Renewable Energy Technologies Potential For the District of Columbia

District Department of the Environment

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1 EXECUTIVE SUMMARY

1.1 BACKGROUND

This study follows up on the renewable energy technical potential study done by the National Renewable Energy Laboratory (NREL) in July 2012 for the fifty states in the US and the District of Columbia. A main objective of this new District Department of the Environment (DDOE) study was (1) to conduct additional research to determine if more recent or more accurate data on renewable energy technologies was available for calculating updated estimates of renewable energy potential in the District and (2) to provide updated estimates of renewable energy potential for the District. Another major objective of this study was to provide detailed information on the cost per unit of energy produced for the renewable energy technologies presented in the July 2012 NREL report. While the July 2012 NREL report did provide estimates of renewable energy potential in the District of Columbia for several technologies, the NREL study did not provide any cost information for the renewable energy technologies examined in that report. The District Department of the Environment approved the scope of work for this study in May 2013 and the study was completed by the consultants (GDS Associates, Inc.) from May to September of 2013.

1.2 SUMMARY OF STUDY METHODOLOGY

The consultants collected up-to-date data on the costs, performance and applicability in the District for each renewable energy technology examined in the July 2012 NREL report. The consultants then updated NREL's estimates of renewable energy potential for the District and these revised estimates are presented in this report. At the request of DDOE, the consultants added to this study an assessment of the costs and renewable energy potential for solar water heating and geothermal heat pumps.

1.3 DATA SOURCES USED FOR THIS STUDY

The consultants obtained data for this study for the District from numerous data sources, including Federal government laboratories, the US Department of Energy, the District Department of the Environment, the July 2013 consultants' energy efficiency potential study for the District and recent studies performed by other organizations on renewable energy technologies. Listed below are the main data sources used by the consultants to complete this study of renewable energy potential in the District.

1) National Renewable Energy Laboratory (NREL)
2) Idaho National Laboratory (INL)
3) Lawrence Berkeley National Laboratory (LBNL)
4) Sun Number
5) District Department of the Environment (DDOE)
6) The U.S. Department of Energy, Energy Information Administration (EIA)
7) Lazard Levelized Cost of Energy Analysis
8) Energy Ventures International
9) American Council for an Energy Efficient Economy
10) In-depth interviews with renewable energy experts in the District

1.4 OVERVIEW OF KEY FINDINGS

1) There is considerable renewable energy potential in the District. The updated estimates of renewable energy potential for the District are presented in Section 4 of this report.

2) The technology with the most technical potential in the District is rooftop solar photovoltaics (PV).
3) Costs for renewable energy technologies range from $0.057/kWh for hydropower to $0.494/kWh for solar rooftop PV (under 6 kW).
4) More research is needed to determine renewable energy potential for the District for offshore wind, utility-scale solar photovoltaic systems and geothermal heat pumps. The applicable offshore wind resource is located off the coasts of Maryland and Delaware.
5) Table 1-1 on the next page provides the consultants' and NREL's estimates for renewable energy potential in the District.

TABLE 1-1: Technical Potential for Renewable Energy Technologies in the District of Columbia (Generation Potential)

	GDS- Megawatt Hour (MWh)	NREL- Megawatt Hour (MWh)	GDS- Megawatt (MW)	NREL- Megawatt (MW)
Rooftop Photovoltaics	1,488,767	2,490,000	1,196	2,000
Urban Utility Scale Photovoltaics	8,000	8,000	<1,000	<1,000
Onshore Wind	0	0	0	0
Offshore Wind	NA	NA	NA	NA
Geothermal (Deep Earth)	698,000	698,000	<1,000	<1,000
Geothermal Heat Pump	30	NA	<1,000	NA
Hydro	547.5	<1,000	0.125	<1,000
Biomass	84,649	66,000	11.5	<1,000
Total Solar Water Heating; Generation Potential	**2,279,994**	**3,262,000**	**1,207**	**2,000**
Energy Efficiency Technical Potential for Solar Water Heating in the District of Columbia (Energy Savings)				
Solar Water Heating - Residential (Electric back-up)	9,788	Not available	3.9	Not available
Solar Water Heating - Residential (Natural Gas back-up; MMBtu savings)	216,714	Not available	0.0	Not available
Solar Water Heating - Commercial - (Electric back -up)	39,413	Not available	8.0	Not available
Solar Water Heating - Commercial - (Natural Gas back-up)	64,384	Not available	0.0	Not available
Total Solar Water Heating; Savings Potential	**330,299**	**Not available**	**11.9**	**Not available**

1.5 COSTS OF RENEWABLE ENERGY TECHNOLOGIES

The consultants collected information in order to be able to provide accurate estimates of the levelized cost per unit of energy produced for the renewable energy technologies examined in this study. To develop the estimates of the levelized cost for each technology, many factors were taken into account. Factors that varied by technology include:

- Overnight capital cost
- Capital Cost Year
- Construction Period
- In Service Year
- Rate Base Book Life
- Fixed O&M Rate ($/kW-Yr)
- Variable O&M Rate ($/MWh)
- Heat Rate (MMBtu/MWh)
- Fuel
- Capacity Factor

Control factors include:

- Construction Escalation
- Return on Rate Base
- Equity Portion of Return
- LTD
- Federal Income Tax Rate
- District Income Tax Rate
- Composite Tax Rate
- Discount Rate
- Operating Cost Year
- Operating Cost Escalation

The levelized cost for each renewable energy technology was calculated in a detailed Excel spreadsheet that uses all of these factors as inputs. The levelized cost per unit of energy was also calculated for three non-renewable electric generation technologies so that the reader of this report could compare the costs of renewable energy technologies to conventional electric generation technologies.

ROOFTOP SOLAR PHOTOVOLTAIC COSTS

For rooftop solar PV, the capacity factor used came from NREL and is specific to the District's region. The overnight capital cost ($/kW) was calculated from actual data for the District reported by NREL. The rate base book life and O&M fixed cost ($/Yr/kW) came from an average of EIA and Lazard figures. Rooftop solar PV was broken down into two categories: smaller than 6 kW and larger than 6 kW. The reason for the breakout of costs for small and large systems is that smaller systems generally cost more per kW to purchase and install than larger systems. There are economies of scale with larger systems.

UTILITY SCALE PHOTOVOLTAIC COSTS

For utility scale PV, the capacity factor used came from NREL and is specific to the District's region. Overnight capital cost ($/kW) was averaged from EIA and Lazard figures multiplied by the NREL Mid-Atlantic cost multiplier. The rate base book life and O&M fixed cost ($/Yr/kW) came from an average of EIA and Lazard figures.

SOLAR WATER HEATING COSTS

The average installed cost of a residential solar water heating system in the District is $8,162 and was obtained from the Pennsylvania Incremental Cost Database v1. The average installed cost of a solar water heating system in a commercial establishment is $26,400. This data can be found in the GN Energy Efficiency Report with Appendices, on page 2, after page 1 Appendix B-2.

The current District Department of the Environment incentives for solar thermal residential systems are 20% of the installed cost up to a maximum of $2,000. The current DDOE incentives for solar thermal non-residential systems are 20% of installed cost up to a maximum of $6,000. Solar water heating systems qualify for these incentives.

OFFSHORE WIND COSTS

For offshore wind, the capacity factor used came from NREL and is specific to the District's region. Overnight capital cost ($/kW) was averaged from EIA and Lazard figures multiplied by the NREL Mid-Atlantic cost multiplier. The rate base book life, O&M fixed and variable costs come from the average of the EIA and Lazard figures.

ONSHORE WIND COSTS

For onshore wind, the capacity factor used came from NREL and is specific to the District's region. The overnight capital cost is the national average for 2012 from the NREL Report (figure 20). The rate base book life, O&M fixed and variable costs come from the average of the EIA and Lazard figures.

BIOMASS COSTS

For biomass, the capacity factor used came from NREL and is specific to the District's region. The overnight capital cost, heat rate, rate base book life, and O&M fixed cost are the averages of the EIA and Lazard figures. For O&M variable cost, the Lazard figure was used as it produces a total variable cost along with the implied fuel cost that is $5/MWh less than the EIA study, which is a representative of a higher fuel and transportation cost.

GEOTHERMAL POWER (DEEP EARTH) COSTS

For geothermal power, the capacity factor used came from NREL and is specific to the District's region. The overnight capital cost is the midpoint of the Lazard study. The EIA study was not used for this because it refers to the least expensive option in the northwest. The rate base book life was taken from the average of the EIA and Lazard figures. The O&M variable cost is the average of the EIA and Lazard figures. $65 was chosen for the O&M fixed cost so that when it is added to the variable O&M cost of $35, it will equal $111, which is equal to the EIA sum of Fixed and Variable O&M.

GEOTHERMAL HEAT PUMP COSTS

The average installed cost of a residential geothermal heat pump system in the District is $4,361 with a $212 savings per year. This estimate for residential heat pump savings were estimated based on a heat pump feasibility study report completed for the U.S. Department of Veterans Affairs Medical Center in Richmond, Virginia in which eQuest building energy simulation modeling was used to determine energy savings. Cost information was based on vendor estimates of equipment costs and RSMeans cost estimates for borehole drilling and finishing and piping. Savings and costs were scaled to an assumed 2.5-ton residential central air conditioner with gas furnace for sizing baseline efficiency purposes.

The average installed cost of a geothermal heat pump system in a commercial establishment is $52,332 with a savings of $2,544 per year. Commercial heat pump savings were estimated based on a heat pump feasibility study report completed for the U.S. Department of Veterans Affairs Medical Center in Richmond, Virginia in which eQuest building energy simulation modeling was used to determine savings. Cost information was based on vendor estimates of equipment costs and RSMeans cost estimates for borehole drilling and finishing and piping. Savings and costs were scaled to an assumed commercial building size of 40,000 square feet, and the existing heating and cooling system was assumed to be a 30-ton rooftop unit for sizing and baseline efficiency purposes.

HYDRO POWER COSTS

For hydropower, the capacity factor used came from NREL and is specific to the District's region. The EIA figure was used for the overnight capital cost. The rate base book life came from the EIA figure, though a much longer useful life is applicable. O&M fixed and variable costs are equal to the EIA figure.

Table 1-1 below presents a summary of the levelized cost per kWh for each of the renewable energy technologies examined in this study.

