1.4	1.10e-6	1,580	0.76
Permafrost – Dense	2.0	1.37e-6	2,070	0.69

The graph at the left in Figure 19 displays the amplitude of the sinusoidal relationship and associated time lag of the ground temperature at several depths and the surface temperature. Notice that the ground temperature at 12 ft is below the air temperature from about the 110th day to the 185th day of the year. This provides a useful temperature differential for a heat exchange system that will exhaust warm building air with cool ground temperatures during the summer months and the opposite in winter.

[33] Natural Resources Canada. "Soil Types." 2007. Reproduced with the permission of the Minister of Natural Resources Canada, 2011. http://www.retscreen.net/ang/home.php.



Surface versus underground temperature time lag

Seasonal soil temperature versus depth

Figure 19. Seasonal cycles of surface versus underground soil temperatures[34]

Figure 20 illustrates the groundwater temperature gradient zones across wide swaths of the United States. A steady thermal source combined with fluctuating temperature-driven loads provide a useful temperature differential for geothermal systems to exploit. Geothermal systems are generally designed to use heat pumps to move heat from where it is not needed to where it is desired. The direction of this thermal energy flow may be opposite in winter than during the summer.

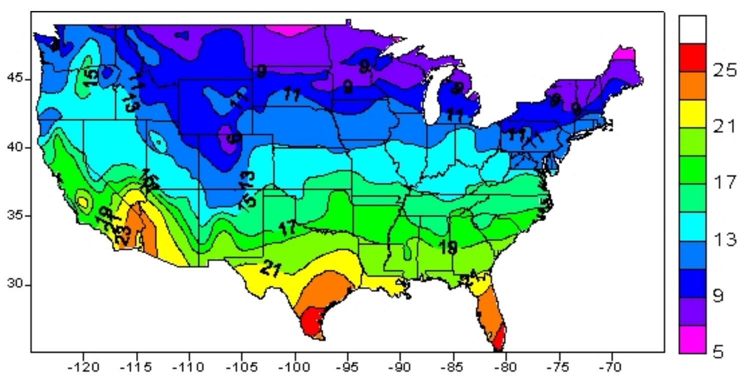


Figure 20. Average temperature (°C) near the surface of the United States from groundwater measurements[35]

A more detailed assessment of Rhode Island soil and sub-soil components can be found in Appendix H along with descriptions of the various types of GSHPs and their common configuration.

[34] Shonder, J. "*Geothermal Heat Pumps.*" Presented at FEMP Renewable Energy Workshop, NREL, 2004.
[35] Blackwell, D.D.; Richards, M. (2004). "U.S. Portion of the Geothermal Map of North America." American Assoc. Petroleum Geologist. http://smu.edu/geothermal/heatflow/surtemp.htm. Accessed October 2, 2011.

3.12 Landfill Gas

The United States has approximately 2,300 municipal solid waste (MSW) facilities or landfills, and currently about 555[36] of these sites are utilizing the landfill gas (LFG) for energy projects with roughly 350 of those generating electricity from the LFG.[37] A brief overview of landfill emissions and landfill gas power plants are provided in Appendix I.

MSW, a common component of landfills, can contain significant portions of organic materials that may produce a variety of gaseous products as decomposition, fueled by anaerobic bacteria, thrives in this oxygen-free environment. Primary products of the decomposition of organic matter are carbon dioxide and methane.

Methane is a hydrocarbon that is a primary component of natural gas (approximately 83%–99%).[38] LFG has a lower concentration of methane than natural gas (approximately 50%–80%); however, they are the third-largest human-related source of methane in the United States, accounting for 17% of all methane emissions in 2009.[39] LFG needs to be processed so it can be combusted directly or combined with natural gas for combustion.

Methane is lighter than air, soluble in water, and is a very potent GHG. Methane prevents the release of long wave radiation from the earth at night to a greater degree than most other GHGs resulting in a greater "greenhouse effect." Methane is over 20 times more effective at trapping heat in the atmosphere than carbon dioxide. At capped landfills, methane can build up under the cap and reach dangerous pressure levels. Historically, the methane was flared at vent pipes throughout the landfill to prevent the pressure buildup. EPA requires that all large landfills install a collection system to minimize the release of methane.

3.12.1 Landfill Gas Use

To make use of the LFG generated at a site, a collection system needs to be installed. The collection system typically consists of a series of wells drilled throughout the landfill and connected by a plastic piping system. The gas entering a gas collection system is saturated with water, and that water must be removed prior to further fuel processing through a technique known as "dewatering." The typical "dry composition" of the low-British-thermal-unit gas is 57% methane, 42% carbon dioxide, 0.5% nitrogen, 0.2% hydrogen, and 0.2% oxygen. A significant number of other compounds can be found in trace quantities.[40]

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[36] EPA. "An Overview of Landfill Gas Energy in the United States." Landfill Methane Outreach Program. http://www.epa.gov/lmop/documents/pdfs/overview.pdf. Accessed October 2, 2011.
[37] EPA. *Technology Transfer Network Clearinghouse for Inventories & Emissions Factors.* AP 42, 5th Edition, Volume I, Chapter 2: "Solid Waste Disposal." http://www.epa.gov/ttn/chief/ap42/ch02/final/c02s04.pdf. Accessed October 2, 2011.
[38] DOE, EERE. "Fuel Properties." Alternative Fuels & Advanced Vehicles Data Center. http://www.afdc.energy.gov/afdc/fuels/properties.html. Accessed October 2, 2011.
[39] EPA. "An Overview of Landfill Gas Energy in the United States." Landfill Methane Outreach Program. http://www.epa.gov/lmop/documents/pdfs/overview.pdf. Accessed October 2, 2011.
[40] California Energy Commission. "Landfill Gas Power Plants." http://www.energy.ca.gov/biomass/landfill_gas.html. Accessed October 2, 2011.

Depending on the quantity of LFG collected and other site factors, the LFG can be put to use in a number of energy applications, including:

- Electricity generation—combusted to generate electricity for on-site use or sale to the utility electric grid
- Direct use—combusted to replace or offset the use of another fuel in a boiler, kiln, or other thermal application
- Cogeneration (aka combined heat and power)—combusted for use in generating both electricity and thermal energy
- Alternate fuels—converted to other useful energy forms, such as medium- or high-British-thermal-unit fuel, compressed-to-liquefied form, or methanol.

3.12.2 McAllister Point Landfill

McAllister Point, an 11-acre site along the shore north of the main campus, is a capped landfill at NAVSTA Newport. The site was an active landfill from 1955 to the mid-1970s and accepted wastes consisting primarily of domestic refuse, acids, solvents, paint, waste oil, and oil contaminated with polychlorinated biphenyls (PCBs).[41] Of primary concern with any activities on this site are the potential impacts of the disturbance of the cap and the material underneath as surface water (i.e., rain and snowmelt) and groundwater flow towards the Narragansett Bay. Disturbances to the landfill have the potential to increase the leaching rate into the bay. Disturbances could also increase the migration of gases, such as methane, into the air. Also of concern are a number of private wells within a 3-mile radius of the landfill that provides drinking water to approximately 4,800 people and irrigation water for around 200 acres of land.[42]

Figure 21. McAllister Point Landfill

Source: Google Earth

[41] EPA. "Waste Site Cleanup & Reuse in New England." http://yosemite.epa.gov/r1/npl_pad.nsf/51dc4f173ceef51d85256adf004c7ec8/a48c071b6a314e1c8525691f0063f6dd?OpenDocument&Highlight=0%2Cnewport. Accessed October 2, 2011.

[42] EPA. "Waste Site Cleanup & Reuse in New England." http://yosemite.epa.gov/r1/npl_pad.nsf/51dc4f173ceef51d85256adf004c7ec8/a48c071b6a314e1c8525691f0063f6dd?OpenDocument&Highlight=0%2Cnewport. Accessed October 2, 2011.

McAllister Point was investigated in 1991, and elevated levels of petroleum hydrocarbons were found in the soils. This lead to a series of studies, plans, and decisions to develop treatments to address lateral flow of groundwater, reduce leachate into the near-shore marine environment, and reduce GHGs. The site continues to be monitored for groundwater migration, vent gas, and ambient air conditions to ensure that emissions are within acceptable parameters. The most recent *Five-Year Review*[43] indicates the source control remedy is complete and groundwater, vent gas, and ambient air monitoring is ongoing. Recent groundwater monitoring annual results show few detections of volatile organic compounds and semi-volatile organic compounds; minor exceedences of the maximum contaminant level for organic compounds and some metals have been observed. Any consideration of this site for a LFG electricity-generating facility would need to begin with the general monitoring requirements outlined in the long-term monitoring program (LTMP).[44]

Any alternative use of the McAllister Landfill (beyond its current use) would involve obtaining permission from EPA and other regulatory authorities as impacts to air quality and runoff into Narragansett Bay would need to be addressed.

3.12.3 McAllister Point as Potential Wind Turbine Site

The variation in the wind speeds between the collected data at Coddington Point and Tank Farm #4 (see Appendix A) points to well-exposed NAVSTA Newport sites along the Narragansett Bay as more likely having a greater wind resource than the inland tank farm sites. During the site visit, McAllister Point was raised a potential location for siting a utility-scale wind turbine.

As shown in Figure 22, the site has reasonable fetch across the water in the south-west-north arc, which helps to minimize surface-roughness-caused turbulence.

Figure 22. McAllister Point Landfill with view to the south-west-north arc

Source: Google Earth

[43] EPA. "Five Year Review Report for Naval Station Newport." Section 2.4.2. http://www.epa.gov/region1/superfund/sites/netc/457973.pdf. Accessed October 2, 2011.
[44] EPA. "Five Year Review Report for Naval Station Newport." Section 2.16. http://www.epa.gov/region1/superfund/sites/netc/457973.pdf. Accessed October 2, 2011.

It is unknown how the regulatory authorities, such as EPA, Rhode Island Coastal Resource Management Council, and Rhode Island Department of Environmental Management, might respond to a wind turbine project proposal for McAllister Point. It would be prudent to inquire about the nature of the issues to resolve before moving forward. A comparable wind turbine project placed on a landfill was successfully implemented in Hull, Massachusetts, in 2006.[45] The project, built on a 13-acre landfill comparable to McAllister Point's 11 acres, provides a framework for consideration at NAVSTA Newport.

Due to the range of challenges to permit this facility for wind, NAVSTA Newport has determined they will not pursue wind on the McAllister Point Landfill.

[45] Town of Hull, Massachusetts. "Hull Wind Turbine Information." http://www.town.hull.ma.us/Public_Documents/HullMA_Light/Hull%20Wind%20Turbine. Accessed August 31, 2011.

4 Methodology

Using data from NAVSTA Newport, NREL performed analysis using geographic information systems (GIS) software, databases, Excel spreadsheet calculations, and optimization software called "Premium Solver,"[46] which is an add-in to Excel.

4.1 Utility Energy Usage and Cost Data

NAVSTA Newport provided NREL with annual utility use and cost (gas, electric, and oil) data for the previous year and other data for use in the analysis, such as square feet of building space. For information not supplied by NAVSTA Newport, standard values for the specific building type were obtained: cubic feet per minute of ventilation air as per ASHRAE Std 62[47]; gallons per day of hot water from Commercial Building Energy Consumption Survey (CBECS)[48]; and lighting levels as per the Illuminating Engineering Society of North America (IESNA) standard.[49]

4.2 NAVSTA Newport Site Factors

NAVSTA Newport provided the following data for FY 2009 and FY 2010 for its buildings: site address, site latitude/longitude, total facility square footage (and when available, building loads, building sizes, and building primary use), and annual utility energy use and cost (gas, electric, and oil). National grid utility data was used for local energy cost and was also supplied by NAVSTA Newport.[50] FY 2009 data was used in the analysis as representative data. This site information was combined with site-specific resource and incentive information from NREL's RE resource databases.[51] NAVSTA Newport did not provide an inventory of waste streams for use in the biomass fuel assessment, so only feedstocks from the surrounding area were considered.

The analysis was conducted with and without tax-based incentives. To do this, DSIRE was used to estimate the installed cost (including incentives and depreciation timeframe).[52] A typical corporate tax liability structure in the 35% tax bracket was assumed for estimating the effects of business ITC and accelerated depreciation.

4.3 Renewable Resource and Technology Cost Data

The RE resources associated with NAVSTA Newport were obtained from the NREL GIS database of solar, wind, weather, and biomass resources.[53]

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[46] Frontline Solvers. "Premium Solver Pro for Excel." http://www.solver.com/pspro.htm. Accessed October 2, 2011.
[47] ANSI/ASHRAE Standard 62.1-2007. "Ventilation for Acceptable Indoor Air Quality American Society of Refrigeration Air Conditioning and Heating Engineers." Atlanta, GA: ASHRAE.
[48] Federal Energy Management Program (FEMP). "Annual Supplement to Handbook 135." http://www1.eere.energy.gov/femp/information/download_blcc.html. Accessed May 2010.
[49] IES HB-9-2000. "IESNA Lighting Handbook." New York: IES.
[50] Reichert, J. Email. NAVSTA Newport, Newport, RI, 4 May 2010.
[51] NREL. "Dynamic Maps, GIS Data, & Analysis Tools." http://www.nrel.gov/gis/. Accessed May 2010.
[52] DSIRE. www.dsireusa.org. Accessed May 2010.
[53] NREL. "Dynamic Maps, GIS Data, & Analysis Tools." http://www.nrel.gov/gis/. Accessed May 2010.

NREL estimated the cost of each technology to be evaluated at each building and incorporated the effects of incentives that may be available from state governments, utilities, or others. Incentives will be as listed in DSIRE.[54] NREL staff compiled the incentives available for each technology at NAVSTA Newport from DSIRE.

NREL employed simple annual-average algorithms to calculate energy delivery as a function of RE resources based on efficiency models. NREL calculated associated energy cost savings based on energy use and cost information supplied by NAVSTA Newport.

Estimates for the installed cost of RE technologies were based on NREL's project experience and cost estimating manuals (RS Means Green Building: Project Planning and Cost Estimating, 2010[55]). NREL estimated annual O&M costs as a fraction of installed cost or as a multiplier on energy production as reported in the *Power Technologies Energy Data Book*[56] and including staff project experience. Costs are adjusted according to the City Cost Adjustments for Newport, Rhode Island, published by RS Means.[57]

4.4 Economic Factors

NAVSTA Newport was interested in viable long-term RE options, so NREL performed a 25-year LCC analysis with future costs discounted to their present value. Twenty-five years was selected as the analysis period because it is the maximum allowed by 10CFR436[58] for electrical and mechanical systems, and these systems are expected to last that long. In order to model costs that are not constant from year to year, such as accelerated depreciation, a 25-year cash flow analysis was prepared. NREL calculated an LCC of all RE technologies combined at the site but also reported a payback period (25 years or less) as figures-of-merit to assess the cost effectiveness of each individual technology. Other results include rate of return and percentage of RE use at each site.

4.5 Renewable Energy Optimization

NREL's REO tool was used to determine the combination of RE technologies that minimize LCC for energy at the site. The best mix of RE technologies depends on several factors, including RE resource availability; technology cost and performance; state, utility, and federal incentives; and economic parameters (e.g., discount rate and inflation rates). Each of these factors was considered in this analysis. Due to the close proximity and same utility pricing among the buildings at NAVSTA, the location was optimized rather than individual buildings.

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[54] DSIRE. www.dsireusa.org. Accessed May 2010.

[55] RS Means. "Green Building Project Planning and Cost Estimating," 2010. http://www.rsmeans.com/bookstore/detail.asp?sku=67338A, Accessed March 2011.

[56] NREL. *Power Technologies Energy Data Book,* Edition Four. http://www.nrel.gov/analysis/power_databook/. Accessed May 2010.

[57] RS Means. "Green Building Project Planning and Cost Estimating," 2010. http://www.rsmeans.com/bookstore/detail.asp?sku=67338A, Accessed March 2011.

[58] GPO Access. 10CFR436. http://ecfr.gpoaccess.gov/cgi/t/text/text-idx?c=ecfr&tpl=/ecfrbrowse/Title10/10cfr436_main_02.tpl. Accessed October 2, 2011.

To conduct the analysis, NREL applied its REO tool and several other programs to systematically analyze:

- Energy needs of each building or set of buildings
- Available RE resources at the base
- Appropriate mix of RE technologies based on the building loads and the available RE resources
- LCCs of appropriate RE solutions compared to LCCs of the base case at each site
- Energy savings for RE solutions compared with today's energy mix (base case).

The installed cost (including the effects of incentives and tax depreciation), energy performance, cost savings, and LCC effectiveness were estimated for the seven RE technologies. After estimating the cost and savings associated with each RE measure, the size of each technology was adjusted to minimize LCC.

Additional investigation and analyses were conducted, without use of the REO tool, for other RE technologies of particular interest to NAVSTA Newport, including:

- Biofuels from algae
- Tidal current power
- GSHPs.

4.6 Iterative "Solving"

Unlike other tools, the NREL REO tool takes into account the effect of the other RE systems being optimized and adjusts sizing accordingly. For example, if REO finds that adding a significant amount of daylighting to a building is LCC effective, the impacts of adding daylighting may increase the heating load in the winter and decrease the cooling load in the summer and the HVAC system would need to compensate accordingly. The REO tool accounts for this compensation when sizing the daylighting and re-calculates the energy impacts of the daylighting. REO does this for all the RE technologies.

Using several RE technologies at NAVSTA Newport reduces the use of purchased energy. This improves energy security and provides a greater hedge against price or fuel supply fluctuations than using a single RE technology. This benefits federal agencies, which are particularly vulnerable to price and supply fluctuations because their energy and O&M budgets tend to be fairly stable or fixed and cannot easily accommodate rapid energy price increases.

Once energy savings (in therms and kilowatt-hours) for each RE technology were determined with the REO tool, carbon dioxide emissions savings were calculated. DOE's multipliers for carbon dioxide emissions per kilowatt-hour of electricity use were based on the local power plant fuel source mix. A standard multiplier for carbon dioxide emissions per therm of natural gas consumption was used. [59]

4.7 GIS Data on Renewable Energy Resources

NREL evaluated RE technologies using a GIS database of RE resource information[60] to represent the magnitude of a RE resource in the area.

NREL datasets used in the analysis include:

- Solar radiation (40 x 40 km grid)
- Horizontal, south-facing vertical, tilt = latitude
- Wind energy (200 m x 1,000 m grid)
- Biomass resources
- Illuminance for daylighting
- State and utility incentives and utility policy[61]
- Temperature, heating, and cooling degree days
- City cost adjustments[62]
- Installed hardware costs[63]
- Economic parameters (e.g., discount rate and inflation rate).[64]

4.8 Optimization Technique

The objective of the optimization is to minimize LCC. Using NAVSTA Newport-supplied inputs on energy usage, cost, building types, and estimated costs and savings associated with each RE measure, the LCC of energy production from each RE technology was determined. Premium Solver[65] was then used to adjust each of the following variables to minimize LCC:

- Kilowatts of PV
- Kilowatts of wind power
- Square feet of SVP

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[59] EPA. "Clean Energy, Greenhouse Gas Equivalencies Calculator." http://www.epa.gov/cleanenergy/energy-resources/refs.html. Accessed May 2010.
[60] NREL. "Dynamic Maps, GIS Data, & Analysis Tools." http://www.nrel.gov/gis/. Accessed May 2010.
[61] DSIRE. www.dsireusa.org. Accessed May 2010.
[62] RS Means. "Green Building Project Planning and Cost Estimating," 2010. http://www.rsmeans.com/bookstore/detail.asp?sku=67338A, Accessed March 2011.
[63] DOE "Building Energy Databook." http://buildingsdatabook.eren.doe.gov/. Accessed May 2010.
[64] FEMP. "Annual Supplement to Handbook 135" http://www1.eere.energy.gov/femp/information/download_blcc.html. Accessed May 2010.
[65] Frontline Solvers. "Premium Solver Pro for Excel." http://www.solver.com/pspro.htm. Accessed October 2, 2011.

- Square feet of solar water heating
- Square feet of solar thermal (parabolic troughs) and kilowatts of solar thermal electric
- British thermal units per hour of biomass boiler capacity and kilowatts of biomass electric using:
    - Combustion
    - Gasification
    - Anaerobic Digestion
- Percentage of office, gymnasium, and warehouse roofs to be occupied by daylighting skylights.

The solver routine calculates the change in LCCs associated with a change in the size of each of the RE technologies. It then moves in the direction of LCC by an amount determined by a quadratic approximation (Figure 23).

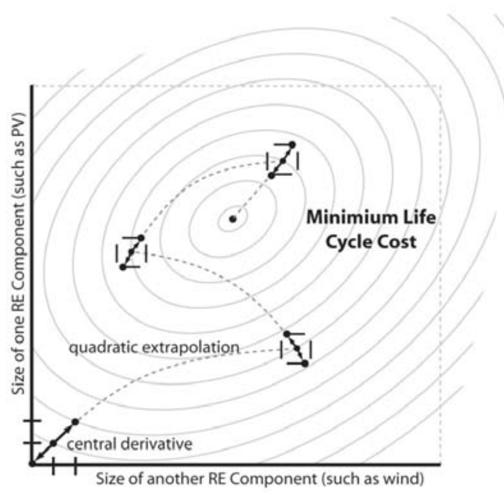

Figure 23. Illustration of the solver routine

Illustration by Jim Leyshon, NREL

The solver routine finds the minimum LCC in 10 variables, but only two variables can be illustrated in this two-dimensional figure. An increase and decrease in the size of each RE component is used to indicate the direction of reducing LCCs. The solver routine involved the following parameters: precision—value of energy use 0.0 ± 0.0001; convergence—change in LCC less than $0.0001 for five iterations; quadratic extrapolation to obtain initial estimates of the variables in a one-dimensional search; central derivatives used to estimate partial derivatives of the objective and constraint functions; and Newtonian Search Algorithm used at each iteration to determine the direction to search.

4.9 Results of LCC Optimization

The key result of the analysis is the size of each RE measure that minimizes LCC for NAVSTA Newport. Results indicate that daylighting can be cost effective at NAVSTA Newport, but attention must be paid to avoid excessive heat loss through skylights. SVP is cost effective due to the long heating season. Solar water heating is viable due to the combination of solar resource and the application at high load buildings. Wind is viable due to the consistency of seasonal and diurnal (daily profile) winds near the water. PV depends heavily on local, state, and federal incentives to be cost effective and is marginally just outside the threshold of being not cost effective at current incentive levels.

4.10 LCC

LCC is calculated by adding initial cost to any annual costs discounted to their present value. Annual costs include maintenance, fuel (as in the case of biomass), standby charges from the utility, payments to the utility associated with the difference between retail and delivered power, and any production incentives or other cash flows.

$$LCC = C_{initial} + (S_{energy} - C_{O\&M} - C_{biomass\ fuel})\ pwf_{25} + (S_{prod\ incentive})\ pwf_{prod\ incentive}$$

where

LCC = life cycle cost

$C_{initial}$ = initial cost of the RE system

S_{energy} = annual savings in electricity and natural gas purchased from the utility

$C_{O\&M}$ = annual cost of RE systems' O&M

$C_{biomass\ fuel}$ = annual cost of delivering biomass fuel to the site

pwf_{25} = present worth factor for future savings stream for 25-year lifetime and 3% real discount rate (specified by NIST for 2008).[66] [Note: real discount rate (3.0%) = nominal discount rate – inflation rate (4.8% – 1.8%)]

$S_{prod\ incentive}$ = annual revenue from production incentive

$pwf_{prod\ incentive}$ = present worth factor associated with the term of the production incentive

Simple payback (SPB) period is not a good criterion because it does not include the analysis period or term of production incentives, but it is a useful indicator of general viability and is given by the equation:SPB = C/S

[66] Platts. http://www.platts.com/Home.aspx. Accessed May 2010.

General O&M costs are escalated at the general inflation rate, and annual costs for fuels and electricity are inflated according to census region and fuel type. All annual costs are discounted according to discount rate. The factors are provided in Table 9.[67]

Table 9. Economic Parameters Used in LCC Calculations

Discount Rate	4.8%
General Inflation Rate	1.8%
Corporate Tax Rate (for case with incentives)	35.0%

Depreciation Schedule (for case with incentives)						
Year	1	2	3	4	5	6
Fraction	0.200	0.320	0.192	0.115	0.115	0.058

4.11 Carbon Dioxide Emissions Impact

Electricity saved from daylighting, wind power, and SVP in kilowatt-hours was totaled. This total was multiplied by the appropriate carbon dioxide offset factor for the zip code, 02841, of the base. The multipliers were taken from the EPA online application.[68]

Therms saved/produced for daylighting (negative), SVP, and solar water heating were multiplied by the carbon dioxide offset factor for natural gas of 11.70 lbs/therm.[69]

4.12 Land Use Requirements

Land use requirements are established for solar PV, wind energy, solar thermal, and solar thermal electric technologies. Land use requirements of the other technologies are not included, but many of these fit within the building or on the building shell. Many locations with cost-effective applications of solar or wind are constrained by the site size.

[67] FEMP. "Annual Supplement to Handbook 135." http://www1.eere.energy.gov/femp/information/download_blcc.html. Accessed May 2010.
[68] EPA, "Clean Energy." http://www.epa.gov/cleanenergy/energy-and-you/how-clean.html. Accessed June 2011.
[69] EPA. "Calculations and References." http://www.epa.gov/cleanenergy/energy-resources/refs.html. Accessed June 2011.

5 Data Summaries

5.1 GIS Data

The following resource data were drawn from NREL's GIS database for use in the REO analysis.

Table 10. GIS Resource Data

GIS Data	
Latitude	41.519400°
Longitude	-71.327250°
Heating Degree Days (65°F)	5,629
Cooling Degree Days (65°F)	729
Annual Average Solar Tilt = Latitude	4.34 $kWh/m^2/day$
Annual Max Solar Tilt = Latitude	6.09 $kWh/m^2/day$
Annual Average Solar Horizontal	3.44 $kWh/m^2/day$
Wind Power Density at 50 m	336 W/m^2
Annual Solar Vent Preheat Delivery	454 $kWh/m^2/day$
Annual Direct Solar on East-West 1-Axis Tracker	2.69 $kWh/m^2/day$
Biomass, Residues Within 50 Miles	
Crops	0
Manure	0
Forest	25,796 tons/year
Primary Mill	30,871 tons/year
Secondary Mill	359,928 tons/year
Urban	0
Landfill	0
Domestic Waste Water Treatment	0
Energy Crops on Conservation Reserve Program Land	0
Total	416,595 tons/year

	Illuminance Data	
March	9 a.m.	31 fc
	11 a.m.	53 fc
	1 p.m.	56 fc
	3 p.m.	41 fc
	5 p.m.	15 fc
June	9 a.m.	40 fc
	11 a.m.	66 fc
	1 p.m.	79 fc
	3 p.m.	71 fc
	5 p.m.	48 fc
September	9 a.m.	25 fc
	11 a.m.	52 fc
	1 p.m.	65 fc
	3 p.m.	56 fc
	5 p.m.	29 fc
December	9 a.m.	11 fc
	11 a.m.	28 fc
	1 p.m.	29 fc
	3 p.m.	15 fc
	5 p.m.	0

5.2 Incentive Data

Incentives offered by federal and state governments, local utilities, and private organizations have a huge effect on renewable project economics and need to be taken into account even at this early planning stage. There are four types of incentives that are considered for each technology: federal business ITC (percent of cost); state tax credit (percent of cost); rebate ($/W or percent of cost); and production incentives ($/kWh produced). The incentives used in this analysis are listed in Table 11 for each site and each technology. Descriptions of incentives available at each facility are taken from DSIRE.[70] It is important to note that most incentive and rebate programs have requirements, such as minimum or maximum size limitations or specific technology specifications, which a system must meet in order to qualify.

Table 11. Incentives*

Incentive Type	Incentive Amount	Name
Wind		
Tax Incentive (% capital cost)	30	Federal Business Energy Tax Credit (100 kW limit)
Renewable Energy Certificate Incentive ($/kWh)	0.03	People's Power and Light Renewable Energy Certificate Incentive (RECs are not claimable by site if this program is used)
Solar Ventilation Preheating		
Tax Incentive (% capital cost)	30	Federal Business Energy Tax Credit
Production Incentive ($/therm)	3	National Grid Solar Thermal Rebate Program (Up to max of 50% installed cost or $100,000 per project)
Solar Water Heating		
Tax Incentive (% capital cost)	30	Federal Business Energy Tax Credit
Production Incentive ($/therm)	3	National Grid Solar Thermal Rebate Program (Up to max of 50% installed cost or $100,000 per project)
Photovoltaics		
Tax Incentive (% capital cost)	30	Federal Business Energy Tax Credit
Renewable Energy Certificate Incentive ($/kWh)	0.03	People's Power and Light Renewable Energy Certificate Incentive (RECs are not claimable by site if this program is used)
Concentrating Solar Power		
Tax Incentive (% capital cost)	30	Federal Business Energy Tax Credit
Biomass		
Tax Incentive (% capital cost)	10	Federal Business Energy Tax Credit
Geothermal Heat Pump		
Tax Incentive (% capital cost)	10	Federal Business Energy Tax Credit

**Note: The net-metering limit for solar or wind is 1,650 kW.*[71]

There are several important points to note in regards to the incentives. Tax credits such as the federal business energy tax credit are for commercial entities that pay taxes and are

[70] DSIRE. http://www.dsireusa.org/. Accessed October 20, 2011.
[71] National Grid. https://www.nationalgridus.com/narragansett/business/energyeff/4_net-mtr.asp. Accessed October 2, 2011.

thus eligible for a tax credit. As a federal entity, NAVSTA Newport does not pay taxes and cannot qualify for the tax credit unless there is third-party ownership of the RE system.

There is a Rhode Island tax credit that is available for 25% of PV and wind systems costing up to $15,000. For SWH and GHPs, the 25% tax credit is available with a system cost limit of $7,000. Given the size limitation of the Rhode Island tax incentive relative to the size of RE systems considered, it should not be used as a decision-making factor. However, when moving forward with an RE project among the eligible technologies with third-party ownership, the tax credit for a portion of the project can serve as a minor incentive.

5.3 Economic Data

The following economic parameters are used in the installed cost and LCC calculations.

Table 12. Economic Parameters

Discount Rate	4.6%
Fuel Escalation Rate	5.8%
Electric Escalation Rate	3.3%
General Inflation Rate	3.4%
City Cost Adjustment Factor	1.025

5.4 Site Data

The following utility and site data was provided by NAVSTA Newport and used to frame the optimization.

Table 13. Site Data

Utility	National Grid
Annual Electric Use[1]	105,735,000 kWh
Annual Electric Cost[1]	$12,683,475
Annual Natural Gas Use[1]	4,780,340 therms
Annual Natural Gas Cost[1]	$5,533,113
Annual Fuel Oil Use[1]	159,810 therms
Annual Fuel Oil Cost[1]	$279,716
Total Building Size	3,534,850 ft^2
Number of Buildings Used in REO	54

[1] FY 2009 data

5.5 Technology Data

Initial cost, efficiency, and O&M cost for each of the RE technologies are characterized according to the cost and performance data reported in the *Power Technologies Energy Data Book*[72] and in "Renewable Energy Technology Characterizations."[73]

As the REO software is an optimization tool, if there is not a cost-effective option, it returns a system size of zero with costs of zero. In these cases, a representative system size has been input to demonstrate the realm of the results (i.e., in some cases the simple payback is negative or more than 50 years).

