Feasibility Study of Economics and Performance of Solar Photovoltaics at the Snohomish County Cathcart Landfill Site in Snohomish County, Washington

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

Dan Olis, James Salasovich, Gail Mosey, and Victoria Healey

Produced under direction of the Environmental Protection Agency (EPA) by the National Renewable Energy Laboratory (NREL) under Interagency Agreement IAG-08-0719 and Task No. WFD3.1001.

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-7A40-58328
April 2013

Contract No. DE-AC36-08GO28308

NATIONAL RENEWABLE ENERGY LABORATORY

Feasibility Study of Economics and Performance of Solar Photovoltaics at the Snohomish County Cathcart Landfill Site in Snohomish County, Washington

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

Dan Olis, James Salasovich, Gail Mosey, and Victoria Healey

Prepared under Task No. WFD3.1001

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.

National Renewable Energy Laboratory
15013 Denver West Parkway
Golden, CO 80401
303-275-3000 • www.nrel.gov

Technical Report
NREL/TP-7A40-58328
April 2013
Contract No. DE-AC36-08GO28308

NOTICE

Cover Photos: (left to right) PIX 16416, PIX 17423, PIX 16560, PIX 17613, PIX 17436, PIX 17721

Printed on paper containing at least 50% wastepaper, including 10% post-consumer waste.

Acknowledgments

The National Renewable Energy Laboratory (NREL) thanks the U.S. Environmental Protection Agency (EPA) for its interest in securing NREL's technical expertise. In particular, NREL and the assessment team for this project are grateful to the Snohomish County Cathcart Landfill facility managers, engineers, and operators for their generous assistance and cooperation.

Special thanks go to Carolyn Gangmark, Lura Matthews, Shea Jones, and Jessica Trice from EPA; Katie Brown, AAAS Science & Technology Policy fellow hosted by EPA; and Manuela Winter from Snohomish County for hosting the site visit. The authors would also like to thank all of those who participated and contributed to the site visit, including representatives of Snohomish County and Snohomish Public Utility District No. 1.

List of Acronyms

AC	alternating current
BOS	balance of system
BPA	Bonneville Power Administration
CHP	combined heat and power
DC	direct current
EPA	U.S. Environmental Protection Agency
FTE	full-time equivalent
JEDI	Jobs and Economic Development Impacts
kW	kilowatt
LCOE	levelized cost of energy
MW	megawatt
NEG	net excess generation
NREL	National Renewable Energy Laboratory
O&M	operations and maintenance
PBI	production-based incentive
PPA	power purchase agreement
PV	photovoltaics
REC	renewable energy certificate
RFP	request for proposals
SNOPUD	Snohomish County Public Utility District
SAM	System Advisor Model
SPE	special purpose entity
SSA	solar services agreement
W	watt

Executive Summary

The U.S. Environmental Protection Agency (EPA), in accordance with the RE-Powering America's Land Initiative, selected the Snohomish County Cathcart Landfill site in Snohomish County, Washington, for a feasibility study of renewable energy production. The National Renewable Energy Laboratory (NREL) provided technical assistance for this project. The purpose of this report is to assess the site for a possible photovoltaic (PV) system installation and estimate the cost, performance, and site impacts of different PV options. In addition, the report recommends financing options that could assist in the implementation of a PV system at the site. This study did not assess environmental conditions at the site.

The Snohomish County Landfill is a municipal landfill that was built in 1980 and was a state-of-the-art facility when it was built. The landfill was closed in 1992 and was capped shortly thereafter. A leachate collection system and landfill gas extraction system were installed at the site. The main contaminants include metals, ammonia nitrogen, chlorine, and sodium.[1] Snohomish County is interested in hosting a PV system on its capped landfill at the Cathcart Way Operations Center to generate clean, renewable energy.

Snohomish County has proposed a PV project up to 5 MW in size. However, the feasibility of a PV system installed is highly impacted by the available area for an array, solar resource, distance to transmission lines, distance to major roads, incentives, and the market. In addition, the operating status, ground conditions, and restrictions associated with redevelopment of landfills impact the feasibility of a PV system. Based on an assessment of these factors, the Snohomish County Cathcart Landfill is physically suitable for deployment of a large-scale PV system, but the project is challenged by the county's low cost of electricity, the site's relatively low electrical load, and the serving utility's 100-kW net-metering limit. Additionally, at present, a viable third-party off-taker for the electricity has not been identified.

The Snohomish County Cathcart Landfill site is approximately 52 acres with about 15.2 acres appropriate for installation of a PV system. While this entire area does not need to be developed at one time due to the feasibility of staging installation as land or funding becomes available, one case in this analysis reflects the solar potential if the total feasible area is used. Based on acreage alone, the site could host up to approximately 3 MW of PV.

The economic feasibility of a potential PV system on the Snohomish County Cathcart Landfill site depends greatly on the purchase price of the electricity produced. The economics of the potential system were analyzed using the current Snohomish County electric rate of $0.075/kWh and incentives available to the site.

Current incentives considered include Snohomish County Public Utility District's (SNOPUD) Solar Express incentive and Washington's production-based incentives (PBI) offered under the Renewable Energy System Cost Recovery Program. The Solar Express incentive provides $500/kW installed up to a $10,000 cap. The state's PBIs vary depending on the project type (community or non-community) and whether in-state manufactured components are used. The incentives range from $0.15/kWh to $1.08/kWh and are paid annually up to a maximum of $5,000/yr per investor through June 2020.

[1] http://www.epa.gov/oswercpa/docs/r10-11-004_snohomish_county.pdf. Accessed August 2012.

As an alternative to the county consuming the electricity produced, a system could sell energy to SNOPUD. However SNOPUD's standard offer under their Small Renewables Program is $0.05–$0.06/kWh for 5 years, which is well below revenue levels required to recover the cost of the system (approximately $0.28/kWh for 25 years). Other third parties might be interested in purchasing energy and may warrant future evaluation. A wholesale project might incur additional costs. For example, SNOPUD and/or Bonneville Power Authority (BPA) would likely add 'wheeling' and other charges to the project to transmit the electricity to market.

Within the state's Renewable Energy Cost Recovery Program, a class of projects categorized as "community solar" is eligible for the highest PBI. Community solar is administered by the hosting site's serving utility. By program rules, the maximum project size is 75 kW and the total obligated program size for each utility is based on the utility's total sales. The Snohomish County Landfill site is served by SNOPUD and the PUD's total community solar program obligated capacity is approximately 108 kW. The program has an estimated available capacity of 86 kW remaining.

Table ES-1 summarizes the system performance and economics of systems of various sizes and benefiting from various incentives. System cost is the total installed cost, including panels, hardware, wiring, inverters, engineering, permits, installation, and utility interconnection. The table shows the annual energy output from each system, the number of average American households that could be powered, and estimated job creation.

The most conventional approach is for the county to purchase a system with county-appropriated funds. A 100-kW system would qualify for net metering (SNOPUD's maximum net-metering limit) and be eligible for two modest incentives, SNOPUD's $10,000 Solar Express incentive and the state's Renewable Energy Cost Recovery Program PBI that would cap at $5,000/yr for 6 years. This system has a simple payback of 72 years and is shown in Table ES-1 as "non-community solar."

A project that qualifies as a community solar project under the state's Renewable Energy Cost Recovery Program can achieve a 25-year payback if the PBI is maximized by using Washington-made solar panels and inverters. There are currently 10 community solar projects in Washington and one in SNOPUD's service territory. Community solar projects are complicated and can be difficult to execute. SNOPUD representatives warn that development of a community solar project can take up to 2 years. Incentive payout under the Renewable Energy Cost Recovery Program expires in June 2020, so the longer it takes to develop a project, the worse the economics become. Community solar projects developed to date have likely used panels and inverters made in Washington because the higher PBI available for these system types greatly improves economics, a payback of 48 years using the lower PBI versus 25 years with the higher PBI when locally fabricated components are used.

A third community solar scenario was explored that exploits federal tax incentives to improve economics. However, this could be a hypothetical case because it is not known to the author of this report if such an arrangement is legal. In addition, a project structure of this type would certainly add complexity and might be impractical to execute even if legally permissible. This is presented in the table as "community solar with WA inverters and modules, $1.08/kWh for

6 years and federal tax incentives" and has an instant payback (0 years) because under this scenario, the county would not have to front any capital and would receive electricity at no cost.

As indicated in Table ES-1, system paybacks have a wide range (0–74 years). However, paybacks between 25 years and 74 years are most likely for a project developed on the Snohomish County Cathcart Landfill. Although the PV panels and rack structure have an expected lifetime of 25 years or more, from a strictly economic perspective, a project with a simple payback of 25 years is not a good investment; it would be cheaper for the county to continue buying electricity from their utility provider than to invest in a PV system.