Table 1-1: Levelized Costs of Renewable Technologies (Page 1 of 2)

DC RENEWABLE INPUT VARIABLES	SOURCE / INPUT	Year Dollars	Solar PV Rooftop <6	Solar PV Rooftop >6	Solar PV Utility	Wind	Wind Offshore	Hydro[5]
DC Model - Levelized $/MWh	**Model**	2013	**$494**	**$454**	**$167**	**$91**	**$139**	**$57**
Lazard Study - Levelized $/MWh	Lazard[1]	2012	**$149 - 204**	**$149 - 204**	**$101 - 149**	**$48 - 95**	**$110 - 199**	**-**
EIA Study - Levelized $/MWh	EIA[2]	2011	**-**	**-**	**$112 - 224**	**$74 - 100**	**$183 - 295**	**$58 - 149**
Capacity Factor	**Model**	2013	**14%**	**14%**	**18%**	**26%**	**46%**	**50%**
	Lazard[1]	2015[7]	20 - 23%	20 - 23%	20 - 27%	30 - 48%	37 - 43%	-
	EIA[2,8]	2011	-	-	22 -32%	30 - 39%	33 - 34%	30 - 65%
	NREL (DC or DE)[3]	2013	13.5%	13.5%	17.9%	26.1%	46.0%	50.0%
Mid-Atlantic Cost Multiplier	EIA[4]	-	n/a	n/a	0.84	n/a	0.92	-
Overnight Capital Cost $/kW	**Model**	2013	**$5,801**	**$5,321**	**$2,596**	**$1,750**	**$4,679**	**$2,400**
	Lazard[1]	2012	$3,000 - 3,500	$3,000 - 3,500	$2,000 - 2,750	$1,500 - 2,000	$4,050	-
	EIA[2]	2011	-	-	$3,805	$2,175	$6,121	$2,397
	Other		-	-	$1,500 - 1,750	$1,750		$1,200 - 3,600
Heat Rate Btu/kWh	**Model**	-	**-**	**-**	**-**	**-**	**-**	**-**
	Lazard[1]	2012	-	-	-	-	-	-
	EIA[2]	2012	-	-	-	-	-	-
Rate Base Book Life	**Model**	-	**20**	**20**	**25**	**25**	**25**	**30**
	Lazard[1]	-	20	20	20	20	20	-
	EIA[2]	-	-	-	30	30	30	30
O&M Fixed ($/Yr/kW)	**Model**	2013	**$17**	**$17**	**$20**	**$34**	**$77**	**$15**
	Lazard[1]	2012	$13 - 20	$13 - 20	$13 - 25	$30	$60 - 100	-
	EIA[2]	2011	-	-	$21	$39	$73	$15
O&M Variable ($/MWh)	**Model - O&M**	2013	**$0**	**$0**	**$0**	**$4**	**$8**	**$6**
	Model - Fuel	2013	**-**	**-**	**-**	**-**	**-**	**-**
	Lazard[1] - O&M	2012	$0	$0	$0	$6 - 10	$13 - 18	-
	Lazard - Fuel ($/MMBtu)	2012	$0	$0	$0	$0	$0	-
	EIA[2] - O&M & Fuel	2011	-	-	$0	$0	$0	$6

Table 1-1: Costs of Renewable Technologies (Page 2 of 2)

DC RENEWABLE INPUT VARIABLES	SOURCE / INPUT	Year Dollars	Geo Thermal[5]	Solar Thermal[6]	Biomass	Coal[9]	Nuclear	Gas[10]
DC Model - Levelized $/MWh	Model	2013	$114	$324	$100	$110	$94	$69
Lazard Study - Levelized $/MWh	Lazard[1]	2012	$89 - 142	$131 - 216	$87 - 116	$62 - 141	$77 - 114	$61 - 89
EIA Study - Levelized $/MWh	EIA[2]	2011	$81 - 100	$190 - 418	$98 - 130.8	$112 - 138	$104 - 115	$60 - 78
Capacity Factor	Model	2013	90%	19%	90%	89%	90%	79%
	Lazard[1]	2015[7]	80 - 90%	30 - 50%	85%	93%	90%	40 - 70%
	EIA[2,8]	2011	92%	11 - 26%	83%	85%	90%	87%
	NREL (DC or DE)[3]	2013	90.0%	-	90%	-	-	-
Mid-Atlantic Cost Multiplier	EIA[4]	-	-	-	0.91	0.91	0.95	0.88 - 0.89
Overnight Capital Cost $/kW	Model	2013	$5,925	$5,715	$3,431	$4,931	$6,800	$1,058
	Lazard[1]	2012	$4,600-7,250	$5,600 - 7,300	$3,000 - 4,000	$3,000 - 8,400	$5,385 - 8,199	$1,006 - 1,318
	EIA[2]	2011	$2,567	$4,979	$4,041	$5,138	$5,429	$901 - 1,006
	Other						$6,800	
Heat Rate Btu/kWh	Model	-	-	-	14,000	11,188	10,451	6,875
	Lazard[1]	2012	-	-	14,500	8,750 - 12,000	10,450	6,800 - 7,220
	EIA[2]	2012	-	-	13,500	12,000	10,452	6,430 - 7,050
Rate Base Book Life	Model	-	25	35	25	35	40	25
	Lazard[1]	-	20	40	20	40	40	20
	EIA[2]	-	30	30	30	30	30	30
O&M Fixed ($/Yr/kW)	Model	2013	$65	$66	$99	$46	$52	$10
	Lazard[1]	2012	$0	$50 - 80	$95	*$20 - 32*	*$13*	*$5 - 6*
	EIA[2]	2011	$111	$66	$104	*$65*	*$92*	*$13 - 15*
O&M Variable ($/MWh)	Model - O&M	2013	$35	$2	$15	$3	*$4*	$3
	Model - Fuel	2013	-	-	Biomass	Coal	Nuclear	Gas
	Lazard[1] - O&M	2012	$30 - 40	$3	$15	$3 - 6	$0	$2 - 3.5
	Lazard - Fuel ($/MMBtu)	2012	$0	$0	$1 - 2	$1.7	$0.5	$4.5
	EIA[2] - O&M & Fuel	2011	$0	$0	$42	$31	$12	$45 - 48

Sources:

(1) Lazard - Lazard Ltd. (2012). Levelized Cost of Energy Analysis - Version 6.0. New York, NY: Lazard Ltd. [Full-text at http://j.mp/Lazard_LCOE_ver6] "Lazard has not manipulated capital costs or capital structure for various technologies, as the goal of the study was to compare the current state of various generation technologies, rather than the benefits of financial engineering."

(2) EIA - Refers to - U.S. Energy Information Administration - Levelized Cost of New Generation Resources in the Annual Energy Outlook 2013 - January 2013

(3) NREL Capacity factors: Used the District for Solar PV, Hydro, Geothermal, Biomass (solid); Used DE for Wind Power; Calculated by: GWh/(GW*8760)

(4) EIA - Regional Cost Multipliers - Capital Cost Assumptions Update (Region 16)

(5) "The EIA table entries represent the cost of the least expensive plant that could be built in the NW power pool region where most proposed sites are located.

(6) The Lazard Study refers to a "Solar Thermal Tower" which is a utility-scale project. EIA is unclear about type of Solar Thermal Technology which could be or include small scale roof-top installations.

(7) Levelized cost of Energy in 2015" is referenced in Lazard Study, therefore we interpret their report and assumptions to be in future (2015) dollars.

(8) "The levelized cost for each technology is evaluated based on the capacity factor indicated, which generally corresponds to the high end of its likely utilization range."

(9) EIA - "Pulverized Coal with carbon sequestration", Lazard - "Advanced supercritical pulverized coal. High end incorporates 90% carbon capture and compression."

(10) EIA - "Adv Gas/Oil Cob Cycle (CC)", Lazard - "Gas Combined Cycle"

2 INTRODUCTION

2.1 OBJECTIVES OF THIS STUDY

This study follows up on the renewable energy technical potential study done for the District by NREL in July 2012. A main objective of this study was to conduct additional research to determine if more recent or more accurate data on renewable energy technologies was available for calculating renewable energy potential in the District. Another major objective of this study was to provide detailed information on the cost per unit of energy produced for the renewable energy technologies presented in the July 2012 NREL report.

2.2 HISTORY OF PAST RENEWABLE ENERGY POTENTIAL STUDIES FOR THE DISTRICT

During the past five years the District Department of the Environment has conducted renewable energy potential studies for on-shore and off-shore wind

2.3 ASSISTANCE PROVIDED BY NREL, IDAHO NATIONAL LAB AND DDOE STAFF

NREL provided technical assistance to the consultants throughout the development of this renewable potential study for the District. NREL provided the consultants with some of the original equations used in their July 2012 technical report. NREL was very helpful in showing the consultants where they obtained most of their information. After renewable energy potential calculations were completed by the consultants, NREL reviewed these equations and provided comments. NREL staff was also available to the consultants to answer any questions that the consultants had.

DDOE staff was an excellent contributor of information to the consultants for this study. DDOE provided the consultants with similar reports done in the District and in other regions, the District's databases, and data about the renewable energy technologies where DDOE provides financial incentives and statistics specific to the District. DDOE staff was also very helpful in reviewing drafts of this report and providing feedback.

The Idaho National Lab provided information about additional hydropower potential in the District. Doug Hall (formerly of the Lab, now retired) provided training to the consultants on INL's Virtual Hydropower Prospector software and showed the consultants how to find and view specific data.

2.4 INPUT RECEIVED FROM THE DISTRICT'S RENEWABLE ENERGY EXPERTS

The consultants talked to several solar experts and gave them a questionnaire of about 30 questions. These experts included:

- Albert Nunez, Principal, Capital Sun Group
- Atta Kiarash, CEO, Solar Solution, LLC
- Emil King, Policy Analyst, DDOE
- Fan Yang, President, Solar Solution, LLC
- Mike Healy, Market Development, Skyline Innovations
- Yuri Horwitz, President and CEO, SolSystems

2.5 ORGANIZATION OF THIS REPORT

The chapters of this report include:

1) Executive Summary
2) Introduction

3) Study Methodology and Data Sources
4) Renewable Energy Technologies Examined in This Study
5) Costs of Renewable Energy Technologies
6) Summary and Conclusions

3 STUDY METHODOLOGY AND DATA SOURCES

3.1 METHODOLOGY

3.1.1 Updating of technology costs and performance where applicable

The consultants reviewed the July 2012 NREL Renewable Energy Potential Study and examined the assumptions and methodology used by NREL to develop renewable energy potential estimates for the District. Then the consultants reviewed all input assumptions for each technology included in the NREL Study to determine if more recent or accurate data were available. Then the consultants updated renewable energy potential estimates for the District based upon this more recent or accurate information. The consultants also collected the latest available cost data for the renewable energy technologies included in this study. The consultants went through this assessment and updating process for each technology included in the July 2012 NREL Study.

3.1.2 Development of Technology Costs

The consultants developed estimates of the cost of energy produced for each renewable energy technology. NREL did not include this cost information in their July 2012 Study. The consultants developed an Excel worksheet model to calculate the cost of energy produced by each renewable energy technology. This cost analysis worksheet uses many input assumptions about the cost, efficiency, and useful life of a technology and calculates a levelized cost per unit of energy produced as the output. The input assumptions developed by the consultants are provided in section 5 of this study. The two inputs that have the biggest influence on the cost of energy produced are the overnight capital cost and the capacity factor. The results provided by the input worksheet are provided in section 5. Section 5 also provides the input assumptions from other studies done by EIA and Lazard. The consultants modified those inputs where necessary to make them more applicable to the District. All numbers used by the consultants to create the levelized cost of energy from each technology are listed in blue on the worksheet.

3.2 DATA SOURCES USED BY THE CONSULTANTS

3.2.1 Data from DDOE renewable energy programs

- US Department of Energy. (2011). 2011 Wind Technologies Market Report.
- US Department of Energy. (2012). SunShot Vision Study

3.2.2 Other data sources used by the Consultants

- Denholm, et al. (2008). Land-use requirements and the per-capita solar footprint for photovoltaic generation in the United States.
- Energy Ventures International. (2011). Wind Power for the Washington, D.C. Government: An Appraisal of Options.
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- National Renewable Energy Lab. (2012). US Renewable Energy Technical Potentials: A GIS-Based Analysis.
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- PV Watts. http://rredc.nrel.gov/solar/calculators/pvwatts/version1/. Used Sterling, VA.