5.5.1 Daylighting

A complete daylighting system consists of apertures to admit and distribute solar light and a controller to modulate artificial light to achieve energy cost savings. There are no scheduled maintenance requirements, but skylights may increase roof maintenance. Table 14 lists the details of the daylighting analysis, including skylight area as a percentage of roof area, cost, annual energy delivery, annual cost savings, and payback period. Daylighting was found to be cost effective for NAVSTA Newport. Although skylights reduce building insulation levels, the cost of the heat lost through the skylights is much smaller than the savings realized from reduced electric light use.

An implication from implementing daylighting is that more heat will be required in the winter due to the reduction of waste heat from electric lighting. The added 59,755 therms for implementing daylighting is due to the impact of reduced waste heat from electric

[72] NREL. "Power Technologies Energy Data Book." http://www.nrel.gov/analysis/power_databook. Accessed October 2, 2011.
[73] DOE. "Renewable Energy Technology Characterizations." EPRI Topical Report No. TR-109496. http://www1.eere.energy.gov/ba/pba/tech_characterizations.html. Accessed October 2, 2011.

lighting that actually offsets a portion of the heating load in a typical office and other types of buildings. This offsets a portion of the savings from daylighting. Overall, the net reduction in energy use from implementing daylighting is the equivalent of 494,000 kWh/yr, resulting in a net cost savings of approximately $59,300/yr.

Table 14. Daylighting Analysis

Characteristic	Measurement	Units
Daylighting Skylight/Floor Area Ratio	1.4%	%
Total Skylight Area	79,572	ft^2
Annual Electric Savings	2,244,628	kWh/yr
Annual Natural Gas Savings	-59,755	therms/yr
Daylighting Capital Cost	3,261,134	$
State Tax Credit	-	$
Federal Tax Credit	-	$
Rebate	-	$
Daylighting Cost w/ Incentives	3,261,134	$
Daylighting Annual Cost Savings	202,747	$/yr
Daylighting Payback Period	16.1	yrs

5.5.2 Wind

NAVSTA Newport intends to develop their wind potential in phases—Phase I will consider properties "inside the fence line," and Phase II will consider properties "outside the fence line."[74] Per NAVSTA Newport's plans for Phase I of its site development for wind, an average installed cost of $3,800/MW was assumed. Table 15 lists details of the wind power analysis, including size of the wind energy facility (kW), cost, annual energy delivery, annual cost savings, and payback period. There was variability in the turbine output depending upon specific siting at NAVSTA Newport. Overall, wind was found to be cost effective at NAVSTA Newport due to good resource and sufficient incentives.

[74] Reichert, J. Email. NAVSTA Newport, Newport, RI, 25 August 2009.

Table 15. Wind Analysis

Characteristic	Measurement	Units
Wind Turbine Swept Area	19,085	m^2
Wind Turbine Swept Area	205,429	ft^2
Wind Capacity	9,000	kW
Wind Initial Cost	34,200,000	$
Wind Rebate	-	$
Wind Production Incentive	-	$/yr
Wind State Tax Credit	-	$
Wind Federal Tax Credit	10,260,000	$
Wind Initial Cost w/ Incentives	23,940,000	$
Wind Net Metering Limit (Up To)	1,650	kW
Wind Annual Energy Delivery	23,843,000	kWh/yr
Capacity Factor	30.2	%
Wind Annual Cost Savings	2,861,160	$
Wind Annual O&M Cost	71,100	$/yr
Wind Payback Period	8.6	yrs

5.5.3 Solar Ventilation Preheating

Table 16 lists the details of the SVP analysis including size of the transpired collector, cost, annual energy delivery, annual cost savings, and payback period. SVP was found to be cost effective for NAVSTA Newport.

Table 16. Solar Ventilation Preheating Analysis

Characteristic	Measurement	Units
SVP Ventilation Rate	2,228,280	CFM
Available Wall Area Constraint	298,104	ft^2
Low Flow Constraint	1,114,140	ft^2
Suggested Size	557,070	ft^2
Solar Vent Preheat Area	260,417	ft^2
Annual Gas Savings	468,632	therms/yr
Initial Cost	11,066,261	$
SVP Rebate	-	$
Production Incentive	-	$/yr
SVP State Tax Credit	-	$
SVP Federal Tax Credit	3,319,854	$
Solar Vent Preheat Cost w/ Incentives	7,746,325	$
Annual Utility Cost Savings	597,402	$/yr
Solar Vent Preheat Payback Period	13.0	yrs

5.5.4 Solar Water Heating

Table 17 lists the details of the solar hot water analysis, including size of the solar water heating system, cost, annual energy delivery, annual cost savings, and payback period. Solar hot water was found to be cost effective for NAVSTA Newport.

Table 17. Solar Water Heating Analysis

Characteristic	Measurement	Units
Hot Water Use	223,968	gal/day
Suggested Solar Hot Water size	160,578	ft^2
Solar Water Heating Area	138,409	ft^2
Solar Water Heating Heat Delivery	298,085	therms/yr
Solar Water Heating Initial Cost	13,522,848	$
SWH Rebate	-	$
Production Incentive	-	$/yr
Solar Hot Water State Tax Credit	-	$
Solar Hot Water Federal Tax Credit	4,056,854	$
Solar Water Heating Cost w/ Incentives	9,465,994	$
Solar Water Heating Fuel Savings	465,758	therms/yr
Solar Water Heating Annual Utility Cost Savings	564,850	$/yr
Solar Water Heating O&M Cost	67,614	$/yr
Solar Water Heating Payback Period	19.0	yrs

5.5.5 Photovoltaics

Table 18 lists the details of the PV analysis, including size of the PV, cost, annual energy delivery, annual cost savings, and payback period. PVs were not found to be cost effective at NAVSTA Newport due to a payback period of 25.8 years. Without incentives, the payback period increases to 36.9 years.

The installed cost of PV systems, particularly the module cost, has been coming down consistently in recent years and may fall below the 25-year payback threshold in the near future. A sensitivity analysis indicated that for a 10% decrease in installed system cost, the payback decreased by approximately 2.6 years. Similarly, a 10% increase in the cost of electricity from the National Grid or a 10% increase in PV module efficiency would decrease the payback by approximately 2.5 years.

Table 18. PV Analysis

Characteristic	Measurement	Units
PV Rating	5,000	kW
PV Size	320,238	ft^2
PV Initial Cost	25,625,000	$
PV Rebate	-	$
PV Production Incentive	-	$/yr
PV State Tax Credit	-	$
PV Federal Tax Credit	7,687,500	$
PV Initial Cost w/ Incentives	17,937,500	$
Net Metering Up To	1,650	kW
PV Annual Energy Delivery	6,095,131	kWh/yr
Capacity Factor	18.1	%
PV Annual Utility Cost Savings	731,416	$
PV Annual O&M Cost	36,571	$/yr
PV Payback Period	25.8	yrs

5.5.6 Concentrating Solar Power

Table 19 lists the details of the solar thermal analysis, including size of the array, cost, annual energy delivery, annual cost savings, and payback period. Concentrating solar power was not found to be cost effective at NAVSTA Newport due to the relatively poor solar resource. Overall, this or any form of “concentrating” solar technology works best in a drier climate with less humidity and few cloudy or overcast days.

Table 19. Concentrating Solar Power Analysis

Characteristic	Measurement	Units
Concentrating Solar Power Area	10,000,000	ft^2
Solar Heat Delivery	15,736,487	therms/yr
Concentrating Solar Power Cogeneration Size	10,000	kW
Thermal Storage (therms)	-	
Concentrating Solar Power Gas Savings	5,089,582	therms/yr
Concentrating Solar Power Electric Delivery	18,615,000	kWh/yr
Concentrating Solar Power Capacity Factor	21.3	%
Concentrating Solar Power Annual Utility Cost Savings	7,024,734	$/yr
Concentrating Solar Power Initial Cost	765,162,500	$
Rebate	-	$
Production Incentive	-	$/kWh
State Tax Credit	-	$
Federal Tax Credit	229,548,750	$
Concentrating Solar Power Cost w/ Incentives	535,613,750	$
Concentrating Solar Power O&M Cost	1,998,577	$/yr
Concentrating Solar Power Payback Period	106.6	yrs

5.5.7 Biomass

Several technologies are available to convert biomass feedstocks into heat and electricity. In this analysis, we consider gasification of dry biomass feedstocks such as crop or wood mill waste available in the area. Table 20 lists the details of the biomass gasifier analysis, including size of the gasifier, cost, annual energy delivery, annual cost savings, and payback period.

Biomass gasification was not found to be cost effective at NAVSTA Newport because the cost of fuel and annual O&M exceeds the value of energy produced**.**

Table 20. Biomass Gasifier Analysis

Characteristic	Measurement	Units
Biomass Gasifier Size	2	MMBTU
Biomass Gasifier SynGas Delivery	148,920	therms/yr
Biomass Initial Cost	922,500	$
Biomass Natural Gas Savings	148,920	therms/yr
Biomass Gasifier Annual Utility Cost Savings	175,227	$/yr
Tons of Fuel Used	1,986	tons
Area to Collect Fuel	38.4	mi^2
Per Ton Fuel Cost	129.35	$/ton
Fuel Cost	256,840	$
Avoided Disposal Cost	-	$
State Tax Credit	-	$
Federal Tax Credit	92,250	$
Rebate	-	$
Biomass Gasifier Cost w/ Incentives	830,250	$
Biomass Gasifier O&M Cost	115,036	$/yr
Biomass Gasifier Payback Period	Negative	yrs

5.5.8 Accommodating Missing Data

The REO analysis was based on actual building size, building electricity usage, and building heating energy as provided by NAVSTA Newport. The data was for the largest energy users on the campus. There were many smaller buildings not accounted for in this dataset resulting in the building cost and load totals being approximately half of the full campus load. To complete the REO analysis with more realistic results, NREL created four "big buildings" that combined to represent the energy and cost loads from the balance of buildings at NAVSTA Newport. These estimated loads and costs are shown in Table 21.

Table 21. Estimated Data

Building Name	Size	Electricity		Natural Gas		#2 Oil	
	ft^2	kWh/yr	$/yr	therms/yr	$/yr	therms	$/yr
Big Building A	739,175	11,428,584	1,371,430	684,090	712,410	2,307	2,458
Big Building B	739,175	11,428,584	1,371,430	684,090	712,410	2,307	2,458
Big Building C	739,175	11,428,584	1,371,430	684,090	712,410	2,307	2,458
Big Building D	764,935	13,397,450	1,607,694	684,090	712,000	2,307	2,455

6 Conclusions and Recommendations

6.1 Results

Overall, the REO results indicate that a combination of wind turbines, SVP, solar hot water heating, and daylighting minimizes the LCC of energy at NAVSTA Newport. These results can be viewed in Table 22. Low resource availability combined with current competing cost of energy (COE) limited state and utility incentives and prevented other RE generation from being cost effective over a 25-year period.

The base case of continuing to purchase electricity and natural gas has zero initial cost but high annual cost, while the RE solutions case has high initial cost but reduced annual cost and a reduced LCC. The optimal solution reduces the 25-year COE from $418.7 million to $371.7 million, thereby saving $47 million.

In practice, many renewable technologies have lifetimes beyond 25 years. Daylighting benefits and savings, for example, will continue to accrue for the entire life of the building it is deployed in. NAVSTA Newport can reasonably expect some of the calculated savings to continue to accrue beyond the 25-year analysis period

Table 22. Sizes of Cost-Effective Renewable Energy Measures

Technology	Size	Units	Electricity Offset	Percent Electricity Reduction	Fuel Offset	Percent Fuel Reduction	Annual Emission Reduction	25 - Year Emission Reduction
			kWh/yr	%	therms/yr	%	lbs CO_2/yr	lbs CO_2
Skylight/ Floor Area Ratio	1.4%	%	2,244,628	2.1%	-59,755	-1.2%	1,279,850	31,996,259
Wind Energy	9,000	kW	23,843,000	22.5%	-	-	21,019,315	525,482,875
Solar Vent Preheat	260,417	ft^2	-	-	468,632	9.5%	5,481,529	137,038,222
Solar Water Heating	138,409	ft^2	-	-	465,758	9.4%	5,447,912	136,197,801
PV	0	kW	-	-	-	-	-	-
Concentrating Solar Area	0	ft^2	-	-	-	-	-	-
Concentrating Solar Electric	0	kW	-	-	-	-	-	-
Biomass Gasifier Size	0	MBtu/hr	-	-	-	-	-	-
Biomass Gasifier Cogen Size	0	kW	-	-	-	-	-	-
Totals			**26,087,628**	**24.6%**	**874,635**	**17.7%**	**33,228,606**	**830,715,157**

Figure 24 outlines visually the overall size and potential energy offset of each technology in the optimized solution.

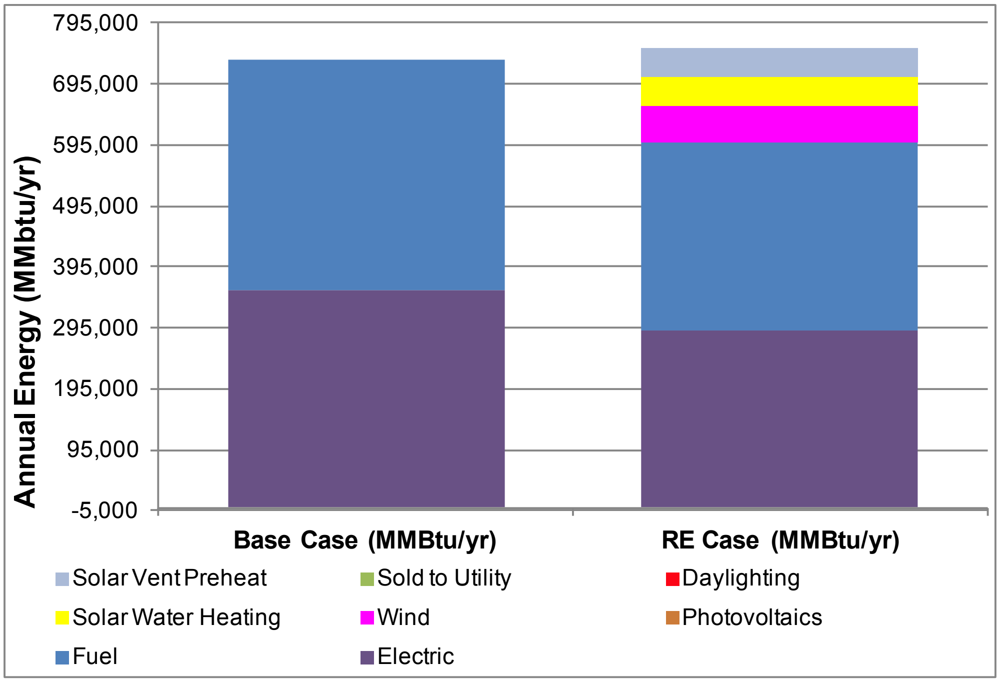

Figure 24. Energy delivery of each renewable energy technology per minimum life cycle cost

Table 23 provides a summary of the RE produced by these systems, in equivalent kilowatt-hour terms, initial cost to implement the optimized RE solution with and without incentives, the annual utility cost savings associated with those measures, and the simple payback period with and without incentives.

Table 23. Renewable Energy Solutions Case—Cost and Savings Summary

Technology	Equivalent Energy Offset	Percent Energy Reduction	Initial Investment with Incentives	Annual Savings	Simple Payback	Initial Investment W/O Incentives	Simple Payback
	equiv kWh/yr	%	$	$/yr	yrs	$	yrs
Daylighting	2,244,628	0.9%	3,261,134	202,747	16.1	3,261,134	16.1
Wind Energy	23,843,000	9.5%	23,940,000	2,790,060	8.6	34,200,000	12.3
Solar Vent Preheat	13,730,918	5.5%	7,746,325	597,402	13.0	11,066,261	18.5
Solar Water Heating	13,646,709	5.4%	9,465,994	497,236	19.0	13,522,848	27.2
Totals	**53,465,255**	**21.3%**	**44,413,453**	**4,087,445**	**11**	**62,050,243**	**15**

6.2 Conclusions

The REO analysis indicates that wind turbines, SVP, daylighting, and solar water heating are cost effective at NAVSTA Newport. An initial investment of around $44 million would be required to implement these technologies and would result in utility cost savings of about $4 million per year. This project has an 11.9% rate of return and an 11-year simple payback period. Implementing these measures would deliver roughly 21.3% of the site's energy use from renewables.

NAVSTA Newport desires to produce 25% of its base energy from renewable sources. Wind is the most cost-effective option at this site with paybacks 35% shorter than the next best option. Adding approximately 5.5 MW of wind, bringing the total to 14.5 MW, will enable the base to achieve its 25% RE goal.

NAVSTA Newport has undertaken a number of energy efficiency audits and retrofits over the years and constructs new buildings with high efficiency goals. Nonetheless, upfront efforts to reduce energy consumption through a program of increased efficiency in operations and equipment combined with modest conservation measures can reduce overall consumption that significantly reduces the bottom line of RE implementation. For every 10% reduction in load, there is a corresponding 2.5% reduction in the number of kilowatt-hours that need to be generated to meet the same 25% RE goal. Therefore, before investing in RE generation, NREL recommends implementing all cost-effective energy efficiency measures. These can be identified through an energy efficiency audit. Conservation is an effective method for reducing energy consumption at little or no cost.

The renewable projects recommended in this screening require additional analysis prior to implementation. The SVP and solar hot water recommendations are based on average ventilation rates and hot water use for this building size and type. Further economic analysis based on actual ventilation rates and hot water use, as well as a site evaluation to determine building suitability, is recommended. An in-depth analysis of wind availability will more accurately predict actual savings. Although not included in this analysis, we also recommend exploration of LFG combustion as a potential self-generation opportunity.

The remaining renewable technologies evaluated, biomass, PV, and solar industrial process heat, were not found to be cost effective over a 25-year period, mainly due to current COE, low resource availability in the area, and the level of incentives. However, there are many reasons for implementing renewable technologies besides cost. Renewables contribute to energy security and independence, provide an emission-free alternative to fossil fuels amid increasing concerns about climate change, and support national goals for increased RE use.

6.2.1 Other Renewable Energy Technologies

While not a part of the optimization model, anaerobic digestion, biofuels from algae, marine-based hydro-generation (wave and tidal power), GSHPs, and LFG are also potential sources of RE. Each has its own challenges for potential use at NAVSTA Newport.

- Anaerobic digestion requires a large source of animal waste, sewage, or industrial effluent and is likely not applicable at NAVSTA Newport.
- Biofuels from algae technologies are in the early stages of development and are many years away from off-the-shelf commercial technologies at competitive prices.[75]
- Conventional hydroelectric power generation is limited due to minimal elevation drop from the bay to the ocean. Marine-based hydro-generation (wave and tidal power) has potential in Newport, but the technology is still in the development stages. Newport's tidal and wave resource is limited, and regulatory authorities make deployment very challenging.
- GSHPs are viable options and warrant further assessment. GSHPs are a commercially available technology that work best within certain soil types, climate zones, and competing energy cost parameters and are framed for NAVSTA Newport in Appendix H.[76]
- LFG merits a more detailed investigation. The overall resource at McAllister Point is not large but may be large enough to have positive economics. Disturbance of contaminants and potential for leeching are critical issues that must be addressed to move forward.

Among the auxiliary technologies, it is prudent to focus on GSHPs first as, with adequate resource and appropriate soil conditions, it may prove to be a long-term thermal energy solution for particular buildings.

[75] Darzins, A.; Driscoll, R. Telephone call. NREL, Golden, CO, 4 June 2010.
[76] Shonder, J. Telephone call. Oak Ridge National Laboratory, Oak Ridge, TN, 8 June 2011.

Appendix A. Coddington Point Wind Data Analysis and Economic Projections

NAVSTA Newport, in conjunction with NREL and Naval Facilities Engineering Service Center (NFESC), has been actively engaged in assessing the wind resource through several ongoing efforts. The full Wind Resource Assessment (WRA) is complete and provides a much more detailed assessment of the wind resource than normally used in REO. A brief summary of the WRA for NAVSTA Newport is provided here.

The key components of the WRA are:

- Coddington Point - Site #9202: 60 m met tower installed and operational at Coddington Point – July 29, 2009
- MiniSODAR unit installed and operational at Coddington Point – February 22, 2010
- Tank Farm #4 - Site #9203: 60 m met tower installed and operational at Tank Farm #4 – March 19, 2010

The intent of the wind resource assessment activities is to attempt to characterize the wind resource for the entire base. Primary wind characteristics that can only be grossly estimated using wind maps, REO, or other available data are:

- Measured wind speed data at or close to sites where wind turbines will be erected correlated to long-term reference wind speeds
- Vertical wind shear factor (VWSF) to determine wind speeds at hub height and through the entire rotor
- Wind frequency distribution (aka probability distribution function).

Wind Resource Assessment Activities at NAVSTA Newport

The wind assessment plan called for two fixed met tower stations at or near the northern and southern ends of the base that would be installed for at least one year. However, the base, being roughly six to seven miles north to south along a somewhat jagged coastline that includes some areas with hills rising quickly from the shore and some areas that are densely populated with one- to four-story buildings, is not easily characterized. See Figure A-1 for met tower locations. Different locations within the base will see somewhat different wind regimes due to topography and surface roughness. These two factors have different impacts in different seasons or times of the day depending on what direction the wind is coming from and its magnitude. The complexity of the site dictated that another dimension be added to the wind resource assessment campaign—the miniSODAR system.

Figure A-1. Map of NAVSTA Newport with met tower locations[77]

Sodar Systems

Sodar (sonic detection and ranging) systems are a relatively new technology being used to enhance (remote) wind resource measurement and characterization. They can be used to measure the vertical turbulence structure and the wind profile of the lower layer of the atmosphere at elevations suitable for wind turbines. Sodar systems operate by issuing an acoustic pulse that travels up into the air and reflects back a return signal as the sound bounces off of moisture or particulates moving in the air. Generally, both the intensity and the Doppler (frequency) shift of the return signal are analyzed to determine the wind speed, wind direction, and turbulent character of the atmosphere. A profile of the atmosphere as a function of height can be obtained by analyzing the return signal over a period of time following the transmission of each pulse. The return signal recorded at any particular delay time provides atmospheric data for a height that can be calculated based on the speed of sound. MiniSODAR systems, such as the one used at NAVSTA Newport, can effectively characterize the wind up to 150–200 m in the air.

[77] DNV Renewables (USA) Inc. "Wind Resource Data Summary." Naval Station Newport, Rhode Island, Data Summary and Transmittal, August 2010.

The miniSODAR system, after initial calibration, alongside the 60 m met tower at Coddington Point, was to be moved to potential wind turbine sites on base every few months. It is known that the wind speed will vary widely at locations close to the ground throughout NAVSTA Newport. At some point above the ground (approximately 300 m, for instance), the wind speed will generally be similar at any location above the base. What is not known is at what height above ground all the potential turbine locations are essentially similar and how different the potential sites are at typical wind turbine rotor heights. The latter is of primary interest as it will determine the economic performance of wind turbines at the potential sites on base.

The goal in the periodic movement of the sodar was to be able to characterize the wind speed, turbulence, wind direction, and VWSF at each site to determine the best sites for wind turbines at NAVSTA Newport. A detailed analysis of the sodar data is outside the scope of this analysis; however, it should be noted that the data aligns well with that collected at the Coddington Point 60 m met tower. The data will be used in a longer-term analysis to determine and rank the best sites for wind turbines at NAVSTA Newport based on the extent of the wind resource. There has not been enough data collected at enough sites to date to make that determination.

Analysis of Collected Wind Data at Coddington Point and Tank Farm #4

A 60 m met tower was erected/commissioned at Coddington Point in July 2009. A second 60 m met tower, configured similarly, was erected at Tank Farm #4 in March 2010. NREL loaned a Wind Explorer™ miniSODAR unit to NAVSTA Newport in March 2010. Combined, these three data collection devices were used to assess the wind resource at NAVSTA Newport. The analysis here will be brief and focused on the characterization of each site and the differences in wind speed pertaining to how they will effect wind turbine annual energy production and economics. A more thorough analysis of the wind at each site will be provided to NAVSTA Newport as part of the wind resource assessment per prior agreement with NFESC.

Wind Data at Coddington Point—Site # 9202

The configuration of the sensors can be seen in Table A-1.

Table A-1. Sensor Configuration at Coddington Point (Site #9202)

Sensor	Quantity	Nominal Sensor Height (m)	Actual Sensor Height (m)	Sensor Orientation (°)	Boom Length (m)
NRG #40C Anem.	2	60	58, 58	274, 187	2.4, 2.4
NRG #40C Anem.	1	50	47.5	275	2.4
NRG #40C Anem.	2	40	40, 40	270, 188	2.4, 2.4
NRG #40C Anem.	1	25	24	270	2.4
NRG #200P Vane	2	50, 30	49, 26	3, 1	2.4, 2.4
NRG #110S Temp.	1	3	-	-	-
Voltmeter	1	-	-	-	-

The sensor configuration at Tank Farm #4 was essentially the same.

The measurement characterizations for Coddington Point and Tank Farm #4 can be seen in Table A-2. To date, there are 19 months of collected data at Coddington Point and 12 months worth of data collected at Tank Farm #4.

Table A-2. Dataset Summary for Coddington Point and Tank Farm #4

Coddington Point	
Variable	**Value**
Latitude	N 41.5194
Longitude	W 71.3273
Elevation	5 m
Start Date	7/29/2009
End Date	3/13/2011
Duration	20.5 months
Length of Time Step	10 minutes
Calm Threshold	3 m/s
Mean Temperature	10.8 °C
Mean Pressure	101.2 kPa
Mean Air Density	1.243 kg/m³
Power Density at 50 m	290 W/m²
Wind Power Class	2
Power Law Exponent	0.147
Surface Roughness	0.0607 m
Roughness Class	1.59
Roughness Description	Rough pasture

Tank Farm #4	
Variable	**Value**
Latitude	N 41.56358
Longitude	W 71.29185
Elevation	29 m
Start Date	3/19/2010
End Date	3/13/2011
Duration	11.9 months
Length of Time Step	10 minutes
Calm Threshold	3 m/s
Mean Temperature	11.6 °C
Mean Pressure	100.9 kPa
Mean Air Density	1.236 kg/m³
Power Density at 50 m	238 W/m²
Wind Power Class	2
Power Law Exponent	0.381
Surface Roughness	2.64 m
Roughness Class	4.72
Roughness Description	Urban

Table A-3 and Table A-4 highlight statistics of the collected data—first for Coddington Point, and then for Tank Farm #4. Coddington Point had a raw data recovery rate greater than 98.4% for all channels before filtering. Tank Farm #4 had a raw data recovery rate greater than 98.4% for all channels before filtering. The data recovery rates shown in the tables are the net recovery rates after filtering to remove unreliable data due to icing and tower shading, for example.

As shown, the mean wind speed at 58 m is approximately 0.34–0.51 m/s higher at Coddington Point than at Tank Farm #4. This difference is more pronounced at 24 m where Coddington Point is approximately 1.47 m/s higher. The difference in wind speed between Coddington Point and Tank Farm #4 is due to the nice "fetch" across the water—low surface roughness and few impediments to wind flow—which Coddington Point has relative to Tank Farm #4. At Tank Farm #4, there is significant ground clutter (trees, shrubs, and grass) and terrain factors (undulating hills sloping up from the Narragansett Bay) that cause turbulence and reduce overall wind speeds.

Table A-3. Wind Speed Sensor Summary at Coddington Point

Coddington Point						
Variable	**Speed 58 m A**	**Speed 58 m B**	**Speed 47.5 m**	**Speed 40 m A**	**Speed 40 m B**	**Speed 24 m**
Measurement Height (m)	58	58	47	40	40	24
Mean Wind Speed (m/s)	6.647	6.447	6.407	6.274	6.208	5.872
Mean of Monthly Means Wind Speed (m/s)	6.516	6.348	6.264	6.139	6.099	5.731
Median Wind Speed (m/s)	6.3	6.1	6.1	5.9	5.9	5.5
Minimum Wind Speed (m/s)	0.4	0.4	0.4	0.4	0.4	0.4
Maximum Wind Speed (m/s)	24	23.5	23.2	23	22.8	22.3
Weibull k	2.031	2.039	1.957	1.957	1.972	1.885
Weibull c (m/s)	7.483	7.252	7.197	7.05	6.978	6.591
Mean Power Density (W/m²)	336	303	308	290	278	246
Mean of Monthly Means Power Density (W/m²)	318	290	289	273	266	230
Mean Energy Content (kWh/m²/yr)	2,940	2,653	2,694	2,537	2,438	2,156
Mean of Monthly Means Energy Content (kWh/m²/yr)	2,782	2,543	2,532	2,390	2,327	2,015
Energy Pattern Factor	1.868	1.847	1.911	1.917	1.901	1.987
Frequency of Calms (%)	13.45	14.22	15.39	16.09	16.25	19.49
Possible Records	85,248	85,248	85,248	85,248	85,248	85,248
Valid Records	81,556	70,674	83,922	81,689	74,845	83,922
Missing Records after Filtering	3,692	14,574	1326	3,559	10,403	1326
Data Recovery Rate (%)	95.67	82.9	98.44	95.83	87.8	98.44

Table A-4. Wind Speed Sensor Summary at Tank Farm #4

Tank Farm #4						
Variable	**Speed 58 m A**	**Speed 58 m B**	**Speed 47.5 m**	**Speed 40 m A**	**Speed 40 m B**	**Speed 24 m**
Measurement Height (m)	58	58	50	40	40	25
Mean Wind Speed (m/s)	6.141	6.109	5.813	5.387	5.45	4.407
Mean of Monthly Means Wind Speed (m/s)	6.141	6.109	5.813	5.387	5.45	4.407
Median Wind Speed (m/s)	5.7	5.7	5.4	5	5	4.1
Minimum Wind Speed (m/s)	0.4	0.4	0.4	0.4	0.4	0.4
Maximum Wind Speed (m/s)	22.6	22.4	21.9	20.7	20.4	17
Weibull k	2.014	2.007	1.949	1.891	1.969	1.839
Weibull c (m/s)	6.917	6.875	6.539	6.049	6.138	4.957
Mean Power Density (W/m²)	273	268	239	195	196	112
Mean of Monthly Means Power Density (W/m²)	273	268	239	195	196	112
Mean Energy Content (kWh/m²/yr)	2,393	2,352	2,089	1,708	1,720	977
Mean of Monthly Means Energy Content (kWh/m²/yr)	2,393	2,352	2,089	1,708	1,720	977
Energy Pattern Factor	1.887	1.884	1.941	1.992	1.938	2.078
Frequency of Calms (%)	16.1	15.85	18.5	21.83	20.46	33.11
Possible Records	51,696	51,696	51,696	51,696	51,696	51,696
Valid Records	50,027	47,049	51,420	49,808	46,712	51,420
Missing Records after Filtering	1,669	4,647	276	1,888	4,984	276
Data Recovery Rate (%)	96.77	91.01	99.47	96.35	90.36	99.47

The mean diurnal profile (hourly averages throughout the day) of each site can be seen in Figure A-2 and Figure A-3. On average throughout the year, the wind picks up velocity during the late morning and continues throughout the day with the peak coming mid-afternoon, which is often a peak loading time for the utility. Though the patterns are the same, the wind speeds vary considerably. The difference between the wind speed at 24 m versus 58 m at Coddington Point varies by approximately 0.6–1.0 m/s (at different times of the day) due to the nice “fetch” across the water—that is, low surface roughness and few impediments to wind flow—whereas the variation is approximately 1.5–2.2 m/s at Tank Farm #4. This is due to the ground clutter and terrain factors.