Table ES-1. Snohomish County Cathcart Landfill PV System Summary

Tie-In Location	System Type	PV System Size	Array Tilt	Annual Output	Number of Houses Powered[b]	Jobs Created[c]	Jobs Sustained[d]
		(kW)	(deg)	(kWh/year)		(job-year)	(job-year)
Cathcart Landfill	Non-community solar	100	20	101,000	9	4.3	0
	Community solar	75	20	75,750	7	3.2	0
	Max. size[a], unknown off-taker	3,000	20	3,030,000	274	78.0	1.0

Tie-In Location	Incentive	System Cost	Incentives	Utility Cost Savings[e]	Annual O&M	Payback Period with Incentives
				($/year)	($/year)	(years)
Cathcart Landfill	Non-community solar, 100kW, $5000/yr max. PBI for 6yrs	$ 400,000	$10,000 SNOPUD rebate + WA PBI	$ 8,080	$ 2,700	72
	Community solar, 75kW, non-WA components, $.30/kWh PBI for 6yrs	$ 300,000	Washington PBI	$ 6,060	$ 2,025	48
	Community solar, 75kW, WA inverters and Modules, $1.08/kWh PBI for 6yrs	$ 487,500	Washington PBI	$ 6,060	$ 2,025	25
	Community solar with WA inverters and Modules, $1.08/kWh for 6yrs and federal tax incentives	$ 487,500	Washington PBI + federal tax incnetives	$ 6,060	$ 2,025	0
	Max. size system, 3MW, uknown offtaker	$ 12,000,000	none	$ 242,400	$ 81,000	74

a Data assume a maximum usable area of 15.2 acres.
b Number of average American households that could hypothetically be powered by the PV system assuming 11,040 kWh/year/household.
c Job-years created as a result of project capital investment including direct, indirect, and induced jobs.
d Jobs (direct, indirect, and induced) sustained as a result of operations and maintenance (O&M) of the system.
e Assumes energy offsets local retail rate of electricity, $.08/kWh

Table ES-1 also includes a 3-MW system, the estimated maximum size that could fit on the site. This case is hypothetical in that the county's current electrical load at Cathcart is 292 kW. A 3-MW system would produce more energy than the county could use, and therefore Snohomish County would not benefit from the added costs. However, because the county's current 292-kW load is greater than the 100-kW net-metering limit, the county may be able to install a system greater than 100 kW but without the benefit of net metering. A system greater than 100 kW would not qualify for SNOPUD's Solar Express incentive, so the economics would be slightly impacted. Also, when a system is operating without net metering, any energy that is generated at any moment in excess of the site's load at that moment will flow back out into the utility's system, and the system owner will not get any credit for that excess energy generated. A careful analysis of the moment-by-moment electrical demand at Carthcart Way Operations Center is necessary to determine if and how much excess energy a system greater than the 100-kW net-metering limit may send to the utility to determine what size would be appropriate and what impact the size will have on overall economic viability. However, the economics will not be better than the 74-year payback presented in the table for the 3-MW case. Costs and utility savings for any system greater than 100 kW are proportional to the values shown for a 3-MW system.

County representatives have indicated that additional Snohomish County development near the landfill will increase the county's power demand nearby. There are also county schools (0.6 miles) and a park (1.0 miles) in the vicinity of the landfill that could use energy generated from a large PV system installed on the landfill. It is not practical, however, to distribute energy generated from a system to a number of different loads located 0.6 miles to 1 mile from the system. This would add costs and extend payback periods beyond 74 years. Virtual net metering is a policy alternative to this scenario that allows aggregation of multiple meter amounts paid by a customer to be credited by energy generated by a system located elsewhere. Washington's net-metering law allows virtual net metering, but the aggregation maximum limit is currently 100 kW per customer. Because the estimate provided by Snohomish County is that the current county loads in the vicinity, plus those from planned future build-out in the area, will have an average annual demand of 4.7 MW, the county would be able to build a 3-MW system on the landfill and make use of all energy produced *if* the virtual-net-metering limit were significantly increased to 3 MW or greater. Under this scenario, given current system costs and energy costs in the region, system paybacks would be 74 years as shown in Table ES-1 for a 3-MW system.

Table of Contents

1 Study and Site Background 1
2 Development of a PV System on Landfills 3
3 PV Systems 5
3.1 PV Overview 5
3.2 Major System Components 6
3.2.1 PV Module 6
3.2.2 Inverter 8
3.2.3 Balance-of-System Components 9
3.2.4 Operation and Maintenance 11
3.3 Siting Considerations 11
4 Proposed Installation Location Information 12
4.1 Snohomish County Cathcart Landfill Site PV System 12
4.2 Utility Considerations 13
4.3 Useable Acreage for PV System Installation 14
4.4 PV Site Solar Resource 14
4.5 Snohomish County Cathcart Landfill Energy Usage 15
4.5.1 Current Energy Use 16
4.5.2 Net Metering 18
4.5.3 Virtual Net Metering 19
5 Economics and Performance 20
5.1 Available Incentives 20
5.2 Assumptions and Input Data for Analysis 21
5.3 SAM Forecasted Economic Performance 22
5.3.1 Case 1 23
5.3.2 Case 2 Through Case 4 23
5.3.3 Summary of the Economic Forecast Results 25
5.3.4 Off-Take, System Size, and Economic Summary 27
5.4 Job Analysis and Impact 31
5.5 Financing Opportunities 32
5.5.1 Owner and Operator Financing 32
5.5.2 Third-Party Developers with Power Purchase Agreements 32
5.5.3 Third-Party “Flip” Agreements 33
5.5.4 Hybrid Financial Structures 33
5.5.5 Solar Services Agreement and Operating Lease 33
5.5.6 Sales/Leaseback 34
5.5.7 Community Solar/Solar Gardens 34
6 Conclusions and Recommendations 36
Appendix A. Provided Site Information 37
Appendix B. Assessment and Calculations Assumptions 42
Appendix C. Solar Access Measurements 43
Appendix D. Results of the System Advisor Model 47
Appendix E. Results of the JEDI Model for 75-kW Community Solar and Site Maximum 3-MW System 50
Appendix F. Contact Information for Local Incentives and Programs 57

List of Figures

Figure 1. Generation of electricity from a PV cell....5
Figure 2. Ground-mounted array diagram....6
Figure 3. Mono- and multi-crystalline solar panels....7
Figure 4. Thin-film solar panels installed on (left) solar energy cover and (middle/right) fixed-tilt mounting system....7
Figure 5. String inverter....9
Figure 6. Aerial view of the feasible area (green) for PV at the Snohomish County Cathcart Landfill site (south is to the left in this image)....12
Illustration done in Google Earth....12
Figure 7. Views of the feasible area for PV at the Snohomish County Landfill....13
Figure A-1. Aerial view of site....37
Figure A-2. Existing infrastructure site map....38
Figure A-3. Sustainable Cathcart proposed project....39
Figure A-4. Gas collection system at Snohomish County Landfill....39
Figure A-5. Tree height in relation to landfill elevation....40
Figure A-6. Garbage depth profiles....40
Figure A-7. Snohomish County Landfill topography....41
Figure A-8. Height above ground surface map....41
Figure C-1. Solar access measurements for south end of Snohomish County Cathcart Landfill PV site, at top edge....43
Figure C-2. Solar access measurements for south edge of Snohomish County Cathcart Landfill PV site, 30 feet north from edge....44
Figure C-3. Solar access measurements for center, adjacent to cars, on Snohomish County Cathcart Landfill PV site....45
Figure C-4. Solar access measurements for east edge of Snohomish County Cathcart Landfill PV site....46
Figure D-1. Monthly energy produced from 3-MW system, fixed-tilt....47
Figure D-2. Monthly energy produced from 75-kW system, fixed-tilt....47
Figure D-3. Levelized cost of energy, no PBI....48
Figure D-4. Levelized cost of energy with PBI of $0.30/kWh for 6 years (base Community Solar program)....48
Figure D-5. Levelized cost of energy with PBI of $1.08/kWh for 6 years (Washington inverters)....49

List of Tables

Table ES-1. Snohomish County Cathcart Landfill PV System Summary vii
Table 1. Energy Density by Panel and System 10
Table 2. Site Identification Information and Specifications 15
Table 3. Performance Results for 1 kW-DC, 20-Degree Fixed-Tilt PV 15
Table 4. Site Electrical Load 16
Table 5. Meters and Rate Schedules 17
Table 6. Existing and Future Loads On and Near Cathcart Way Operations Center 18
Table 7. Installed System Cost Assumptions...21
Table 8. Installed Costs Versus PBI Assumptions for Community Solar Cases 24
Table 9. PV Cost of Energy by Development Scenario 26
Table 10. Existing Community Solar Systems in Washington 29
Table 11. PV System Summary 30
Table 12. JEDI Analysis Assumptions 31
Table B-1. Cost, System, and Other Assessment Assumptions 42
Table E-1. JEDI Model Fixed-Tilt Project Data Summary for 75-kW Community Solar 50
Table E-2. JEDI Model Fixed-Tilt Project Data Summary for 3-MW Site Maximum Size Project 51
Table E-3. JEDI Model Fixed-Tilt Local Economic Impacts Summary for 75 kW Community Solar 52
Table E-4. JEDI Model Fixed-Tilt Local Economic Impacts Summary for 3-MW Site Maximum Size Project 53
Table E-5. JEDI Model Fixed-Tilt Detailed PV Project Data Costs Summary for 75-kW Community Solar 54
Table E-6. JEDI Model Fixed-Tilt Detailed PV Project Data Costs Summary for 3-MW Site Maximum Size Project..54
Table E-7. JEDI Model Fixed-Tilt PV System Annual Operating and Maintenance Costs for 75-kW Community Solar 55
Table E-8. JEDI Model Fixed-Tilt PV System Annual Operating and Maintenance Costs for 3-MW Site Maximum Size Project 56

1 Study and Site Background

The U.S. Environmental Protection Agency (EPA), in accordance with the RE-Powering America's Land initiative, selected the Snohomish County Cathcart Landfill site in Snohomish County, Washington, for a feasibility study of renewable energy production. The National Renewable Energy Laboratory (NREL) provided technical assistance for this project. The purpose of this report is to assess the site for a possible photovoltaic (PV) system installation and estimate the cost, performance, and site impacts of different PV options. In addition, the report recommends financing options that could assist in the implementation of a PV system at the site. This study did not assess environmental conditions at the site.