- Sun Number. (2013). Solar Analysis of Washington D.C. Prepared for the consultants.
- US Energy Information Administration. (2013). Levelized Cost of New Generation Resources in the Annual Energy Outlook 2013.
- US Energy Information Administration. (2013). Updated Capital Cost Estimates for Utility Scale Electricity Generating Plants.

4 RENEWABLE ENERGY TECHNOLOGIES EXAMINED IN THIS STUDY

This section of the report provides a description of each renewable energy technology examined by the consultants as well as an updated estimate of the renewable energy potential in the District for each technology.

4.1 SOLAR PHOTOVOLTAIC

4.1.1 Description

Photovoltaic (PV) cells convert sunlight directly into electricity. This process starts when photons (tiny packets of energy that come from the sun) collide with a semiconductor on a solar panel. When the photons hit the solar cell, electrons are freed in the semiconductor material, creating an electric current. The current is harnessed by wires connected to the positive and negative sides of the cell. This discovery of efficient silicon solar cells was made by Bell Labs researchers Pearson, Chapin, and Fuller in 1954. Commercial licenses for silicon PV technologies were sold by Western Electric starting in 1955.[1]

To provide enough power for homes and businesses, solar cells are combined into modules. A solar module, or panel, holds about 40 cells. Panels are mounted at a fixed angle facing south, or on a tracking device that follows the sun, allowing for prime sunlight exposure. Small photovoltaic modules range in output from 10 to 300 Watts[2]. If more power is necessary, a solar array can be installed. A solar array is formed when many solar panels are combined together. Utility-scale photovoltaic systems are created when hundreds of solar arrays are interconnected for large electric utility or industrial applications.

There are three types of solar cells. Traditional solar cells are made from silicon and are usually flat-plate. Second-generation solar cells are made from amorphous silicon or non-silicon materials. These cells use layers of semiconductor materials only a few micrometers thick and can double as rooftop shingles, building facades, or glazing for skylights due to their flexibility. Third-generation solar cells are not made from silicon – they are made from materials that include solar inks, solar dyes, and conductive plastics. They can be very expensive, but cost effective because so little is needed.[3]

Solar energy has a positive environmental impact compared to typical power generation methods because there are no emissions, no moving parts or noise involved, and no water or fossil fuels are necessary to power the technology. Solar energy is ideal because it can be located right where the power is needed (at a home or business, for instance), or it can be tied into the power grid and used anywhere.

4.1.2 Incentives in the District

The current incentives paid by DDOE for fiscal year 2013, are $0.50/watt for photovoltaic systems, with a cap of $10,000 (equivalent to 20 kW).[4] As of August 9, 2013, DDOE has granted incentives for over 720 rooftop solar photovoltaic systems since 2009.

4.1.3 Rooftop Solar Photovoltaic

4.1.3.1 Description of NREL's 2012 Estimate of Usable Rooftop Area in the District [5]

The July 2012 NREL estimates of the District rooftop square footage available for rooftop solar installations came from Denholm and Margolis[6], who calculated roof footprint by dividing the building

[1] http://inventors.about.com/od/timelines/a/Photovoltaics.htm
[2] http://energy.gov/energysaver/articles/small-solar-electric-systems
[3] http://www.nrel.gov/learning/re_photovoltaics.html
[4] DDOE Data
[5] NREL Report on US Renewable Energy Technical Potentials- July 2012

footprint by the number of floors. They estimated 8% of residential rooftops[7] and 63% of commercial rooftops[8] in the US were flat. Usable roof area in the District was calculated by NREL from the District's total roof area using an availability factor that accounted for shading, rooftop obstructions, and constraints.

4.1.3.2 Costs & Size

The average cost ($/kW) for a solar PV unit under 6 kW is $5,801 in 2013, calculated from only 2012-2013 data[4]. The average cost for a solar PV unit that is greater than or equal to 6 kW, but less than 60 kW is $5,321.07. The following cost data comes from DDOE incentive database for the period 2009 to 2013. This database only includes PV systems that were granted financial incentives by DDOE, and does not include all systems in the District.

Table 4-1: Rooftop PV Costs for 2012-2013 Where DDOE Provided an Incentive

kW Size	# of Systems	Average Cost per kW	Average Installed Cost	Average Incentive
1 to 5	228	$5,801.36	$23,170	$8,343
6 to 10	43	$5,450.61	$41,951	$12,116
11 to 15	3	$5,452.04	$67,772	$17,452
16 to 20	2	$4,703.69	$93,676	$24,580
21 to 25	-	-	-	-
26 to 100	2	$3,544.46	$161,559	$16,500
100+	-	-	-	-

Table 4-2: Rooftop PV Costs for 2011 Where DDOE Provided an Incentive

kW Size	# of Systems	Average Cost per kW	Average Installed Cost	Average Incentive
1 to 5	105	$7,061.64	$27,323	$11,001
6 to 10	17	$6,056.12	$45,661	$17,985
11 to 15	5	$5,300.59	$64,878	$25,269
16 to 20	4	$4,419.72	$86,326	$32,645
21 to 25	0	$ -	$ -	$ -
26 to 100	1	$5,245.54	$296,100.00	$33,000.00
100+	1	$4,839.71	$487,915	$33,000

[6] Denholm, P., and R. M. Margolis. (2008). "Land Use Requirements and the Per-Capita Solar Footprint for Photovoltaic Generation in the United States." *Energy Policy*. 36, 3531-3543.
[7] Based on estimates from Navigant Consulting
[8] Based on Commercial Building Energy Consumption Survey (CBECS) database

Table 4-3: Rooftop PV Costs for 2010 Where DDOE Provided an Incentive

kW Size	# of Systems	Average Cost per kW	Average Installed Cost	Average Incentive
1 to 5	178	$7,545.85	$25,457	$9,898
6 to 10	22	$5,884.52	$42,102	$17,313
11 to 15	1	$2,256.82	$31,609	$27,006
16 to 20	3	$2,863.45	$55,403	$31,090
21 to 25	0	0	0	0
26 to 100	1	$6,650.00	$179,550.00	$33,000.00
100+	0	0	0	0

Table 4-4: Rooftop PV Costs for 2009 Where DDOE Provided an Incentive

kW Size	# of Systems	Average Cost per kW	Average Installed Cost	Average Incentive
1 to 5	60	$8,847.03	$26,505	$8,773
6 to 10	1	$9,508.89	$64,185	$16,500
11 to 15	0	0	0	0
16 to 20	0	0	0	0
21 to 25	0	0	0	0
26 to 100	0	0	0	0
100+	0	0	0	0

The following size data for PV systems in the District comes from the District Public Service Commission (PSC) database. Data is given for all systems installed since 2009 that were registered through the PSC.

Table 4-5: Rooftop PV Frequency Distribution of kW Sizes for rooftop panels installed since 2009[9]

kW size	Number of Systems
Under 5 kW	470
5 to 10 kW	196
10 to 15 kW	21
15 to 20 kW	8
20 to 100 kW	19
Over 100 kW	7
Total	721

Table 4-6: Average size of panel, smallest panel, and largest panel installed since 2009

Average Size (kW)	6.88
Smallest Size (kW)	0.93
Largest Size (kW)	171.36

4.1.3.3 Sun Number's Rooftop PV Potential

The consultants obtained an updated estimate of rooftop solar PV potential from Sun Number, a firm located in Denver, Colorado. This rooftop solar potential was estimated by Sun Number for Washington D.C. using a proprietary processing algorithm that estimates the areas of rooftops suitable for solar PV in the District. The data used in this process is a 1m surface elevation model depicting the heights and shapes of objects on the earth's surface (ex. buildings, trees, etc.). The Sun Number processing algorithm simulates the duration of direct solar radiation and takes into account the rooftop shape, shading from vegetation, and shading from adjacent buildings. Suitable rooftop planes were identified and measured based on the assumptions listed below. Electricity generation was computed using NREL's PV Watts tool.

Figure 4-1: Large silicon solar array on the roof of a commercial building

The following conditions were established by Sun Number for a rooftop area to be considered a suitable roof plane for installation of rooftop solar PV:

- Slope less than 72 degrees
- Aspect greater than 80° and less than 280°
    - Aspects that meet this threshold are categorized into one of the following categories:
        - Flat (slope less than 7°)
        - East (80° to 135°)
        - South (135° to 225°)

[9] PSC Renewables Database

- West (225° to 280°)

- Solar duration on a roof surface must exceed 3 hours on an average day

To calculate rooftop solar PV potential and the estimated electricity generation potential, Sun Number implies that a PV system efficiency of 16% is used[10]. PV Watts is used to compute the electricity output assuming a 0.77 derate factor fixed tilt PV system. An offset of 1 m around the building perimeter is included in the analysis.

To calculate the PV Potential, Sun Number used a simple relationship that at 16% efficiency, a homeowner needs 80 ft² per 1 kW of solar power[11]. This could be converted to 135 watt/m², which is equal to the power density in the NREL equation. The PV Potential is then multiplied by a per kW output, derived from PV Watts. These outputs are located in Table 4-7.

Table 4-7: Unit System Outputs

		AC kWh/yr
Energy @ 1kW	Flat	1050
	East	930
	South	1228
	West	939

Table 4-8: Results of Sun Number Study

Aspect	Suitable Area (Ft²)	PV Potential (kW)	Estimated Annual Electricity Generation (MWh/Yr)
Flat	57,614,576	720,182	756,191
East	15,912,857	198,911	184,987
South	21,919,456	273,993	336,464
West	14,523,119	181,539	170,465
Total	109,970,008	1,374,625	1,448,107

The consultants used an average of 13.5% efficiency for PV systems, which is the figure that NREL used in its July 2012 Technical Report. However, if higher or lower efficiency systems are used, the total potential will increase or decrease. The consultants created a range of efficiencies to show:

- The minimum potential, in the case that only low (11%) efficiency systems are installed.
- The maximum potential shows the potential if only high (20%) efficiency systems are installed.

[10] The NREL report that reference using a 16% efficiency claims that 80 ft² / kW is needed. However, when that is converted to w/m² a power density of 135 is calculated.

[11] National Renewable Energy Lab. (2003). A Consumer's Guide: Get Your Power from the Sun. [Full-text at http://www.nrel.gov/docs/fy04osti/35297.pdf]

Table 4-9: Range of Efficiencies Using Sun Number's Method

	Power density (kW/m^2)	Potential (MWh/yr)
Minimum	11%	1,194,315
Maximum	20%	2,185,822

4.1.3.4 Calculating Rooftop PV Potential using NREL's equation

The consultants also calculated an updated estimate of rooftop solar PV potential for the District using NREL's mathematical algorithms, but updating the efficiency factors used in the NREL approach. The consultants determined that the NREL approach and the Sun Number approach produce almost identical estimates.