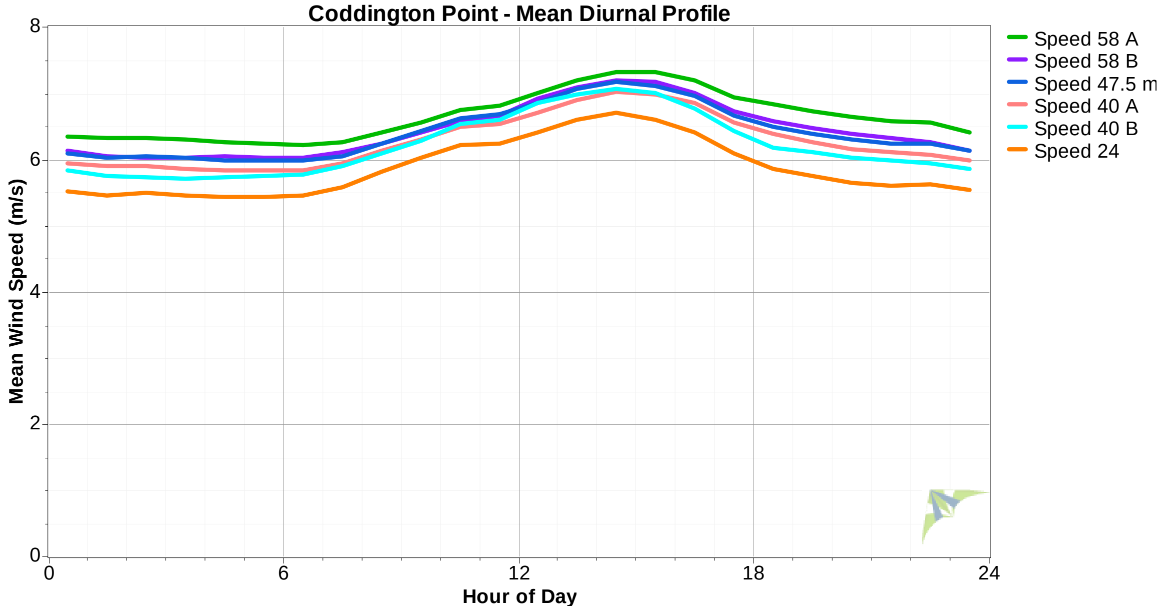

Figure A-2. Coddington Point—Diurnal wind profile

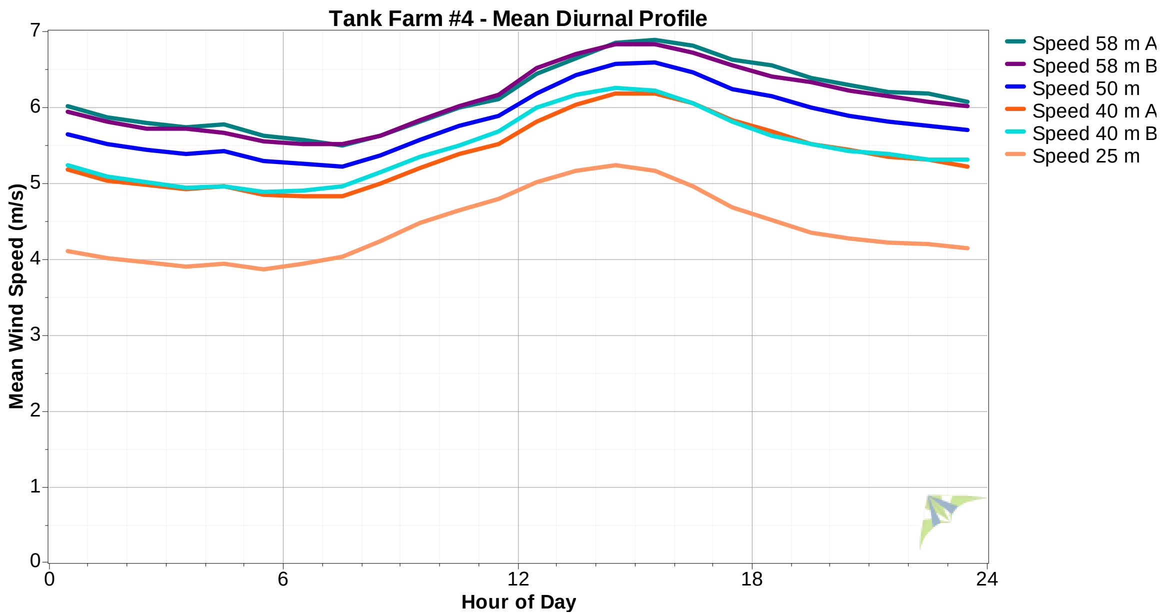

Figure A-3. Tank farm #4—Diurnal wind profile

The wind speeds at 58 m at the two sites vary considerably. Again, Coddington Point gets good fetch off the water with low ground clutter and higher wind speeds overall.

Other variations between the two sites can be seen in the monthly box plots in Figure A-4 and Figure A-5. The higher wind speeds are relatively similar between the sites, but the mean wind speeds and low wind speeds vary considerably. Also, the daily range of wind speeds is larger at Tank Farm #4.

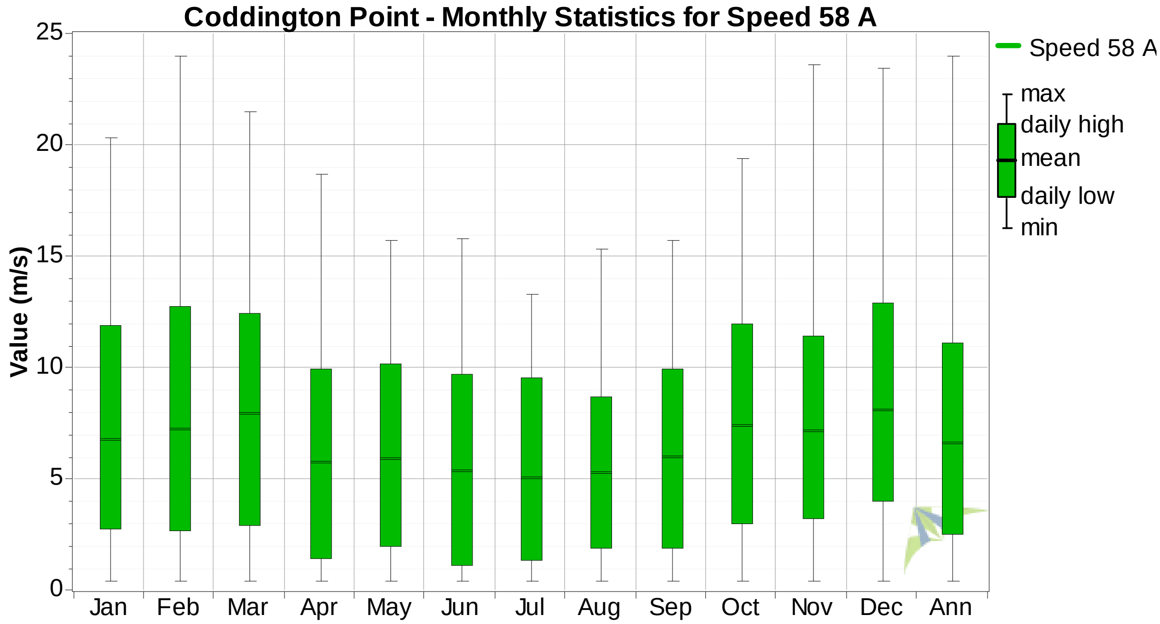

Figure A-4. Coddington Point boxplot

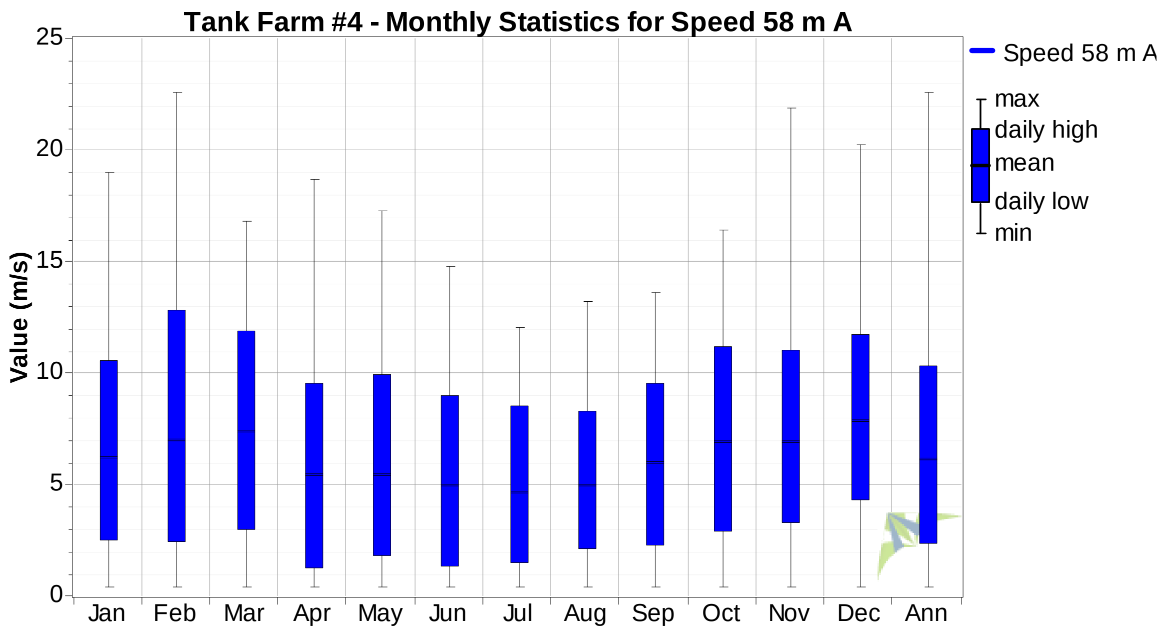

Figure A-5. Tank Farm #4 boxplot

The probability distribution function (aka frequency distribution) for Coddington Point can be seen in Figure A-6.

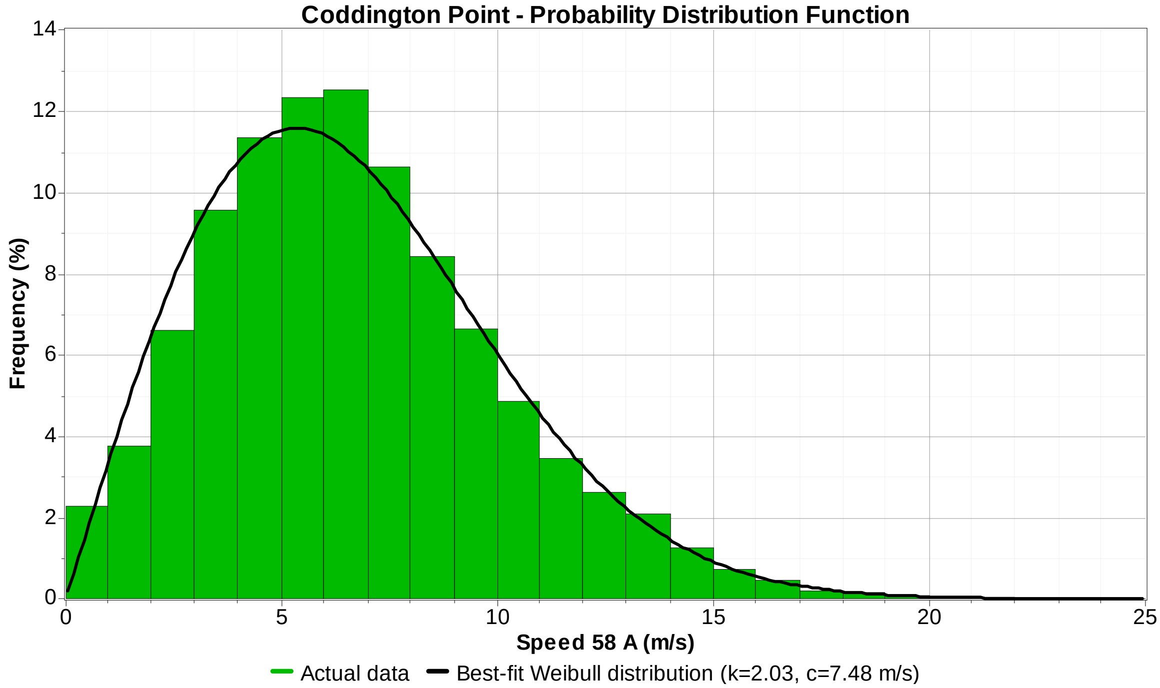

Figure A-6. Overall frequency distribution at Coddington Point

The probability distribution function for Tank Farm #4 can be seen in Figure A-7.

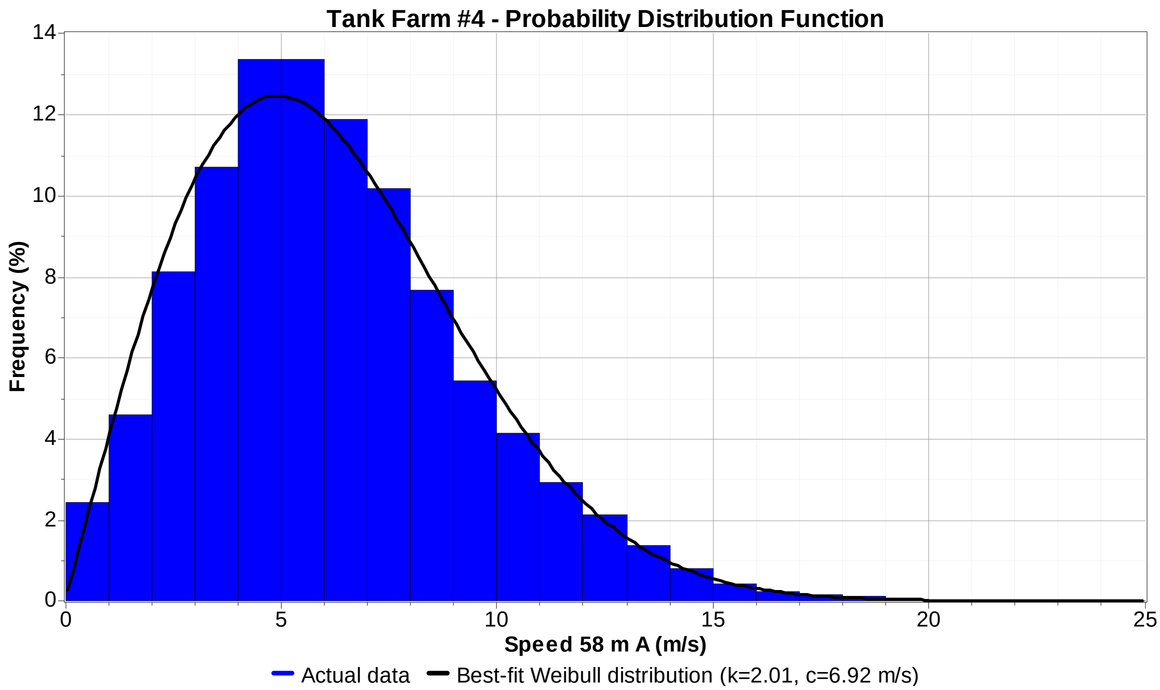

Figure A-7. Overall frequency distribution at Tank Farm #4

The turbulence intensity for both sites is shown in Figure A-8 and Figure A-9.

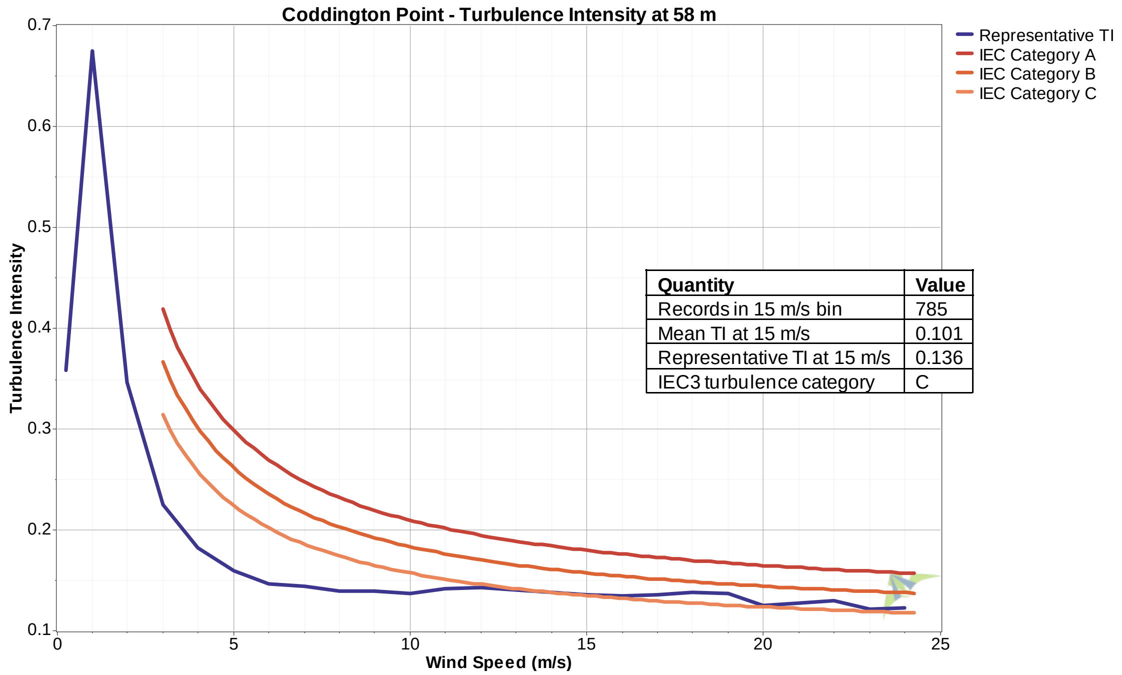

Figure A-8. Turbulence intensity at Coddington Point

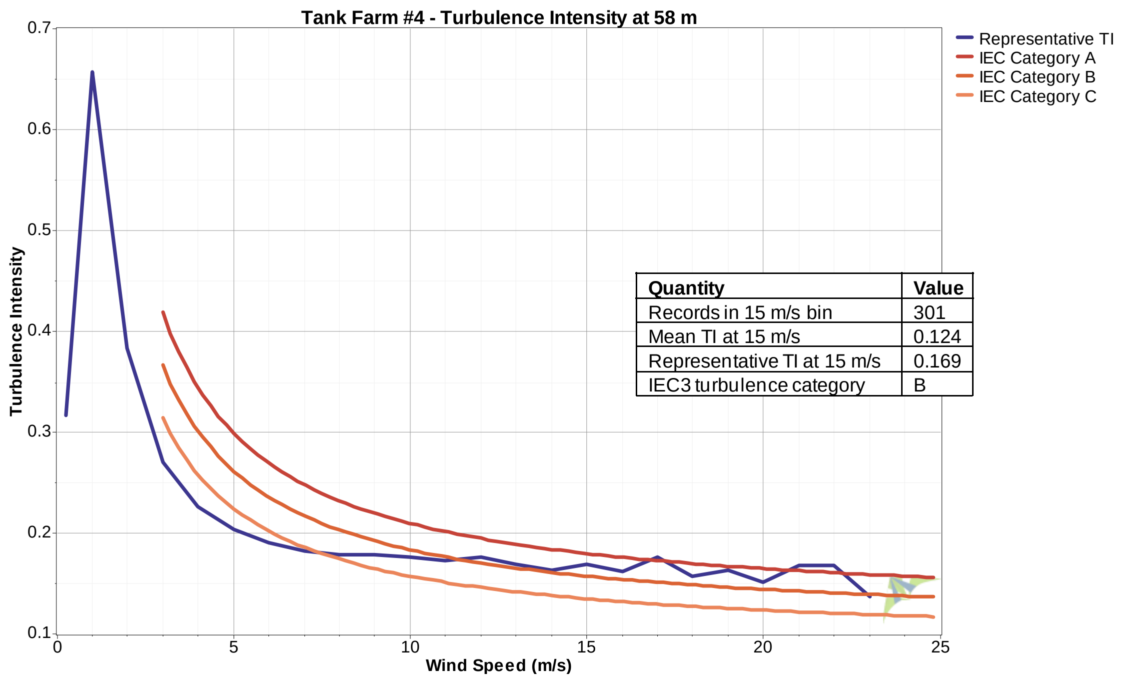

Figure A-9. Turbulence intensity at Tank Farm #4

In Figure A-10, the wind rose for each site shows the total energy by direction. Also noteworthy is how the trees and hills to the north of Tank Farm #4 reduce the relative wind energy from that direction compared to the more open fetch at Coddington Point.

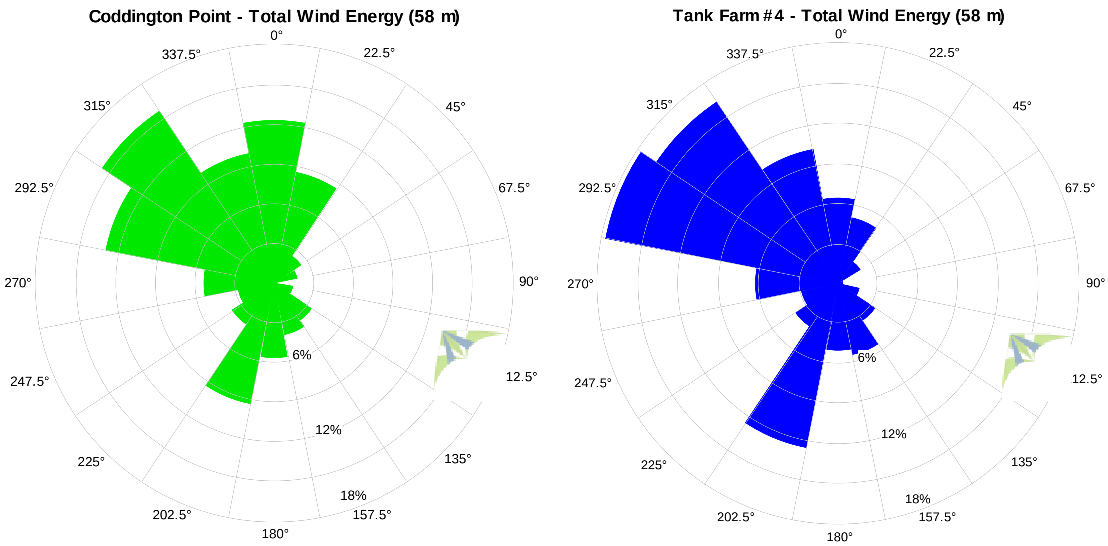

Figure A-10. Wind rose—Total energy by direction at Coddington Point and Tank Farm #4

The monthly wind roses at Coddington Point in Figure A-11 provide a better view of how the wind direction changes through the year and what directions and months provided the greatest wind energy.

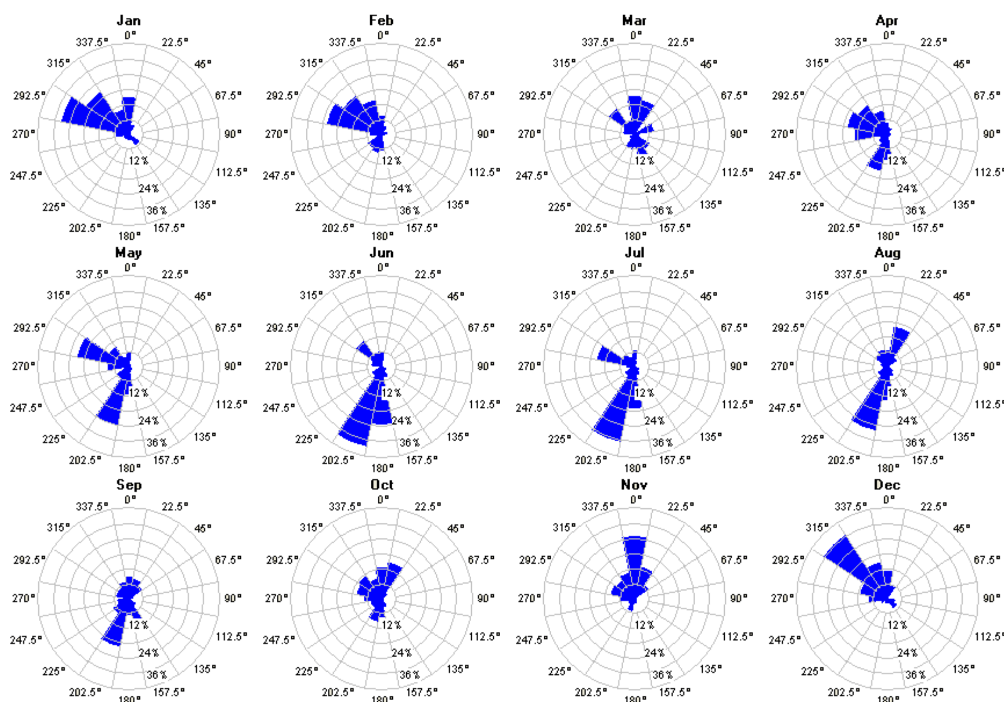

Figure A-11. Monthly wind roses—Total energy by direction at Coddington Point

The monthly wind roses at Tank Farm #4 in Figure A-12 provide a better view of how the wind direction changes through the year and what directions and months provided the greatest wind energy.

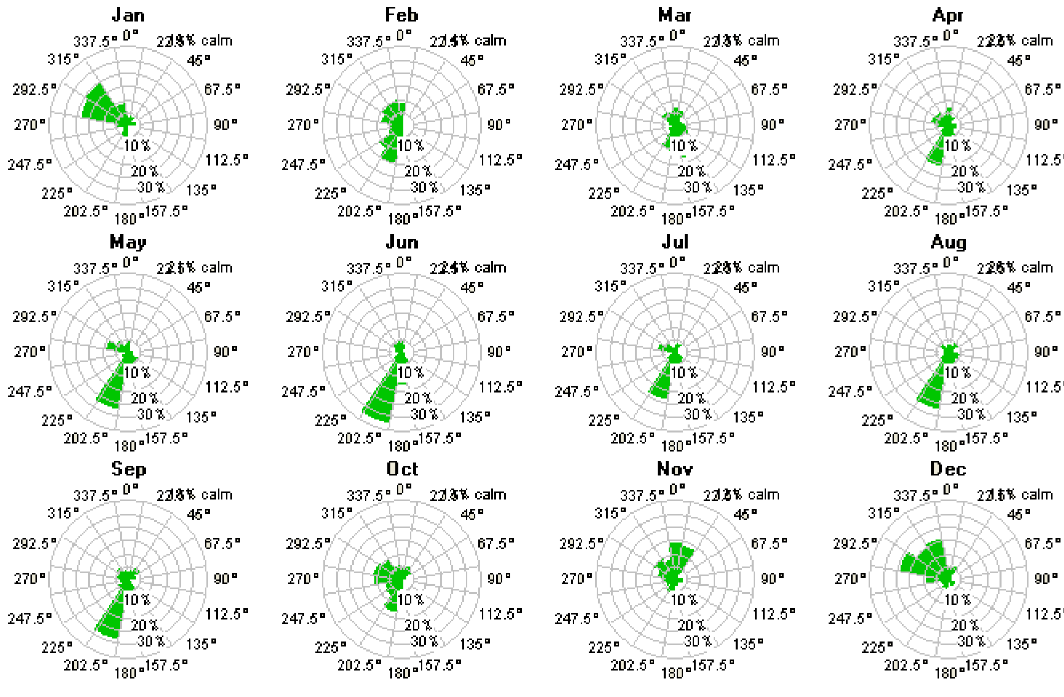

Figure A-12 Monthly wind roses—Total energy by direction at Tank Farm #4

Relationship of Collected Data to Long-Term Data

Normal industry wind resource assessment practice calls for collecting wind and other data as close to the proposed wind turbine site as possible and as close to the proposed wind turbine hub height as possible for a minimum of 1 year, providing a suitable long-term reference wind station can be found. Not every long-term reference station provides an adequate correlation factor, especially if there are significant data gaps or measurement intervals are different.

With 12 months of quality, on-site data, the long-term reference station is used to “normalize” the collected data to approximate the expected long-term wind resource at the site. This normalization is accomplished through an analytic mathematical technique called “Measure-Correlate-Predict” (MCP). The data collected at Coddington Point and at the Newport Airport are the “measure” component. The sites can be seen in the map in Figure A-13.

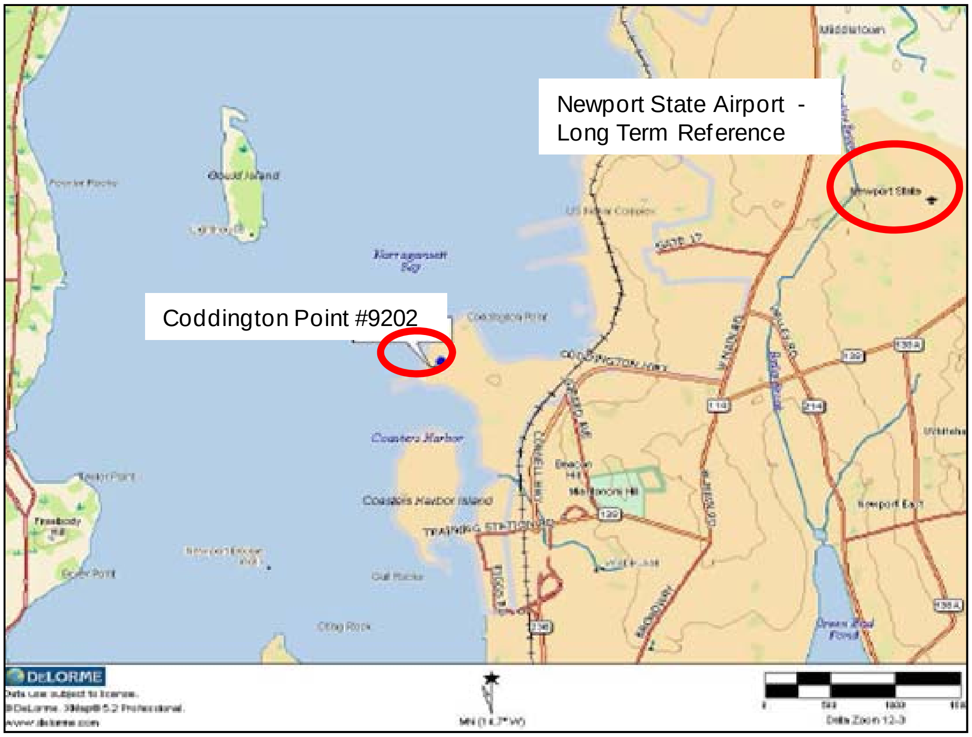

Figure A-13. Coddington Point and Newport Airport met tower sites[78]

The long-term reference station used was a 10 m met tower at the Newport State Airport, which is approximately 2.5 miles from the 60 m met tower at Coddington Point. The Newport Airport is about 2.2 miles from the Tank Farm #4 met tower. The airport data, identified as Automated Airport Weather Station (AWOS) KUUU Newport, was obtained from the Utah State University Climate Center.[79] The best available data from this station was a 5-year period from October 1, 2005, through October 1, 2010. Generally, longer-term data in the 10–15 year range is preferred as the wind resource is often difficult to fully characterize from a 5-year data source.