The Snohomish County Cathcart Landfill is located within the boundary of the county's Cathcart Way Operations Center in Snohomish County, Washington. The county seat is located in the City of Everett, which is approximately 25 miles north of Seattle. The City of Everett has an approximate population of 100,000 people,[2] while the total county population is approximately 700,000.[3]

There are approximately 250 county employees at the site. The site includes office space, vehicle fleet parking and maintenance, industrial wastewater treatment (from landfill leachate collection system), and other county maintenance functions.[4] The site is zoned light industrial.

The 52-acre landfill is owned by the county and maintained by the county's Public Works Solid Waste Division. It holds approximately 3.2 million tons of municipal waste in six cells. The landfill is capped and was active between 1980 and 1992. It is regulated by the Snohomish County Health District and is currently being operated under a 30-year post-closure permit. Any development on the cap will require approval by the Snohomish County Health District.

The cap's vegetative layer and soil are part of the functional design of the landfill. Therefore, the soil on the cap cannot be disturbed, although some material infill might be permitted to level parts of the site. Further, piles cannot be driven into the cap because this will risk puncturing the cap membrane.

The landfill is lined and includes both methane gas and liquid leachate collection systems. The landfill's six cells were filled chronologically from north to south. Cell 6 is at the southernmost end of the landfill, and has the youngest waste, so it therefore has the highest rates of settlement as waste degrades. Site personnel reported that the landfill experienced approximately 7 feet of settlement over the last 10 years. PV development can occur after settlement rates have slowed. Typically, a landfill site will not be developed for PV during the first 10 years after closure; however, each landfill's rate of settlement will have to be studied to make this determination.

[2] http://www.everettwa.org/default.aspx?ID=314.
[3] http://www.ofm.wa.gov/pop/census2010/sf1/data/county/wa_2010_sf1_county_05000US53061.pdf.
[4] http://www1.co.snohomish.wa.us/Departments/Public_Works/Services/Roads/Completed_Projects/Project_RC1081.htm.

The landfill has steep sides, especially at the southern end but has relatively flat regions along the center. Because the cap cannot be penetrated, any PV system will be of the ballasted type, meaning it will rest on top of the earth and be weighted down to resist wind. Because ballasted systems rely on gravity and friction to hold them in place, they are not appropriate for steep slopes with a risk of slippage. Grades of 5% and less are considered appropriate for ballasted PV systems.

The site's serving utility is Snohomish County Public Utility District (SNOPUD). The site is served by 11 electricity usage meters. An existing 4.5-kW PV roof-mounted system is installed on the site on one of the vehicle maintenance buildings. The site's total annual consumption in 2011 was 2,555 MWh, and the calculated average load was 292 kW.

The blended average cost of electricity for Snohomish County (i.e., the rate the county pays the utility) is approximately $0.07–$0.08/kWh, depending on the meter and the rate tariff.

Feasibility assessment team members from NREL, Snohomish County, and EPA conducted a site visit on May 23, 2012, to gather information integral to this feasibility study. The team considered information including solar resource, transmission availability, community acceptance, and ground conditions.

2 Development of a PV System on Landfills

Through the RE-Powering America's Lands initiative, EPA has identified several benefits for siting solar PV facilities on landfills, noting that they:

- Can be developed in place of limited greenfields, preserving the land carbon sink
- Might have environmental conditions that are not well suited for commercial or residential redevelopment and could be adequately zoned for renewable energy
- Generally are located near existing roads and energy transmission or distribution infrastructure
- Could provide an economically viable reuse for sites that may have significant cleanup costs or low real estate development demand
- Can provide job opportunities in urban and rural communities
- Can advance cleaner and more cost effective energy technologies, and reduce the environmental impacts of energy systems (e.g., reduce greenhouse gas emissions).

By taking advantage of these potential benefits, PV can provide a viable, beneficial reuse of land, in many cases, generating significant revenue on a site that would otherwise go unused.

The Snohomish County Cathcart Landfill is owned by Snohomish County, which is interested in sustainable development on the site. For many landfill sites, the local community has significant interest in the redevelopment of the site and community engagement is critical to match future reuse options to the community's vision for the site. Snohomish County plans to develop a sustainable community on county property adjacent to the landfill which would include housing, retail, and a public transportation hub. County officials said that a PV system on the landfill would contribute towards development of their sustainable vision for this property.

The subject site has potential to be used for other functions beyond the solar PV systems proposed in this report. Any potential use should align with the community vision for the site and should work to enhance the overall utility of the property.

Fort Carson Project as a Model

Understanding opportunities studied and realized by other similar sites demonstrates the potential for PV system development. The U.S. Army installed a 2-MW PV system on a 15-acre former landfill at Fort Carson, which is located south of Colorado Springs. The landfill was in operation from 1965 to 1973 and is composed primarily of inert construction debris. The PV system is made up of flat-plate thin film panels that are at a fixed tilt. The project was financed through a power purchase agreement (PPA) and the project cost was $13 million in 2008 when the project was completed. The Fort Carson PV system generates 3,200 MWh of electricity per year, which is enough to power the equivalent of 540 homes (http://www.epa.gov/oswercpa/docs/success_fortcarson_co.pdf).

There are many compelling reasons to consider moving toward renewable energy sources for power generation instead of fossil fuels, including:

- Renewable energy sources offer a sustainable energy option in the broader energy portfolio
- Generating energy without harmful emissions or waste products can be accomplished through renewable energy sources
- Renewable energy can have a net positive effect on human health and the environment
- Deployment of renewable energy bolsters national energy independence and increases domestic energy security
- Fluctuating electric costs can be mitigated by locking in electricity rates through long-term power purchase agreements (PPAs) linked to renewable energy systems.

3 PV Systems

3.1 PV Overview

Solar PV technology converts energy from solar radiation directly into electricity. Solar PV cells are the electricity-generating component of a solar energy system. When sunlight (photons) strikes a PV cell, an electric current is produced by stimulating electrons (negative charges) in a layer in the cell designed to give up electrons easily. The existing electric field in the solar cell pulls these electrons to another layer. By connecting the cell to an external load, this current (movement of charges) can then be used to power the load (e.g., light bulb).

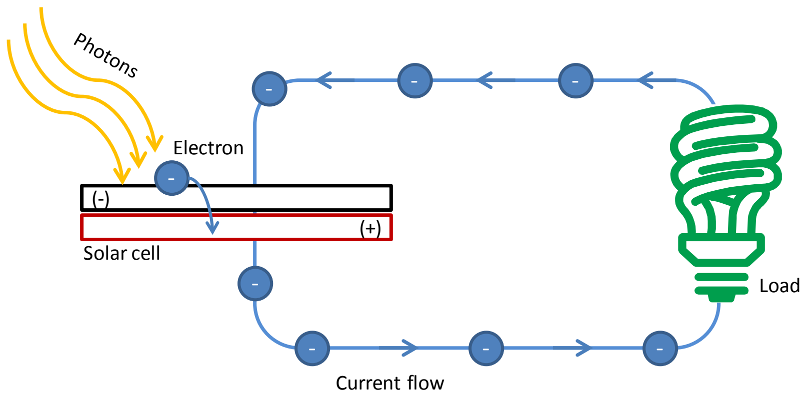

Figure 1. Generation of electricity from a PV cell

Source: EPA

PV cells are assembled into a PV panel or module. PV modules are then connected to create an array. The modules are connected in series and then in parallel as needed to reach the specific voltage and current requirements for the array. The direct current (DC) electricity generated by the array is then converted by an inverter to useable alternating current (AC) that can be consumed by adjoining buildings and facilities or exported to the electricity grid. PV system size varies from small residential (2–10 kW), to commercial (100–500 kW), to large utility scale (10+ MW). Central distribution plants are also currently being built in the 100+ MW scale. Electricity from utility-scale systems is commonly sold back to the electricity grid.

3.2 Major System Components

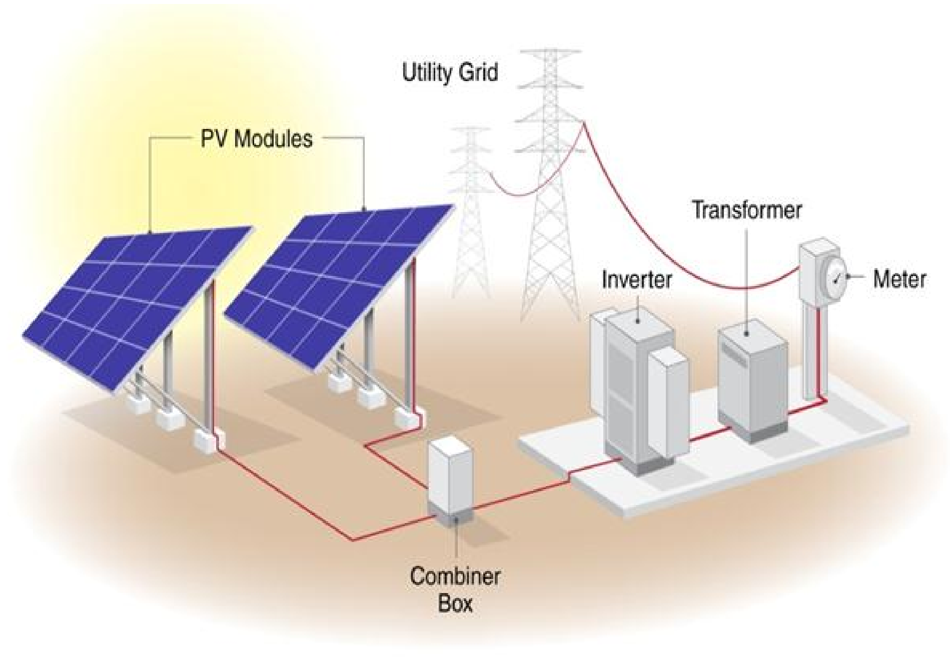

Figure 2. Ground-mounted array diagram

Source: NREL

A typical PV system is made up of several key components including:

- PV modules
- Inverter
- Balance-of-system (BOS) components (e.g., mounting system and wiring).