1) The consultants first found the total kWh generation for each flat and sloped direction using PV Watts[12]. A tilt of 25° (the most common angle of solar panels installed in the District) was used for each direction-- south, east, west. Anything north-facing is not included. The average size for PV systems in the District is 6.88 kW, so the consultants used 7 kW on PV Watts. A 0.77 derate factor is assumed. The District of Columbia is not available on PV Watts so we used Sterling, VA.

$$kWh\ Generation\ (flat) = 7427\ kWh$$
$$kWh\ Generation\ (sloped, south) = 8572\ kWh$$
$$kWh\ Generation\ (sloped, east) = 7072\ kWh$$
$$kWh\ Generation\ (sloped, west) = 7064\ kWh$$

2) The kWh generation for each direction was used to calculate the capacity factor for each direction, using the formula: $Capacity\ Factor = \frac{kWh\ Generation}{8760 * Wattage\ for\ Unit}$

$$Capacity\ Factor\ (flat) = \frac{7427\ kWh}{8760\ h * 7\ kW} = 0.1211$$
$$Capacity\ Factor\ (sloped, south) = \frac{8572\ kWh}{8760\ h * 7\ kW} = 0.1398$$
$$Capacity\ Factor\ (sloped, east) = \frac{7072\ kWh}{8760\ h * 7\ kW} = 0.1153$$
$$Capacity\ Factor\ (sloped, west) = \frac{7064\ kWh}{8760\ h * 7\ kW} = 0.1152$$

3) Sun Number calculated the total suitable rooftop square footage for each direction[13]. Suitable roof planes are less than 72 degrees. Flat roofs are defined as having a slope less than 7 degrees. To be considered suitable, solar duration on a roof surface must exceed 3 hours of sunlight on an average day. Sun Number did not include the north-facing direction. The consultants converted the space to square meters.

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[12] PV Watts - http://rredc.nrel.gov/solar/calculators/pvwatts/version1/

[13] Sun Number. (2013). Solar Analysis of Washington D.C. Prepared for the consultants in August 2013 by Sun Number.

$$Rooftop\ Space\ (flat) = 57{,}614{,}576\ ft^2 * 0.3048^2\ {m^2}/{f^2} = 5{,}352{,}569.26\ m^2$$

$$Rooftop\ Space\ (sloped, south) = 21{,}919{,}456\ ft^2 * 0.3048^2\ {m^2}/{f^2} = 2{,}036{,}384.1\ m^2$$

$$Rooftop\ Space\ (sloped, east) = 15{,}912{,}857\ ft^2 * 0.3048^2\ {m^2}/{f^2} = 1{,}478{,}352.79\ m^2$$

$$Rooftop\ Space\ (sloped, west) = 14{,}523{,}119\ ft^2 * 0.3048^2\ {m^2}/{f^2} = 1{,}349{,}241.91\ m^2$$

4) The rooftop potential was found for each direction by using the equation: $Potential = Rooftop\ space * Power\ density * Capacity\ Factor * Hours\ per\ year$. Power density is the efficiency of the average system[14].

$$Potential\ (flat) = 5{,}352{,}569.26\ m^2 * 0.135 * 12.1\% * 8760 = 766{,}674{,}928\ kWh$$
$$Potential\ (sloped, south) = 2{,}036{,}384.1 m^2 * 0.135 * 14.0\% * 8760 = 336{,}649{,}056\ kWh$$
$$Potential\ (sloped, east) = 1{,}478{,}352.79 m^2 * 0.135 * 11.5\% * 8760 = 201{,}630{,}338\ kWh$$
$$Potential\ (sloped, west) = 1{,}349{,}241.91 m^2 * 0.135 * 11.5\% * 8760 = 183{,}812{,}928\ kWh$$

5) Potentials were converted from kWh to MWh and add rooftop potentials for each direction to get the total rooftop potential.

$$Total\ rooftop\ potential = 766{,}675 + 336{,}649 + 201{,}630 + 183{,}813 = 1{,}488{,}767\ MWh$$

A range of efficiencies was created using this equation as well. This shows the minimum potential, in the case that only low (11%) efficiency systems are installed. The maximum potential shows the potential if only high (20%) efficiency systems are installed.

Table 4-10: Range of Efficiencies Using NREL Equation

	Power density (kW/m²)	Potential (MWh/yr)
Minimum	11%	1,213,070
Maximum	20%	2,205,581

4.1.4 Utility Scale Photovoltaics

4.1.4.1 Urban Utility-Scale Photovoltaics[15]

Urban utility-scale photovoltaics are large-scale PV (at least 1 MW) deployed within urban boundaries on an urban open space. The July 2012 NREL study assumed the following limitations on areas than can be considered for utility scale solar PV installations:

- Those within urbanized area boundaries as defined by the US Census Bureau
- These areas are limited to those with slopes less than or equal to 3%

[14] Denholm, P., and R. M. Margolis. (2008). "Land Use Requirements and the Per-Capita Solar Footprint for Photovoltaic Generation in the United States." Energy Policy. 36, 3531-3543.
[15] NREL Report on US Renewable Energy Technical Potentials- July 2012

- Parking lots, roads, and urbanized areas are excluded by identifying areas with imperviousness greater than or equal to 1%
- Areas of the remaining land less than 18,000 square meters are removed to ensure the total size is large enough to be considered a utility-scale project

Calculating the technical potential for urban utility-scale photovoltaics presents many challenges. When breaking photovoltaics into different categories, it is important to make sure that none of the categories overlap. For example, if a rooftop is large enough to provide 1 MW of PV, is it considered rooftop PV, or is it utility-scale PV? Should utility-scale PV only include surface parking lots or also parking structures? Could utility-scale PV be placed over reservoirs?

4.1.4.2 Costs & Size

For a photovoltaic unit with a nominal capacity of 20 MW, the overnight capital cost is $4183/kW. The fixed O&M cost is $27.75/kW-yr. The variable O&M cost is $0/MWh. For a photovoltaic unit with a nominal capacity of 150 MW, the overnight capital cost is $3873/kW. The fixed O&M cost is $24.69/kW-yr. The variable O&M cost is $0/MWh.[16]

4.1.4.3 FedEx Field (An Example of Utility-Scale Solar PV)

FedEx Field is a football stadium located in Landover, Maryland and is home to the Washington Redskins. In 2011, the Redskins worked with NRG Energy Company to install 8,285[17] solar panels, producing 2 MW of peak power. This is the largest solar power installation in the District's metropolitan area. 7,572 panels are part of an 841-space parking structure that provides clean power and protection from the elements. FedEx Field generates about 2,036,560 kWh per month, which is roughly 24,439,918 kWh per year. The parking structure provides ten electric vehicle charging stations that are free of charge. The remaining 713[18] solar panels are in the stadium and ramp structure. The electricity produced by the solar panels is enough to power 20% of the energy used on game day and 100% of energy on non-game days[12]. This amount of electricity produced is enough to power 300 homes in the metro DC area[12].

[10] *Figure 4-2: Solar panels at FedEx Field*

[16] "Updated Capital Cost Estimates for Utility Scale Electricity Generating Plants" report by the US Energy Information Administration in April 2013.
[17] http://planetforwardgw.wordpress.com/2012/12/10/1173/
[18] http://www.nrgsolar.com/wp-content/uploads/2013/06/FeExField-Fact-Sheet-2013.pdf

4.1.4.4 Urban Utility scale potential in the District

The consultants examined the potential for utility-scale photovoltaic systems in the District and have determined that there is no potential for such development in the District due to lack of available land area. This finding is consistent with the findings of NREL's July 2012 renewable energy potential study.

4.1.4.5 Rural Utility-Scale Photovoltaics[19]

Rural utility-scale photovoltaics are large-scale PV deployed outside urban boundaries. NREL's July 2012 study had the following limitations for rural utility-scale PV systems:

- Excluding urban areas as defined by the US Census Bureau's urbanized area boundaries data set
- These areas are limited to those with slopes less than or equal to 3%
- Federally protected lands, inventoried road-less areas, and areas of critical environmental concern are also excluded
- A 1-km^2 contiguous area filter was applied to produce a final available land layer

Rural utility-scale photovoltaics are not found in the District of Columbia.

4.1.4.6 Concentrating Solar Power [15]

Concentrating solar power is power from a utility-scale solar power facility in which the solar heat energy is collected in a central location. Concentrating solar power is not found in the District of Columbia.

4.1.4.7 Solar Water Heating

Description

Solar thermal water heating systems use solar panels, otherwise known as 'collectors', that are typically installed on the roof of a residential, commercial or industrial facility. The heat transfer fluid in these collectors receives the heat from the sun and transfer the stored heat to fresh water that is circulated through a heat exchanger. The heated fresh water is then stored in a water tank. The main purpose of the collector is to collect the sun's energy in order to heat fresh water. Solar water heating is an excellent clean energy source because the sunlight, which is free and limitless, has no harmful emissions when the sunlight is converted to energy. This efficient water heating system is also the second most effective hot water measure in the energy efficiency potential study.

[19] NREL Report on US Renewable Energy Technical Potentials- July 2012

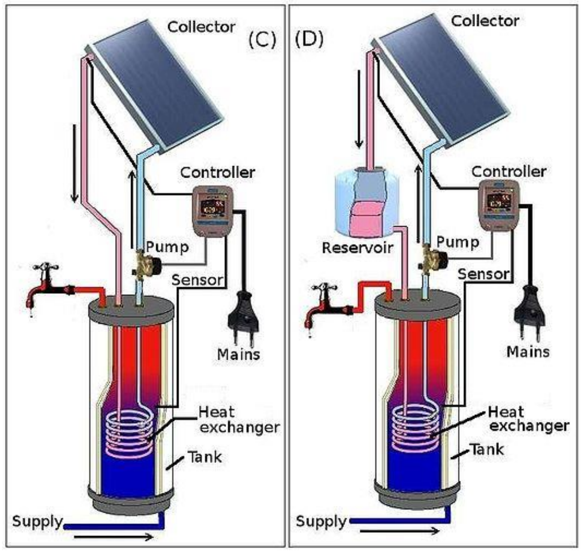

Figure 4-3: Solar Water Heating System Diagram

In the District, a solar water heating system typically uses a conventional electric or natural gas water heater as a back-up water heating system. A typical solar water heating system can save about two-thirds of the annual energy used by a conventional electric or natural gas water heating system.

Incentives for Solar Water Heating Systems

The District Property Tax Incentive gives a 100% exemption starting 7/25/2012, to the applicable sectors: commercial, residential, and industrial facilities.

The District's Solar Water Heating Rebate Program offers a rebate of $2,000 per residential solar water heating system and $6,000 for a non-residential solar water heating system. In addition, the District has in place a Property Tax Incentive that provides a 100% exemption for property taxes on the value of the solar water heating installation. This property tax exemption started on 7/25/2012 and is applicable to commercial, residential, and industrial facilities.

Note that the program is providing incentives until September 30, 2013.

Costs

The initial cost for equipment and installation for a residential solar water heating system in the District (with a back-up electric water heater) is estimated to be $8,162. The initial equipment and installation cost for a solar water heating system (with a back-up natural gas water heater) is $9,652. The cost of purchasing and installing a commercial solar hot water system was estimated at $26,400. This estimate was developed from a National Institute of Building Sciences report on Solar Water Heating specifying a range of installation costs of $90 to $120/ft^2 of solar panel collector area.

Solar Thermal Potential in the District

The per unit savings for a residential solar water heating system were developed by the consultants using known water heating savings algorithms and inputs from a variety of sources such as the Pennsylvania Technical Reference Manual (TRM) and ENERGY STAR market profile data. The estimate of average hot water usage per occupant was obtained from the ENERGY STAR market profile data. The useful life was obtained from the Mid-Atlantic TRM. The costs were taken from the Pennsylvania incremental cost database for the electric back-up option and the California Solar Initiative for the gas back-up option. Solar water heating in the residential sector has a technical potential for savings of 9,788 MWh and 3.9 MW on a cumulative annual basis for the CEP study period (2014 to 2023).