Invalid data was flagged and a correlation analysis was run between the data from these two met towers for the concurrent period of August 1, 2009 through September 30, 2010.

As shown in Figure A-14, the wind speeds from 10 m from Newport Airport were then plotted against wind speeds from 24 m at Coddington Point and a linear regression analysis (first-order polynomial) conducted to determine the trendline with resulting equation and r^2 (coefficient of determination) correlation factor for each direction sector. The linear regression equation, in the form of "$y = mx + b$" enables the prediction of wind speeds at Coddington Point over a longer time scale using the long-term averaged data at

[78] DNV Global Energy Concepts, Inc. "Wind Resource Data Summary." Naval Station Newport, Rhode Island, Data Summary and Transmittal, November 2009.
[79] Utah State University. "Climate Center: Data Products." http://climate.usurf.usu.edu/products/data.php?tab=awos. Accessed October 5, 2011.

the Newport Airport. The same process was applied to Tank Farm #4. The resultant equations are:

Coddington Point

Y	=	mx	+ b	r^2
Y	=	1.037	2.0858	0.6645

Tank Farm #4

Y	=	mx	+ b	r^2
Y	=	0.85153	1.4077	0.6707

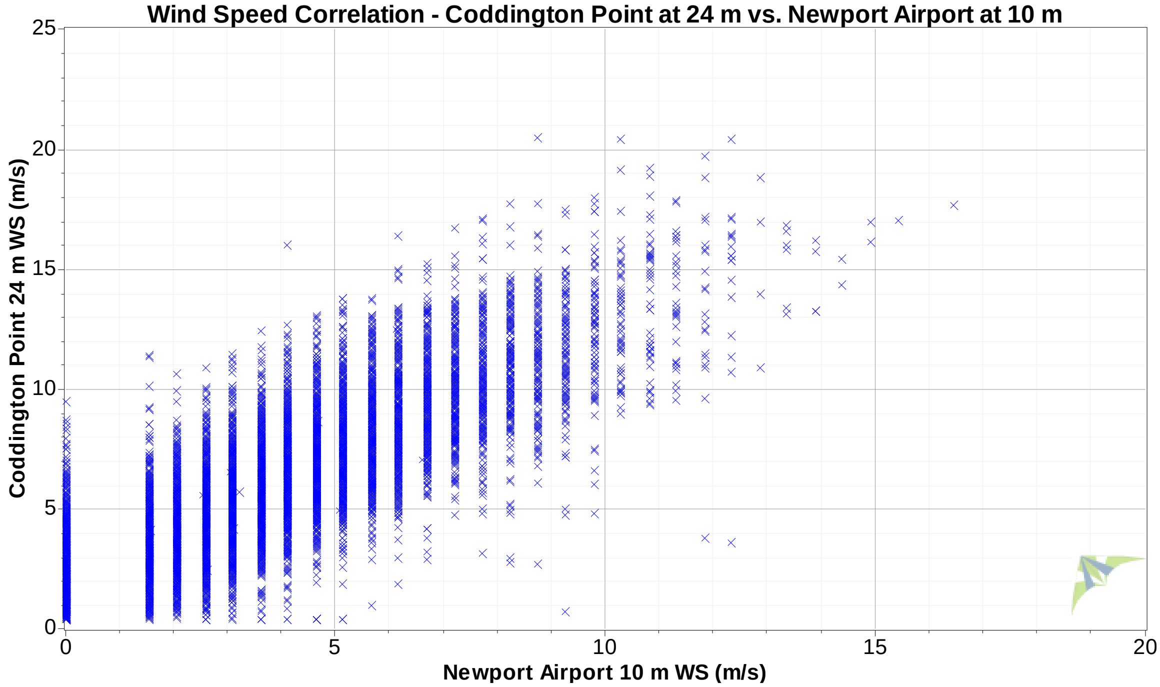

Figure A-14. Correlation of concurrent Newport airport data to Coddington Point

With the relationship between the Newport Airport and Coddington Point wind data established, the correlation equation was then applied to the Newport Airport data from January 14, 1999, to February 27, 2011, to establish the "long-term profile" of the wind speed at 24 m at Coddington Point. The VWSF from the collected data at Coddington Point between 24 m and 40 m was then applied to get the estimated long-term wind profile at 40 m at Coddington Point. The same process was applied to the VWSF from 40 m to 47.5 m, and then from 47.5 m to 58 m, to establish a long-term dataset for Coddington Point up through the height of the met tower located there.

Figure A-15 compares, on a long-term basis, the mean wind speeds at Coddington Point to Tank Farm #4 at two heights. As shown, the wind speeds at 24 m at Coddington Point are greater (by a small margin) than the expected wind speeds at 80 m at Tank Farm #4. The greater exposure to the wind off of the waters of Narragansett Bay coupled with low surface roughness in the south-west-north arc result in higher wind speeds and wind power density at Coddington Point.

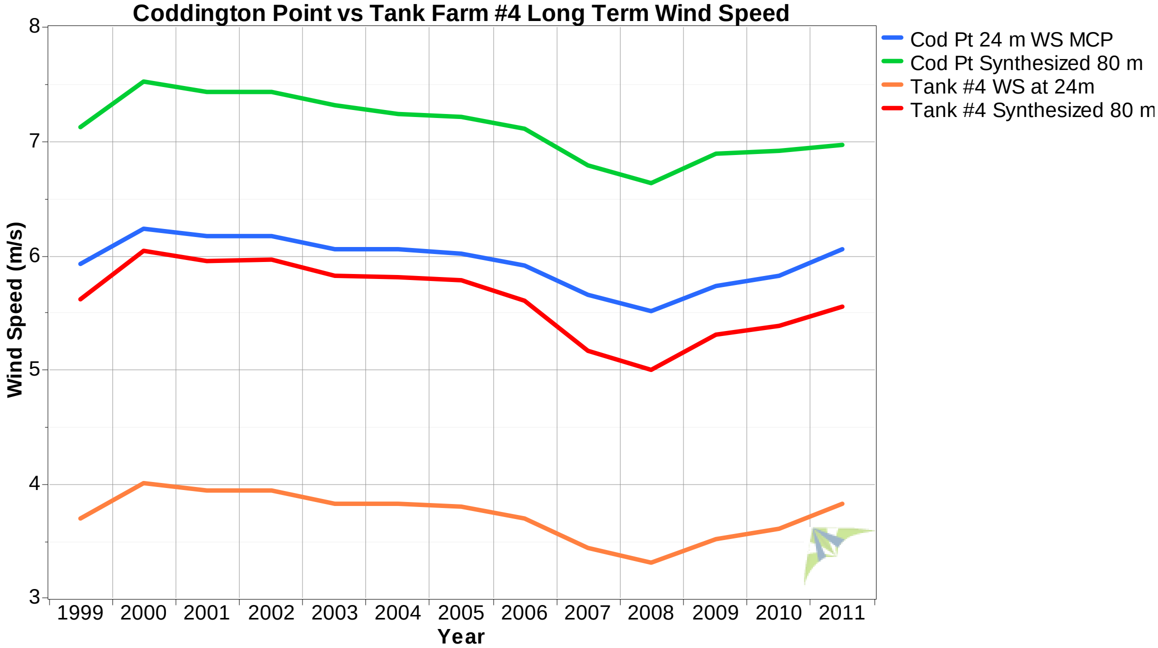

Figure A-15. Long-term wind profiles at Coddington Point and Tank Farm #4

The VWSF from the collected SODAR data at Coddington Point was applied in 10 m increments resulting in a profile of the wind speed up to 120 m at Coddington Point. The results of the shearing up to 120 m can be seen in the diurnal wind profile shown in Figure A-16. This represents a 12-year profile.

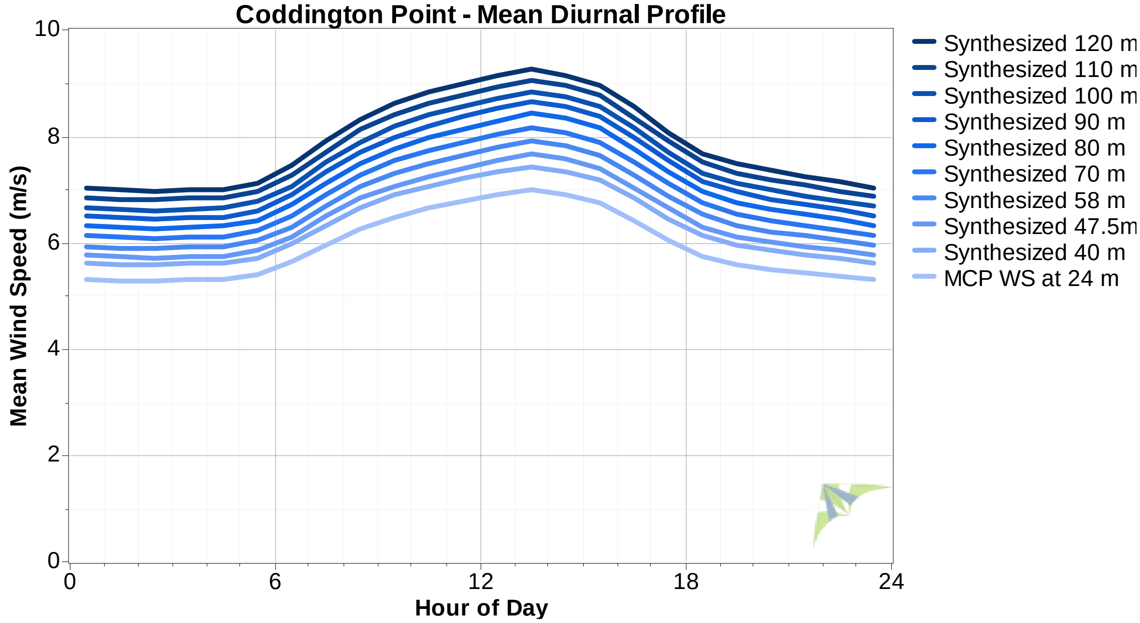

Figure A-16. Mean diurnal profile of Coddington Point

This same process was applied between the Newport Airport data and the collected data at Tank Farm #4. The same vertical wind shear profile from the SODAR at Coddington Point was applied as the best available data at the time of the analysis. The results can be seen in Figure A-17. The same process can be reapplied with a vertical wind shear profile from SODAR from a site closer to Tank Farm #4.

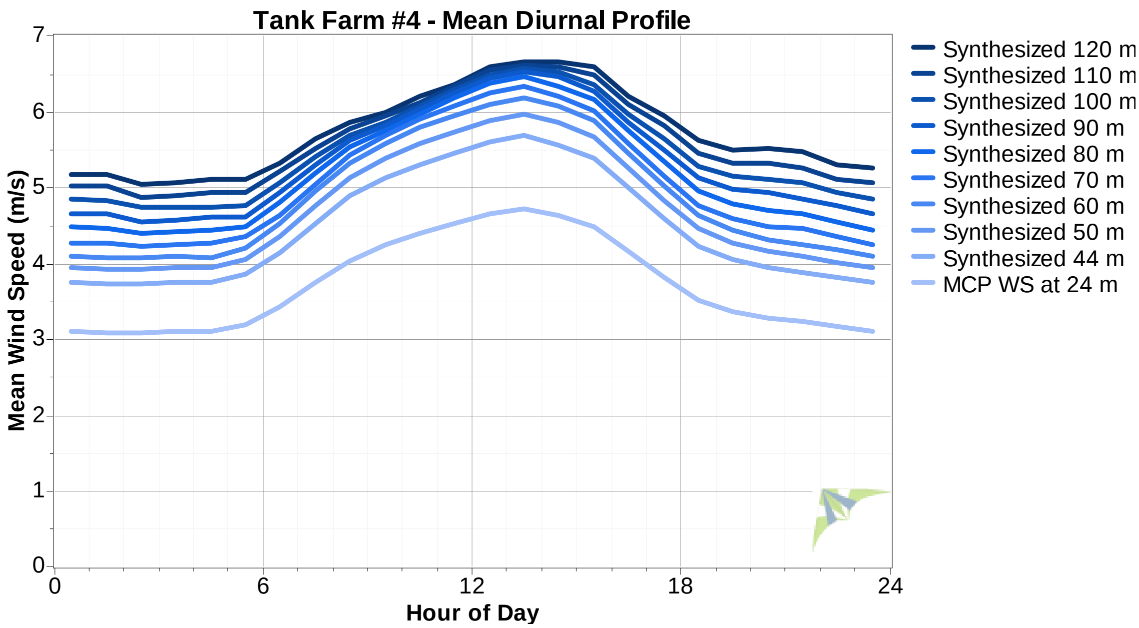

Figure A-17. Mean diurnal profile of Coddington Point

Wind Turbine Energy Production

The normalized long-term wind data was used to estimate the annual energy production of a number of utility-scale wind turbines to serve as a reference of what may be possible to frame the scale of production and the relative economics. The results are not intended to be used to determine what turbine should be purchased. NAVSTA Newport has applied to the Federal Aviation Administration (FAA) for wind turbine installation approval, and the preliminary response indicated that the tip of the blade could be no higher than 500 ft (152 m) above mean sea level.[80] The turbine height may vary at each particular site due to this factor. All of these turbines meet this criterion, as shown in Table A-5.

Table A-5. Turbine Power, Class, and Dimension

Turbine Model	Power Rating	Stated Turbine Class	Hub Height	Rotor Span	Max Height	Max Height	# Turbines for 9 MW
	MW	Class	m	m	m	ft	#
Siemens 2.3 MW 101	2.3	III	80	101	130.5	428	3.9
GE 1.5 XLE	1.5	III	80	82.5	121.25	398	9
RePower MM92	2.0	III	80	92	126	413	4.5
Vestas V90 1.8 MW	1.8	III	80	90	125	410	5
Clipper Liberty C101	2.5	III	80	101	130.5	428	3.6
Nordex N100	2.5	III	80	100	130	427	3.6

Table A-6. Height Tolerance for Potential Wind Turbine Sites

Site	Site Elevations	Max Turbine Height	Siemens 2.3 MW 101	GE 1.6 XLE	RePower MM92	Vestas V90 1.8 MW	Clipper Liberty C101	Nordex N100
	m ASL*	m	m	m	m	m	m	m
Coddington Point	7	145.4	130.5	121.25	126	125	130.5	130
Tank Farm 1	30	122.4	130.5	121.25	126	125	130.5	130
Tank Farm 2	50	102.4	130.5	121.25	126	125	130.5	130
Tank Farm 3	30	122.4	130.5	121.25	126	125	130.5	130
Tank Farm 4	30	122.4	130.5	121.25	126	125	130.5	130
Tank Farm 5	30	122.4	130.5	121.25	126	125	130.5	130
McAllister Point	10	142.4	130.5	121.25	126	125	130.5	130
Gould Island	21	131.4	130.5	121.25	126	125	130.5	130
Directors Shipyard	10	142.4	130.5	121.25	126	125	130.5	130
Coddington Cove	15	137.4	130.5	121.25	126	125	130.5	130
Helipad	5	147.4	130.5	121.25	126	125	130.5	130

Note: * ASL = Above Surface Level

Note: Color code — Outside tolerance limit (pink); Within tolerance limit (green)

Other sites may have to use a short tower or smaller rotor to meet Federal Aviation Administration (FAA) requirements.

[80] Reichert, J. Email. NAVSTA Newport, Newport, RI, 19 May 2010.

In Table A-7 and Table A-8, the estimated output per wind turbine at each site is shown. The hub height wind speed variation is the driving force behind the output variation. There may be a small degree of turbine parameter adjustment that can provide slight improvements to overall annual energy production, but these factors will vary site by site and will need to be optimized once the wind flow characteristics of the entire site have been modeled.

Table A-7. Coddington Point Wind Turbine Annual Energy Production

Turbine	Hub Height (m)	Hub Height Wind Speed (m/s)	Time At Zero Output (%)	Time At Rated Output (%)	Mean Net Power Output (kW)	Mean Net Energy Output (kWh/yr)	Capacity Factor (%)
Siemens SWT-2.3-101	80	7.16	11	3.7	771.2	6,756,085	33.5
GE 1.5xle	80	7.16	0	5.7	462.8	4,053,887	30.9
REpower MM92	80	7.16	11	7.4	700.1	6,133,311	35.0
Vestas V90 - 1.8 MW	80	7.16	11	3.8	601.3	5,267,641	33.4
Clipper Liberty C99	80	7.16	11	3.7	760.7	6,664,157	30.4
Nordex N90/2500 LS	80	7.16	11	1.3	688.9	6,034,679	27.6

Table A-8. Tank Farm #4 Wind Turbine Annual Energy Production

Turbine	Hub Height (m)	Hub Height Wind Speed (m/s)	Time At Zero Output (%)	Time At Rated Output (%)	Mean Net Power Output (kW)	Mean Net Energy Output (kWh/yr)	Capacity Factor (%)
Siemens SWT-2.3-101	80	5.62	21	2.9	522.0	4,573,080	22.7
GE 1.5xle	80	5.62	11	4.4	314.3	2,753,158	21.0
REpower MM92	80	5.62	26	5.5	470.8	4,124,429	23.5
Vestas V90 - 1.8 MW	80	5.62	21	3.0	401.7	3,518,894	22.3
Clipper Liberty C99	80	5.62	21	2.9	513.7	4,499,855	20.5
Nordex N100/2500	80	5.62	21	2.8	529.5	4,638,293	21.2

There are many factors involved in choosing a wind turbine for NAVSTA Newport. It would be beneficial to collect more data, determine the number of sites that can support a wind turbine both economically and through permitting, and then issue a request for proposals (RFP) and determine the best option based on the responses from qualified contractors. For this report, the economics will be based on a single turbine located at Coddington Point and purchased through an Energy Conservation and Investment Program (ECIP) grant, so there will be no financing fees.

Economic Assumptions for the Wind Analysis

Project Life

The project life is assumed to be 20 years. Wind turbine design life is typically at least 20 years. The wind turbine useful life is estimated to be 20–30 years. This generation of 1+ MW turbines is not yet 20 years old so there is no actual field experience to point towards in suggesting another basis.

Wind Turbine Cost

An average turbine cost of $3.80/kW of installed capacity was used to approximate the cost of several commercial wind turbines. NAVSTA Newport has initial plans to purchase 9 MW of wind at a cost of approximately $34.2 million. Industry averages, based on wind farms of 50–500 MW, do not apply when installing a small number of turbines as NAVSTA Newport will. The average size of the turbines modeled was 2.1 MW. This cost is not necessarily representative of individual turbine prices, but these costs vary depending on a variety of factors (e.g., the economy, turbine/contractor availability, currency fluctuations, and part of the country). RFP responses are the best method to get truly realistic cost figures for particular turbines.

Annual Energy Output

The "average" turbine for Coddington Point was scaled based on average output for all the modeled turbines and average power rating of these turbines to arrive at a megawatt-hour per year output per megawatt (2,770,000 MWh/yr/MW). Due to the lower wind speeds at Tank Farm #4, the same approach yielded a rating of 1,913,000 MWh/yr/MW. It was assumed only one turbine would approach the productivity of Coddington Point—the one sited there. All other wind turbines needed to reach approximately 9 MW would perform in lower wind speeds and have lower outputs. It was assumed that Tank Farm #4 represents an "average" wind site among the potential sites identified by NAVSTA Newport. Of course, additional wind modeling will need to be done to determine if this was a reasonable assumption. To reach NAVSTA Newport's RE goal of 25% generated on-site, it was estimated that another 5.5 MW of wind will need to be installed. In estimating this figure, it was assumed that subsequent sites would have lower annual energy output than Tank Farm #4. An estimate of 1,700,000 MWh/yr/MW was used for these calculations. Again, additional wind modeling will need to be done to determine if this is a reasonable assumption.

Operations and Maintenance

O&M costs are assumed to average $21/MWh over the life of the project, and the gearbox will need to be replaced after 10 years of operation.[81] This cost may seem comparatively high, but several factors combine to give a high level of uncertainty. First, there is reason to believe that larger turbines may have a small economy of scale on O&M costs, as tens of thousands of megawatts of wind continue to be installed in the near term, serving to drive this cost down. There are substantial research and development investments currently being made by both the private and public sector aimed at reducing O&M costs. However, several internal NREL studies[82] have shown that various component failures, such as gearbox failure, will drive this cost up on average for this generation of turbines. In summary, there is speculation and uncertainty as to how the average cost of O&M should be modeled for utility-scale turbines, especially in small projects such as this.

Salvage Value

The expected salvage value of the wind turbine, which has a significant number of components made of steel, copper, and other useful materials, is expected to have enough residual value to cover the demolition costs. In many sites that have smaller, older wind

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[81] Wiser, R.; Bolinger, M. "Wind Technologies Market Report." DOE, EERE, 2009, p.54.
[82] Oyague, F.; Butterfield, C.P.; Sheng, S. "Gearbox Reliability Collaborative Analysis." Round Robin, WINDPOWER 2009 Conference.

turbines, 15–20 years old, a process called repowering is taking place, in which the existing turbine nearing the end of its useful life is replaced with a newer, sometimes larger, turbine because the permitting, electrical, and other issues have already been addressed. Full turbine/foundation demolition and site restoration are not common.

Escrow Unscheduled Maintenance Repair Fund

During the 20-year life of a wind turbine project, it is expected that a turbine will have need for a major repair at a significant cost in the hundreds of thousands of dollars range. If the project were financed through an energy savings performance contract (ESPC), utility energy savings contract (UESC), or even a power purchase agreement scenario, it is assumed that embedded in the price, NAVSTA Newport would pay for the renewable electricity output of the turbine, and there would be an additional amount set aside by the project operator to fund a major repair when the need arises. It is also possible that the contract could specify an escrow fee, independent of the price paid for electricity, for unscheduled repairs.

In the scenario in which NAVSTA Newport owns the turbine as a result of a cash purchase, it is highly recommended that it institutes a self-funded mechanism, such as an escrow account, to fund a reserve account to be tapped when the need for a major repair arises. The purpose of the escrow account would be to cover capital repairs, such as blade failure and gearbox failure, to ensure smooth, continuous operation with minimal downtime in the event of catastrophic equipment failure. Though it is not possible to predict exactly when these types of repairs will be necessary, having this fund ready will enable NAVSTA Newport to have repairs taken care of quickly, as there will be no need to search for funds to pay for them. The funding and expense stream are not possible to match, but the escrow fund should prepare NAVSTA Newport to meet any capital repair expenses that arise.

Economic Projections of a 2.0 MW Wind Turbine at Coddington Point

These costs were modeled using RETScreen Wind software[83] with the wind resource data from the normalized Coddington Point dataset.

The results of the modeling can be seen in Table A-9.

[83] RETScreen International, Natural Resources Canada. http://www.retscreen.net/ang/home.php. Accessed October 5, 2011.

Table A-9. Economics of Generic 2.0 MW Wind Turbine at Coddington Point

Characteristic	Measurement	Units
Wind Turbine Swept Area	19,085	m^2
Wind Turbine Swept Area	205,429	ft^2
Wind Capacity	9,000	kW
Wind Initial Cost	34,200,000	$
Wind Rebate	-	$
Wind Production Incentive	-	$/yr
Wind State Tax Credit	-	$
Wind Federal Tax Credit	10,260,000	$
Wind Initial Cost w/ Incentives	23,940,000	$
Wind Net Metering Limit (Up To)	1,650	kW
Wind Annual Energy Delivery	23,843,000	kWh/yr
Capacity Factor	30.2	%
Wind Annual Cost Savings	2,861,160	$
Wind Annual O&M Cost	71,100	$/yr
Wind Payback Period	8.6	yrs

The recorded wind speeds at Coddington Point have been shown to support a solid project on economic ground assuming that ECIP funding is available, the project would essentially involve a cash purchase with no financing costs, and the annual O&M would be paid for out of cost savings.

Given NAVSTA Newport's RE goals, it makes sense to fully explore a multiple wind turbine project. A more complete assessment that includes all of the potential wind turbine sites, as planned, is the recommended course of action. As shown by the data at Coddington Point and Tank Farm #4, there is a significant level of variability in the wind resource at these two sites. It is expected there will be at least that level of variability, possibly more at several of the other potential sites. With a more complete dataset from across the entire base, a more thorough economic analysis can be completed.

Appendix B. Solar Vent Preheat Systems

Solar Vent Preheat System Sizing

For a given amount of ventilation air, the suggested size is given by the equation

$$A_c = V_{bldg}/v_{wall}$$

where

A_c = solar collector area (ft^2 or m^2); might be limited by available wall area

V_{bldg} = building outside air flow rate (CFM or l/min)

v_{wall} = per-unit-area airflow through wall (CFM/ft^2 or $l/min/m^2$); typically 4–8 CFM/ft^2. If wall area is sufficient, use the lower value of 4 CFM/ft^2.

The size of the south-facing wall is a constraint. A size that results in a flow rate of less than 2 CFM/ft^2 is also a constraint, so that the boundary-layer effect that leads to the high efficiency is valid.

Energy delivered by the SVP system and fuel energy saved are calculated by the equations

$$Q_{solar} = A_c\, q_{useful} \times (\#days/week/7)/\ \eta_{heating}$$

and

$$Q_{saved} = Q_{solar}/\eta_{heating}$$

where

Q_{solar} = annual heat delivery of solar system (kWh/yr or MBtu/yr)

Q_{saved} = annual fuel energy saved (kWh/yr)

$\eta_{heating}$ = heating system efficiency

Additional fan power required to pull the ventilation air through the SVP system is calculated by the equation

$$Q_{fan} = A_c q_{fan} \times (\#hours/day \times \#days/week \times \#weeks/year)$$

where

q_{fan} = fan energy required to pull air through the collector (taken to be 1 W/ft^2 for this analysis)

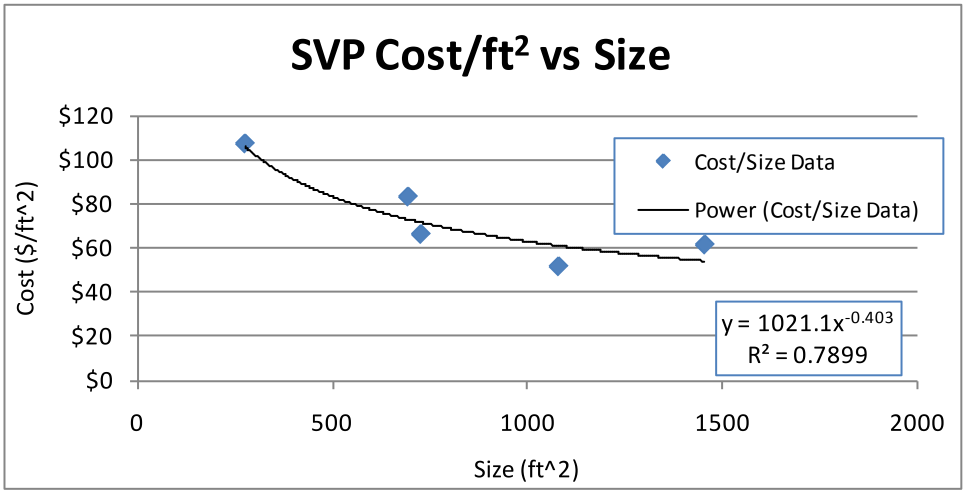

Figure B-1. Solar vent preheat cost curve

Credit: Andy Walker and Dan Olis, NREL

Appendix C. Solar Hot Water Systems

Suggested size for the solar water heating system is estimated using the equation

$$A_c = \frac{L}{\eta_{solar} \times I_{max}}$$

where

A_c = collector area (m^2)

L = daily load (kWh/day)

η_{solar} = efficiency of solar system (typically 0.429 for all locations from reference[84])

I_{max} = maximum daily solar radiation ($kWh/m^2/day$)

Using I_{max} in the above equation means the system is designed to meet the load on the sunniest days of the year. This sizing strategy optimizes economic performance since there is no excess capacity. Annual energy savings (kWh/year) is estimated by the equation

$$E_s = \frac{A_c \times I_{avg} \times \eta_{solar} \times 365}{\eta_{boiler}}$$

where

I_{avg} = average solar radiation ($kWh/m^2/day$)

η_{boiler} = auxiliary heater efficiency. Auxiliary water heater efficiency is taken[85] for different types of water heaters: gas 0.43 to 0.86, assume 0.57; electric 0.77 to 0.97, assume 0.88; heat pump, assume 2.0; propane 0.42 to 0.86, assume 0.57; oil 0.51 to 0.66, assume 0.52. If fuel use was not provided, electricity was assumed to be used for water heating.

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[84] Christensen, C.; Barker, G. *Annual System Efficiencies For Solar Water Heating.* Golden CO: National Renewable Energy Laboratory.

[85] Gas Appliance Manufacturer's Association, http://www.gamanet.org/ . Accessed May 2009.

Solar system cost is estimated according to the formula

$$C = (c_{solar}\ A_{c\text{-}rebate}) \times (1 - \text{federal tax credit}) \times (1 - \text{state tax credit})$$

where

C = installed cost of solar system ($)

C_{solar} = per-unit-area cost of installed solar system ($/m^2), typically $400/m^2 for large systems up to $1,200/m^2 for small systems. The value used in this analysis is $73/ft^2 ($800/m^2). Any incentives, in terms of percent-of-cost rebate or dollar-per-square-meter rebate are subtracted from the installed cost.

Annual cost savings are estimated by the equation

$$S = Es\ C_e - C_{O\&M} + Es \times C_{production\ incentive}$$

where

S = annual cost savings ($/year)

C_e = cost of auxiliary energy ($/kWh).

$C_{production\ incentive}$ = payments or credits for delivered energy ($/kWh). The COE is calculated for the water heating fuel type from use and cost data provided for each center.

Any other annual costs or revenues, such as O&M costs or production incentives, are added or subtracted from the annual cost savings.