These, along with other PV system components, are discussed in turn below.

3.2.1 PV Module

Module technologies are differentiated by the type of PV material used, resulting in a range of conversion efficiencies from light energy to electrical energy. The module efficiency is a measure of the percentage of solar energy converted into electricity.

Two common PV technologies that have been widely used for commercial- and utility-scale projects are crystalline silicon and thin film.

3.2.1.1 Crystalline Silicon

Traditional solar cells are made from silicon. Silicon is quite abundant and nontoxic. This technology builds on a strong industry on both material supply (silicon industry) and the product maturity side. This technology has been demonstrated for a consistent and high efficiency over 30 years in the field. The performance degradation, a reduction in power generation due to long-term exposure, is under 1% per year. Silicon modules have a lifespan range of 25–30 years but can keep producing energy beyond this range.

Typical overall efficiency of silicon solar panels is between 12% and 18%. However, some manufacturers of mono-crystalline panels claim an overall efficiency nearing 20%. This range of efficiencies represents significant variation among the crystalline silicon technologies available. The technology is generally divided into mono- and multi-crystalline technologies, which indicates the presence of grain-boundaries (i.e., multiple crystals) in the cell materials and is controlled by raw material selection and manufacturing technique. Crystalline silicon panels are widely used worldwide.

Figure 3 shows two examples of crystalline solar panels: mono- and multi-silicon installed on tracking mounting systems.

Figure 3. Mono- and multi-crystalline solar panels. ***Photos by (left) SunPower Corporation, NREL 23816 and (right) SunPower, NREL 13823***

3.2.1.2 Thin Film

Thin-film PV cells are made from amorphous silicon (a-Si) or non-silicon materials, such as cadmium telluride (CdTe). Thin-film cells use layers of semiconductor material only a few micrometers thick. Due to the unique nature of thin films, some thin-film cells are constructed into flexible modules, enabling such applications as solar energy covers for landfills, such as a geomembrane system. Other thin-film modules are assembled into rigid constructions that can be used in fixed-tilt systems or, in some cases, tracking systems.

The efficiency of thin-film solar cells is generally lower than for crystalline cells. Current overall efficiency of a thin-film panel is between 6% and 8% for a-Si and 11% and 12% for CdTe. Figure 4 shows thin-film solar panels.

Figure 4. Thin-film solar panels installed on (left) solar energy cover and (middle/right) fixed-tilt mounting system. ***Photos by (left) Republic Services Inc., NREL 23817, (middle) Beck Energy, NREL 14726, and (right) U.S. Coast Guard Petaluma Site, NREL 17395***

Industry-standard warranties of both crystalline and thin-film PV panels typically guarantee system performance of 80% of the rated power output for 25 years. After 25 years, they will continue producing electricity at a lower performance level.

3.2.2 Inverter

Inverters convert DC electricity from the PV array into AC and can connect seamlessly to the electricity grid. Inverter efficiencies can be as high as 98.5%.

Inverters also sense the utility power frequency and synchronize the PV-produced power to that frequency. When utility power is not present due to a fault condition, the inverter will stop producing AC power to prevent "islanding" or putting power into the grid while utility workers are trying to fix what they assume is a de-energized distribution system. This safety feature is built into all grid-connected inverters in the market. Electricity produced from the system may be fed to a step-up transformer to increase the voltage to match the grid.

There are two primary types of inverters for grid-connected systems: string and micro-inverters. Each type has strengths and weakness and may be recommended for different types of installations.

String inverters are most common and typically range in size from 1.5–1,000 kW. These inverters tend to be cheaper on a capacity basis, and provide high efficiency and lower O&M costs. String inverters offer various sizes and capacities to handle a large range of voltage output. For larger systems, string inverters are combined in parallel to produce a single point of interconnection with the grid. Warranties typically run between 5 and 10 years with 10 years being the current industry standard. On larger units, extended warranties up to 20 years are possible. Given that the expected life of the PV panels is 25–30 years, an operator can expect to replace a string inverter at least one time during the life of the PV system.

Micro-inverters are dedicated to the conversion of a single PV module's power output. The AC output from each module is connected in parallel to create the array. This technology is relatively new to the market and in limited use in larger systems due to potential increase in O&M associated with significantly increasing the number of inverters in a given array. Current micro-inverters range in size between 175 W and 380 W. These inverters can be the most expensive option per watt of capacity. Warranties range from 10–20 years. Small projects with irregular modules and shading issues typically benefit from micro-inverters.

With string inverters, small amounts of shading on a solar panel will significantly affect the entire array production. Instead, it impacts only that shaded panel if micro-inverters are used. Figure 5 shows a string inverter. However, larger commercial systems are typically sited where shading will not occur, and this is the expectation for the Snohomish County Cathcart Landfill site.

Figure 5. String inverter. ***Photo by Warren Gretz, NREL 07985***

3.2.3 *Balance-of-System Components*

In addition to the solar modules and inverter, a solar PV system consists of other parts called BOS components, which includes:

- Mounting racks and hardware for the panels
- Wiring for electrical connections.

3.2.3.1 Mounting Systems

The array has to be secured and oriented optimally to maximize system output. The structure holding the modules is referred to as the mounting system.

3.2.3.1.1 Ground-Mounted Systems

For ground-mounted systems, the mounting system can be either directly anchored into the ground (via driven piers or concrete footers) or ballasted on the surface without ground penetration. Mounting systems must withstand local wind loads, which range from 90–120 mph range for most areas or 130 mph or more for areas with hurricane potential. Depending on the region, snow and ice loads must also be a design consideration for the mounting system. For landfill applications where the cap cannot be disturbed, ballasted systems are used.

Typical ground-mounted systems can be categorized as fixed tilt or tracking. Fixed-tilt mounting structures consist of panels installed at a set angle, typically based on site latitude and wind conditions, to increase exposure to solar radiation throughout the year. Fixed-tilt systems are used at many landfill sites because settlement of the site will cause problems for mechanical drive components in tracking systems. Fixed-tilt systems have lower maintenance costs but generate less energy (kWh) per unit power (kW) of capacity than tracking systems.

Tracking systems rotate the PV modules so they are following the sun as it moves across the sky. This increases energy output, but also increases maintenance and equipment costs slightly. Single-axis tracking, in which the PV panels are rotated on a single axis, can increase energy output up to 25% or more. With dual-axis tracking, PV is able to directly face the sun all day, potentially increasing output up to 35% or more. Depending on underlying soil conditions, single- and dual-axis trackers may not be suitable due to potential settlement effects, which can interfere with the alignment requirements of such systems. Tracking systems are unlikely to be installed on landfills because of this settling issue.

Table 1. Energy Density by Panel and System

System Type	Fixed-Tilt Energy Density ($DC\text{-}Watts/ft^2$)	Single-Axis Tracking Energy Density ($DC\text{-}Watts/ft^2$)
Crystalline Silicon	4.0	3.3
Thin Film	3.3	2.7

The selection of mounting type is dependent on many factors, including installation size, electricity rates, government incentives, land constraints, latitude, and local weather. Contaminated land applications might raise additional design considerations due to site conditions, including differential settlement.

Selection of the mounting system is also heavily dependent on anchoring or foundation selection. The mounting system design will also need to meet applicable local building code requirements with respect to snow, wind, and seismic zones. Selection of mounting types should also consider frost protection needs, especially in cold regions such as New England. Based on information provided during the site visit to the Snohomish County Cathcart Landfill, penetration of the cap is not permitted. Therefore, a ballasted mounting system is required to be compatible with the landfill closure requirements.

3.2.3.2 Wiring for Electrical Connections

Electrical connections, including wiring, disconnect switches, fuses, and breakers, are required to meet electrical code (e.g., NEC Article 690) for both safety and equipment protection.

In most traditional applications, wiring from (1) the arrays to inverters and (2) inverters to point of interconnection is generally run as direct burial through trenches. In landfill applications, this wiring might be required to run through above-ground conduit due to restrictions with cap penetration or other concerns. Therefore, developers should consider noting any such restrictions, if applicable, in requests for proposals in order to improve overall bid accuracy. Similarly, it is recommended that PV system vendors reflect these costs in the quote when costing out the overall system.

3.2.3.3 PV System Monitoring

Monitoring PV systems can be essential for reliable functioning and maximum yield of a system. It can be as simple as reading values, such as produced AC power, daily kilowatt-hours, and cumulative kilowatt-hours locally on an LCD display on the inverter. For more sophisticated monitoring and control purposes, environmental data, such as module temperature, ambient temperature, solar radiation, and wind speed, can be collected. Remote control and monitoring can be performed by various remote connections. Systems can send alerts and status messages to the control center or user. Data can be stored in the inverter's memory or in external data loggers for further system analysis.