Based upon estimates of 250 gallons of hot water usage per day and average occupancy of 15 to 18 people per commercial installation, it was determined from a Department of Energy solar water heating system sizing guide that 240 square feet of solar panel collector area are needed for a commercial installation. Solar water heating in the commercial sector has a technical potential for savings of 39,413 MWh and 8 MW on a cumulative annual basis for the CEP study period (2014 to 2023).

Table 4-11: Solar Water Heating Technical Potential

Type of Unit	Technical Potential Cumulative Annual MW Savings	Technical Potential Cumulative Annual MWH Savings
Residential with Electric back-up	3.9	9,788
Commercial/ Industrial	8	39,413
Total	**11.9**	**49,201**

4.2 WIND

4.2.1 Description

Figure 4-4: These wind turbines near Lamar, Colorado, are part of the 162-MW Colorado Green Wind Farm. Each turbine produces 1.5 megawatts of electricity.

Wind turbines use the wind's energy to generate electricity. Utility scale turbines are mounted on a tower at 100 feet or more above the ground[20]. At this height, they can take advantage of higher wind speed and less turbulent wind. Capturing faster wind means more energy is created. Larger turbines are generally more efficient, because they intercept more wind and produce more power. Most turbines have automatic overspeed-governing systems that keep the rotor from spinning out of control in high winds. Wind turbines also have weather vanes on top of them that are connected to a computer to make sure the turbine is always turned into the wind to capture the most energy. Wind power dates back to 1887, when the first windmill used for electricity production was built by Professor James Blyth of Anderson's College, Glasgow. It was used to power his Scottish home for 25 years[21].

Turbines have two or three propeller-like blades that are mounted on a shaft to form a rotor. The shape of the blades on a wind turbine is very similar to an airplane's wing and the blades are usually made out of a composite material, such as fiberglass. The shape of the blade causes a pocket of low-pressure air to form on the downwind side of the blade when the wind passes around both sides of the blade. The air pocket pulls the blade toward it and the rotor turns. The combination of this force with the wind's force against the front side of the blade causes the rotor to spin like a propeller. The blades are attached to a shaft, which spins at about 18 RPM. This is much too small to make enough electricity, so the rotor shaft spins a series of gears that increase the rotation up to 1800 RPM. The turning gears spin a generator, creating electricity.[22]

[20] NREL. Wind Energy Basics: How Wind Turbines Work. http://www.nrel.gov/learning/re_wind.html
[21] The Guardian. Timeline: The History of Wind Power. http://www.guardian.co.uk/environment/2008/oct/17/wind-power-renewable-energy
[22] Energy.gov. Small Wind Electric Systems. http://energy.gov/energysaver/articles/small-wind-electric-systems

Wind turbines can be very versatile. They can be used as stand-alone applications, or connected to a utility power grid. They can also be combined with a photovoltaic system for maximum energy output. Large numbers of wind turbines that are built close together form wind plants, or wind farms. These are primarily used for utility-scale sources of wind energy. Electricity providers frequently use wind plants to provide power to their customers. Smaller wind farms can create enough energy to power 9000 homes! Anyone in windy areas, sites with 10 mile per hour or greater wind speeds, can use stand-alone wind turbines to cut their electric bills. Best of all, wind turbines have zero emissions and pollution, and are considered a green power source.

4.2.2 Costs

For an onshore wind turbine with a nominal capacity of 100 MW, the overnight capital cost is $2213/kW. The fixed O&M cost is $39.55/kW-yr. The variable O&M cost is $0/MWh. For an offshore wind turbine with a nominal capacity of 400 MW, the overnight capital cost is $6230/kW. The fixed O&M cost is $74/kW-yr. The variable O&M cost is $0/MWh. These costs come from the "Updated Capital Cost Estimates for Utility Scale Electricity Generating Plants" report by the US Energy Information Administration in April 2013.

4.2.3 Incentives in the District

There are currently no incentives offered for this technology by DDOE in the District of Columbia.

4.2.4 Offshore wind

4.2.4.1 Description[23]

A suitable offshore wind resource has an average wind speed greater than or equal to 6.4 meters per second at 90 meters above the surface. The offshore resource data extend 50 nautical miles from shore. Estimates are further filtered to eliminate shipping lanes, marine sanctuaries, and other areas deemed unlikely to be developed. Annual generation estimates assume a power density of 5 MW/km^2 and capacity factors based on wind speed interval and depth-based wind farm configurations to account for anchoring and stabilization for the turbines. Offshore wind power is not found in the District of Columbia. The District could purchase offshore wind power from turbines located along the coast of Maryland and Delaware.

4.2.4.2 Offshore Wind Potential in the District

Offshore wind obviously does not apply to the District, but the District could potentially import off-shore wind power from the coasts of Maryland or Delaware. The consultants did not find any more up-to-date information on off-shore wind potential for the District, so the potential given below is from the 2012 NREL report.

Table 4-12: Offshore Wind Potential from July 2012 NREL Report[23]

State	Offshore Wind (GWh)	Offshore Wind (GW)	Offshore Wind (km2)
DC	N/A	N/A	N/A
Delaware	60,654	15	3,008
Maryland	200,852	52	10,382

[23] NREL Report on US Renewable Energy Technical Potentials- July 2012

4.2.5 Onshore wind

4.2.5.1 Description[24]

Onshore wind power is a wind resource at 80 meters height above surface that results in an annual average gross capacity factor of 30%, using typical utility-scale wind turbine power curves. Estimates are processed to eliminate areas unlikely to be developed, such as urban areas, federally protected lands, and onshore water features. The net capacity factor is calculated by assuming a power density of 5 MW/km^2 and 15% energy losses. Onshore wind power is not found in the District of Columbia.

4.2.5.2 Onshore Wind Potential in the District

The July 2012 NREL study did not report any onshore wind potential in the District proper, but it is possible to import on-shore wind power from Maryland, Delaware or other States. The consultants did not find any more up-to-date information on wind potential, so the potential given is based upon the July 2012 NREL report.

Table 4-13: Onshore Wind Potential from July 2012 NREL Report

State	Onshore Wind (GWh)	Onshore Wind (GW)	Onshore Wind (km2)
DC	0	0	0
Delaware	22	0	2
Maryland	3,632	1	297

4.3 BIOMASS

4.3.1 Description

Biomass energy is the energy from plants and plant-derived materials. Sources include wood, food crops, grassy and woody plants, residues from agriculture or forestry, oil-rich algae, and the organic component of municipal and industrial wastes. Biomass is a great petroleum alternative because it is evenly distributed over the Earth's surface, and may be exploited using relatively environmentally friendly technologies. Biomass can be used for fuels, power production, and making products that would normally be produced from fossil fuels.

4.3.1.1 Biofuels

Biomass can be converted directly into liquid fuels (biofuels) for transportation use. Ethanol is one type of biofuel. It is an alcohol made by fermenting biomass high in carbohydrates from starches and sugars. The majority of ethanol is currently made from corn, but new technologies are being developed to make ethanol from other agricultural and forestry resources. NREL is developing technology to allow ethanol to be made from the materials that make up the majority of plant matter, cellulose and hemicelluloses[25].

[24] NREL Report on US Renewable Energy Technical Potentials- July 2012
[25] NREL. Biomass Energy Basics. http://www.nrel.gov/learning/re_biomass.html

Gasification is another process that produces ethanol. Gasification systems use high temperatures and a low-oxygen environment to convert biomass into synthesis gas, which can be chemically converted into ethanol. Ethanol is used as a blending agent with gasoline to decrease carbon monoxide and other emissions, while increasing octane. Vehicles must be made to run on this alternative fuel. The most common form of ethanol blended fuel is E85, which is 85% ethanol and 15% gasoline. Use of E-85 is growing: more than 7 million vehicles are on the road today that can use the alternative fuel[26]. Besides ethanol, another type of liquid biofuel is called biodiesel. This is made by combining alcohol with vegetable oil, animal fat, or recycled cooking grease. It can be added to gasoline to reduce emissions, or in its pure form as a fuel for diesel engines.

4.3.1.2 Biopower

The term biopower refers to the use of biomass to generate electricity. There are five biopower system technologies. The first, and most common system used in biopower plants is called a direct-fired system. This system burns bioenergy feedstocks directly to produce steam. The steam drives a turbine, and the turbine turns a generator that converts power into electricity. Co-firing is the next type of system. It involves mixing biomass with fossil fuels in conventional power plants. Co-firing systems can be used in coal-fired power plants to reduce emissions. Gasification is another biopower system, and its by-product of synthesis gas can be converted into other fuels, burned in a conventional boiler, or used instead of natural gas in a gas turbine. Pyrolysis is very similar to gasification. While gasification only limits oxygen, pyrolysis excludes oxygen completely and pyrolizes biomass into a liquid. Pyrolysis oil can be burned to generate electricity or used to make fuels, plastics, adhesives, or other bioproducts. The final type of biopower system is called anaerobic digestion. Natural bacteria are used to decompose organic matter in the absence of oxygen in closed reactors. Gas is produced and is used in power production.

4.3.1.3 Bioproducts

Most products that are made from fossil fuels can be made from biomass. Biomass components are carbohydrates, which are various combinations of carbon, hydrogen, and oxygen. Biochemical conversion technology breaks down biomass to component sugars, and thermochemical conversion technology breaks biomass down to carbon monoxide and hydrogen. New products are created when these by-products go through fermentation, chemical catalysis, and other processes. A few examples of bioproducts are antifreeze, plastics, glues, textiles, synthetic fabrics, wood adhesives, and foam insulation.

4.3.2 Costs

For CC biomass energy with a nominal capacity of 20 MW, the overnight capital cost is $8180/kW. The fixed O&M cost is $356.07/kW-yr. The variable O&M cost is $17.49/MWh. For BFB biomass energy with a nominal capacity of 50 MW, the overnight capital cost is $4114/kW. The fixed O&M cost is $105.63/kW-yr. The variable O&M cost is $5.26/MWh. These costs come from the "Updated Capital Cost Estimates for Utility Scale Electricity Generating Plants" report by the US Energy Information Administration in April 2013.

4.3.3 Incentives in the District

There are currently no incentives offered for this technology by DDOE in the District of Columbia.

4.3.4 Calculating Biomass Potential

To calculate estimates of biomass renewable energy potential, the consultants obtained estimates of solid biomass resources for crop, forest, primary mill residues, secondary mill residues, and urban wood waste

[26] US DOE. Bioenergy FAQs. http://www1.eere.energy.gov/biomass/biomass_basics_faqs.html

from NREL.[27]. The following list presents the estimated biomass potential in bone dry tonnes (BDT) obtained by the consultants from NREL:

- Crop Residues: 2007_Res (DC = 0 BDT)
- Forest and Primary Mill Residues:
  - Forest: Forest (DC = 0 BDT)
  - Primary Mill: PrimMill (DC = 0 BDT)
- Urban Wood and Secondary Mill Residues:
  - Urban Wood: Toturbwood (DC = 75,133.7 BDT)
  - Secondary Mill Residues: Totsecmres (DC = 1,820 BDT)

1) The consultants then added all BDT to get the total potential.
$$75{,}133.7 BDT + 1{,}820 BDT = 76{,}953.7 BDT$$

2) The total BDT was then multiplied by 1.1 to convert potential to MWh.
$$76{,}953.7 BDT * 1.1 \frac{MWh}{BDT} = 84{,}649.1\ MWh$$

3) The consultants multiplied the potential in MWh by 0.001 to convert to GWh.
$$84{,}649.1\ MWh * 0.001 \frac{GWh}{MWh} = 84.6\ GWh$$

NREL's July 2012 renewable energy report had a total potential of 61.798 GWh for solid Biopower. The number that the consultants calculated is higher because the consultants used more up-to-date numbers for biomass potential in bone dry tonnes.