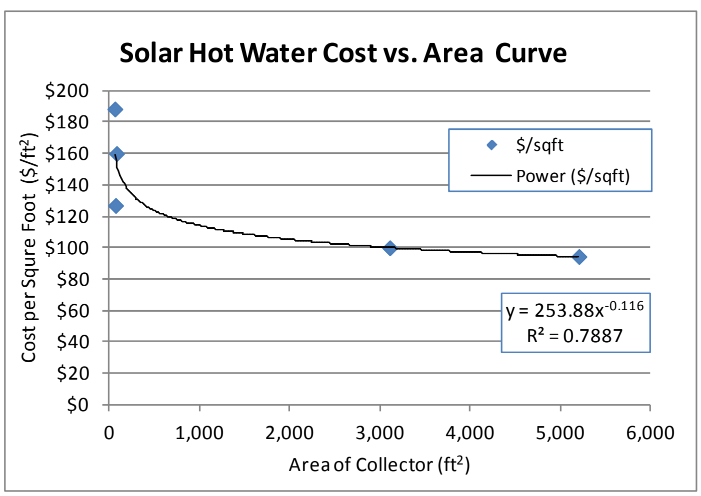

Figure C-1. Solar hot water cost curve

Credit: Andy Walker and Dan Olis, NREL

Appendix D. Photovoltaic Systems

The size of the PV system in kilowatts of rated output is determined by the optimization. In the equation below, note that units of I, solar radiation, are sun-hours per day. This unit has the same value as kilowatt-hours per square meter per day in the data because PV devices are rated at 1 kW/m^2 radiation. Solar system size is:

P_{rated} = rated PV power (kW)

Balance-of-system (BOS) efficiency is taken to be 77% to represent mismatch losses in the array and losses in the inverter and transformer. Annual electric energy savings are estimated as

$$E_s = 0.77 \times P_{rated}\, I_{avg} \times 365$$

where

I_{avg} = average solar radiation (sun-hours/day or kWh/m^2/day)

PV system cost is estimated by the equation

$$C = (c_{solar}\, P_{rated} - \text{rebate}) \times (1 - \text{federal tax credit}) \times (1 - \text{state tax credit})$$

where

C = installed cost of solar system ($)

c_{solar} = per-unit cost of installed solar system, typically $5.10–$9.10/W. For this analysis we use the value $7.10/Watt-DC installed cost.

Annual cost savings are estimated by the equation

$$S = E_s\, C_e - C_{O\&M}$$

where

S = annual cost savings ($/year)

C_e = cost of utility energy ($/kWh)

$C_{O\&M}$ = annual cost of O&M, taken as 0.143% of installed cost.

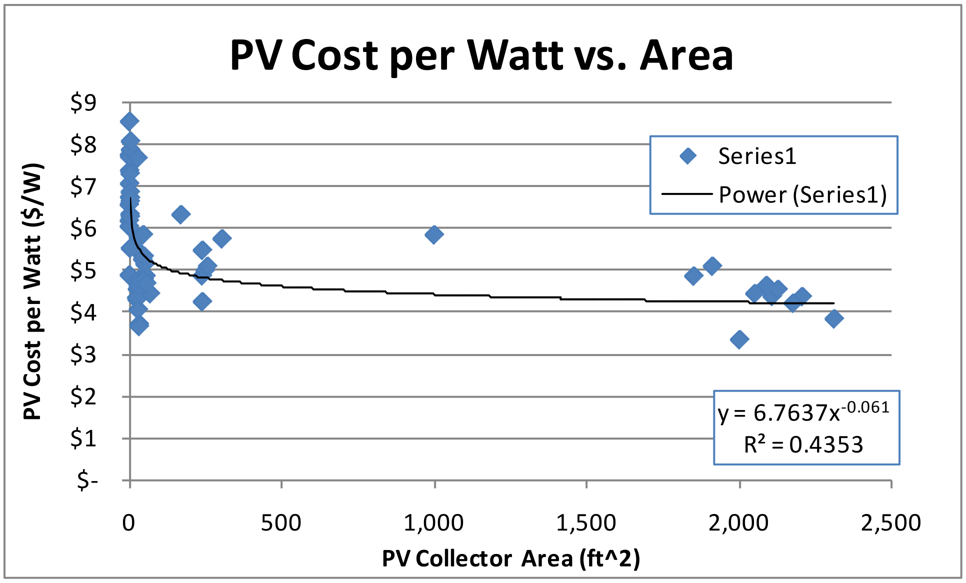

Figure D-1. PV cost curve

Credit: Andy Walker and Dan Olis, NREL

Appendix E. Solar Industrial Process Heat and Solar Thermal Electric

The governing equations for sizing a concentrating solar system include:

$$E_{s,\,gas} = \frac{A_c \times I_{avg} \times \eta_{solar} \times 365 \times (1 - \eta_{cogeneration}) \times e_{hx}}{\eta_{boiler}}$$

$$E_{s,\,electric} = A_c \times I_{avg} \times \eta_{solar} \times 365 \times \eta_{cogeneration}$$

where

I_{avg} = average solar radiation (kWh/m^2/day)

$\eta_{cogeneration}$ = efficiency of the electric generator

e_{hx} = effectiveness of the heat recovery heat exchanger

η_{boiler} = auxiliary heater efficiency

Appendix F. Biomass Energy

Biomass Resource Data

Data on biomass resources available at NAVSTA Newport were taken from existing biomass resource inventory conducted by NREL in 2008and available at: http://www.nrel.gov/gis/data_biomass.html. No on-site biomass data was provided. Biomass resources considered from surrounding areas include: crop residues, forest residues, primary mill residues, secondary mill residues, urban wood waste, methane emissions from landfills, methane emissions from manure management, and methane emissions from domestic wastewater treatment. The data is by county, in dry tones/year for solid biomass and tonnes/year for the gaseous resources (methane).

Crop Residues

The following crops were included in this analysis: corn, wheat, soybeans, cotton, sorghum, barley, oats, rice, rye, canola, dry edible beans, dry edible peas, peanuts, potatoes, safflower, sunflower, sugarcane, and flaxseed. The quantities of crop residues that can be available in each county are estimated using total grain production, crop-to-residue ratio, and moisture content and take into consideration the amount of residue left on the field for soil protection, grazing, and other agricultural activities.

Forest Residues

Forest residues are logging residues and other removable material left after carrying out silviculture operations and site conversions. Logging residue consists of unused portions of trees, cut or killed by logging, and left in the woods. Other removable materials are the unutilized volume of trees cut or killed during logging operations from.

Primary Mill Residues

Primary mill residues include wood materials (coarse and fine) and bark generated at manufacturing plants (primary wood-using mills) when round wood products are processed into primary wood products, like slabs, edgings, trimmings, sawdust, veneer clippings and cores, and pulp screenings.

Secondary Mill Residues

Secondary mill residues include wood scraps and sawdust from woodworking shops—furniture factories, wood container and pallet mills, and wholesale lumberyards.

Urban Wood Waste

This analysis includes wood residues from municipal solid wastes, utility tree trimming and private tree companies, and construction and demolition sites.

Methane Emissions from Landfills

Three key factors were considered to evaluate the methane emissions from landfills: total waste in place, landfill size, and geographic location (arid or non-arid climate).

Methane Emissions from Manure Management

The following animal types were included in this analysis: dairy cows, beef cows, hogs and pigs, sheep, chickens and layers, broilers, and turkeys. The methane emissions were calculated by animal type and manure management system.

Methane Emissions from Domestic Wastewater Treatment

The methane generation is estimated using methodology from the EPA[86] and 2000 population data from the U.S. Census Bureau[87].

System Sizing and Economics

A number of the indicative metrics for energy efficiency, equipment capital costs, and plant O&M costs were derived from industry figures and project costs assembled by Econergy,[88] an NREL consultant. Other costs not accounted for in this analysis include development cost, land, enclosure buildings, and balance of plant.[89]

The primary equations and relationships include:

$$E_{s,\,gas} = C_{boiler} \times \eta_{biomass\ boiler} \times 8{,}760 \times CF_{boiler} \left(1 - \eta_{cogeneration} + (1 - \eta_{cogeneration}) \times e_{hx}/\eta_{gasboiler}\right.$$

$$E_{s,\,electric} = C_{boiler} \times \eta_{biomass\ boiler} \times 8{,}760 \times CF_{boiler} \times \eta_{cogeneration}$$

where

C_{boiler} = biomass boiler size (MBtu/h) = variable determined by the optimization

CF_{boiler} = capacity factor (percent of time operational)

$\eta_{cogeneration}$ = the efficiency of the electric generator

e_{hx} = the effectiveness of the heat recovery heat exchanger

η_{boiler} = auxiliary heater efficiency.

Boiler heat delivery (therms) = boiler size × capacity factor

Biomass initial cost ($) = boiler size × cost per thousands of BTUs per hour (MBH) + electric Cogen size × kW of Cogen × city cost adjustment factor from RS Means cost estimating manuals

[86] Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2003, http://epa.gov/climatechange/emissions/downloads06/05CR.pdf.

[87] U.S. Census Bureau. "2000 County Business Patterns." http://www.census.gov/econ/cbp/. Accessed September 2005.

[88] Emissions from Integrated MSW Strategies, http://www.p2pays.org/ref/11/10516/emissions.html. Accessed May 2010.

[89] *NREL Biomass Plant Costs*, Letter Report: Boulder, CO: Econergy International Agency. November 13, 2007. www.econergy.com. Accessed May 2010.

Biomass cogeneration size (kW) = variable determined by optimization

Biomass gas savings (therms/year) = minimum of site gas use and thermal energy provided by boiler - that converted to electricity ÷ heat recovery steam generator effectiveness

Biomass electric delivery (kWh/year) = minimum of electric energy generation as calculated by Cogen capacity × capacity factor or as limited by boiler capacity, boiler efficiency, and boiler capacity factor

Biomass capacity factor = electric delivery ÷ Cogen capacity and 8,760 h/y

Biomass annual utility cost savings ($/year) = minimum of Cogen capacity or demand (kW) credited at retail rate + any generation in excess of that credited at avoided cost + federal production incentive × electric generation + gas savings × gas rate

Tons of fuel used = boiler heat delivered for both process heat and Cogen ÷ boiler efficiency ÷ heating value of fuel

Radius to collect fuel (miles) = radius calculated from area quotient of fuel required (tons) and density (tons/square mile)

Per ton fuel cost ($/ton) = fixed cost ($/ton) + trucking cost ($/ton/mile)

Fuel cost ($) = fuel used - fuel available onsite × fuel cost ($/ton)

State tax credit (%) = variable to be input by user

Federal tax credit (%) = variable to be input by user

Rebate ($) = variable to be input by user

Biomass cost with incentives ($) = boiler cost above - any rebates or tax credits

Biomass O&M cost ($/year) = $ per MBH of boiler capacity per year

Biomass payback period (years) = cost with incentives ÷ cost savings - O&M costs and - fuel costs.

Air Quality Concerns

Unlike the other RE technologies considered in this report, on-site use of biomass resources involves atmospheric emissions, solid waste residues (ash), and possibly water-borne wastes. While the decomposition of waste into simpler compounds by gasification should reduce emissions, detailed data for gasification could not be found in the literature (except for coal and clean wood). It may be expected, however, that emissions from a gasification operation could be no worse than those of a direct-burn operation, which may be found in the literature. The following values of pounds per ton for direct combustion of refuse-derived-fuel are from *Emissions From Integrated MSW Strategies*[90]: particulates 0.05; carbon monoxide (CO) 2.06; hydrocarbons 0.08; nitrogen oxide (NO_x) 2.64; methane 2.29; carbon dioxide (CO_2) 1,460; water 970; non-methane organic compound (NMOC) 0.12; dioxin/furan 0.0038; sulfur 1.1; and hydrogen 0.26. Also, the following values are for the same publication for anaerobic digestion: particulates 0.02; CO 0.79; hydrocarbons 0.08; NO_x 0.32; methane 14.34; CO_2 437; water 188; NMOC 0.75; and dioxin/furan, sulfur, and hydrogen are not applicable. In addition to these air emissions, ash from a gasifier using waste as fuel may contain metals that could leach out in a landfill, depending on the nature of the waste. Office paper, cardboard, and waste from convenience food operations have been found to be very uniform and free of metals, polyvinyl chloride (PVC), and other materials that may be of special concern.

Table F-1. Selected Emissions Data for Each Biomass Conversion Considered

Fuel	CO_2 emissions (kg/TJ)	Nitrous Oxide (N_2O) emissions (kg/TJ)
Natural Gas	56,100	0.1
Wood	112,000	4.0
Biodiesel	70,800	0.6
Bio-gas	54,600	0.1

TJ = trillion joules[91]

Combustion Platform

Direct combustion of biomass to generate heat for steam production has been the most common application of biomass. It can also be used in a topping cycle for steam cogeneration of heat and power. Direct combustion systems utilize either a spreader stoker grate or fluidized bed in the combustion chamber. The overall costs and efficiencies of these approaches are similar and are not analyzed separately. The results apply to both.

Configuration 1A Biomass Combustion/Steam Cycle

Biomass heat is provided by a boiler of a capacity determined as a result of the optimization. Cost and combustion efficiency of the boiler are specified. Some of the heat output of the boiler may be converted to electricity by a steam turbine in a cogeneration topping cycle. Boiler fuel may be wood chips or bio-oil. Bio-oil could be used by existing boilers and storage tanks with minimal modifications.

Gasification Platform

Gasification is a high-temperature process that is optimized to produce a fuel gas with a minimum of liquids and solids. Gasification consists of heating the feed material in a

[90] SRI International. "Emissions from Integrated MSW Strategies." NREL Technical Report, NREL/TP-431-4988-A. http://www.p2pays.org/ref/11/10516/emissions.html. Accessed May 2010.
[91] Gomez, D., Watterson, J. "Volume 2: Energy Table 2.2 Default Emission Factors for Stationary Combustion in the Energy Industries (kg of greenhouse gas per TJ on a Net Calorific Basis)." http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_2_Ch2_Stationary_Combustion.pdf. Accessed May 2005.

vessel with or without the addition of oxygen. Water may or may not be added. Decomposition reactions take place, and a mixture of hydrogen and CO are the predominant gas products, along with water, methane, and CO_2.

Configuration 2A Biomass Gasification/Steam Cycle
Configuration 2A is a biomass gasification system that fuels a steam cycle. The system gasifies biomass and immediately burns the syngas in a heat-recovery steam generator (HRSG) to produce steam for the steam turbine. The combined gasification and boiler efficiency is about 64%. The steam-to-electricity conversion efficiency of a standard steam cycle is taken as 50% while heat can be recovered at about 80% effectiveness. O&M costs should be very similar to a conventional biomass fired boiler.

Configuration 2B Biomass Gasification/Spark Ignition Reciprocating Engine
Configuration 2B considers a slightly more advanced biomass gasification process called pyrolytic gasification whereby a high-British-thermal-unit content syngas is produced by externally heating biomass. The syngas generated in this process then has sufficient energy content to run spark-ignition reciprocating engines. Typically these engines are de-rated to account for the reduced energy content of the syngas when compared with natural gas. Hence the engine combined heat and power (CHP) costs on a dollar-per-kilowatt basis are higher than for a natural gas system. The fuel-to-electricity conversion efficiency of a gas engine operating on syngas is roughly 37% based on lower heating value, and heat recovery effectiveness is typically around 80%. The O&M costs reflected here represent the O&M costs for the gasification plant and the gas engines, or roughly $18/MWh.

Configuration 2C Biomass Gasification/Combustion Turbine Combined Cycle
The last configuration considered for gasification systems is the combined cycle. This is the least commercialized configuration of the three systems and costs are, therefore, less certain. The gasification system cost has been assumed to be equal to Configuration 2B; however, it may actually require more gas-cleanup systems and could likely be higher. The combined-cycle cost is indicative of natural gas combined-cycle costs with a slight power output de-rating for the syngas. The same gasification efficiency has been assumed as for Configuration 2B, and the combined cycle will see a decreased efficiency relative to the natural gas baseline. However, future improvements in process design should be able to bring the efficiency up considerably. Heat recovery has been assumed at zero because the system would likely be at utility scale and would use a condensing steam turbine for maximum electrical generation. The system has a lower O&M cost compared to the gas engine configuration but higher O&M cost than the steam cycle. Future integrated gasification and combined cycle (IGCC) configurations utilizing pressurized oxygen-blown gasification have higher plant efficiencies than what is shown here.

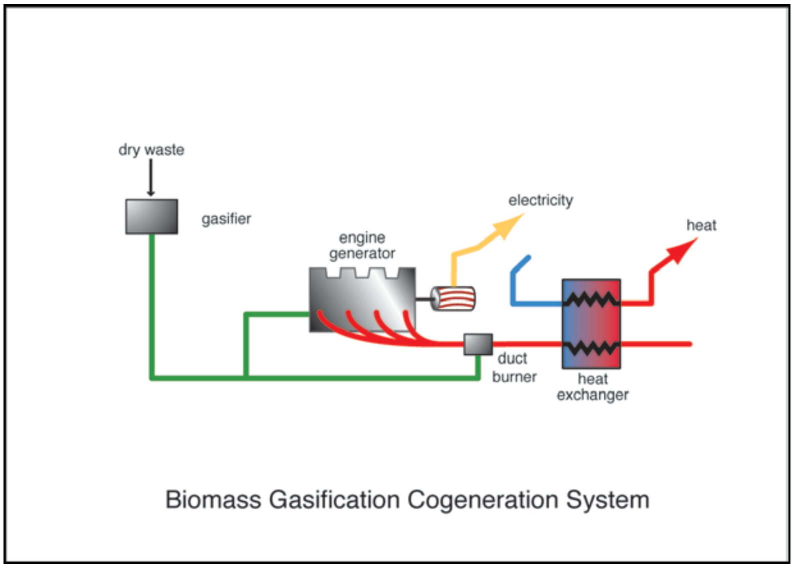

Figure F-1. Platform 2B biomass gasification with syngas utilization via spark-ignition reciprocating engines

Credit: Jim Leyshon, NREL

Pyrolysis Platform

Configuration 3A Pyrolysis/Steam Cycle

Configuration 3A is fast pyrolysis followed by a conventional steam cycle. The efficiency of biomass pyrolysis to bio-oil is about 77%, while the boiler efficiency is roughly 80%, resulting in a total efficiency of 61%. The cost for the pyrolysis plant is given in dollars per hourly million British thermal units of bio-oil production. The steam-to-electricity conversion efficiency of a standard steam cycle is taken as 50% and heat recovery as 70%. O&M costs include the O&M for the steam cycle and the pyrolysis plant in terms of hourly million British thermal units of bio-oil utilization.

Configuration 3B Pyrolysis/Compression Ignition Engine

The second pyrolysis configuration considers a fast-pyrolysis plant fueling modified compression ignition engines. This system has an advantage over 1B because liquid-fueled compression-ignition engines have higher efficiencies. Published literature indicates that diesel engines burning bio-oil achieve comparable efficiencies to those using diesel fuels, although modifications to the fuel-handling system for preheating the bio-oil are required. Heat recovery effectiveness is assumed to be 80%.

Configuration 3C Pyrolysis/Combustion Turbine Combined Cycle

The final configuration for a fast-pyrolysis plant is to fire the bio-oil in a combustion turbine combined cycle. Research on the subject indicates that modified simple-cycle combustion turbines can easily reach 28% fuel-to-electricity conversion efficiency with an expected combined-cycle efficiency of 35%. However, they have been shown to operate at or above rated turbine power output; thus, the combined cycle is not de-rated and the cost is shown for a conventional natural gas combined cycle. It is likely that the first commercial system using this configuration will have much higher combined-cycle efficiencies, but this probably represents the current state of the art. As in Configuration 2C, it is assumed that a bio-oil-fired combined cycle will not have heat recovery for district heating applications.

Anaerobic Digestion Platform

Configuration 4A Anaerobic Digestion/Spark Ignition Engine

This configuration involves anaerobic digestion (AD) of mixed energy crops and manure, which would be typical for farm-based applications in the 100–500 kW scale. These smaller-scale gas engines operating on digester gas are typically not de-rated as much as for syngas and have lower installed costs. The digester efficiency has been assumed to be 57%, which is an average efficiency for different types of energy crop and manure feedstocks. The efficiency for AD systems is lower because they can only utilize the volatile solids content while the lignocellulosic material is removed and sold as fiber. The efficiency of smaller-scale gas engines is slightly lower at 35% compared to larger engines, while heat recovery is also less efficient. Plant capacity factors are dependant mainly on the AD systems, and 92% is the goal for many applications.

Configuration 4B Anaerobic Digestion/Microturbine

Microturbines can also be used with digester gas and offer a good fit at these small scales. These systems offer lower electrical efficiency but higher heat recovery because of the higher-temperature flue gases.

Configuration 4C Anaerobic Digestion/Molten Carbonate Fuel Cell

The final configuration considers an anaerobic digester supplied by a molten carbonate fuel cell (MCFC). The MCFC is the only commercialized CHP fuel cell and has been proven on biogas. This configuration has the highest electrical efficiency but lower heat recovery efficiency because heat is consumed by the internal-reforming process of the fuel cell. Capacity factor for MCFC running on biogas has been observed at around 85% but can be expected to increase as their commercial use increases. This system is also the most expensive of the three platforms considered here but could qualify for incentives for both the AD system and the fuel cell.

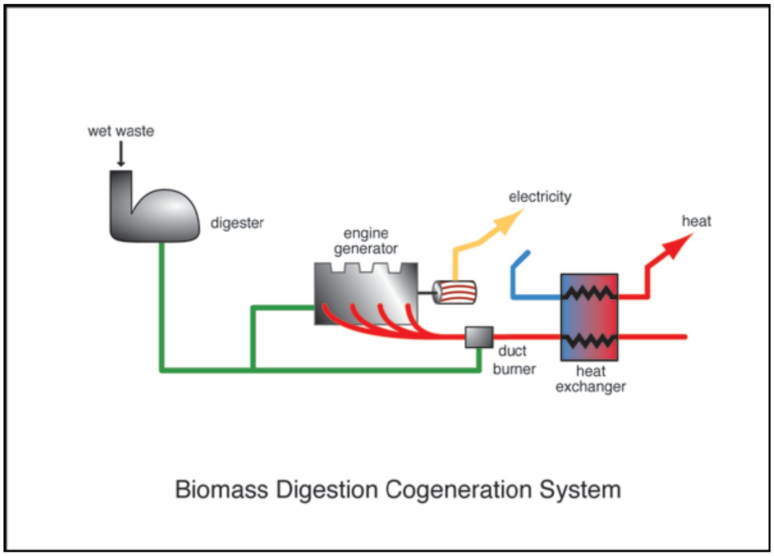

Figure F-2. Platform 4A anaerobic digester and spark-ignition engine with heat recovery

Credit: Jim Leyshon, NREL

Table F-2. Characteristics of Biomass Heat and Power Technologies[92]

	Combustion with steam topping cycle cogeneration	Biomass gasification with syngas utilization via conven-tional steam cycle	Biomass gasification with syngas utilization via spark-ignition reciprocating engines	2C Biomass gasification with syngas utilization via combus-tion turbine combined cycle	Biomass fast pyrolysis with bio-oil utilization via conventional steam cycle	Biomass fast pyrolysis with bio-oil utilization via compression-ignition reciprocating engines	Biomass fast pyrolysis with bio-oil utilization via combustion turbine combined cycle	Anaerobic Digestion of biomass with biogas utilization via spark ignition reciprocating engines	AD of biomass with biogas utilization via micro-turbine	AD of biomass with biogas utilization via molten carbonate fuel cell
Gasifier/Boiler/Digester Cost ($/MBH)	500,000	195,802	195,802	195,802	223,590	223,590	223,590	419,918	419,918	419,918
Cogen Cost ($/kW)	1,650	700	1,300	815	700	1,300	747	1,000	1,225	4,500
Fuel Storage and Handling ($/MBH)	250,000	250,000	250,000	250,000	250,000	250,000	250,000	250,000	250,000	250,000
Boiler Efficiency	0.75	0.64	0.75	0.75	0.61	0.77	0.9	0.57	0.57	0.57
Cogen Efficiency	0.3	0.5	0.37	0.47	0.33	0.45	0.35	0.35	0.3	0.45
Boiler Capacity Factor	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.92	0.92	0.85
Hx Effectiveness	0.7	0.8	0.8	0	0.8	0.8	0	0.6	0.66	0.38
Fixed Cost Per Ton	20	20	20	20	20	20	20	20	20	20
Trucking Cost ($/mi/ton)	1	1	1	1	1	1	1	1	1	1
Federal Production Tax Credit ($/kWh)	0.01	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019
Biomass O&M Cost ($/yr-MBH)	15,000	25,079	57,518	43,139	25,079	31,452	24,913	43,377	44,372	42,669

[92] ANSI/ASHRAE Standard 62.1-2007. "Ventilation for Acceptable Indoor Air Quality American Society of Heating, Refrigerating, and Air-Conditioning Engineers." Atlanta, GA: ASHRAE. http://www.ashrae.org/pressroom/detail/16298. Accessed May 2010.

Appendix G. Tidal Energy

Tidal Resource Assessment

The tides are caused by the gravitational pulls on Earth by both the moon and the sun, with the moon's gravitational effect, due to its close proximity to Earth, being the primary driver of Earth's tides and the sun's gravitational pull being a secondary driver. The lunar orbital period is 24 hours and 50 minutes, while Earth's rotational period, 24 hours, dictates the timing of the sun's tidal effects. The availability of peak tidal power occurs twice each day but is 50 minutes later each day. This effect can best be explained through several diagrams. The vectors on Earth's surface, shown in Figure G-1, represent the difference in the gravitational force the moon exerts at a given point on the surface versus the force it would exert at the center of the Earth. The resultant force vectors visually represent what happens to the water—in the Earth-moon plane (left-to-right as shown), the water is attracted to the moon causing the waters to "bulge" (i.e., high tide) towards the moon. Concurrently, a similar effect is seen on the opposite side. The net impact on the top and bottom of the sphere is the waters move away resulting in low tide.

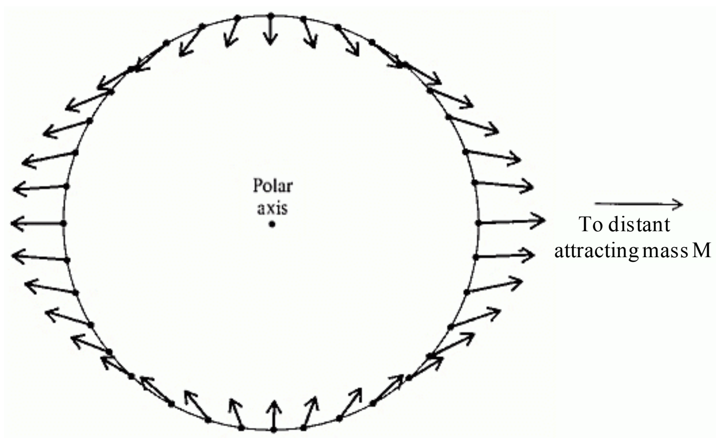

Figure G-1. Tide-generating forces based on Earth-moon interactions[93]

The axis that Earth rotates on, relative to Earth's orbital plane as it revolves around the sun, is tilted approximately 23°. This tilt angle is known as the declination angle. There is a comparable declination angle when describing Earth's axis of rotation relative to the moon's orbital plane. This positional relationship, as shown in Figure G-2, results in the wide range of tidal effects experienced around the globe. Areas near the equator experience semi-diurnal tides (i.e., two high and two low tides per day designated by the red and blue labels H1 and H2), while high latitudes experience diurnal tides (shown as the green L and H). Mid-latitude regions experience mixed diurnal tides—two tides per day—but with significant diurnal inequality between successive high and low tides.

[93] Simanek, D., Emeritus Prof. of Physics, Lock Haven University of Pennsylvania. Email 12/4/2011.

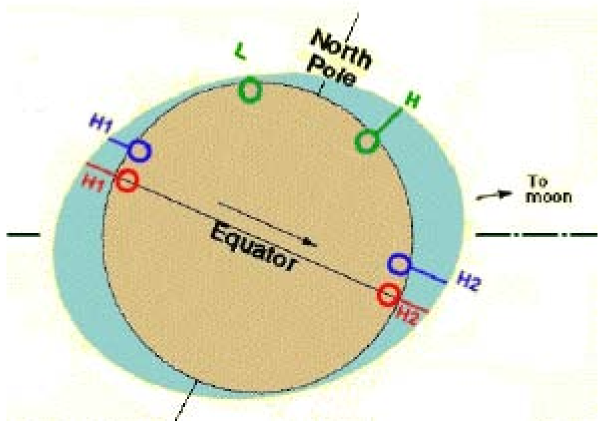

Figure G-2. Influence of the moon's declination on tidal forces[94]

The periodic nature and variances of the semi-diurnal, mixed, and diurnal tides can be seen in Figure G-3. The period of the lunar tides is roughly 12 hours and 25 minutes, and they are semi-diurnal—occurring twice each day (or, more precisely, twice every 24 hours and 50 minutes). The influence of the moon on the tides changes as the moon's declination progresses from its extreme position over the north tropics to over the south tropics in 14 days, with the strongest tidal pulls from the moon at these extremes. In between, when the moon is over the equator, the diurnal inequality of the tides is minimized, as occurs twice per tropical month (every 27.3 days).

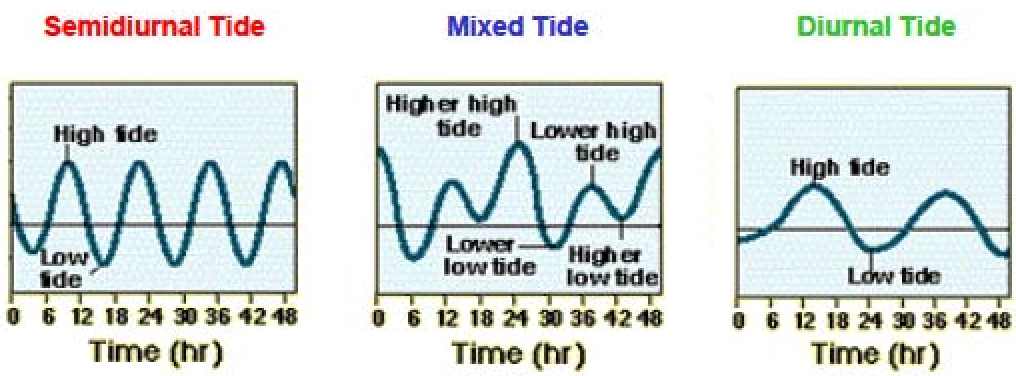

Figure G-3. Graphical depiction of tidal patterns[95]

The moon's gravitational pull causes the tidal bulge (i.e., water levels rise). The sun's gravitational pull also causes a tidal bulge, but its amplitude is only 46% as high as the lunar bulge.[96] In the absence of the moon, the solar tides would be very periodic or diurnal—every 12 hours. Additionally, the solar tidal bulge would always be towards the

[94] Hagerman, G.; Polagye, B. "Methodology for Estimating Tidal Current Energy Resources and Power Production by Tidal In-Stream Energy Conversion (TISEC) Devices," EPRI, 2006.
[95] Hagerman, G.; Polagye, B. "Methodology for Estimating Tidal Current Energy Resources and Power Production by Tidal In-Stream Energy Conversion (TISEC) Devices," EPRI, 2006.
[96] Hagerman, G.; Polagye, B. "Methodology for Estimating Tidal Current Energy Resources and Power Production by Tidal In-Stream Energy Conversion (TISEC) Devices," EPRI, 2006.

sun; in other words, it would be the same time every day with high tide at solar noon (with corresponding high tide on the opposite side of the earth at solar midnight).