Collection of this basic information is standard for solar systems and not unique to landfill applications.

Weather stations are typically installed with large-scale PV systems. Weather data, such as solar radiation and temperature, can be used to predict energy production, enabling comparison of the target and actual system output and performance, and identification of under-performing arrays. Operators can also use this data to identify required maintenance, shade on panels, and accumulating dirt on panels, for example. Monitoring system data can also be used for outreach and education. This can be achieved with publicly available, online display, wall-mounted systems, or even smart phone applications.

3.2.4 Operation and Maintenance

PV panels typically have a 25-year performance warranty. Inverters, which come standard with a 5-year or 10-year warranty (extended warranties available), would be expected to last 10–15 years. System performance should be verified on a vendor-provided website. Wire and rack connections should be checked annually. This economic analysis uses an annual O&M cost computed as $20/kW/yr, which is based on the historical O&M costs of installed fixed-axis grid-tied PV systems. In addition, it is expected that the system will need replacement inverters in year 15 at a cost of $0.25/W.

3.3 Siting Considerations

PV modules are very sensitive to shading. When shaded (either partially or fully), the panel is unable to optimally collect the high-energy beam radiation from the sun. As explained above, PV modules are made up of many individual cells that all produce a small amount of current and voltage. These individual cells are connected in series to produce a larger current. If an individual cell is shaded, it acts as resistance to the whole series circuit, impeding current flow and dissipating power rather than producing it.

The NREL solar assessment team uses a Solmetric SunEye solar path calculator to assess shading at particular locations by analyzing the sky view where solar panels will be located. By assessing shading, the NREL team can determine if the area is appropriate for solar panels.

In addition to solar access, site topography is also important. For ballasted systems appropriate for landfill sites, slopes less than and equal to a 5% grade are considered appropriate. Ballasted systems on steeper grades could slip with high winds or ground moisture from rain or melting snow.

Following the successful collection of solar resource data using the Solmetric SunEye tool and determination that the site is adequate for a solar installation, an analysis to determine the ideal system size must be conducted. System size depends highly on the average energy use of the facilities on the site, incentives available, and utility policy.

4 Proposed Installation Location Information

This section summarizes the findings of the NREL solar assessment site visit on May 23, 2012.

4.1 Snohomish County Cathcart Landfill Site PV System

As discussed in Section 1, the Snohomish County Cathcart Landfill site is owned and operated by Snohomish County.

In order to get the most out of the ground area available, it is important to consider whether the site layout can be improved to better incorporate a solar system. If there are unused structures, fences, or electrical poles that can be removed, the un-shaded area can be increased to incorporate more PV panels. The Snohomish County landfill is mostly open except for gas collection wells and piping.

Figure 6 shows an aerial view of the Snohomish County Cathcart Landfill site taken from Google Earth; the feasible area for PV is shaded in green and one possible electrical tie-in point for the PV system is indicated. As shown, there are two large expanses of relatively flat, un-shaded land, which makes it a suitable candidate for a PV system. The total area of the site that appears feasible for PV is approximately 15.2 acres, limited by the availability of flat areas, not shading concerns.

Figure 6. Aerial view of the feasible area (green) for PV at the Snohomish County Cathcart Landfill site (south is to the left in this image)

Illustration done in Google Earth

In Snohomish County, Washington, the average global horizontal annual solar resource—the total solar radiation for a given location, including direct, diffuse, and ground-reflected radiation—is 3.73 kWh/m^2/day, while U.S. maximum values of 6.7 kWh/m^2/day exist in the desert southwest. In general, the coastal region of the Northwest is a lower tier region of the country in terms of annual power production potential from PV systems. However, PV is technically suitable anywhere in the United States, and economic viability of PV depends as much on local incentives and local utility prices as it does on local solar resources.

Figure 7 shows various views of the Snohomish County Cathcart Landfill site.

Figure 7. Views of the feasible area for PV at the Snohomish County Landfill. ***Photos by Dan Olis, NREL***

4.2 Utility Considerations

The precise electrical tie-in point will depend on who is the off-taker (i.e., the consumer of the power produced)—Snohomish County or SNOPUD. For offsetting county load at Cathcart, the tie-in will likely be close to the southeast corner of the landfill. A PV system larger than 100 kW requires a SNOPUD System Impact Study and possibly a Facility Study. For larger systems that need to tie in on the utility's distribution system, the interconnection might be on Cathcart Way. SNOPUD indicated that systems greater than 3 MW would require a power system study to determine whether the system would need to tie in to a dedicated feeder and to which substation this feeder would connect.

After the site visit, SNOPUD scheduled a conference call with Snohomish County personnel, an NREL representative, and the Bonneville Power Administration (BPA) to discuss interconnection because SNOPUD resides within BPA's balancing area. During this call, it was learned that SNOPUD and BPA have separate interconnection processes and procedures. Therefore, to interconnect a PV system on the local distribution, Snohomish County or the developer would have to submit dual applications and undertake dual review processes, one for SNOPUD and one for BPA. This is unusual. During this call, the 3-MW maximum size limit for local interconnection was reiterated by BPA. One possible feeder is approximately 2.5 miles west of the site. Others might be closer. It would cost roughly $1 million per mile to run the electrical cables from Cathcart to the appropriate substation identified in the power flow study.

In addition to these technical issues, the energy generated and injected into the distribution system would need a buyer. An analysis of the wholesale market is beyond the scope of this report; however, projects of this type are usually tens to hundreds of megawatts in size. SNOPUD and/or BPA would likely add "wheeling" and other charges to the project to transmit the electricity to market.

4.3 Useable Acreage for PV System Installation

Typically, a minimum of 2 useable acres is recommended to site large-scale PV systems. Useable acreage is typically characterized as "flat to gently sloping" southern exposures that are free from obstructions and get full sun for at least a 6-hour period each day. For example, eligible space for PV includes under-utilized or unoccupied land, vacant lots, and/or unused paved area (e.g. a parking lot or industrial site space), as well as existing building rooftops. As described above, an estimated 15.2 acres of the landfill are appropriate for PV development. More precise analysis of site slope characteristics and shading projections with tree growth will be completed by developers in a formal request for proposals (RFP) process.

4.4 PV Site Solar Resource

The Snohomish County Cathcart Landfill site has been evaluated to determine the adequacy of the solar resource available using both on-site data and industry tools.

The assessment team for this feasibility study collected multiple Solmetric SunEye data points and found a solar access greater than 90% within the boundaries identified. All data gathered using this tool is available in Appendix C.

The predicted array performance was found using PVWatts Version 2[5] for Snohomish County, Washington. Table 2 shows the station identification information, PV system specifications, and energy specifications for the site. For this summary array performance information, a hypothetical system size of 1 kW was used to show the estimated production for each kilowatt so that additional analysis can be performed using the data indicated below. It is scaled linearly to match the proposed system size.

[5] http://www.nrel.gov/rredc/pvwatts/.

Table 2. Site Identification Information and Specifications

Station Identification	
Cell ID	019328
State	Washington
Latitude	47.813° N
Longitude	122.054° W
PV System Specifications	
DC Rating	1.00 kW
DC to AC Derate Factor	0.8
AC Rating	0.770 kW
Array Type	Fixed Tilt
Array Tilt	20°
Array Azimuth	180°
Energy Specifications	
Cost of Electricity	$0.08/kWh

Table 3 shows the performance results for a 20-degree fixed-tilt PV system in Snohomish County, Washington, as calculated by PVWatts.

Table 3. Performance Results for 1 kW-DC, 20-Degree Fixed-Tilt PV

Month	Solar Radiation ($kWh/m^2/day$)	AC Energy (kWh)	Energy Value ($)
1	1.50	32	2.56
2	2.44	51	4.08
3	3.37	79	6.32
4	4.49	103	8.24
5	5.26	123	9.84
6	5.89	130	10.40
7	6.22	141	11.28
8	5.77	130	10.40
9	4.58	101	8.08
10	2.83	64	5.12
11	1.46	31	2.48
12	1.22	24	1.92
Year	3.76	1,010	80.72

4.5 Snohomish County Cathcart Landfill Energy Usage

The Snohomish County Cathcart Landfill site is owned and operated by Snohomish County. The landfill is located with the county's Cathcart Way Operations Center, which is home to about 250 county employees. The site includes office space, vehicle fleet maintenance, industrial waste water treatment (from landfill leachate collection system), and other county maintenance functions. It is important to understand the energy use of the site to aid a full analysis of whether or not energy produced would be sold or if it could offset on-site energy use.

4.5.1 Current Energy Use

The site has 11 SNOPUD meters showing 2011 total energy consumption of 2,555,333 kWh and indicating a demand of approximately 292 kW. The site meters operate under SNOPUD rate tariffs 20 and 25, General Service Medium Load and General Service Small Load, respectively.[6]

The loads at each meter and the production from the existing PV system are shown in Table 4. The site reports the data may be incomplete however; the annual average load is estimated to be 292 kW.