4.4 GEOTHERMAL

4.4.1 Description

Geothermal energy is the heat from the earth. This heat can be drawn from hot water or steam reservoirs deep in the earth, geothermal reservoirs located near the earth's surface, or shallow ground near the Earth's surface that maintains a constant temperature of 50-60°F.[28]

Geothermal energy has many uses. It can be used to produce electricity for a utility's customers, used directly in buildings, roads, agriculture, or industrial plants, or it can be used to provide heating and cooling in homes and other buildings.

The four types of ground loop systems are: horizontal, vertical, and pond/lake (all closed-loop), and open-loop[29]. Heat pumps in the District must be vertical, closed-loop systems.

4.4.1.1 Geothermal Energy Production (Deep Earth)

Commercial geothermal power plants use steam or hot water miles below the Earth's surface to produce electricity. Steam rotates a turbine that activates a generator, which

[27] http://www.nrel.gov/gis/data_biomass.html
[28] NREL. Geothermal Energy Basics. http://www.nrel.gov/learning/re_geothermal.html
[29] Energy.gov. Geothermal Heat Pumps. http://energy.gov/energysaver/articles/geothermal-heat-pumps

produces electricity. Dry Steam power plants draw from underground steam resources. The steam is directly piped to the power plant where it is directed into a turbine or generator unit. The only dry steam plants in the United States are at the Geysers in northern California. Flash steam power plants use geothermal reservoirs of water with temperatures above 360°F. The water flows up through wells in the ground, decreasing in pressure as it flows upward. The hot water boils into steam, which is then separated from the water and directed into a turbine or generator. Flash steam power plants are the most common geothermal power plants. Binary cycle power plants operate on water temperatures of about 225-360°F. These plants use heat from the hot water to boil a working fluid that has a low boiling point. The working fluid is vaporized in a heat exchanger and used to turn a turbine. The water and working fluid are kept separate during the process, creating little or no air emissions.

4.4.1.2 Geothermal Direct Use

Heat is provided directly from geothermal reservoirs of hot water found a few miles below the Earth's surface. Wells are drilled into geothermal reservoirs to provide steady streams of hot water. Once the water is brought up through the well, a mechanical system of pipes, a heat exchanger, and controls delivers the heat directly for its intended use. Its uses include heating buildings, raising plants in greenhouses, drying crops, heating water at fish farms, and several industrial processes. A disposal system injects the cooled water underground or disposes of it on the surface.

4.4.1.3 Geothermal Heat Pumps

Geothermal heat pumps, also known as ground source heat pumps, rely on the constant temperature of the upper 10 feet of the Earth, which has a temperature between 50-60°F year-round. This temperature is warmer than the air in the winter and cooler in the summer. Since this heat is drawn from the ground, heat pumps are more efficient and use less energy than conventional heating systems, saving energy and money, and reducing air pollution. These systems can be installed in horizontal loop or vertical loop systems. They are also very efficient in the US, because they can be used just about anywhere.

4.4.2 Costs

For a dual flash geothermal unit with a nominal capacity of 50 MW, the overnight capital cost is $6243/kW. The fixed O&M cost is $132/kW-yr. The variable O&M cost is $0/MWh. For a binary geothermal unit with a nominal capacity of 50 MW, the overnight capital cost is $4362/kW. The fixed O&M cost is $100/kW-yr. The variable O&M cost is $0/MWh. These costs come from the "Updated Capital Cost Estimates for Utility Scale Electricity Generating Plants" report by the US Energy Information Administration in April 2013.

4.4.3 Incentives in the District

There are currently no incentives offered for this technology in the District of Columbia.

4.4.4 Geothermal Potential in the District

There have been very few permits given out since 2011 by the District Department of the Environment. Perhaps this is because the permits are very hard to get and people are discouraged by the process.

Table 4-14: Number of Geothermal Permits Given Out Since 2011

Year	Total # of Geothermal Permits	Pending Permits
2013	10	2
2012	21	0
2011	26	0

This section of the study presents estimates of the achievable potential energy savings for geothermal heating and cooling systems in the District. Based on the average numbers of permits issued by DDOE for ground water wells for such geothermal systems over the past few years, it is likely that there will be 20 permits issued per year over the next decade. The consultants estimate that about half of these systems will be installed in the residential sector and about half in the commercial sector. The consultants estimate that a typical residential system will save 51.5 MMBtu annually while adding 2,500 kWh of net electricity consumption for pumps and other auxiliary equipment. The consultants estimate that net annual energy savings per home will be 43 MMBtu. A geothermal system installed in a typical commercial facility will save 618 MMBtu of natural gas annually, but add 30,000 kWh of net electricity consumption, leading to an annual net savings of about 515.6 MMBtu. These savings figures are based upon the assumption that a typical home system has a capacity of 2.5 tons while a small commercial facility (40,000 sq. ft.) as a system capacity of 30 tons. Table X-X below provides a forecast of the achievable potential for geothermal heating/cooling systems for the next 10 years (2014 to 2013).

Residential *For your typical home system (rough estimates)

YEAR	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Number of residential program participants	10	10	10	10	10	10	10	10	10	10
Annual kWh savings per participant	12,611.00	12,611.00	12,611.00	12,611.00	12,611.00	12,611.00	12,611.00	12,611.00	12,611.00	12,611.00
Total Annual kWh Savings – All Participants in Year Specified	126,110.00	126,110.00	126,110.00	126,110.00	126,110.00	126,110.00	126,110.00	126,110.00	126,110.00	126,110.00
Cumulative Annual kWh Savings	126,110.00	252,220.00	378,330.00	504,440.00	630,550.00	756,660.00	882,770.00	1,008,880.00	1,134,990.00	1,261,100.00
Cumulative Program Particpants	10	20	30	40	50	60	70	80	90	100
Cost Per Participant	$4,573.00	$212.00	$212.00	$212.00	$212.00	$212.00	$212.00	$212.00	$212.00	$212.00
Total Cumulative Cost	**$4,573.00**	**$4,785.00**	**$4,997.00**	**$5,209.00**	**$5,421.00**	**$5,633.00**	**$5,845.00**	**$6,057.00**	**$6,269.00**	**$6,481.00**

Commercial *Small commercial facility (40,000 sq. ft.)

YEAR	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Number of residential program participants	10	10	10	10	10	10	10	10	10	10
Annual kWh savings per participant	151,224.00	151,224.00	151,224.00	151,224.00	151,224.00	151,224.00	151,224.00	151,224.00	151,224.00	151,224.00
Total Annual kWh Savings – All Participants in Year Specified	1,512,240.00	1,512,240.00	1,512,240.00	1,512,240.00	1,512,240.00	1,512,240.00	1,512,240.00	1,512,240.00	1,512,240.00	1,512,240.00
Cumulative Annual kWh Savings	15,122,400.00	16,634,640.00	18,146,880.00	19,659,120.00	21,171,360.00	22,683,600.00	24,195,840.00	25,708,080.00	27,220,320.00	28,732,560.00
Cumulative Program Particpants	10	20	30	40	50	60	70	80	90	100
Cost Per Participant	$54,876.00	$2,544.00	$2,544.00	$2,544.00	$2,544.00	$2,544.00	$2,544.00	$2,544.00	$2,544.00	$2,544.00
Total Cumalative Cost	**$54,876.00**	**$57,420.00**	**$59,964.00**	**$62,508.00**	**$65,052.00**	**$67,596.00**	**$70,140.00**	**$72,684.00**	**$75,228.00**	**$77,772.00**

4.5 HYDRO

4.5.1 Description

Hydroelectric power plants produce electricity by using falling water to turn a turbine, which turns a metal shaft in an electric generator, which is the motor that produces electricity. By building a dam on a large river that has a big drop in elevation, the dam will store lots of water behind it in the reservoir. At the bottom of the dam wall is where the turbine's water intake is located. Gravity causes it to fall through the dam, turning the turbine propeller. The shaft connected to the turbine goes up into the generator and converts this mechanical energy into electricity.[30]

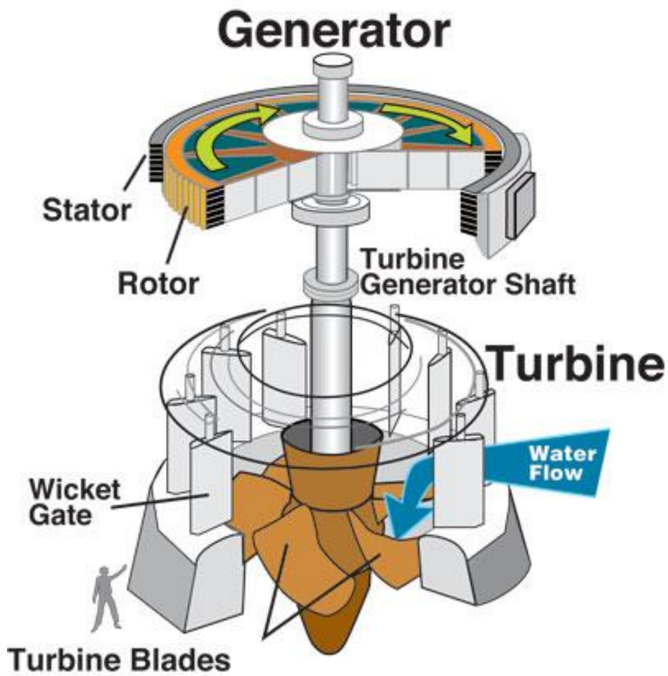

Figure 4-7: Solar Thermal Heating equipment. A simple diagram of all the gadgets associated with this technology.

There are several advantages to hydroelectric power. There is minimal pollution because fuel is not burned. The costs are low because the water is provided by nature, so it's free and the power plants have relatively low operations and maintenance costs. The technology is reliable and renewable.[31]

4.5.2 Costs

For conventional hydroelectric power with a nominal capacity of 500 MW, the overnight capital cost is $2936/kW. The fixed O&M cost is $14.13/kW-yr. The variable O&M cost is $0/MWh. These costs come from the "Updated Capital Cost Estimates for Utility Scale Electricity Generating Plants" report by the US Energy Information Administration in April 2013.

4.5.3 Incentives in the District

There are currently no incentives offered for this technology in the District of Columbia.

[30] http://ga.water.usgs.gov/edu/hyhowworks.html
[31] http://ga.water.usgs.gov/edu/wuhy.html

4.5.4 Potential in the District

Initial estimates of hydropower potential came from the Virtual Hydropower Prospector software developed by Doug Hall of the Idaho National Laboratory[32]. This software tool allows the user to zoom in on any part of the US and view potential hydropower locations. The top of the legend on page 1 of this software lists several types of water energy resource sites. To view these sites, the top box must be checked by the user of this software. The software user can click "identify" and select any number of sites to view specifics about the site. At the bottom of the legend, the software user can choose not to see excluded areas, which includes land excluded for federal and environmental reasons. After choosing to not see the excluded areas, one location is left on the Potomac River. Table 4-14 shows the information about the one hydropower site in the District that is suitable for hydro redevelopment.