Figure G-4 illustrates the varying influence of the moon and sun on Earth's tides. The light royal blue oval represents the lunar bulge and the turquoise oval represents the solar bulge. When the moon and the sun are pulling in the same direction (first Earth diagram on the left in Figure G-4), it causes the highest high tide, known as the spring tide. In the next phase (i.e., shown as third quarter), the moon and sun are pulling in different directions 90° apart. This results in lower high tides and higher low tides. This phenomenon is known as the neap tide, and it occurs during both the first and third quarters of the moon. During the half moon, new moon, and full moon, the lunar and solar tidal bulge work in unison, resulting in a spring tide, due to the effect described in Figure G-1.

There are other factors that affect the tides, such as wind, storms, salinity, or even spring run-off, but often the factors have smaller magnitudes and longer periods (except for storm impacts). For all practical purposes, a 29-day site-specific resource analysis yields enough information to generate a reliable tidal flow assessment enabling a usable annual tidal flow prediction.

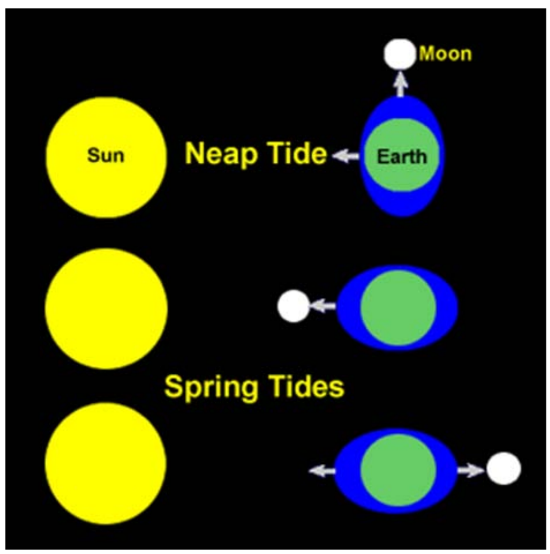

Figure G-4. Position of the moon and resultant lunar and solar spring and neap tides[97]

Tidal Parameters for Power Production

The tidal current speed is a critical parameter in resource assessment; however, since it does vary significantly through the various periodic influences of the moon and sun, it is also critical to determine how many periods the tidal current is at each distinct velocity using the frequency distribution approach used in wind resource assessment.

[97] Night Skies, Moon, Absolute Axarquia. http://www.absoluteaxarquia.com/nightsky/moon.html. Accessed Sept 2010.

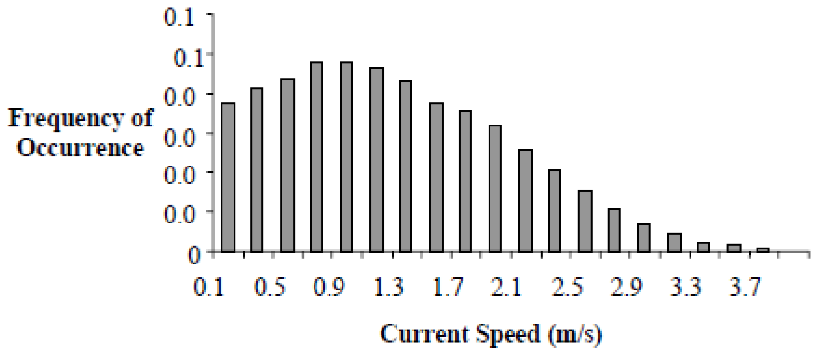

Figure G-5. Sample tidal current speed distribution[98]

The turbines operate in three regions: below cut-in speed, cut-in speed to rated speed, and greater than rated speed in the same manner as wind turbines. This can be seen graphically in Figure G-6.

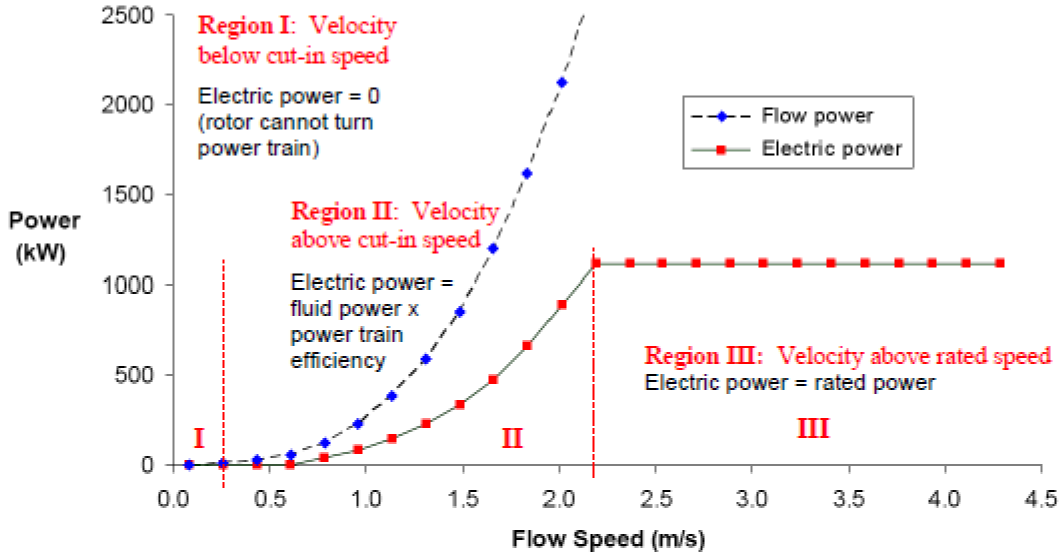

Figure G-6. Sample turbine output power versus flow speed[99]

Newport Tidal Height and Period Assessment

There is an existing station, Newport - Station ID: 8452660,[100] for measuring the tides at NAVSTA Newport that reports regularly to the National Oceanic and Atmospheric Administration (NOAA) Tides & Currents database.

The following series of four graphs (Figure G-7, Figure G-8, Figure G-9, and Figure G-10) illustrates the variability in the periodic tide levels at the Newport station. The mean

[98] Hagerman, G.; Polagye, B. "Methodology for Estimating Tidal Current Energy Resources and Power Production by Tidal In-Stream Energy Conversion (TISEC) Devices," EPRI, 2006.
[99] Hagerman, G.; Polagye, B. "Methodology for Estimating Tidal Current Energy Resources and Power Production by Tidal In-Stream Energy Conversion (TISEC) Devices," EPRI, 2006.
[100] National Oceanographic and Atmospheric Administration. "Tides & Currents." http://tidesandcurrents.noaa.gov/station_info.shtml?stn=8452660%20Newport,%20RI. Accessed October 8, 2011.

range (MN) of the tides is the difference in height between the mean high water mark and the mean low water mark. For Newport, the MN is 3.47 ft. The diurnal range (GT) is the difference in height between the mean higher high water and the mean lower low water mark. For Newport, the GT is 3.85 ft.

The periodic nature of tidal flow means the tidal current will reverse flow direction four times per day for ebb (towards low tide) and flood (towards high tide) cycles. For most of the day, the tides are either moving in or out. It is only during the transitional time from tide coming in versus going out, aka slack water, that there is very little velocity current in the water. The slack water duration varies site to site, but the duration is usually in the 5–30-minute range with shorter times associated with higher tidal current velocities and vice versa. The approximate velocity of the tide is represented visually by the steepness of the sinusoidal curves in Figure G-7. The tops and bottoms of these curves are where the tidal current slows and then becomes neutral (i.e., zero current speed) as it transitions from ebb to flood or vice versa. Figure G-7 shows a fairly "normal" two-day tidal oscillation. The graph shows the water level relative to the mean lower low water level, which serves as the baseline.

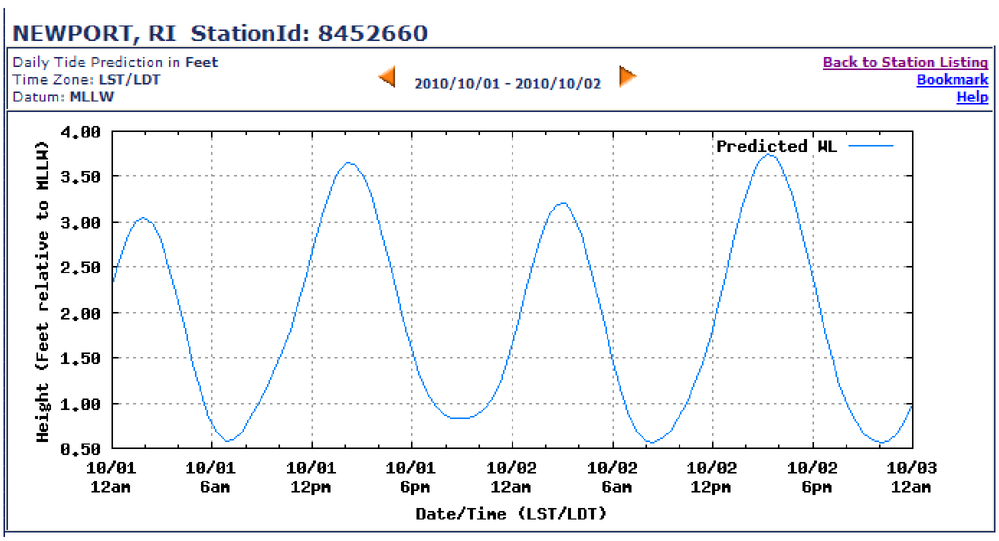

Figure G-7. Newport tide level per mean lower low water—48 hr profile (MLLW)[101]

Figure G-8 demonstrates the accuracy of tidal predictions with the predicated water levels in blue, the actual water levels in red, and the difference between them shown in green.

[101] National Oceanographic and Atmospheric Administration. "Tides & Currents." http://tidesandcurrents.noaa.gov/noaatidepredictions/viewDailyPredictions.jsp?Stationid=8452660. Accessed October 20, 2011.

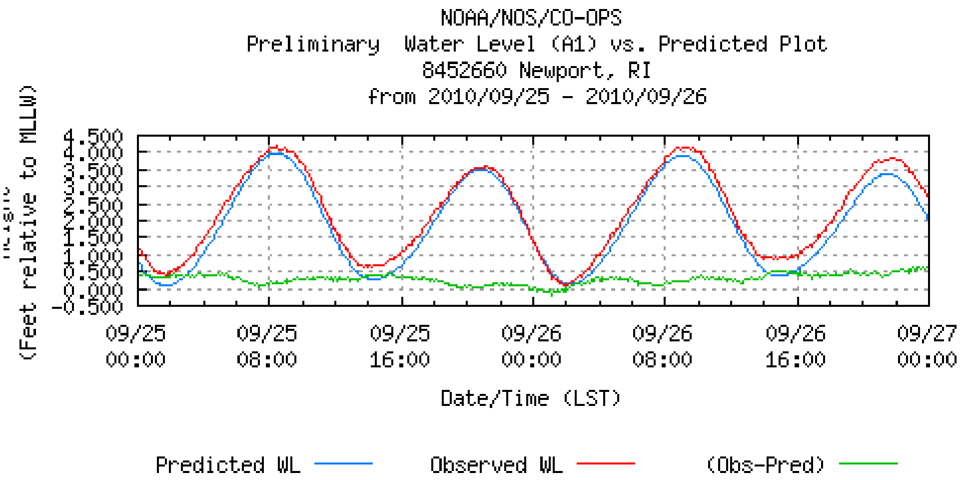

Figure G-8. Predicted versus observed tide levels in Newport[102]

The seven-day timeframe for Figure G-9 more clearly illustrates the impact of the solar tides on the lunar tides.

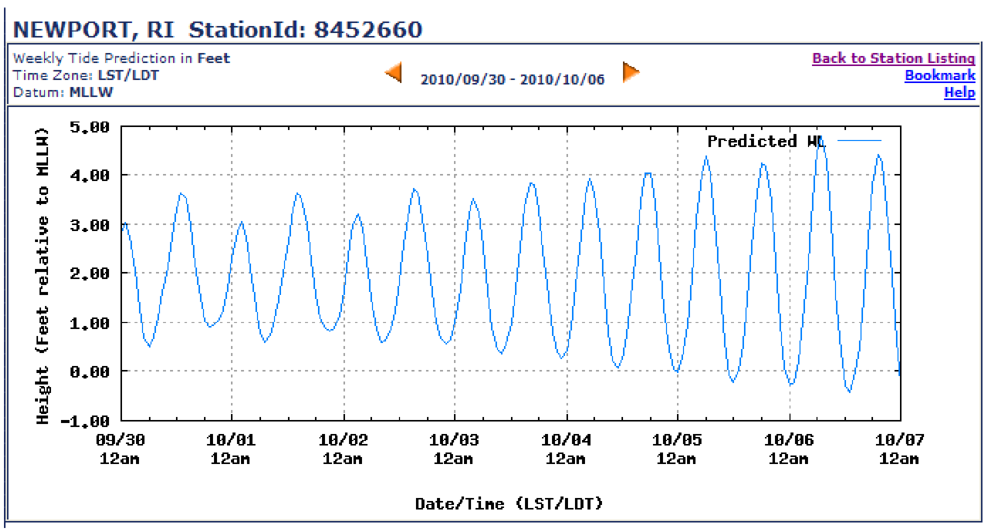

Figure G-9. Newport tide level per mean lower low water level—Seven-day profile[103]

The 30-day profile, as shown in Figure G-10, shows great consistency in period length but considerable variation in the water height or amplitude.

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[102] National Oceanographic and Atmospheric Administration. "Tides & Currents." http://tidesandcurrents.noaa.gov/gmap3/. Accessed October 8, 2011.

[103] National Oceanographic and Atmospheric Administration. "Tides & Currents." http://tidesandcurrents.noaa.gov/noaatidepredictions/viewDailyPredictions.jsp?Stationid=8452660. Accessed October 8, 2011.

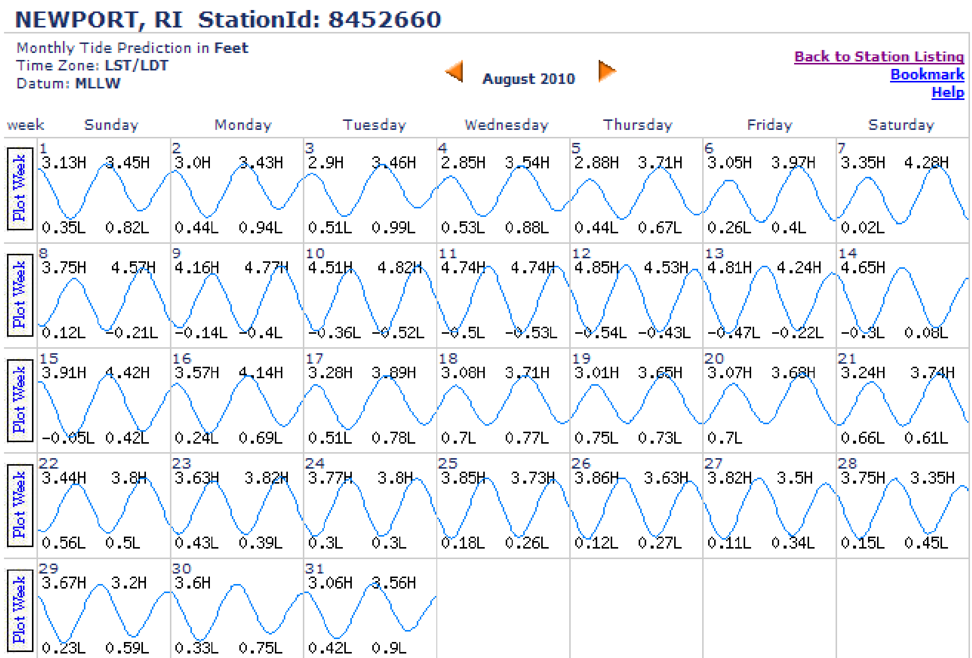

Figure G-10. Newport tide level per mean lower low water level—30-day profile[104]

Tidal Current Assessment

Wind power is a very site-specific renewable resource; tidal power even more so. Site characteristics that are generally more favorable to better tidal current flows are narrow channels between land masses that large volumes of water must pass through. Due to lunar and solar gravitational pull, a given volume of water will need to accelerate to move through the channel. The full tidal stream resource is a function of both the speed of the tidal current (incident power density) and the channel cross-sectional area (width and depth).[105]

The impact of terrain on the viability of a particular site is very significant. To analyze that terrain, two studies will need to be undertaken: (1) a detailed bathymetry mapping of NAVSTA Newport's accessible waterway bed (in Narragansett Bay) and (2) a tidal current flow study with measurements at specific sites of interest as identified by the bathymetric study.

Shown in Figure G-11 and Figure G-12 are high-level bathymetry maps of Narragansett Bay. The complexity of terrain above the water can be similar to the complexity below the water surface in many areas; however, the impact of this terrain variation on viable current flow (i.e., power in the water flow) underwater is greatly magnified compared to the influence of the terrain on wind current flow (i.e., power in the wind) due to the greatly increased density of the fluid in the bay (water density = 62.32 lb_m/ft^3 or 998.2

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[104] National Oceanographic and Atmospheric Administration. "Tides & Currents." http://tidesandcurrents.noaa.gov/noaatidepredictions/viewDailyPredictions.jsp?Stationid=8452660. Accessed October 8, 2011.

[105] Hagerman, G.; Polagye, B. "Methodology for Estimating Tidal Current Energy Resources and Power Production by Tidal In-Stream Energy Conversion (TISEC) Devices," EPRI, 2006.

kg/m^3) versus the air above the bay (air density = 0.076 lb$_m$/ft^3 or 1.2 kg/m^3). Topographical maps are used to illustrate the terrain gradients above the water; bathymetrical maps are used to illustrate terrain gradients below the surface.

For the bathymetry map in Figure G-11, the lighter blue shading indicates shallow water, the darker blue indicates deeper channels. The Navy chose Newport as a Naval base site because the waterway was deep enough for large Navy vessels. For tidal current, generally shallow and narrow channels are preferred as these features tend to accelerate the flow of the volume of water that is moving due to the lunar and solar tidal pull.

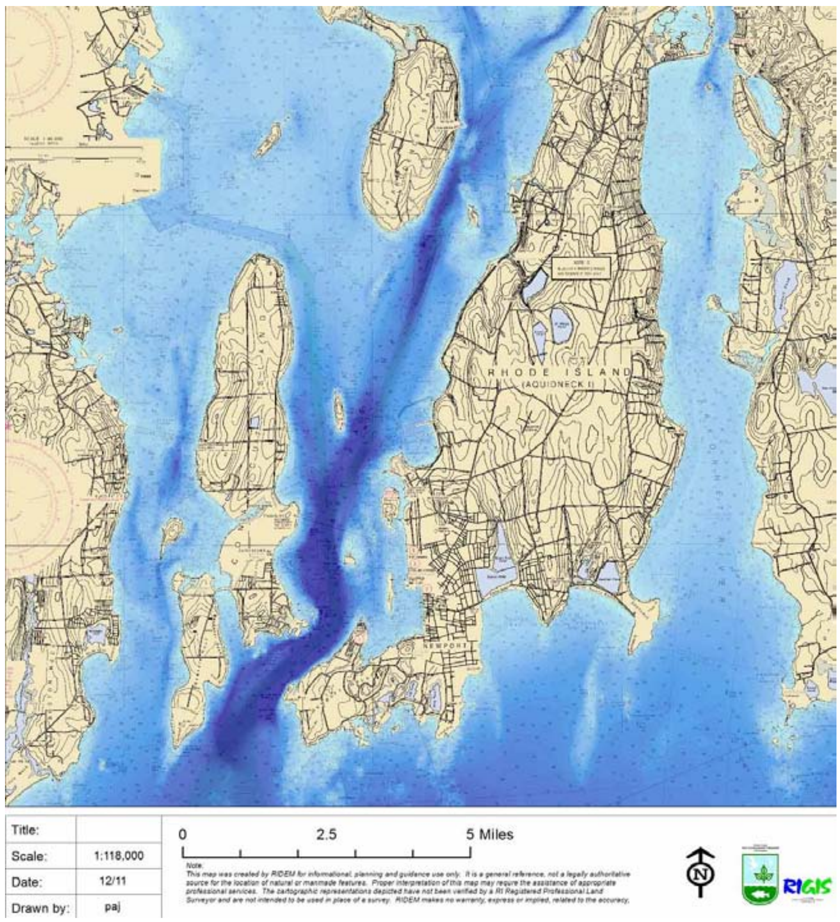

Figure G-11. Bathymetry map of Rhode Island

Credit: Paul Jordan, Rhode Island Department of Environmental Management

The contour map (Figure G-12) gives better definition to the channels and depths, though it is still lacking in enough site-specific resolution to determine best locations for increased tidal current flows. Micro-siting is used to determine the best location for wind turbines on land. Extreme micro-siting with much higher resolution are needed for investigation of the potential tidal current resource.

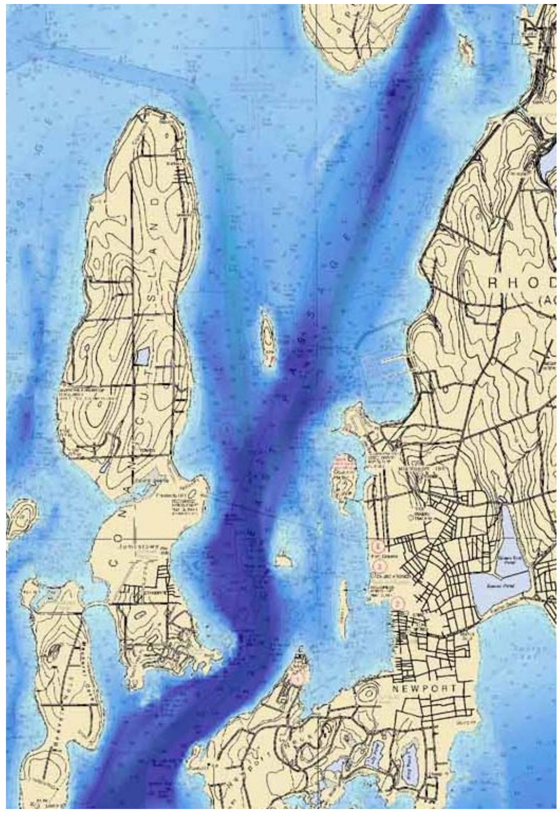

Figure G-12. 10 ft (3.1 m) contour map of Narragansett Bay

Credit: Paul Jordan, Rhode Island Department of Environmental Management

To determine the extent of the tidal resource available to NAVSTA Newport, it would be useful to effectively characterize the surface of the Narragansett Bay floor in areas that NAVSTA Newport could install a turbine if the resource proves viable. Key features of interest are canyons or channels—features that would cause the acceleration of the tidal current.

Tidal Current Data

Table G-1 shows the type of data NAVSTA Newport will need to collect to be able to determine if the tidal resource is economic. The table shows the tidal current speeds (in knots and m/s) and direction (flood = +, ebb = -). Looking across the pink highlights for Day 1, the maximum current is at 6:21 a.m. at 0.3 knots (0.15 m/s). At 11:17 a.m., the maximum current is -0.5 knots (-0.26 m/s). The vertical green shaded boxes show how the time of the maximum velocity is a little bit later in successive days by approximately 20–55 minutes.

Table G-1. Predicted Tidal Currents at Quonset Point in Narragansett Bay[106]

Quonset Point, Narragansett Bay, Rhode Island									NOAA, National Ocean Service									
Predicted Tidal Current		January, 2006							Flood Direction, 21 True.				Ebb (-)Direction, 200 True.					
Day	Slack Water Time h.m.	Max Current Time h.m.	Max Current Veloc knots	Max Current Veloc m/s	Slack Water Time h.m.	Max Current Time h.m.	Max Current Veloc knots	Max Current Veloc m/s	Slack Water Time h.m.	Max Current Time h.m.	Max Current Veloc knots	Max Current Veloc m/s	Slack Water Time h.m.	Max Current Time h.m.	Max Current Veloc knots	Max Current Veloc m/s	Slack Water Time h.m.	
1	151	621	0.3	0.15	834	1,117	-0.5	-0.26	1,452	1,852	0.3	0.15	2,056	2,333	-0.5	-0.26		
2	242	713	0.3	0.15	925	1,205	-0.5	-0.26	1,538	1,947	0.3	0.15	2,149			0.00		
3		23	-0.5	-0.26	333	811	0.3	0.15	1,017	1,255	-0.5	-0.26	1,621	2,044	0.3	0.15	2,242	
4		117	-0.5	-0.26	425	909	0.3	0.15	1,110	1,347	-0.5	-0.26	1,703	2,139	0.3	0.15	2,337	
5		211	-0.5	-0.26	521	1,006	0.3	0.15	1,206	1,438	-0.5	-0.26	1,750	2,233	0.3	0.15		
6	32	303	-0.5	-0.26	637	1,103	0.3	0.15	1,301	1,527	-0.4	-0.21	1,847	2,328	0.3	0.15		
7	128	357	-0.4	-0.21	909	1,159	0.3	0.15	1,357	1,621	-0.4	-0.21	1,954			0.00		
8		23	0.3	0.15	225	502	-0.4	-0.21	1,019	1,253	0.3	0.15	1,454	1,727	-0.4	-0.21	2,058	
9		115	0.3	0.15	325	623	-0.4	-0.21	1,115	1,347	0.3	0.15	1,553	1,839	-0.4	-0.21	2,153	
10		210	0.3	0.15	431	728	-0.4	-0.21	1,203	1,444	0.3	0.15	1,653	1,937	-0.4	-0.21	2,241	
11		313	0.3	0.15	533	820	-0.4	-0.21	1,243	1,545	0.3	0.15	1,748	2,028	-0.4	-0.21	2,326	
12		413	0.3	0.15	625	909	-0.5	-0.26	1,315	1,638	0.3	0.15	1,837	2,117	-0.5	-0.26		
13	9	501	0.3	0.15	710	955	-0.5	-0.26	1,339	1,721	0.3	0.15	1,922	2,204	-0.5	-0.26		
14	54	539	0.3	0.15	752	1,040	-0.5	-0.26	1,408	1,800	0.3	0.15	2,006	2,250	-0.5	-0.26		
15	140	614	0.3	0.15	831	1,123	-0.5	-0.26	1,442	1,838	0.3	0.15	2,050	2,335	-0.5	-0.26		
16	228	648	0.3	0.15	909	1,205	-0.5	-0.26	1,518	1,917	0.3	0.15	2,132			0.00		
17		20	-0.5	-0.26		726	0.2	0.10		1,248	-0.4	-0.21		2,000	0.2	0.10		
18		106	-0.4	-0.21		812	0.2	0.10		1,329	-0.4	-0.21		2,043	0.2	0.10		
19		151	-0.4	-0.21		901	0.2	0.10		1,407	-0.4	-0.21		2,127	0.2	0.10		
20		230	-0.4	-0.21		949	0.1	0.05		1,439	-0.3	-0.15		2,210	0.2	0.10		
21		303	-0.3	-0.15		1,039	0.1	0.05		1,509	-0.3	-0.15		2,257	0.2	0.10		
22		336	-0.3	-0.15		1,129	0.1	0.05		1,545	-0.3	-0.15		2,346	0.2	0.10		
23		417	-0.3	-0.15		1,218	0.1	0.05		1,632	-0.2	-0.10				0.00		
24		35	0.2	0.10		527	-0.2	-0.10		1,307	0.1	0.05		1,749	-0.3	-0.15		
25		125	0.2	0.10		704	-0.3	-0.15		1,358	0.2	0.10		1,908	-0.3	-0.15		
26		221	0.2	0.10		756	-0.3	-0.15		1,459	0.2	0.10		2,001	-0.4	-0.21	2,313	
27		327	0.3	0.15	545	841	-0.4	-0.21		1,603	0.2	0.10		2,050	-0.4	-0.21		
28	0	427	0.3	0.15	638	927	-0.5	-0.26	1,302	1,657	0.3	0.15	1,857	2,139	-0.5	-0.26		
29	48	517	0.4	0.21	728	1,013	-0.5	-0.26	1,347	1,745	0.3	0.15	1,949	2,228	-0.5	-0.26		
30	138	605	0.4	0.21	817	1,059	-0.5	-0.26	1,432	1,833	0.4	0.21	2,040	2,317	-0.5	-0.26		
31	231	655	0.4	0.21	907	1,145	-0.6	-0.31	1,514	1,925	0.3	0.15	2,131			0.00		

Once the best potential locations for tidal current concentration or acceleration are determined via the detailed bathymetrical analysis, installing an underwater data acquisition system (DAS) with open channel flow meter is recommended. For expediency, installing several flowmeters at a time is recommended. Due to the periodic nature of the tidal flows as explained over the previous several pages, the measurement campaign per site only needs to be 29 days long; then the various influences on the tidal flow repeat. The assessment of 5–20 locations should take 3–18 months, depending on how many DAS are deployed.

Tidal Power Calculations

Due to the much higher density of water than air, the tidal current velocities for effective power conversions are considerably lower than the air or wind velocities required for wind turbines. There are variations in the tidal stream speeds per the above discussion on

[106] National Oceanographic and Atmospheric Administration. "Tides & Currents." http://tidesandcurrents.noaa.gov/currents06/QUONSET.shtml. Accessed October 8, 2011.

lunar, solar, and other factors. An effective range for the average of the spring and neap tidal current speeds is in the range of 2–3 m/s or 4–6 knots.[107]

The power equation for water is essentially the same as for wind, only the fluid has changed (from air to water).

The power available in the tidal current is given by:

$$P = \frac{1}{2} * A * \rho * V^3$$

where

P = power of the tidal current [W]

A = swept area of the rotor (blades) [m^2] = $\pi D^2/4 = \pi r^2$

ρ = density of the water [kg/m^3] (1,000 kg/m^3 at sea level at 5°C)

V = velocity of the water [m/s]

The velocity of the water, being cubed for power calculations, has a significant impact on the viability of any site. Rearranging the equation, the power density can be determined by

$$(P/A) = \frac{1}{2} * \rho * V^3 \text{ (watts / } m^2\text{)}$$

[107] Hagerman, G.; Polagye, B. "Methodology for Estimating Tidal Current Energy Resources and Power Production by Tidal In-Stream Energy Conversion (TISEC) Devices," EPRI, 2006.

Table G-2 shows the impact of tidal current speed on power density as a result of the cubic relationship that exists between the two.

Table G-2. Power Density at Different Tidal Current Speeds[108]

ρ (kg/m^3)	V (knots)	V (m/s)	P/A_0 (W/m^2)
1,025	0.5	0.26	9
1,025	1.0	0.51	70
1,025	1.5	0.77	235
1,025	2.0	1.03	558
1,025	2.5	1.29	1,090
1,025	3.0	1.54	1,884
1,025	3.5	1.80	2,992
1,025	4.0	2.06	4,466
1,025	5.0	2.57	8,722
1,025	6.0	3.09	15,071
1,025	7.0	3.60	23,933
1,025	8.0	4.12	35,725

[108] Hagerman, G.; Polagye, B. "Methodology for Estimating Tidal Current Energy Resources and Power Production by Tidal In-Stream Energy Conversion (TISEC) Devices," EPRI, 2006.