Table 4. Site Electrical Load

2011	Total Consumption (kWh)	PV Meter 546966 (kWh)	Total (kWh)	Average Load (kW)
Jan	210,280		210,280	283
Feb	255,455		255,455	380
Mar	230,360		230,360	310
Apr	222,753		222,753	309
May	212,220		212,220	285
Jun	200,547	-527	200,020	278
Jul	151,780	-544	151,236	203
Aug	189,929	-456	189,473	255
Sep	171,940	-583	171,357	238
Oct	199,613	-291	199,322	268
Nov	226,720	-209	226,511	315
Dec	286,354	-8	286,346	385
Total	**2,557,951**	**-2,618**	**2,555,333**	**292**

The blended average cost of electricity for the county is approximately \$0.07–\$0.08/kWh, depending on the meter and the rate tariff. Rate tariff, peak loads, and consumption by meter are shown in Table 5.

[6] http://www.snopud.com/AboutUs/Rates.ashx?p=1166.

Table 5. Meters and Rate Schedules

Meter ID	Rate Schedule	Peak (kW) 2011	Total Annual Energy Consumption (kWh)	Mean Monthly Energy Consumption (kWh)
129713	20	161.1	769,200	64,100
124513	20	112.2	528,000	44,000
125778	20	332.7	749,400	62,450
140063	20	140.5	170,280	14,190
128320	20	77.9	131,120	10,927
124731	25	-	47,480	3,957
124732	25	-	51,680	4,307
128598	20	-	88,080	7,340
530554	25	-	20,630	1,719
129795	25	82.6	2,080	173
412840	25	-	-	-
PV meter 546966	25	-	(2,618)	(218)
Annual Site Total (kWh)			**2,555,333**	

In addition, other county and school district loads in the region of Catchcart Way Operations Center were provided, plus estimated loads that will result from planned future build-out on and near the site. These are shown in Table 6. The combined total of all regional loads existing and planned is estimated to be 4,698 kW, or 4.7 MW.

Table 6. Existing and Future Loads On and Near Cathcart Way Operations Center

	Annual Usage (kWh)	Average Load (kW)
Cathcart South future estimated		
Retail	6,110,000	697
Park & Ride Vehicle Charging Station	438,000	50
Cathcart West future estimated		
High-Density Housing, 700 units	6,118,000	698
Single-Family Dwelling, 156 units	5,911,723	675
Urban Village	6,223,400	710
Business Park / Light Industrial	10,725,000	1,224
Snohomish School District (existing)		
Glacier Peak High School	2,306,440	263
Little Cedars Elementary School	705,794	81
Other		
Willis Tucker Park (existing)	73,360	8
Cathcart Way Operations Center	2,555,333	292
TOTAL	**41,167,050**	**4,698**

4.5.2 Net Metering

Net metering is an electricity policy for consumers who own renewable energy facilities. "Net," in this context, is used to mean "what remains after deductions"—in this case, the deduction of any energy outflows from metered energy inflows. Under net metering, a system owner receives retail credit for at least a portion of the electricity it generates. As part of the Energy Policy Act of 2005 under Sec. 1251, all public electric utilities are required upon request to make net metering available to their customers:

> (11) NET METERING.—Each electric utility shall make available upon request net metering service to any electric consumer that the electric utility serves. For purposes of this paragraph, the term 'net metering service' means service to an electric consumer under which electric energy generated by that electric consumer from an eligible on-site generating facility and delivered to the local distribution facilities may be used to offset electric energy provided by the electric utility to the electric consumer during the applicable billing period.

Washington's net-metering law,[7] which took effect in 1998, requires utilities to offer net metering to all customers with solar thermal electric, PV, wind, hydroelectric, fuel cells, and combined heat and power (CHP)/cogeneration systems up to 100 kW.

If the renewable energy system generates more energy than is consumed, the net excess generation (NEG) is carried forward as a credit at the customer's retail rate (i.e., \$0.07–\$0.08/kWh for Snohomish County) on the customer's next month bill. In Washington, NEG balances at the end of each 12-month period are surrendered to the utility, without compensation, on April 30 of each year.

Renewable energy certificates (RECs),[8] also known as green certificates, green tags, or tradable renewable certificates, are tradable commodities in the United States that represent proof of electric energy generation from eligible renewable energy resources (renewable electricity). The RECs that are associated with the electricity produced and used on site remain with the customer-generator. RECs sometimes have significant value in states or other regional markets with renewable portfolio standard mandates. There is no compliance REC market in Washington, so the RECs generated by a project in Snohomish County have little monetary value besides what they may garner in voluntary markets, which are too low to influence project economics. If the county were to accept SNOPUD's Solar Express incentive, the RECs from the project are transferred to the utility.

4.5.3 Virtual Net Metering

Washington's net-metering law also allows customers with multiple meters to virtually aggregate loads on each meter into a total customer load to allow a single, larger net-metered renewable energy system offset energy consumed on multiple utility meters. However, meter aggregation is limited to 100 kW total per customer. This means that Snohomish County could install up to 100 kW of PV and receive net-metering benefits that could be applied to some or all of the meters at the Cathcart Way Operations Center or elsewhere in the county.

[7] For the full description see, http://www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=WA01R&re=1&ee=1.

[8] For a description of RECs, see http://apps3.eere.energy.gov/greenpower/markets/certificates.

5 Economics and Performance

The economic performance of a PV system installed on the site is evaluated using a combination of the assumptions and background information discussed previously, a number of industry-specific inputs determined by other studies, and information provided by local developers and other individuals familiar with Washington's incentives. For the analysis, this study uses the NREL System Advisor Model (SAM).[9]

SAM is a performance and economic model designed to facilitate decision making for people involved in the renewable energy industry, ranging from project managers and engineers to incentive program designers, technology developers, and researchers.

SAM makes performance predictions for grid-connected solar, solar water heating, wind, and geothermal power systems and makes economic calculations for both projects that buy and sell power at retail rates, and power projects that sell power through a PPA.

SAM consists of a performance model and financial model. The performance model calculates a system's energy output on an hourly basis (sub-hourly simulations are available for some technologies). The financial model calculates annual project cash flows over a period of years for a range of financing structures for residential, commercial, and utility projects. It calculates the cost of generating electricity based on information entered about a project's location, installation and operating costs, type of financing, applicable tax credits and incentives, and system specifications.

5.1 Available Incentives

The financial viability of a project depends greatly on the incentives offered by utilities and governments. Under SNOPUD's Solar Express program, Snohomish County is eligible to receive $500/kW for PV systems up to a $10,000 cap. The maximum system size allowed under this program is 100 kW-DC, the same as the net-metering limit.

In addition to SNOPUD's Solar Express program, Washington State offers production-based incentives (PBI) under the Renewable Energy System Cost Recovery program. The PBIs vary depending on the project type (community project and non-community projects) and whether in-state manufactured components are used. The incentives range from $0.15–$1.08/kWh and are paid annually up to a maximum of $5,000/yr through June of 2020.

The state program is fairly complicated, but two possible components of the program are applicable to a project sited at Cathcart Operations Center. If the county purchases the system, the system is categorized as a "non-community project," and the production incentives are $0.15/kWh and increase to $0.54/kWh if in-state-manufactured PV panels and inverters are used. If Snohomish County instead hosts a project under the program's Business Owned Community Solar definition, the PBI is $0.30/kWh and increases to $1.08/kWh if in-state-manufactured panels and inverters are used.

[9] For additional information on the NREL System Advisor Model, see https://sam.nrel.gov/cost.

A system that qualifies for the state's non-community PBI is also eligible to receive SNOPUD's Solar Express rebate. But a system that qualifies the state's community solar PBI cannot also claim the Solar Express rebate.[10]

The federal government offers tax incentives to encourage solar PV development. Under investment tax credit (ITC) policy, a taxpayer can deduct 30% of qualified system costs from income earnings. Under the modified, accelerated cost-recovery system (MACRS), a business can claim accelerated depreciation on the renewable energy investment. Because the county does not pay taxes, they would not benefit from these federal incentives if they procure the system themselves. However, under some third-party ownership structures, it is possible the county could reap some of these benefits if they were to enter into a long-term (20 years or more) PPA.

5.2 Assumptions and Input Data for Analysis

Cost of a PV system depends on the system size and other factors, such as geographic location, mounting structure, type of PV module, and local building code requirements. Based on significant cost reductions seen in 2011, the average cost for utility-scale ground-mounted systems have declined from \$4.80/W in the first quarter of 2010 to \$3.20/W in the fourth quarter of 2011. With an increasing demand and supply, potential of further cost reduction is expected as market conditions evolve.

For this analysis, the installed cost of fixed-tilt ground-mounted systems was assumed to be \$3.20/W.

The estimated increase in cost from this baseline for a landfill system is 25%. This increased cost is due to limitations placed on design and construction methods due to the ground conditions at the site. Such limitations include restrictions on storm water runoff, weight loading of construction equipment, inability to trench for utility lines, additional engineering costs, permitting issues, and non-standard ballasted racking systems. The installed system cost assumptions are summarized in Table 7.

Table 7. Installed System Cost Assumptions

System Type	Fixed-Tilt ($/Watt)
Baseline system	3.20
Landfill premium	0.80
Total installed cost	4.00

These prices include the PV array and the BOS components for each system, including the inverter and electrical equipment, as well as the installation cost. A \$4/W price is equivalent to \$4,000/kW. This includes estimated taxes and a national-average labor rate but does not include land cost. The economics of grid-tied PV depend on incentives, the

[10] Details of the state's PBI are available at: http://apps.leg.wa.gov/wac/default.aspx?cite=458-20-273. Details of SNOPUD's Solar Express program are available at: http://www.snopud.com/home/green/solarexpress/photovoltaic.ashx?p=1490.

cost of electricity, the solar resource, and panel tilt and orientation. For this analysis, the cost of conventional electricity was assumed to be $0.08/kW, as reported by Snohomish County based on electric bills for the site.