Table 4-15: Hydropower Site in the District[33]

Power Class	Power Potential	Reach Length	Reach Start Elevation	Reach End Elevation
	(MW)	(ft)	(ft)	(ft)
Low Power/ Unconventional	0.125	5054.649	4.364	4.232

Low power in this situation means that it creates less than 1 MW. Unconventional means that there is less than an 8 foot elevation change. The annual electric generation that can be produced from the redevelopment of this hydro site was not provided in the Idaho National Laboratory Hydropower Prospector software. .Based on an average annual capacity factor of 50% (obtained from the National Renewable Energy Laboratory, the annual electric generation that can be produced from the redevelopment of this hydro site is 547.5 MWh.

32 http://gis-ext.inl.gov/vhp/Default.aspx

33 http://hydropower.inl.gov/prospector/index.shtml

5 COSTS OF RENEWABLE ENERGY TECHNOLOGIES

The consultants collected information in order to be able to provide accurate estimates of the levelized cost per unit of energy produced for the renewable energy technologies examined in this study. To develop the estimates of the levelized cost for each technology, many factors were taken into account. Factors that varied by technology include:

- Overnight capital cost
- Capital Cost Year
- Construction Period
- In Service Year
- Rate Base Book Life
- Fixed O&M Rate ($/kW-Yr)
- Variable O&M Rate ($/MWh)
- Heat Rate (MMBtu/MWh)
- Fuel
- Capacity Factor

Control factors include:

- Construction Escalation
- Return on Rate Base
- Equity Portion of Return
- LTD
- Federal Income Tax Rate
- District Income Tax Rate
- Composite Tax Rate
- Discount Rate
- Operating Cost Year
- Operating Cost Escalation

The levelized cost for each renewable energy technology is calculated in a detailed Excel spreadsheet that uses all of these factors as inputs. The levelized cost was also calculated for three non-renewable electric generation technologies so that the reader of this report could compare the costs of renewable energy technologies to conventional electric generation technologies.

5.1 ROOFTOP SOLAR PHOTOVOLTAIC COSTS

For rooftop solar PV, the capacity factor used came from NREL and is specific to the District's region. The overnight capital cost ($/kW) was calculated from actual data for the District reported by NREL. The rate base book life and O&M fixed cost ($/Yr/kW) came from an average of EIA and Lazard figures. Rooftop solar PV was broken down into two categories: smaller than 6 kW and larger than 6 kW. The reasoning behind this comes from the assumption that smaller systems generally cost more money.

5.2 UTILITY SCALE PHOTOVOLTAIC COSTS

For utility scale PV, the capacity factor used came from NREL and is specific to the District's region. Overnight capital cost ($/kW) was averaged from EIA and Lazard figures multiplied by the NREL Mid-Atlantic cost multiplier. The rate base book life and O&M fixed cost ($/Yr/kW) came from an average of EIA and Lazard figures.

5.3 SOLAR WATER HEATING COSTS

The average installed cost of a residential solar water heating system in the District is $8,162 and was obtained from the PA Incremental Cost Database v1 1(For TUS Review) (2), located in the 'Res Database' tab, in cell G73. The average installed cost of a solar water heating system in a commercial establishment is $26,400. This data can be found in the GN Energy Efficiency Report with Appendices, on page 2, after page 1 Appendix B-2.

5.4 OFFSHORE WIND COSTS

For offshore wind, the capacity factor used came from NREL and is specific to the District's region. Overnight capital cost ($/kW) was averaged from EIA and Lazard figures multiplied by the NREL Mid-Atlantic cost multiplier. The rate base book life, O&M fixed and variable costs come from the average of the EIA and Lazard figures.

5.5 ONSHORE WIND COSTS

For onshore wind, the capacity factor used came from NREL and is specific to the District's region. The overnight capital cost is the national average for 2012 from the NREL Report (figure 20). The rate base book life, O&M fixed and variable costs come from the average of the EIA and Lazard figures.

5.6 BIOMASS COSTS

For biomass, the capacity factor used came from NREL and is specific to the District's region. The overnight capital cost, heat rate, rate base book life, and O&M fixed cost are the averages of the EIA and Lazard figures. For O&M variable cost, the Lazard figure was used as it produces a total variable cost along with the implied fuel cost that is $5/MWh less than the EIA study, which is a representative of a higher fuel and transportation cost.

5.7 GEOTHERMAL (DEEP EARTH) COSTS

For geothermal power, the capacity factor used came from NREL and is specific to the District's region. The overnight capital cost is the midpoint of the Lazard study. The EIA study was not used for this, because it refers to the least expensive option in the northwest. The rate base book life was taken from the average of the EIA and Lazard figures. The O&M variable cost is the average of the EIA and Lazard figures. $65 was chosen for the O&M fixed cost so that when it is added to the variable O&M cost of $35, it will equal $111, which is equal to the EIA sum of Fixed and Variable O&M.

5.8 GEOTHERMAL HEAT PUMP (COSTS)

The average installed cost of a residential geothermal heat pump system in the District is $4,361 with a $212 savings per year. This estimate for residential heat pump savings were estimated based on a heat pump feasibility study report completed for the U.S. Department of Veterans Affairs Medical Center in Richmond, Virginia in which eQuest building energy simulation modeling was used to determine savings. Cost information was based on vendor estimates of equipment costs and RSMeans cost estimates for borehole drilling and finishing and piping. Savings and costs were scaled to an assumed 2.5-ton residential central air conditioner with gas furnace for sizing baseline efficiency purposes.

The average installed cost of a geothermal heat pump system in a commercial establishment is $52,332 with a savings of $2,544 per year. Commercial heat pump savings were estimated based on a heat pump feasibility study report completed for the U.S. Department of Veterans Affairs Medical Center in Richmond, Virginia in which eQuest building energy simulation modeling was used to determine savings. Cost information was based on vendor estimates of equipment costs and RSMeans cost estimates for borehole drilling and finishing and piping. Savings and costs were scaled to an assumed commercial building size of 40,000 square feet, and the existing heating and cooling system was assumed to be a 30-ton rooftop unit for sizing and baseline efficiency purposes.

5.9 HYDRO POWER COSTS

For hydropower, the capacity factor used came from NREL and is specific to the District's region. The EIA figure was used for the overnight capital cost. The rate base book life came from the EIA figure, though a much longer useful life is applicable. O&M fixed and variable costs are equal to the EIA figure.

Table 5-1: Costs of Renewable Technologies (Part 1)

DC RENEWABLE INPUT VARIABLES	SOURCE / INPUT	Year Dollars	Solar PV Rooftop <6	Solar PV Rooftop >6	Solar PV Utility	Wind	Wind Offshore	Hydro[5]
DC Model - Levelized $/MWh	Model	2013	$494	$454	$167	$91	$139	$57
Lazard Study - Levelized $/MWh	Lazard[1]	2012	$149 - 204	$149 - 204	$101 - 149	$48 - 95	$110 - 199	-
EIA Study - Levelized $/MWh	EIA[2]	2011	-	-	$112 - 224	$74 - 100	$183 - 295	$58 - 149
Capacity Factor	Model	2013	14%	14%	18%	26%	46%	50%
	Lazard[1]	2015[7]	20 - 23%	20 - 23%	20 - 27%	30 - 48%	37 - 43%	-
	EIA[2,8]	2011	-	-	22 -32%	30 - 39%	33 - 34%	30 - 65%
	NREL (DC or DE)[3]	2013	13.5%	13.5%	17.9%	26.1%	46.0%	50.0%
Mid-Atlantic Cost Multiplier	EIA[4]	-	n/a	n/a	0.84	n/a	0.92	-
Overnight Capital Cost $/kW	Model	2013	$5,801	$5,321	$2,596	$1,750	$4,679	$2,400
	Lazard[1]	2012	$3,000 - 3,500	$3,000 - 3,500	$2,000 - 2,750	$1,500 - 2,000	$4,050	-
	EIA[2]	2011	-	-	$3,805	$2,175	$6,121	$2,397
	Other		-	-	$1,500 - 1,750	$1,750		$1,200 - 3,600
Heat Rate Btu/kWh	Model	-	-	-	-	-	-	-
	Lazard[1]	2012	-	-	-	-	-	-
	EIA[2]	2012	-	-	-	-	-	-
Rate Base Book Life	Model	-	20	20	25	25	25	30
	Lazard[1]	-	20	20	20	20	20	-
	EIA[2]	-	-	-	30	30	30	30
O&M Fixed ($/Yr/kW)	Model	2013	$17	$17	$20	$34	$77	$15
	Lazard[1]	2012	$13 - 20	$13 - 20	$13 - 25	$30	$60 - 100	-
	EIA[2]	2011	-	-	$21	$39	$73	$15
O&M Variable ($/MWh)	Model - O&M	2013	$0	$0	$0	$4	$8	$6
	Model - Fuel	2013	-	-	-	-	-	-
	Lazard[1] - O&M	2012	$0	$0	$0	$6 - 10	$13 - 18	-
	Lazard - Fuel ($/MMBtu)	2012	$0	$0	$0	$0	$0	-
	EIA[2] - O&M & Fuel	2011	-	-	$0	$0	$0	$6

Table 5-2: Costs of Renewable Technologies (Part 2)

DC RENEWABLE INPUT VARIABLES	SOURCE / INPUT	Year Dollars	Geo Thermal[5]	Solar Thermal[6]	Biomass	Coal[9]	Nuclear	Gas[10]
DC Model - Levelized $/MWh	**Model**	2013	**$114**	**$324**	**$100**	**$110**	**$94**	**$69**
Lazard Study - Levelized $/MWh	Lazard[1]	2012	**$89 - 142**	**$131 - 216**	**$87 - 116**	**$62 - 141**	**$77 - 114**	**$61 - 89**
EIA Study - Levelized $/MWh	EIA[2]	2011	**$81 - 100**	**$190 - 418**	**$98 - 130.8**	**$112 - 138**	**$104 - 115**	**$60 - 78**
Capacity Factor	**Model**	2013	**90%**	**19%**	**90%**	**89%**	**90%**	**79%**
	Lazard[1]	2015[7]	80 - 90%	30 - 50%	85%	93%	90%	40 - 70%
	EIA[2,8]	2011	92%	11 - 26%	83%	85%	90%	87%
	NREL (DC or DE)[3]	2013	90.0%	-	90%	-	-	-
Mid-Atlantic Cost Multiplier	EIA[4]	-	-	-	0.91	0.91	0.95	0.88 - 0.89
Overnight Capital Cost $/kW	**Model**	2013	**$5,925**	**$5,715**	**$3,431**	**$4,931**	**$6,800**	**$1,058**
	Lazard[1]	2012	$4,600-7,250	$5,600 - 7,300	$3,000 - 4,000	$3,000 - 8,400	$5,385 - 8,199	$1,006 - 1,318
	EIA[2]	2011	$2,567	$4,979	$4,041	$5,138	$5,429	$901 - 1,006
	Other						$6,800	
Heat Rate Btu/kWh	**Model**	-	**-**	**-**	**14,000**	**11,188**	**10,451**	**6,875**
	Lazard[1]	2012	-	-	14,500	8,750 - 12,000	10,450	6,800 - 7,220
	EIA[2]	2012	-	-	13,500	12,000	10,452	6,430 - 7,050
Rate Base Book Life	**Model**	-	**25**	**35**	**25**	**35**	**40**	**25**
	Lazard[1]	-	20	40	20	40	40	20
	EIA[2]	-	30	30	30	30	30	30
O&M Fixed ($/Yr/kW)	**Model**	2013	**$65**	**$66**	**$99**	**$46**	**$52**	**$10**
	Lazard[1]	2012	$0	$50 - 80	$95	*$20 - 32*	*$13*	*$5 - 6*
	EIA[2]	2011	$111	$66	$104	*$65*	*$92*	*$13 - 15*
O&M Variable ($/MWh)	**Model - O&M**	2013	**$35**	**$2**	**$15**	**$3**	***$4***	**$3**
	Model - Fuel	2013	**-**	**-**	Biomass	Coal	Nuclear	Gas
	Lazard[1] - O&M	2012	$30 - 40	$3	$15	$3 - 6	$0	$2 - 3.5
	Lazard - Fuel ($/MMBtu)	2012	$0	$0	$1 - 2	$1.7	$0.5	$4.5
	EIA[2] - O&M & Fuel	2011	$0	$0	$42	$31	$12	$45 - 48

Sources:

(1) Lazard - Lazard Ltd. (2012). Levelized Cost of Energy Analysis - Version 6.0. New York, NY: Lazard Ltd. [Full-text at http://j.mp/Lazard_LCOE_ver6] "Lazard has not manipulated capital costs or capital structure for various technologies, as the goal of the study was to compare the current state of various generation technologies, rather than the benefits of financial engineering."