Appendix H. Geothermal Energy

Systems Configuration and Characteristics

Geothermal systems are not a "one-size-fits-all" technology. There are a number of variables and factors that must be considered for each system that encompass factors, such as available land area (determines vertical versus horizontal system), soil type (conductivity, moisture content, and diffusivity), seasonal weather variation (temperature and humidity), building loads (energy use and building envelope), type of system (groundwater, ground-coupled, and lake loop), and type of loop (vertical, horizontal, or spiral). For example, heat pump efficiencies for all energy systems vary significantly according to type of equipment and operating conditions. The energy requirements of the location vary according to the outside air conditions (temperature, wind, and humidity) and the envelope of the structure (insulation, infiltration, and fenestration).

The typical closed loop GSHP system consists of three types of loops: a ground or subsurface loop, a refrigerant loop, and the cooling/heating distribution loop. The subsurface loop typically consists of polyethylene or polybutylene pipe, which is placed in the ground either horizontally in a trench or vertically in a boring or well. This thin-walled pipe acts as a heat exchanger, which transfers heat from or to the ground (may also be designed to exchange with a body of water). Antifreeze fluids inside the pipe are circulated to the heat exchanger of an indoor heat pump where it releases heat to the refrigerant. The refrigerant loop typically consists of copper pipes that contain a refrigerant. The cooling/heating distribution loop of the system consists of the forced air or hydronic system to distribute the heated or cooled air throughout the building.[109] A fluid (usually water or a mixture of water and antifreeze) circulates through the pipes to absorb or relinquish heat within the ground.

A GSHP connects to the earth as its heat sink for thermal exchange. This connection can be earth, groundwater, or surface water coupled. Details of several types of the ground exchange systems typically used today can be found in Appendix C.

Heat Pumps

The heat pump itself is a critical piece of equipment in GSHP systems. The use of heat pumps in GSHP systems is what allows the system to effectively take advantage of the heating or cooling provided by the earth.

Heat pumps operate in a very efficient manner as they are not generating heat per se, they are merely moving it. It takes a lot less energy to move heat than to generate it. A comparison of how much energy a system delivers compared to how much it consumes helps to illustrate why the energy savings can be so great in these systems compared to conventional HVAC systems. The efficiency of heating equipment is often measured by its coefficient of performance (COP). The COP is a ratio of how much energy a system delivers relative to what it consumes in the process. It is defined, more specifically, as the heating capacity (in Btu/hr) of the heating unit divided by its electrical input (also in

[109]Bureau of Water Quality Management. "3. Closed-Loop GSHP Systems," Appendix L, *Ground Source Heat Pump Manual*, Commonwealth of Pennsylvania, Department of Environmental Protection, Lancaster County Planning Commission. http://www.co.lancaster.pa.us/planning/cwp/view.asp?a=3&Q=268215. Accessed October 8, 2011.

Btu/hr) at standard (ARI/ISO 13256-1) conditions of 32°F (0°C) entering water for closed loop models and 50°F (10°C) entering water.[110]

Some average COP values for heating equipment are[111]:

- Advanced water to air heat pump 4.0
- Water to air heat pump 3.0
- Air to air heat pump 2.0
- Electric resistance 1.0
- Natural gas furnace 0.7
- Coal furnace 0.7.

Figure H-1 illustrates the major components of a heat pump. The water-to-refrigerant coil exchanges heat with the ground loop.

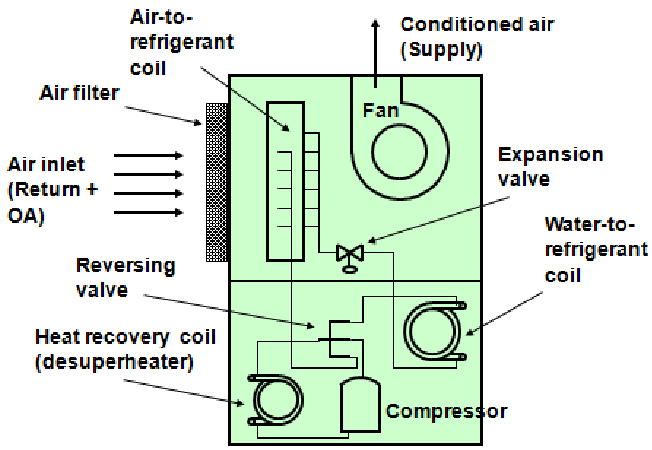

Figure H-1. Typical geothermal heat pump configuration[112]

Figure H-2 illustrates how the entering water temperature (from the earth) impacts the GHP performance relative to its capacity, which in turn affects its ability to meet the load. The steady temperatures provided by the earth enable the heat pumps to operate near peak capacity in both heating and cooling modes. An air-source heat pump, which relies on ambient air for a large part of its thermal energy, can operate at low heating capacities when the outside air is below 50°F (10°C) and at low cooling capacities when outside air is above 80°F (27°C).

[110] DOE FEMP. "How to Buy an Energy-Efficient Ground-Source Heat Pump." http://www.ornl.gov/sci/femp/pdfs/gshp-pro-chal.pdf. Accessed October 8, 2011.
[111] Lancaster County Planning Commission. Appendix L: IGSHPA Closed-Loop/Geothermal Heat Pump Systems - Design and Installation Standards, Commonwealth of Pennsylvania, Department of Environmental Protection. http://www.millersvilleborough.org/planning/cwp/view.asp?A=2&Q=268208. Accessed October 8, 2011.
[112] Shonder, J. "Geothermal Heat Pumps." Presented at FEMP Renewable Energy Workshop, NREL 2004.

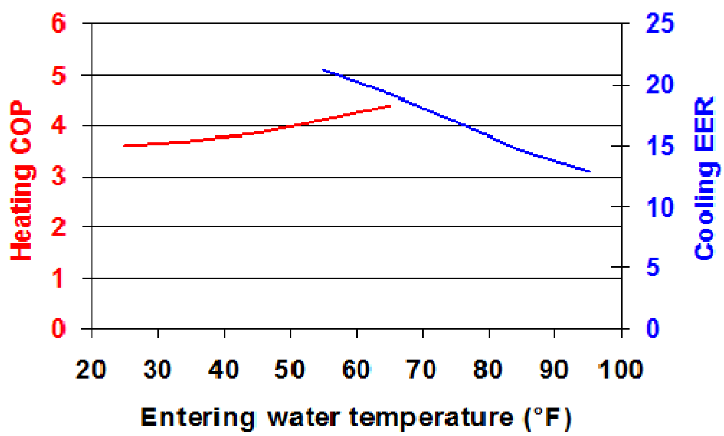

Figure H-2. Capacity of a typical 4-ton GHP versus EWT[113]

In Figure H-3, the impact of entering water temperature on the heating COP and cooling energy efficiency ratio (EER) can be readily seen. Again, the steady earth temperatures enable a GHP to operate near both peak heating COP and peak cooling EER, which results in more British thermal units of heating or tons of cooling delivered per kilowatt-hour consumed.

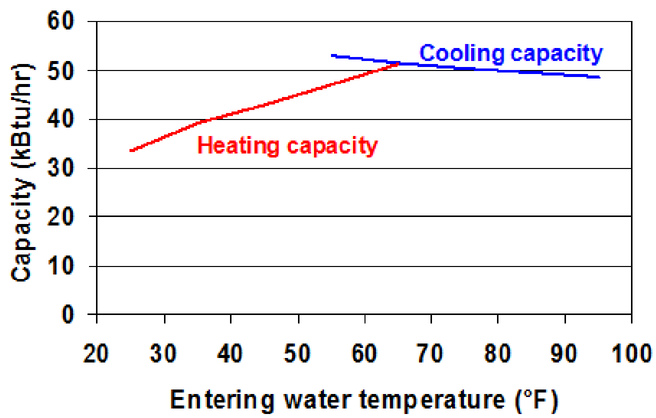

Figure H-3. Efficiency of a typical 4-ton GHP as a function of EWT[114]

There are a number of variables and factors that must be considered for each system on an individual basis. Working with qualified, experienced professionals on all aspects of geothermal systems is highly recommended.

Once the site conditions are fully analyzed and the GSHP system is designed to meet the load, the energy performance of a GSHP system can be influenced by three primary factors: the heat pump machine, the circulating or well pump, and the ground-coupling or groundwater characteristics. An optimized GSHP system considers the interaction of these factors. Case studies of school and commercial building GSHP energy and economic performance results were less conclusive than those for the residential sector.

[113] Shonder, J. "Geothermal Heat Pumps." Presented at FEMP Renewable Energy Workshop, NREL 2004.
[114] Shonder, J. "Geothermal Heat Pumps." Presented at FEMP Renewable Energy Workshop, NREL 2004.

Given all the potential influences upon school and commercial building energy use, predictions of savings to be achieved with a GSHP system become a very site-specific endeavor.[115]

High efficiency circulation pumps are recommended throughout the system. They are the consumers of electricity and if inefficient, will consume more electricity than necessary throughout the life of the system.

GSHP Economic Parameters

The economic justification for GSHP systems is, as is the case for many RE systems, tied directly to what it is being compared to. In new construction, the design alternatives are compared based on energy system modeling using current energy and construction cost data. For retrofits, a similar approach taken though the existing system typically has much firmer cost numbers associated with it than purely modeled systems.

In both cases, the economic comparison has two components:

- Capital costs for the design, construction, and installation of the system
- Operational costs that include cost of fuel, routine O&M, and major repairs.

In replacement of existing HVAC systems, typically, there are GSHP savings from reduced energy bills for heating due to the elimination of natural gas consumption. There are cooling energy savings due to the reduction of cooling compressor energy. There are also reduced O&M bills due to the simplicity of the system relative to conventional HVAC systems. It should be noted that if the GSHP system is replacing an electrical heating system, for the vast majority of the year it will be using significantly less electrical energy to heat the building. During a few very cold periods, the heat pumps have difficulty extracting enough heat from the cold and they either operate continuously but at low efficiency or supplement heating will be needed. The result may be an increase in the demand for electricity for supplemental heating.

In new construction applications, it is assumed that there will be competing HVAC systems for a GSHP system to be evaluated against. The capital cost of equipment, the price of fuel, and the annual O&M costs are the primary considerations. GSHP systems are generally considered to have higher upfront capital costs and lower O&M costs, though the mix of natural gas versus electricity will likely change. A GSHP system may have increased electricity consumption compared to a conventional HVAC system because the heat pumps are electrically driven. However, it would be expected that the heating fuel (natural gas, fuel oil, or electricity) consumption would decrease significantly through the use of a geothermal system.

Capital Costs

Generally, the vertical GSHP systems are more expensive to drill, grout, and backfill than horizontal or surface/ground water systems. The horizontal GSHP systems require the

[115] Lienau, P.; Boyd, T.; Rogers, R. "Ground-Source Heat Pump Case Studies and Utility Programs." Klamath Falls, OR: Geo-Heat Center, Oregon Institute of Technology; p. 40, April 1995. http://geoheat.oit.edu/pdf/hp1.pdf. Accessed October 8, 2011.

most piping and land area. Typical installed cost ranges for horizontal systems are $850–$3,200/kW. For vertical systems, the cost range is $1,050–$5,900/kW.[116] Water well systems, either open loop or standing column well, are in the $850–$1,500/kW range.

Others cite a range of costs based on building size with the caveat that a number of critical system design factors cannot be known before investigation, so there is uncertainty in the estimates. For commercially sized new construction, the estimated cost is in the $13–$17/ft^2 range.[117] For commercial retrofit applications where re-using portions of the existing ducting and delivery system is likely, the range is $10–$13/ft^2 (wide variation due to small dataset).[118] For water well systems, the installed cost per ton is in the $3,000–$5,000/ton range (open loop and standing column well).[119]

Operating Costs and Savings Based on Fuel Prices

As shown in Figure H-4, the annual dollar savings for a GSHP application are greater when the cost of natural gas is high and the cost of electricity is low. The estimated savings when replacing natural gas in the United States is in the $8–$900/year range. The cost of natural gas and electricity in the United States is relatively low compared to most of the other countries in the study. The current U.S. natural gas price of approximately $3.00/GJ is roughly equivalent to $3.37/MMBtu or dekatherm.[120] With these extremely low natural gas prices, the economics of GSHP systems become more challenging.

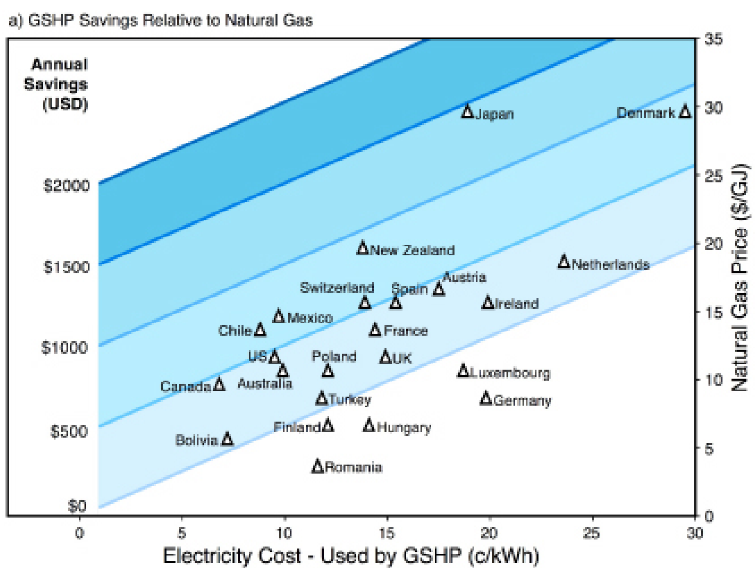

Figure H-4. Annual GSHP savings versus cost of natural gas[121]

[116] RETScreen. Online Manual. Version 4. www.retscreen.net/download.php/Ang/470/0/SWH3.pdf. Accessed October 8, 2011.
[117] Shonder, J. "Geothermal Heat Pumps." Presented at FEMP's Implementing Renewable Energy Projects Workshop. August 2006.
[118] Ibid.
[119] Ibid.
[120] U.S. EIA. "Natural Gas Weekly." http://www.eia.doe.gov/oog/info/ngw/ngupdate.asp. Accessed October 8, 2011.
[121] Hanova, J.; Dowlatabadi, H. *Strategic GHG Reduction Through the Use of Ground Source Heat Pump Technology.* Vancouver, Canada: University of British Columbia, 2007. http://iopscience.iop.org/1748-9326/2/4/044001/fulltext. Accessed October 8, 2011.

Figure H-5 is similar to Figure H-4, except that the comparison is for the GSHP replacing fuel oil used in a furnace or boiler. The annual savings have increased by approximately $200 to about $1,000 annually. Note that fuel oil is not readily available or used for heating in a number of the countries that were used in the natural gas comparison of the previous graph, hence there are only a small number of countries in the comparison.

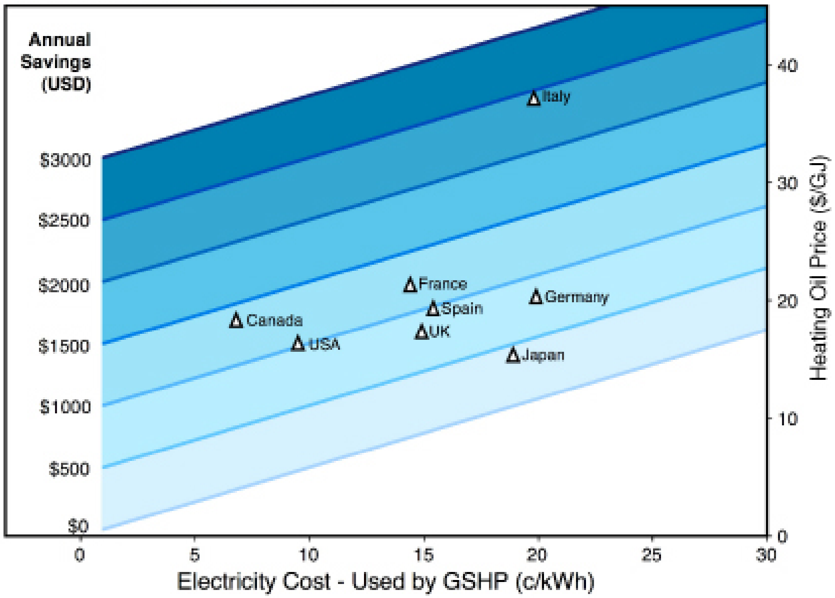

Figure H-5. Annual GSHP savings versus cost of natural gas[122]

In Figure H-6, the comparison is to replacing heating by electricity with resistive heaters to GSHP. The annual savings, at approximately $1,500/year, are nearly twice that of replacing natural gas heaters with GSHP systems.

[122] Hanova, J.; Dowlatabadi, H. *Strategic GHG Reduction Through the Use of Ground Source Heat Pump Technology.* Vancouver, Canada: University of British Columbia, 2007. http://iopscience.iop.org/1748-9326/2/4/044001/fulltext. Accessed November 8, 2011.

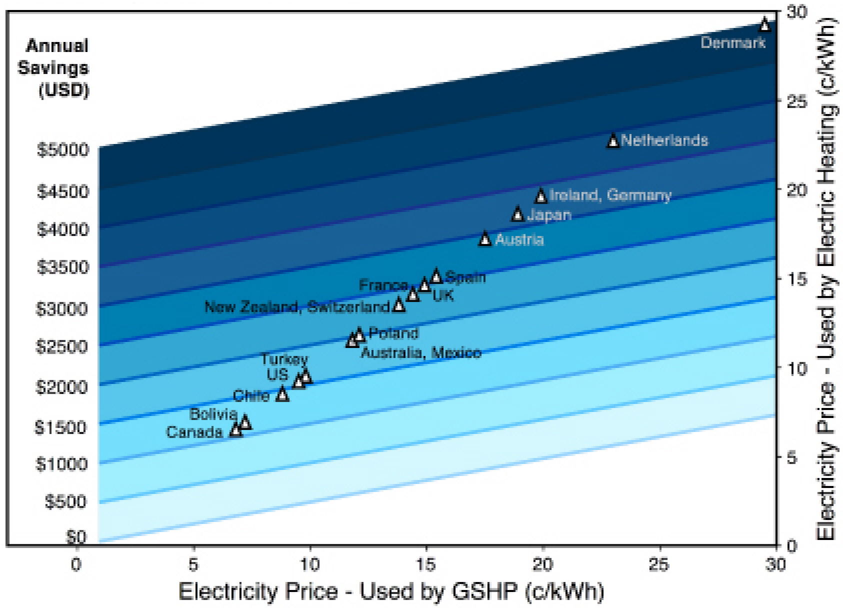

Figure H-6. Annual GSHP savings versus cost of electricity for heating[123]

Operation and Maintenance Costs

As with any mechanical system, the O&M costs for GSHP systems can vary widely depending upon a variety of factors. One key factor is the variation in system types and configurations. Vertical, horizontal, groundwater source, and ground-coupled systems all operate under different parameters so it is difficult to make a comparison of operating costs across all systems. Based on recent studies by Kentucky Utilities and Nebraska's Lincoln Electric System,[124] the O&M costs of GeoExchange systems were estimated to be 12%–19% lower than traditional systems over a 20-year period. AHSRAE manuals estimate up to 50% O&M savings with maintenance costs averaging \$0.12–\$0.15/ft^2 versus \$0.30/ft^2 for conventional systems.[125]

GSHP Annual Emissions Impacts

The annual emissions reduction associated with GSHPs is dependent upon the fuel source of the HVAC system it is displacing. For example, there are more GHGs and other emissions typically associated with coal-fired electricity than with direct burning of natural gas in a boiler. There are few GHGs associated with wind, solar, or nuclear power. The fossil fuel consumption reductions attributed to the GSHP will depend on the specifics of the application. If electricity consumption increases for heating with heat pumps versus heating with natural gas, emission impact calculations must include both the added emissions for increased electricity consumption and the offset for natural gas consumption reduction.

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[123] Hanova, J.; Dowlatabadi, H. *Strategic GHG Reduction Through the Use of Ground Source Heat Pump Technology*. Vancouver, Canada: University of British Columbia, 2007. http://iopscience.iop.org/1748-9326/2/4/044001/fulltext. Accessed November 8, 2011.
[124] GEOEXCHANGE. "The Best Business Decision for Heating and Cooling Commercial Buildings." http://www.sesnet.com/GeoExchange.pdf . Accessed June 2011.
[125] GEOEXCHANGE. http://www.geoexchange.org/pdf/School2.pdf. Accessed October 8, 2011.

If the GSHP is replacing an all-electric HVAC system and will use significantly less electrical energy overall, the emissions benefits are straightforward and substantial compared to scenarios where the GSHP is replacing natural gas heating.

Due to the variables outlined above and their individual impacts on system design approaches and costs, even though they are dependent upon site-specific geotechnical information, which can both vary widely and drive the design decisions in very different directions, no cost modeling was undertaken. It is recommended that when an appropriate candidate building has been identified for a potential GSHP system, NAVSTA Newport (or NREL) initiates a geotechnical investigation to establish the parameters from which a reasonable economic analysis can be undertaken.

Newport Soil Characteristics

Geotechnical investigations—a soil analysis—is one of the first activities that should be completed when considering a GSHP as the results of the analysis will drive both the types of systems to consider and the sizing of ground-coupled, heat exchange loop. Generally speaking, soil that has high conductivity, density, and heat capacity will provide greater heat exchanging capability and will positively impact overall system performance and economics. Wet or damp soil is generally a better heat transfer medium than dry soil. Fine-grained soil is generally a better heat transfer medium than coarse-grained soil.

High conductivity is needed to effectively exchange heat from the fluid in the system pipes to the ground on a seasonal basis. With high conductivity, the heat exchange will occur more rapidly and the system performance will be more effective. Thermal capacitance of the soil is another characteristic that will enhance GSHP system performance. Soil reports for Newport were found online and are in Appendix B. Overall, the soil descriptions and moisture content appear to be within the parameters often used with GSHP. Of course, these conditions are site specific and a geotechnical investigation should be conducted for each building that NAVSTA Newport proposes a GSHP system.

Figure H-7 indicates that Rhode Island soils have a low potential to result in scaling to GSHP systems. This is a positive finding for GSHPs in general as high-scaling potential can reduce system performance and increase O&M.

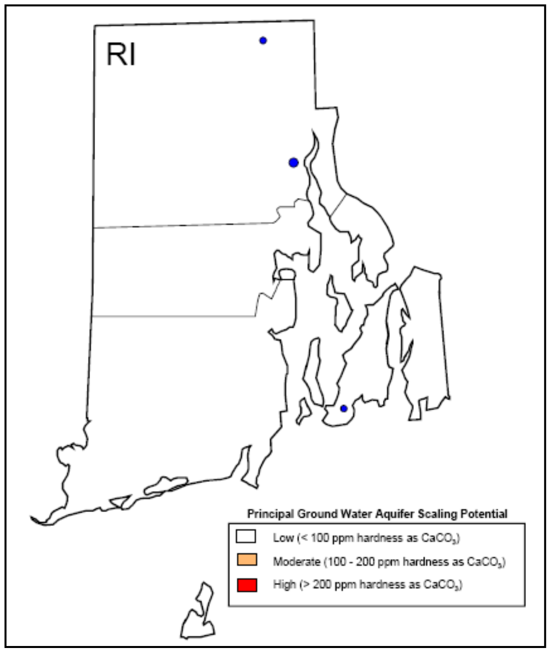

Figure H-7. Scaling potential of groundwater aquifer[126]

The bedrock in the Newport area will typically be granite.[127] The depth to bedrock is usually greater than 6 ft.[128] In the Providence area there are locations where it is known to be several hundred feet down. This investigation did not reveal a comparable level of known bedrock depth in Newport, but descriptions of glacial movements and general terrain imply it is considerably shallower. Depth to bedrock will determine if a vertical or horizontal piping orientation is the most economic. Solid rock can be effective as the heat exchange medium in vertically-oriented systems but is typically more expensive to drill.

As the Wisconsin Ice Sheet receded about 10,000 years ago, it traveled southward and scraped away the existing soil and rock down to the bedrock. The soil and rock were carried in the ice until it melted, at which time the soil was re-deposited as a well-graded mixture of gravel, sand, silt, and clay called glacial till. Glacial till is typically encountered immediately overlying bedrock and can be composed of transported material as well as local bedrock. The composition of the till in Rhode Island varies depending on the bedrock that the till is derived from. The Narragansett till plains around Narragansett

[126] Rafferty, K. "Scaling in Geothermal Heat Pump Systems." Geo-Heat Center, Oregon Institute of Technology, Klamath Falls, OR. http://www.docstoc.com/docs/68850745/Scaling-in-Geothermal-Heat-Pump-Systems. Accessed October 27, 2011.
[127] "Baxter, C.D.P., Page, M., and Bradshaw, A.S., and Sherrill, M. (2005). Guidelines for Geotechnical Site Investigations in Rhode Island. FHWA-RIDOT-RTD-05-1S, p. 104.
[128] NEsoil.com. New England Soil Profiles, Newport Series. http://nesoil.com/muds/newport.htm. Accessed October 8, 2011.

Bay are derived from sedimentary rock, shale, sandstone, conglomerate, and, in some locations, coal.[129]

Closed Loop Systems

A horizontal closed loop system, shown in Figure H-8, is based on the stacking of two pipes in a horizontally-oriented heat exchange field. These systems may be connected in series or in parallel. The horizontal heat exchange fields may be a single pipe as shown or there may be multiple pipes (two, four, or six) or a spiral-wound coil, aka “slinky” (Figure H-9). The multiple pipe or coil systems are designed to increase the heat exchange surface area. The system as shown is in heating mode as low temperature heat exchange fluid in the subsurface loop is rejected from the building, exchanged with the earth and warmer temperature heat exchange fluid is returned to the building.

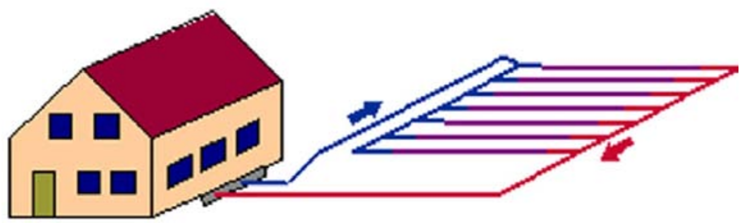

Figure H-8. Horizontal bore, closed loop GSHP system[130]

These horizontally-oriented systems often have the lowest initial costs but require the largest area. These systems may be located in an adjacent field (e.g., athletic field, playground/park, or vacant), next to a building, or under a parking lot. The construction process for these systems can be disruptive at existing building sites. The location of underground utilities must be considered in the initial design phase. Once installed, however, the piping is expected to have an in-ground life of 30–40 years (the International Ground Source Heat Pump Association states 50 years[131]), so near-term land disturbances should not be an issue. Of course, future use of the land must be considered as there will be limitations on activities that may be undertaken at the site.

Horizontal systems generally require 250–300 ft^2 (23–28 m^2) of land per ton of heating or cooling. Horizontal systems that employ wound coils typically extend 4–8 ft (1.2–2.4 m) in diameter and 2–8 ft (0.6–2.4 m) down. There is a much higher total heat exchange surface area per square foot (or square meter) of bore field, but there is some loss of efficiency due to the short distance between the coiled tubes. However, when limited space is an issue or if there is a desire to lower the installation cost, this sort of borehole field compression can prove to be worthwhile.

[129] Baxter, C.; Page, M.; Bradshaw, A.; Sherrill, M. “Guidelines for Geotechnical Site Investigations in Rhode Island – Final Report.” Rhode Island Department of Transportation, March 2005. http://www.dot.ri.gov/documents/engineering/research/Reports/Site_inv_guidelines.pdf. Accessed October 8, 2011.
[130] Sanner, B. “Shallow Geothermal Energy.” http://geoheat.oit.edu/bulletin/bull22-2/art4.pdf. Accessed October 8, 2011.
[131] International Ground Source Heat Pump Association. “Ground Source Heat Pumps Offer Great Benefits.” http://www.igshpa.okstate.edu/geothermal/commercial.htm. Accessed October 8, 2011.

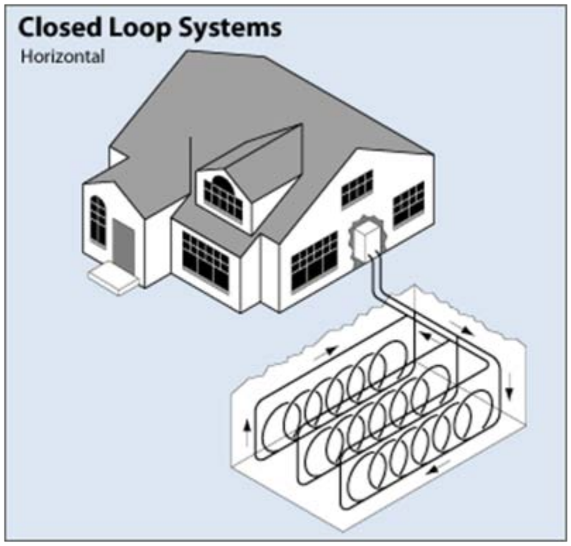

Figure H-9. Horizontal bore, closed loop GSHP with spiral coil[132]

The energy performance of a GSHP system can be influenced by three primary factors: the heat pump machine, the circulating or well pump, and the ground-coupling or groundwater characteristics.[133] An optimized GSHP system considers the interaction of these factors.

Horizontal systems are best suited to applications that have both heating and cooling loads, even simultaneously, as they can best take advantage of solar-radiation-driven surface temperature fluctuations on an annual basis. Since these systems depend on the solar radiation for a significant portion of thermal recharging, attention should be paid to the types of covering of the surface above the horizontal system in the ground. Any coverings that significantly alter the solar radiation impacts on the surface should be avoided.[134]

[132] DOE. "Types of Geothermal Heat Pump Systems." http://www.energysavers.gov/your_home/space_heating_cooling/index.cfm/mytopic=12650. Accessed October 8, 2011.
[133] Lienau, P.; Boyd, T.; Rogers, R. *Ground-Source Heat Pump Case Studies and Utility Programs*. Klamath Falls, OR: Geo-Heat Center, Oregon Institute of Technology; p. 13, April 1995. http://geoheat.oit.edu/pdf/hp1.pdf. Accessed October 8, 2011.
[134] Sanner, B. "Shallow Geothermal Energy." Giessen, Germany: Justus-Liebig University. http://geoheat.oit.edu/bulletin/bull22-2/art4.pdf. Accessed October 8, 2011.

The vertical closed loop system in Figure H-10 is based on a one U-tube per borehole type ground heat exchanger. When land area for the system is limited, this is often the system of choice even though installation costs are higher than with horizontal systems. The operational costs of these systems are usually lower than horizontal systems due to overall higher efficiencies as the heat source and sink have a near-constant year-round temperature. Because of the depth of these systems, the impact of solar radiation is minimal, so there are not typically any restrictions on surface coverings.

Plastic pipes (polyethylene or polypropylene) are installed in the boreholes and back-filled with grout to ensure effective heat transfer. There may be one, two, or three U-tubes per borehole. Due to the cost of drilling boreholes for vertical systems, test boreholes are commonly drilled to assess the thermal conductivity of the soil. This is critical information for system sizing the ground-coupled loop.