In the economic analysis, $4/W is the assumed system total installed cost except for Community Solar scenarios using Washington-sourced components. For analysis of Washington's Community Solar program, a $2.50/W cost premium is added to system costs when considering the higher incentives available when Washington-made modules and inverters are used. In this case, the analysis assumes $6.50/W. This cost premium is based on conversations with individuals in Washington familiar with costs of these components.

It is important to consider all applicable incentives or grants to make PV as cost effective as possible. If the PV system is owned by a private tax-paying entity, this entity may qualify for federal tax credits and accelerated depreciation on the PV system. The total potential tax benefits to the tax-paying entity can be as high as 45% of the initial system cost. Because local, state, and federal governments do not pay taxes, private ownership of the PV system would be required to capture tax incentives. The PPA price analysis assumes federal tax incentives are captured. In addition, discussion of the impact of these tax incentives on the Community Solar program is presented; however, it is not clear at this time if or how this can be accomplished. For a Snohomish County purchased system, federal taxes are not included because the county is not a tax-paying entity.

For the purposes of the analyses in this report, the project is expected to have a 25-year life, although the systems can be reasonably expected to continue operation past this point. Inflation is assumed to be 1.5%, and the county's nominal discount rate is assumed to be 5%. The panels are assumed to have a 0.5% per year performance degradation rate, a typical value. The operations and maintenance (O&M) expenses are estimated to be $20/kW/yr for the life of the system. In addition, it is expected that there will be a $250/kW ($0.25/W) charge to O&M in year 15 to replace the inverters associated with the system. A system DC-to-AC conversion of 80% was assumed. This includes energy losses in the inverter, wire losses, PV module losses, soiling, and system availability. The PVWatts system model within SAM was used to calculate expected energy performance and system economics for county-purchased and third-party-financed procurements. In addition, the incentives available under Washington's Community Solar program were considered.

5.3 SAM Forecasted Economic Performance

Using the inputs and assumptions described above, the SAM tool predicts the levelized cost of energy (LCOE). The LCOE is calculated from the initial investment cost, O&M costs, projected energy produced, expected lifetime of the equipment, and an appropriate discount rate. The LCOE for energy produced by a renewable energy system is a useful figure of merit because it allows easy comparison among technology options and system sizes. It also has the same units ($/kWh) as utility purchased electricity, so it is a metric familiar to most consumers.

The LCOE can be thought of as the average cost of energy produced by the PV system. However, the *value* of this energy to the system owner, in economic terms, is equal to the price of the utility-purchased electricity the PV system displaces. If the LCOE produced by the PV system is less than the cost of utility-purchased energy, the system is considered cost effective.

The entire results and summary of inputs to SAM is available in Appendix D.

The project financial results depend on the business arrangement under which the project is developed. The system could be procured directly by Snohomish County or private capital could be sought to improve economics of the project.

5.3.1 Case 1

Case 1 assumes Snohomish County self-finances the project using county appropriated funds. In this case, the county is eligible for a SNOPUD rebate under their Solar Express Rebate Program. The rebate is $500/kW and has a maximum incentive cap of $10,000. The maximum system size eligible is 100 kW-DC—the same size as the net-metering limit.

In addition to SNOPUD's rebate, the system would also be eligible for the state PBI under the Renewable Energy System Cost Recovery Program. In this case, the system can earn incentives as a non-community project with a PBI of $0.15/kWh, which increases to $0.54/kWh if in-state-manufactured PV panels and inverters are used. However, because the maximum PBI payout is $5,000/yr, a 100-kW system will max out the benefit regardless of whether in-state components or cheaper components are used. This case is not eligible for higher PBIs in the program available under the community solar program.

For this case, it is assumed that the maximum size of 100 kW-DC is installed and that the installed costs are consistent with national trends, or $4/W. SNOPUD's rebate program requires use of SNOPUD registered installers. Depending on which and how many installers are registered with SNOPUD, this cost assumption could be optimistic. The $2.50/W cost premium for Washington-sourced components is not included because this program does not have this requirement and using higher cost components would further harm the economics.

The LCOE from a system in this case is estimated to be $0.275/kWh, almost 3.5 times the current cost of electricity. The $10,000 SNOPUD rebate lowered the LCOE about $0.01/kWh while the state PBI dropped it about $0.06/kWh.

5.3.2 Case 2 Through Case 4

Case 2 through Case 4 consider a system developed under Washington's Community Solar program, which has higher PBIs and a means to raise the cap on total payouts well above the $5,000/yr limit imposed on non-community projects. Community Solar projects are limited to a 75 kW-DC maximum size.

For the scenarios considered here, individual community subscribers to a community solar project receive the PBI, while the site host, Snohomish County in this case, would consume the electricity generated. Program rules set an annual cap on PBI payment per subscriber (investor) to $5,000/yr. By bringing in more subscribers, larger total incentive payments can flow into a project, improving economics. The subscribers need to be SNOPUD customers.

The community solar analyses assume the $5,000/yr incentive cap is maximized for each investor and that each investor requires a 7% return on investment for their money. Total subscriber capital that is brought to a project is calculated considering the maximum incentive, PBI, and energy generated per year. It is also assumed that Snohomish County finances the remaining balance of total capital costs using county-appropriated funds.

Washington's PBI expires June 30, 2020. This analysis assumes that the system is installed by June 30, 2014, so that the project could capture 6 years of the PBI.

The community solar program's base PBI is $0.30/kWh but increases to $1.08/kWh for systems with inverters and modules manufactured in Washington. The cost-benefit of higher cost Washington components versus higher-earned PBI is considered here. Table 8 shows the PBI versus system unit cost assumptions. As mentioned above, after consultation with a couple individuals familiar with total installed costs for systems that include Washington-manufactured components, a $2.50/W cost premium is assumed for a total cost of $6.50/W for developments on landfills that use local components.

Table 8. Installed Costs Versus PBI Assumptions for Community Solar Cases

Components Used	Installed cost	PBI
Sourced from international supply chains	$4.00/W	$0.30/kWh
Washington made	$6.50/W	$1.08/kWh

5.3.2.1 Case 2

Case 2 is a 75 kW-DC Community Solar system with panels and inverters purchased through global supply chains. Therefore, a $4/W total system cost consistent with the national average for systems installed on landfills is assumed. The PBI in this case is $0.30/kWh, the base rate PBI offered through the program. The assumption in this case is that the federal tax incentives are not captured by the project.

Under this scenario, the LCOE to the county is approximately $0.235/kWh, or three times the county's current cost of electricity. Subscriber payments would cover 36% of the costs and the county would pay 64%, or $193,000.

5.3.2.2 Case 3

Case 3 is a 75 kW-DC Community Solar project that maximizes the PBI incentive by sourcing Washington-made modules and inverters. In this case, the PBI is $1.08/kWh and installed costs are assumed to be $6.50/W, as described above. This case also does not include any federal tax incentives.

The estimated LCOE is $0.138/kWh, or approximately 40% more than what the county currently pays. This case demonstrates that the community solar rebate for in-state components more than makes up for their additional costs. The cost share is 79% for subscribers and 21% (about $102,000) for the county due to higher PBI payments.

5.3.2.3 Case 4

Case 4 is the same as Case 3, except that it assumes that the business entity that is created to develop the project is able to take advantage of the Community Solar PBI and also capture the federal investment tax credit and accelerated depreciation. ***Note that this case could be a hypothetical scenario because it might be difficult or prohibited by law to develop a project under this scenario***. In this case, it is assumed that an investor with a tax liability pays for the full cost of the system and then collects subscriber payments from individuals in the community. The tax investor gets the tax incentives and upfront subscriber payments, community subscribers get the PBI, and the county as site host gets the electricity.

Under this case, the subscriber fees and tax incentives appear to cover the full system costs so the county would not need to front any capital and would therefore receive energy output at no cost. Note however that, as previously stated, even if it is legally possible, constructing the business deal might be so complex that it cannot be practically executed.

5.3.2.4 Case 5

Case 5 analysis is for a third-party financed and maintained system with energy output sold to the county. This is called a PPA. PPA procurement models are described in a later section. Under this scenario, the system would be sized to best match the site's electricity demands, in the range of 100–300 kW. More discussion of system size and site loads occurs in a later section.

This case also assumes $4/W total installed costs and considers how federal tax incentives influence economics. Under this scenario, neither the Solar Express rebate nor the Community Solar rebates can be captured. Due to their complicated structure and need to attract large institutional investors, systems developed for PPAs are typically greater than a few megawatts in size. However, it is possible that smaller systems could be included in this scenario if bundled together with other smaller projects under a larger umbrella project.

The cost of energy from a system in this case is estimated to be $0.194/kWh under a PPA, more than two times the current cost of electricity. In addition to the high cost of energy under this scenario, Snohomish County could be challenged to find participants developing PPAs for systems this small.

5.3.3 Summary of the Economic Forecast Results

A summary of the results of the case scenarios and economic analyses are shown in Table 9.