(2) EIA - Refers to - U.S. Energy Information Administration - Levelized Cost of New Generation Resources in the Annual Energy Outlook 2013 - January 2013

(3) NREL Capacity factors: Used the District for Solar PV, Hydro, Geothermal, Biomass (solid); Used DE for Wind Power; Calculated by: GWh/(GW*8760)

(4) EIA - Regional Cost Multipliers - Capital Cost Assumptions Update (Region 16)

(5) "The EIA table entries represent the cost of the least expensive plant that could be built in the NW power pool region where most proposed sites are located.

(6) The Lazard Study refers to a "Solar Thermal Tower" which is a utility-scale project. EIA is unclear about type of Solar Thermal Technology which could be or include small scale roof-top installations.

(7) Levelized cost of Energy in 2015" is referenced in the Lazard Study, therefore we interpret their report and assumptions to be in future (2015) dollars.

(8) "The levelized cost for each technology is evaluated based on the capacity factor indicated, which generally corresponds to the high end of its likely utilization range."

(9) EIA - "Pulverized Coal with carbon sequestration", Lazard - "Advanced supercritical pulverized coal. High end incorporates 90% carbon capture and compression."

(10) EIA - "Adv Gas/Oil Cob Cycle (CC)", Lazard - "Gas Combined Cycle"

(11) Solar thermal was not included in the renewable potential study, but is included in the energy efficiency potential study.

Specific sources for these tables are located in Appendix A.

6 SUMMARY AND CONCLUSIONS

1) There is considerable renewable energy potential in the District. The updated estimates of renewable energy potential for the District are presented in Sections 1 and 4 of this report.
2) The technology with the most technical potential in the District is rooftop solar photovoltaics (PV).
3) Costs for renewable energy technologies range from $0.057/kWh for hydropower to $0.494/kWh for solar rooftop PV (under 6 kW).
4) More research is needed to determine renewable energy potential for the District for geothermal ground source heat pumps, utility-scale solar and offshore wind. The applicable offshore wind resource is located off the coasts of Maryland and Delaware.

APPENDIX A: REFERENCE FOR TABLES 5-1 AND 5-2

DC RENEWABLE INPUT VARIABLES	SOURCE / INPUT	Year Dollars	Solar PV Rooftop	Solar PV Utility	Wind	Wind Offshore	Hydro[5]
DC Model - Levelized $/MWh	Model		Approx 100 sqft/kW - Need roofs with 20-100k sqft to gain economies of scale associated with Lazard figures. The NREL figures indicates very small systems.	Costs are still relatively high in today's dollars relative to other generation options, however, Lazard indicates a much lower cost/kW projected for 2015 as technology evolves and competition increases (all of which are dependant upon demand which is driven by gas prices and government incentives whether it be anti-carbon or pro-renewable). If the energy production is mostly aligned with peak loads, solar plants can generate reliability capacity credit as an intermittent resource but certainly not at 100% As always, LCOE is driven by capacity factor and energy production capability relative to Sunlight which is very regional specific.	Wind has gained much attention and investment due to it's significant decrease in costs and increase in capacity factor. However, they are limited to areas where wind is strong and consistent and there is land available to install giant towers. The second item to overcome is the intermittent nature of wind which usually requires almost a 1-1 backup with typically inexpensive gas generation with firm fuel supply.	Same pros and cons as onshore wind but with a better capacity factor and heftier price tag.	Hydro is an excellent opportunity if suitable locations (pretty limited potential for this type of generation in DC area most likely) can be found without environmental issues.
Lazard Study - Levelized $/MWh	Lazard[1]						
EIA Study - Levelized $/MWh	EIA[2]						
Capacity Factor	Model		NREL regional specific.	NREL regional specific.	NREL regional specific.	NREL regional specific.	NREL regional specific.
	Lazard[1]						
	EIA[2,8]						
	NREL (DC or DE)[3]						
Mid-Atlantic Cost Multiplier	EIA[4]						
Overnight Capital Cost $/kW	Model		Actual data for DC area s reported by NREL. These costs might should be	Average of EIA and Lazard figures multiplied by the NREL regional cost	The national average for 2012 from NREL Report Figure 20	Average of EIA and Lazard figures multiplied by the NREL regional cost	EIA Figure or Inflated midpoint of the Hydro Study
	Lazard[1]						
	EIA[2]						
	Other			Lazard "estimated capital costs in 2015.	NREL 2011 Wind Technologies Market Report		Table 5.8 and Figure 5.19 from Hydro Study - inflated from 2005 at 2.5%
Heat Rate Btu/kWh	Model						
	Lazard[1]						
	EIA[2]						
Rate Base Book Life	Model		Average of the EIA and Lazard figures.	Average of the EIA and Lazard figures.	Average of the EIA and Lazard figures.	Average of the EIA and Lazard figures.	EIA figure. Though, depending on the type of technology used, a much
	Lazard[1]						
	EIA[2]						
O&M Fixed ($/Yr/kW)	Model		Average of the EIA and Lazard figures.	Average of the EIA and Lazard figures.	Average of the EIA and Lazard figures.	Average of the EIA and Lazard figures.	Equal to EIA figure.
	Lazard[1]						
	EIA[2]						
O&M Variable ($/MWh)	Model - O&M		n/a	n/a	Average of the EIA and Lazard figures.	Average of the EIA and Lazard figures.	Equal to EIA figure.
	Model - Fuel						
	Lazard[1] - O&M						
	Lazard - Fuel ($/MMBtu)						
	EIA[2] - O&M & Fuel						

DC RENEWABLE INPUT VARIABLES	SOURCE / INPUT	Year Dollars	Geo Thermal[5]	Solar Thermal[6]	Biomass	Coal[9]	Nuclear	Natural Gas[10]
DC Model - Levelized $/MWh	**Model**		Geo Thermal is a very efficeint technology from a cost and capacity factor persepctive, however, they locations in which the natural heat resource can be found is very limited which makes the potential for this resource very low in the DC area.	Solar Thermal can vary in scal just like PV does, from residential roof top water heater systems to utility scale solar towers with energy storage capacity. As with PV, LCOE is driven by capacity factor and energy production capability relative to Sunlight which is very regional specific.	Biomass is essentially a green version of traditional burn fuel and turn a generation technology as it's fuel is a renewable resource. The limiting factors for Biomass are 1) the low price of Natural Gas and 2) the expensive cost of transportation of fuel. Unlike most other renewable resources, Biomass is is certainly not intermittent but needs to be run as a base load resource with high capacity factor in order to compete economically.	While Coal is relatively cheap today, there is a negative sociatal stigma to it's perceived dirty production and utilities see large scale investment into coal as a particuarly risky venture due to the potential environmental regulation associated with carbon emissions especially given the Natural Gas alternatives.	The current construction projects in GA and SC will have long lasting effects on the nuclear industry as they are the new prototype for both design and whether or not large scale nucelar is cost effective. A rise in gas prices will assist Nuclear in overcoming it's sociatal stigma and challenging financing challenges. The very attractive element of nuclear is that it is relatively exempt from carbon related penalties should they come into play.	Natural Gas plants have emerged as today's option for new capacity because extraction of the resource via Fracking has become much less costly which has dramatically increased the supply of the fuel. Depending on whether Fracking is eventually lauded as safe or unsafe, Gas prices will respond which will influence the rest of the energy generation environment.
Lazard Study - Levelized $/MWh	Lazard[1]							
EIA Study - Levelized $/MWh	EIA[2]							
Capacity Factor	**Model**		NREL regional specific.	Mid point of given EIA Range.	NREL regional specific.	Avg of EIA &Lazard figures.	Avg of EIA &Lazard figures.	Avg of EIA &Lazard figures.
	Lazard[1]							
	EIA[2,8]							
	NREL (DC or DE)[3]							
Mid-Atlantic Cost Multiplier	EIA[4]							
Overnight Capital Cost $/kW	**Model**		Midpoint of Lazard study, EIA refers to least expensive option in NW	Average of the EIA and Lazard figures.	Average of the EIA and Lazard figures.	Average of the EIA and Lazard figures.	Jacobs Reference	Avg of EIA &Lazard figures.
	Lazard[1]							
	EIA[2]							
	Other						Reference from Dr. Bill Jacobs regarding current Vogtle 3&4 Costs.	
Heat Rate Btu/kWh	**Model**				Average of the EIA and Lazard figures.	Average of the EIA and Lazard figures.	Average of the EIA and Lazard figures.	Average of the EIA and Lazard figures.
	Lazard[1]							
	EIA[2]							
Rate Base Book Life	**Model**		Average of the EIA and Lazard figures.	Average of the EIA and Lazard figures.	Average of the EIA and Lazard figures.	Average of the EIA and Lazard figures.	Typical Licensing Period.	Average of the EIA and Lazard figures.
	Lazard[1]							
	EIA[2]							
O&M Fixed ($/Yr/kW)	**Model**		$65 chosen so that when added to the Variable O&M cost of $35 (midpoint	Average of the EIA and Lazard figures.	Average of the EIA and Lazard figures.	Average of the EIA and Lazard figures.	Average of the EIA and Lazard figures.	Average of the EIA and Lazard figures.
	Lazard[1]							
	EIA[2]							
O&M Variable ($/MWh)	**Model - O&M**		Average of the EIA and Lazard figures.	Average of the EIA and Lazard figures.	Lazard figure was used as it produces a total variable cost along with the implied	The low end of the Lazard figures was used as it produces a total variable	4$ was used as it produces a total variable cost along with the implied fuel cost	The midpoint of the Lazard figures was used as it produces a total variable
	Model - Fuel							
	Lazard[1] - O&M							
	Lazard - Fuel ($/MMBtu)							
	EIA[2] - O&M & Fuel							