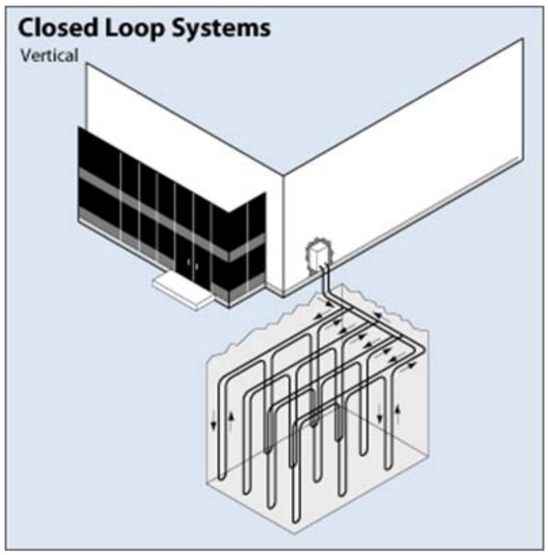

Figure H-10. Vertical bore, closed loop GSHP system[135]

[135] DOE. "Types of Geothermal Heat Pump Systems." http://www.energysavers.gov/your_home/space_heating_cooling/index.cfm/mytopic=12650. Accessed October 8, 2011.

The slinky approach, shown in Figure H-11, can be used on shallow vertical systems, though these are more typically used in residential-size systems with limited borehole-field area.

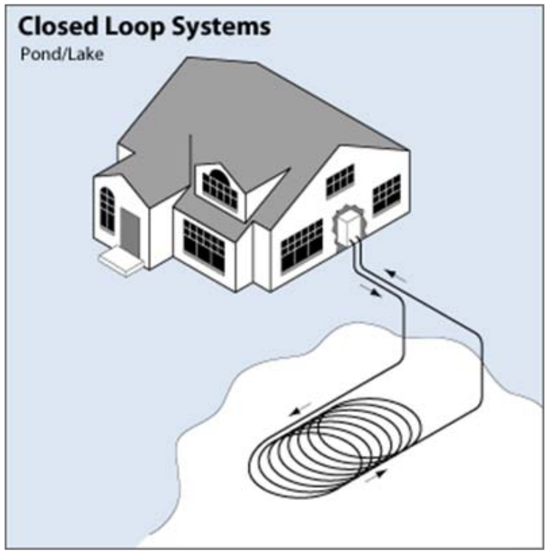

Figure H-11. Closed loop, water-source coil system[136]

A water source closed loop system can be employed in a variety of climates providing the water source has enough depth to provide year-round temperatures above freezing. A typical thermal pattern for lakes in the winter has the coldest water (or ice) near the surface while the water near the bottom is around 39°F (4°C), at which maximum density for water occurs.[137] Propylene glycol is commonly used as the heat exchange medium in these systems as it also an effective anti-freeze.

Open Loop Systems

Given the proximity of the Narragansett Bay, open loop systems deserve a thorough investigation to ascertain if it is possible to use the bay as the heat sink/source for an open loop system. Open loop GHP systems require an open body of water such as a bay, lake, or stream.

The water itself is the heat source or sink. In general, these systems are restricted to warmer climates as the heat pump and heat exchange equipment will not work effectively when water temperatures drop below 45°F (7°C). The exception to this is buildings in cooler climates with year-round cooling needs due to high internal gains.

The characteristics of the water source has a lot of system design implications, so a detailed temperature profile with seasonal variations should be developed or obtained from existing sources (state or federal geological surveys may have appropriate

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[136] DOE. "Types of Geothermal Heat Pump Systems." http://www.energysavers.gov/your_home/space_heating_cooling/index.cfm/mytopic=12650. Accessed October 8, 2011.

[137] *Outside the Loop*. Winter 1999–Volume 2, Number 1. http://geoheat.oit.edu/otl/otl02-01.pdf. Accessed October 8, 2011.

temperature information).[138] Deeper lakes may be thermally stratified so cooler temperature water may be available 30–50 ft (9–15 m) below the surface on a nearly year-round basis. A minimum depth of 10 ft (3 m) is recommended. This depth should be measured at the lowest seasonal level. The maximum recommended capacity is 20 tons/acre (8 tons/hectare) in a cooling-dominated climate and 10 tons/acre (4 tons/hectare) in a heating-dominated climate.[139]

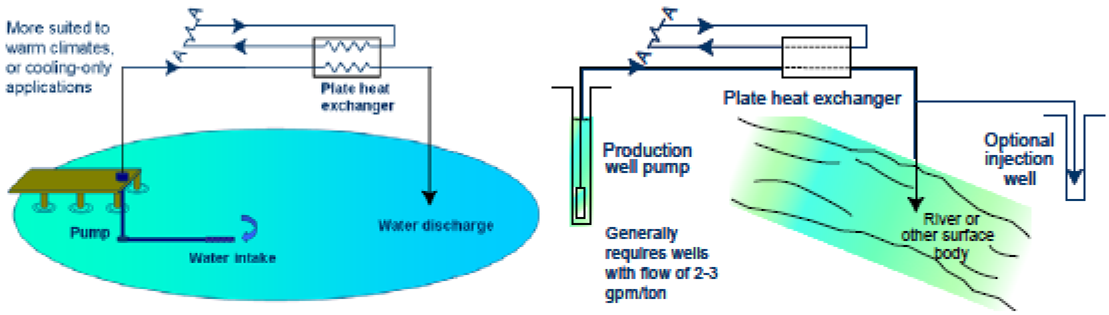

Figure H-12. Open loop lake system at left; open loop system with river or well at right[140]

Two aspects of using a nearby water source should be considered in detail before the design stage. One is the likelihood of obtaining the necessary permits to both use and to discharge water from a surface or underground source. Discharge of water from an open loop system to a surface water body, such as a stream, may require a National Pollutant Discharge Elimination System (NPDES) permit.[141]

The other aspect is in regards to the water quality itself. Hard water or water prone to scaling due to calcium or magnesium salts content will reduce the heat exchanger effectiveness over time.[142] Other water source issues, such as fouling or filtration, can be readily addressed using solutions developed by the power generation and process industries, which have used rivers and lakes extensively over the years.

A type of open loop system used commonly in the Northeast is the standing column system. The systems often have very deep wells (800–1,500 ft range). In these systems, with favorable soil conditions, one or two wells are typically dug with no test bores done ahead of time.[143] These systems operate at temperatures between typical open and closed loop systems. Water quality is a critical issue in these systems and water with low pH and hardness are desirable qualities as they reduce the potential for scaling on the pump or heat exchange equipment. These systems are most often used in areas with hard rock geology under the surface and water flow rates too low for a conventional open loop

[138] *Outside the Loop*. Winter 1999–Volume 2, Number 1. http://geoheat.oit.edu/otl/otl02-01.pdf. Accessed October 8, 2011.
[139] Ibid.
[140] Shonder, J. "Geothermal Heat Pumps." Presented at FEMP's Implementing Renewable Energy Projects Workshop. August 2006.
[141] "Ground Source Heat Pump (GSHP) Systems." Pennsylvania Department of Environmental Protection. http://www.elibrary.dep.state.pa.us/dsweb/Get/Document-80630/3920-FS-DEP2006.pdf. Accessed October 8, 2011.
[142] Raferty, K. "Scaling in Geothermal Heat Pump Systems." *Geo-Heat Center Quarterly Bulletin*, March 2000, pp. 11–15. http://geoheat.oit.edu/bulletin/bull21-1/bull21-1-all.pdf. Accessed October 8, 2011.
[143] Shonder, J. Telephone call. Oak Ridge National Laboratory, Oak Ridge, TN, 8 June 2011.

system.[144] As discussed in *Newport Soil Analysis* section below, the Newport area has both hard rock geology (granite) and water with low pH and hardness. A schematic of the system is shown in Figure H-13.

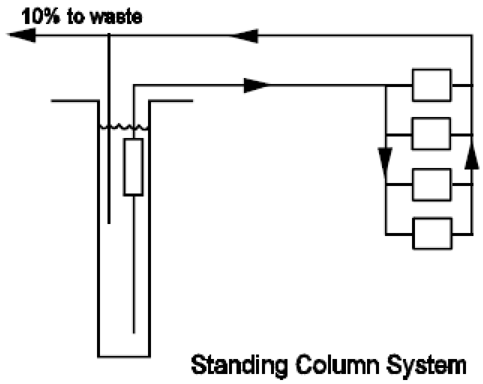

Figure H-13. Standing column open loop GHP system[145]

Another version of a vertical system is an open loop system that involves the use of groundwater in a production well and the return of that groundwater in an injection well. Again, a permit may be needed for discharge into the injection well—check with local authorities.

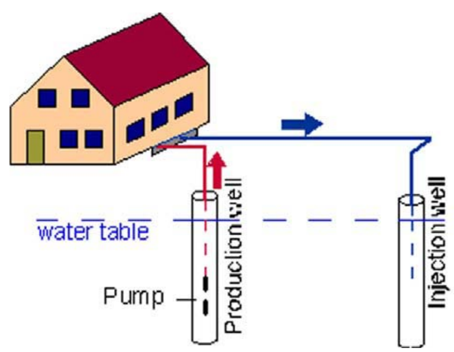

Figure H-14. Vertical open loop water well GHP system[146]

The more cost-effective approach with GSHP systems is to design the system to supply all of the heating and cooling for a building. This is most typically done in new construction applications. In retrofit applications, these systems can be integrated into an existing HVAC system's ducting and delivering system with boilers or chillers from the existing system being used for auxiliary heating/cooling or as a back-up system. When integrated with other HVAC components, the entire system is often termed a hybrid GSHP system. Sometimes the hybrid approach is taken so the GSHP system can avoid

[144] Rafferty, K. "Design Aspects of Commercial Open-Loop Heat Pump Systems." http://geoheat.oit.edu/pdf/tp104.pdf. Accessed October 8, 2011.
[145] Rafferty, K. "Design Aspects of Commercial Open-Loop Heat Pump Systems." http://geoheat.oit.edu/pdf/tp104.pdf. Accessed October 8, 2011.
[146] Sanner, B. "Shallow Geothermal Energy." http://geoheat.oit.edu/bulletin/bull22-2/art4.pdf. Accessed October 8, 2011.

the added cost of being sized for peak loads while operating significantly below peak for most of the year.

Newport Soil Analysis

The Newport soil analysis provided below provides useful background of the range of soil conditions found at the surface and below the surface for much of the state of Rhode Island. The information is akin to the wind maps used in the initial phases of wind resource assessment; they point towards areas that merit more detailed, site-specific investigation.

As indicated in the Five Year Review[147] of McAllister Point, NAVSTA Newport is located at the southeastern end of the Narragansett Basin, which consists on non-marine sedimentary rock of the Pennsylvanian age. The bedrock is primarily of the Rhode Island Formation, and it is overlaid with glacially-derived unconsolidated deposits. According to the study by TtNUS (1999), cited in the Five Year Review, these surficial deposits consist of till, sand, gravel, and silt and range in thickness from 1 to 150 ft. NAVSTA Newport is located on the Narragansett till plain with stratified drift or outwash deposits composed of sorted sand, silt, and gravel overlying the till.

If NAVSTA Newport desires to pursue GSHP technology, a site-specific geotechnical study will be done at several viable sites to determine the thickness of the surface deposits and the depth required to reach bedrock as these two factors will drive both appropriate system design (vertical or horizontal) and economics. Next is a profile of the soils in the area from the Newport Series study. It provides a great general reference, but detailed site-specific information is needed for next steps.

[147] EPA. "Five Year Review Report." http://www.epa.gov/region1/superfund/sites/netc/457973.pdf. Accessed October 8, 2011.

New England Soil Profiles, Newport Series[148]
Newport Soils: Very deep well-drained soils formed in compact glacial till dominated by dark colored (Carboniferous) minerals. Newport soils are on till plains, smooth convex sideslopes of uplands and on drumlins. Newport soils are mapped primarily in the northern portion of the county.

Newport Pedon Description 2332501

Map Unit (s): 325B, 325C, 325E, 326B, 326C, 326E

Map Phases:

325B Newport fine sandy loam, 3 to 8 percent slopes.

325C Newport fine sandy loam, 8 to 15 percent slopes.

325E Newport fine sandy loam, 15 to 35 percent slopes.

326B Newport fine sandy loam, 3 to 8 percent slopes, very stony.

326C Newport fine sandy loam, 8 to 15 percent slopes, very stony.

326E Newport fine sandy loam, 15 to 35 percent slopes, very stony.

Taxonomic Classification: Coarse - loamy, mixed, mesic, Oxyaquic Haplorthods.

Drainage Class: Well drained.

Parent Material: Dense glacial till derived from dark colored sedimentary rocks.

Permeability: Moderate in the solum, slow or very slow in the dense substratum.

Available Water Holding Capacity: Moderate.

Soil Reaction: Very strongly acid to moderately acid throughout. .

Depth to Bedrock: Greater than 65 inches.

Seasonal High Watertable: Depth: 2.5 to 4 feet.

Type: Perched

Months: January to May.

Hydrologic Group: C.

Hydric Soil: No.

Flooding/Ponding Potential: Frequency and Type: None.

Potential Inclusions: Paxton and Montauk soils are similar inclusions. Moderately well drained Pittstown, Scituate, and Woodbridge soils are on concave and level slopes. Poorly drained Norwell, and Ridgebury soils are along drainageways. Also included are soil which have bedrock within 65 inches.

Soil Suitability:

Agriculture: Map unit 325B is a prime farmland soil. Map units 325C, 326C and 326B are important farmland soils

Woodland: Well suited for woodland

[148] NEsoil.com. New England Soil Profiles, Newport Series. http://nesoil.com/muds/newport.htm. Accessed October 8, 2011.

Development: Major limitations related to slow permeability in the dense till substratum. Large surface and subsurface stones and boulders may interfere with excavation. Erosion hazards are likely during development, measures should be taken to prevent erosion.

NEWPORT SERIES[149]

The Newport series consists of well drained loamy soils formed in lodgement till derived mainly from dark sandstone, conglomerate, argillite, and phyllite. The soils are very deep to bedrock and moderately deep to a densic contact. They are nearly level through moderately steep soils on till plains, low ridges, hills and drumlins. Slope ranges from 0 through 35 percent. Saturated hydraulic conductivity is moderately high or high in the surface layer and subsoil and low or moderately high in the dense substratum. Mean annual temperature is 49 degrees F. (9 degrees C.) and mean annual precipitation is 48 inches (1219 mm).

TAXONOMIC CLASS: Coarse-loamy, mixed, superactive, mesic Oxyaquic Dystrudepts

TYPICAL PEDON: Newport silt loam - cultivated field. (Colors are for moist soil unless otherwise noted.)

Ap-- 0 to 8 inches (0 to 20 centimeters); very dark brown (10YR 2/2) silt loam, light brownish gray (10YR 6/2) dry; weak medium granular structure; very friable; many fine and medium roots; 5 percent channers and gravel; strongly acid; clear smooth boundary. (6 to 10 inches (15 to 25 centimeters) thick.)

Bw-- 8 to 18 inches (20 to 46 centimeters); olive brown (2.5Y 4/4) channery silt loam; weak medium subangular blocky structure; friable; common fine and medium roots; 15 percent channers and gravel; strongly acid; clear wavy boundary.

Bw-- 18 to 24 inches (46 to 61 centimeters); olive (5Y 4/3) channery silt loam; weak medium and coarse subangular blocky structure; friable; few roots; 15 percent channers and gravel; strongly acid; clear wavy boundary. (Combined thickness of the Bw horizon is 14 to 37 inches (36 to 94 centimeters).)

Cd-- 24 to 65 inches (61 to 165 centimeters); olive gray (5Y 4/2) channery loam; few dark yellowish brown (10YR 3/4) pockets in the upper 6 inches; weak thick platy structure; very firm, brittle; few silt films on rock fragments; 25 percent channers and gravel; strongly acid.

TYPE LOCATION: Newport County, Rhode Island; town of Middletown, 690 feet north of the junction of Green End Avenue and Indian Avenue, and 160 west of Indian Avenue. USGS Westport, RI topographic quadrangle; Latitude 41 degrees, 30 minutes, 33.9 seconds N. and Longitude 71 degrees, 14 minutes, 25.9 seconds W. NAD 1927.

RANGE IN CHARACTERISTICS: Thickness of the solum ranges from 20 through 40 inches (50 through 100 centimeters) and typically corresponds to the depth to the dense substratum. Depth to bedrock is commonly more than 6 feet feet (2 meters). Rock fragments range from 5 through 30 percent by volume in the solum and from 10 through 35 percent in the substratum. Except where the

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149 New England Soil Profiles from NEsoil.com. "Newport Series." Established Series, Rev. RAS-EHS-DAS, March 2010. https://soilseries.sc.egov.usda.gov/OSD_Docs/N/NEWPORT.html. Accessed October 8, 2011.

surface is stony, the fragments are mostly flat and less than 6 inches in diameter. Channers and gravel typically make up 75 percent or more of the total rock fragments. Unless limed, reaction ranges from very strongly acid through slightly acid. Low chroma colors in the B and C horizons are lithochromic.

Some pedons have an O horizon.

The Ap horizon has hue of 7.5YR through 5Y, value of 2 through 4, and chroma of 1 through 3. Dry value is 6 or more. Undisturbed pedons have a thin A horizon with value of 2 or 3 and chroma of 1 or 2. The Ap or A horizon is silt loam, very fine sandy loam, loam, or fine sandy loam in the fine-earth fraction. It has weak or moderate granular structure and is friable or very friable.

The Bw horizon has hue of 2.5Y or 5Y, value of 2 through 5, and chroma of 1 through 4. Some pedons have redoximorphic features just above the Cd horizon. The Bw horizon is silt loam, very fine sandy loam, loam, or fine sandy loam in the fine-earth fraction. It has weak subangular blocky or granular structure, or the horizon is massive. Consistence is friable or very friable.

The Cd horizon has hue of 2.5Y or 5Y, value of 2 through 5, and chroma of 1 through 4. It is silt loam, very fine sandy loam, loam, or fine sandy loam in the fine-earth fraction. The horizon has weak or moderate, thin through thick plates, or it is massive. Consistence is firm or very firm.

COMPETING SERIES: These are the Halfbluff(T) and Maggodee series. Both of these are from outside Region R. Halfbluff(T) does not have an OSD on file to compete. Maggodee soils are formed in alluvium on floodplains.

GEOGRAPHIC SETTING: Newport soils are nearly level through moderately steep and are on till plains, low ridges, hills and drumlins. Slope ranges from 0 through 35 percent. The soils formed in acid lodgement till derived mainly from dark carboniferous, sandstone, conglomerate, argillite, and phyllite. Mean annual temperature ranges from 45 through 52 degrees F. (7 through 11 degrees C.), mean annual precipitation ranges from 40 through 50 inches (1016 through 1270 mm), and the growing season ranges from 135 through 185 days.

Appendix I. Landfill Gas

As waste in a landfill decomposes, it breaks down to form LFGs, such as methane, carbon dioxide, smog-causing volatile organic compounds (VOCs), and air toxics. Landfills are the third-largest anthropogenic source of methane emissions in the United States.[150] Methane is a potent GHG that contributes to global warming. Methane is 20 times more potent by weight than carbon dioxide. [151]

Natural gas is a non-toxic, non-corrosive, and non-carcinogenic mixture of hydrocarbons, with methane being the largest component (approximately 83%–99%).[152] LFG has a much lower concentration of methane, approximately 50%, with carbon dioxide comprising almost all of the remaining 50%. There is a small concentration (< 1%) of other non-methane organic compounds.[153]

Landfill Emissions

Burning natural gas for energy results in lower overall emissions per unit of heat than coal or other fossil fuels (refined fuel oils). The average emissions rates in the United States from natural-gas-fired generation are: 1,135 lbs/MWh of carbon dioxide, 0.1 lbs/MWh of sulfur dioxide, and 1.7 lbs/MWh of nitrogen oxides. Compared to the average air emissions from coal-fired generation, natural gas produces half as much carbon dioxide, less than a third as much nitrogen oxides, and 1% as much sulfur oxides at the power plant. In addition, the process of extraction, treatment, and transport of the natural gas to the power plant generates additional emissions.[154]

Characteristics of Landfills

Modern landfills are designed to extract the gas created from waste decomposition and collect it. The captured gas may either be flared (to reduce methane migration into the atmosphere), combusted to provide heat or generate electricity. A cutaway schematic of a landfill, its collection system and flare/generator system is shown in Figure I-1.

[150] EPA. "Landfill Methane Outreach Program." http://www.epa.gov/lmop/basic-info/index.html. Accessed October 8, 2011.
[151] EPA. "An Overview of Landfill Gas Energy in the United States." http://www.epa.gov/lmop/documents/pdfs/overview.pdf. Accessed October 8, 2011.
[152] DOE. "Fuel Properties." http://www.afdc.energy.gov/afdc/fuels/properties.html. Accessed October 8, 2011.
[153] EPA. "An Overview of Landfill Gas Energy in the United States." http://www.epa.gov/lmop/documents/pdfs/overview.pdf. Accessed October 8, 2011.
[154] EPA. "Natural Gas." http://www.epa.gov/cleanenergy/energy-and-you/affect/natural-gas.html. Accessed October 8, 2011.

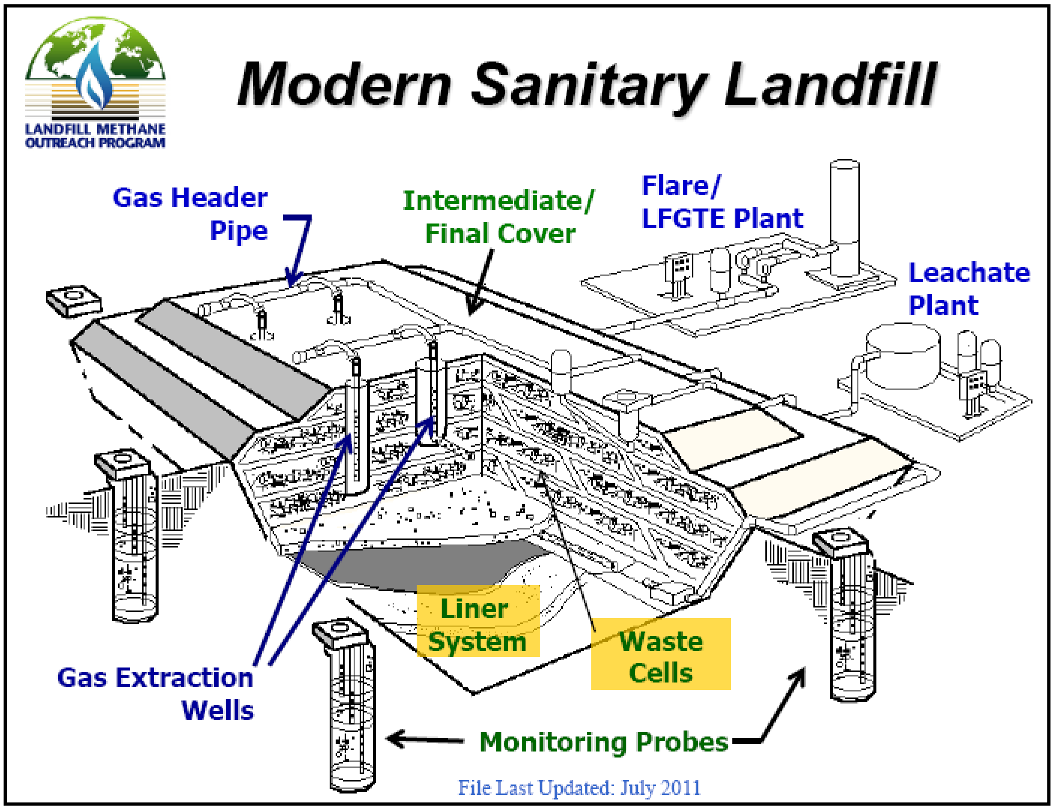

Figure I-1 Landfill collection system schematic[155]

Characteristics of Landfill Gas Power Plants

LFG power plants, by burning the LFG, help to control LFG emissions from the landfill that would otherwise be released into the atmosphere and contribute to smog and global warming. For every 1 million tons of MSW in a landfill, approximately 432,000 ft^3/day of LFG are created, which can be burned to generate 780 kW of electricity.[156]

LPG is recognized as renewable energy resource by EPA's Green Power Partnership, the National Resources Defense Council and 36 states. There are at least 555 operational LFG power plants operating in 46 states around the country. Combined these utilize 102 billion ft^3/yr of LFG and generate 14 billion kWh/yr of electricity.[157]

It is estimated that LFG currently provides power to 1 million homes and heating to 737,500 homes.[158]

155 EPA. "An Overview of Landfill Gas Energy in the United States." http://www.epa.gov/lmop/documents/pdfs/overview.pdf. Accessed October 8, 2011.
156 EPA. "An Overview of Landfill Gas Energy in the United States." http://www.epa.gov/lmop/documents/pdfs/overview.pdf. Accessed October 8, 2011.
157 Ibid.
158 EPA. "An Overview of Landfill Gas Energy in the United States." http://www.epa.gov/lmop/documents/pdfs/overview.pdf. Accessed October 8, 2011.

Table I-1. Waste Energy Consumption[159]

Landfill Gas

Data For: 2006
Release Date: April 2008
Next Release Date: April 2009

Table 1.7 Waste Energy Consumption by Type of Waste and Energy Use Sector, 2006
(Trillion Btu)

Type	Sector				
	Commercial	Industrial	Electric Power		Total
			Electric Utilities	Independent Power Producers	
Total	**36**	**140**	**15**	**216**	**407**
Landfill Gas	4	74	8	64	150
MSW Biogenic[a]	26	6	4	135	171
Other Biomass[b]	7	61	3	16	86

[a] Includes paper and paper board, wood, food, leather, textiles and yard trimmings.
[b] Agriculture byproducts/crops, sludge waste, and other biomass solids, liquids and gases.
MSW = Municipal Solid Waste
Note: Totals may not equal sum of components due to independent rounding.
Sources: Energy Information Administration, Form EIA-906, "Power Plant Report," Form EIA-920, "Combined Heat and Power Plant Report," and Government Advisory Associates, Resource Recovery Yearbook and Methane Recovery Yearbook; U.S. Environmental Protection Agency, Landfill Methane Outreach Program estimates; and analysis conducted by the Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels.

[159] DOE EIA. "Landfill Gas." http://www.eia.doe.gov/cneaf/solar.renewables/page/landfillgas/landfillgas.html. Accessed October 8, 2011.

Table I-2 provides a comparison of emissions from a variety of sources.

Table I-2. Emissions from Combustion Generation[160]

Table 1. Summary of Carbon Dioxide Emissions and Net Generation in the United States, 1998 and 1999				
	1998	**1999**[p]	**Change**	**Percent Change**
Carbon Dioxide (thousand metric tons)[a]				
Coal	1,799,762	1,787,910	-11,852	-0.66
Petroleum	110,244	106,294	-3,950	-3.58
Gas	291,236	337,004	45,768	15.72
Other Fuels [b]	13,596	13,596	-	-
U.S. Total	**2,214,837**	**2,244,804**	**29,967**	**1.35**
Generation (million kWh)				
Coal	1,873,908	1,881,571	7,663	0.41
Petroleum	126,900	119,025	-7,875	-6.21
Gas	488,712	562,433	73,721	15.08
Other Fuels [b]	21,747	21,749	2	-
Total Fossil-fueled	**2,511,267**	**2,584,779**	**73,512**	**2.93**
Nonfossil-fueled [c]	**1,105,947**	**1,106,294**	**347**	**0.03**
U.S. Total	**3,617,214**	**3,691,073**	**73,509**	**2.04**
Output Rate [d] (pounds CO_2 per kWh)				
Coal	2.117	2.095	-0.022	-1.04
Petroleum	1.915	1.969	0.054	2.82
Gas	1.314	1.321	0.007	0.53
Other Fuels [b]	1.378	1.378	-	-
U.S. Average	**1.350**	**1.341**	**-0.009**	**-0.67**

[a] One metric ton equals one short ton divided by 1.1023. To convert carbon dioxide to carbon units, divide by 44/12.

[b] Other fuels include municipal solid waste, tires, and other fuels that emit anthropogenic CO_2 when burned to generate electricity. Nonutility data for 1999 for these fuels are unavailable; 1998 data are used.

[c] Nonfossil includes nuclear, hydroelectric, solar, wind, geothermal, biomass, and other fuels or energy sources with zero or net zero CO_2 emissions. Although geothermal contributes a small amount of CO_2 emissions, in this report it is included in nonfossil.

[d]U.S. average output rate is based on generation from all energy sources.

[P]= Preliminary data.

- = No change.

Note: Data for 1999 are preliminary. Data for 1998 are final.

Sources: •Energy Information Administration, Form EIA-759, "Monthly Power Plant Report"; Form EIA-767,"Steam-Electric Plant Operation and Design Report"; Form EIA-860B, "Annual Electric Generator Report - Nonutility"; and Form 900, "Monthly Nonutility Power Report." •Federal Energy Regulatory Commission, FERC Form 423, "Monthly Report of Cost and Quality of Fuels for Electric Plants."

[160] DOE. "Carbon Dioxide Emissions from the Generation of Electric Power in the United States." EPA, July 2000. http://www.eia.gov/cneaf/electricity/page/co2_report/co2report.html. Accessed Oct 28, 2011.

Appendix J. NAVSTA Newport Electric Load Data FY 2010

Table J-1. NAVSTA Newport Utility Data[161]

nationalgrid

Summary Statistics

Description: **5040435000 US NAVY**

Total Energy Usage (kWh)	104,812,180
Total Weekday Energy Usage (kWh)	78,063,953
Total Weekend Energy Usage (kWh)	26,748,227
Weekday Maximum Demand (kW)	20,480
Weekend Maximum Demand (kW)	15,404
Power Factor at Time of Maximum Demand	95.79%
Load Factor	58.42%
Number of Missing Datapoints	100.0
Date / Time of First Missing Datapoint	01/12/2010 00:15
Date / Time of Last Missing Datapoint	03/14/2010 03:00
Total Energy (kWh)	104,812,180
Maximum Demand (kW)	20,480
Maximum Demand Time	08/10/2010 13:45

Selected Date Range Thursday, October 01, 2009 Through Thursday, September 30, 2010

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[161] Reichert, J. Email. National Grid Summary Statistics for NAVSTA Newport, Newport, RI, 4 May 2010.

Contacts

Project Leader
Gail Mosey
National Renewable Energy Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393
Phone: (303) 384-7356
Fax: (303) 384-7411
Email: gail.mosey@nrel.gov

Principal Investigator
Robi Robichaud
National Renewable Energy Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393
Phone: (303) 384-6969
Fax: (303) 384-7411
Email: robi.robichaud@nrel.gov

EPA Program Manager
Lura Matthews
U.S. Environmental Protection Agency
Office of Solid Waste and Emergency Response
Center for Program Analysis
Ariel Rios Building
1200 Pennsylvania Avenue, N.W.
Washington, DC 20460
Phone: (202) 566-2539
Email: matthews.lura@epa.gov

EPA Regional Manager
Ginny Lombardo
Remedial Project Manager
U.S. EPA Region I
Federal Facilities Superfund Section
5 Post Office Square
Suite 100 (OSRR 07-3)
Boston, MA 02109-3912
Phone: (617) 918-1754
Fax: (617) 918-0754
Email: lombardo.ginny@epa.gov