Table 9. PV Cost of Energy by Development Scenario

	Development Case	LCOE ($/kWh)	Installed Costs*	Incentives
Case 1	County procurement, non-community solar, 100 kW	$0.275	$4.00/W	$0.50/W, $10,000 max SNOPUD Solar Express Rebate & WA non-community solar PBI $0.15/kWh for 6 years
Case 2	Community Solar, base PBI, 75 kW	$0.235	$4.00/W	WA Community Solar PBI $0.30/kWh for 6 years
Case 3	Community Solar, max PBI, 75 kW	$0.138	$6.50/W	WA Community Solar PBI $1.08/kWh for 6 years
Case 4	Community Solar, max PBI and federal tax incentives, 75 kW	no cost energy	$6.50/W	$1.08/kWh PBI and federal tax incentives
Case 5	PPA, 3 MW or greater	$0.194	$4.00/W	Federal tax incentives

*$4/W is representative of national average costs for landfill development. $6.50/W includes a $2.50/W premium for system using in-state-made components to capture maximum PBI.

In Case 3, "Community Solar, maximum PBI, 75 kW," the capital raised from the investors covers 79% of total system costs, while the county would pay the remaining 21%. This would require 16 investors, each bringing about $24,100 to the project. The county would provide about $102,000 in funds. Under this scenario, the resulting energy would cost Snohomish County approximately $0.14/kWh from the system over the 25-year analysis period.

The results indicate that the economics are very challenging for Cases 1 through 3 and Case 5. From these four cases, Case 3 is the least cost; the county could pursue a sustainable project at cost of about $100,000.

As described above, Case 4 might be hypothetical, but the results suggest the county might be able to participate in a sustainable project without having to provide any upfront capital. If a development firm can legally form and attract interested parties in a timely manner to capture both the PBI and federal tax incentives, the analysis suggests the county could offtake free electricity in exchange for hosting the Community Solar project.

Note, however, that discussions with SNOPUD and others who have done Community Solar projects in Washington have indicated that these projects are complex and could take up to 2 years to execute. So in addition to the cash outlay under Case 4, the county would have to expend personnel resources to see a project to fruition.

Case 5, the PPA scenario, is presented to demonstrate how federal tax incentives are often captured under third-party financing arrangements to allow a non-tax paying entity to still benefit from them. In this case, the county would have to sign a 20-year power contract and pay approximately $0.19/kWh for electricity. Typically, PPAs project sizes are often greater than 10 MW. It is unlikely that a PPA would work considering the cost of energy and limited demand at the site.

5.3.4 Off-Take, System Size, and Economic Summary

The county expressed an interest in maximizing the system's size. A good rule of thumb for PV area footprint requirements is 5–6 acres of land for each 1 MW-DC of system size. The estimate includes spacing between rows, access roads, and area for inverters. With the previous estimate that 15.2 acres of the landfill are appropriate for development, the site will accommodate approximately 2.5–3.0 MW of PV. This is only an estimate. The maximum potential will be determined by developers based on careful analysis of shading from trees, both current and with future growth projections, and site elevation data to find relatively flat land area.

SNOPUD said that a system 3 MW or greater might have to interconnect approximately 2.5 miles to the west of the Cathcart site. This could add up to $1/W on the cost of the installation. Further, the off-taker of the energy produced in this scenario is unidentified. A market analysis would be required (but is not recommended due to poor economic outlook) to find off-takers and determine potential value of energy generated, as well as distribution charges to wheel that power to the potential customers. Systems that sell into wholesale markets are usually one or two orders of magnitude in size greater than the potential described here. With an unknown off-taker, added development costs, and added overhead of distribution tariffs to market the power across BPA's system, it is recommended that this option not be further considered.

In addition to the constraints based on total land appropriate for development and regional interconnection, the maximum size of the system also depends on which entity consumes the power generated. For this site, the most likely off-taker could be either Snohomish County or SNOPUD.

During the site visit, SNOPUD indicated that they would consider purchasing up to 2 MW from the system under their Small Renewables Program but would only be interested in signing a 5-year contract for approximately $0.05–$0.06/kWh for the renewable energy generated. These terms are insufficient to support PV development for Snohomish PUD as off-taker. As can be seen in Case 1 in Table 9, a system of 100 kW has a cost of energy of $0.275/kWh over a 25-year analysis period. A system larger than this would not qualify for SNOPUD's Solar Express Rebate so the cost of energy would increase slightly. If SNOPUD would pay greater than $0.28/kWh for electricity on a 25-year contract, then a project with SNOPUD as the power off-taker would be economically feasible.

As described above, Snohomish County's energy consumption on the Cathcart site is 2,555,333 kWh/year. A 2.53-MW-DC system would provide all the energy the Cathcart site consumes in a year.[11] However, the timing and magnitude of the power output from the system will exceed the site load many hours of the year so excess energy generated would spill over the utility. Net-metering policies allow this excess energy to be captured as a credit; however, the current net-metering limit is only 100 kW. Therefore, the excess

[11] 1 kW of PV generates 1,010 kWh/yr in Snohomish County.

generation would be forfeited to the utility according to Washington's net-metering policy.

Snohomish County could install a system greater than the net-metering limit but limit its size so that little excess energy spills into the grid. The average site load in 2011 was 292 kW-AC. A 365-kW-DC system will produce 292 kW-AC power output under standard conditions. This suggests that Snohomish County could install a 365-kW-DC system and make use of most or all of the power produced. Note that this is only an approximation and that developers would perform a careful analysis of the site's hourly or sub-hourly power demand data before recommending a system size for this scenario. As shown in Case 1 in Table 9, the cost of energy from a 100-kW system, which includes a SNOPUD Solar Express incentive, is $0.275/kWh over a 25-year analysis period. A system greater than 100 kW does not qualify for this incentive so the cost of energy will increase slightly. Energy from a system of this size will cost Snohomish County approximately 3.5 times more than their current cost of electricity.

Another option, and the most economically viable one, is development of a system within the constraints of Washington's Community Solar program. The program rules indicate that a system "will qualify if it generates 75 kW of electricity or less. If the solar energy system or a community solar project produces more than 75 kW the entire project is ineligible for the incentive payment program."[12] The program rules indicate that additional systems up to 75 kW in size can be added at a site as long as the system has a separate inverter, meter, and owners.

Total funding levels that a utility is required to make available for the PBI are 0.5% of the utility's total annual taxable power sales. Additionally, 5% of this total is slated for Community Solar projects of the type considered here ("business owned") according to program rules. A SNOPUD representative indicated that this calculates out to approximately a total program capacity of 108 kW. This representative indicated that there is currently only a single 4-kW Community Solar system in SNOPUD service territory and that this system will expand to 22 kW this year.[13] This leaves an available balance of 86 kW in program capacity for SNOPUD administered business-owned Community Solar. This means that there is room in the program for only one more 75-kW system.

Table 10 shows systems currently installed in Washington under the Community Solar program. The system in SNOPUD's program is the Frances Anderson Community Center in Edmonds.

[12] http://apps.leg.wa.gov/wac/default.aspx?cite=458-20-273.
[13] Phone conversation with Leslie Moynihan, Renewables Program Manager, SNOPUD.

Table 10. Existing Community Solar Systems in Washington[14]

Name	Location	Size (kW)
Bainbridge Island City Hall	Bainbridge	71
Twisp Public Development	Twisp	35
Jefferson Park	Seattle	23
Port Townsend Airport	Port Townsend	4
Clark County Fairgrounds	Ridgefield	25
Frances Anderson Community Center	Edmonds	4
Kingston High School	Kingston	47
Winthrop Community Solar Project	Winthrop	23
Port of Coupeville Greenbank Farm	Greenbank	51
Poulsbo Middle School	Poulsbo	75
	Total	**358 kW**

In summary, the most economic system size is constrained by these factors:

1. 292-kW Cathcart site average load
2. 86-kW Community Solar total program available capacity with SNOPUD
3. 100-kW net-metering limit
4. 75-kW maximum incremental Community Solar project size.

A system size of 75 kW appears to be the most likely project size for Cathcart; however, as stated earlier, Community Solar program rules might allow additional Community Solar project to be developed with certain requirements that might challenge expanded development.

Table 11 provides a summary of system energy production and economic potential.

[14] Provided by Phil Lou by email correspondence. Lou is point of contact for state incentives through Washington State University Extension Energy Program.

Table 11. PV System Summary

Tie-In Location	System Type	PV System Size (kW)	Array Tilt (deg)	Annual Output (kWh/year)	Number of Houses Powered[b]	Jobs Created[c] (job-year)	Jobs Sustained[d] (job-year)
Cathcart Landfill	Non-community solar	100	20	101,000	9	4.3	0
	Community solar	75	20	75,750	7	3.2	0
	Max. size[a], unknown off-taker	3,000	20	3,030,000	274	78.0	1.0

Tie-In Location	Incentive	System Cost	Incentives	Utility Cost Savings[e] ($/year)	Annual O&M ($/year)	Payback Period with Incentives (years)
Cathcart Landfill	Non-community solar, 100kW, $5000/yr max. PBI for 6yrs	$ 400,000	$10,000 SNOPUD rebate + WA PBI	$ 8,080	$ 2,700	72
	Community solar, 75kW, non-WA components, $.30/kWh PBI for 6yrs	$ 300,000	Washington PBI	$ 6,060	$ 2,025	48
	Community solar, 75kW, WA inverters and Modules, $1.08/kWh PBI for 6yrs	$ 487,500	Washington PBI	$ 6,060	$ 2,025	25
	Community solar with WA inverters and Modules, $1.08/kWh for 6yrs and federal tax incentives	$ 487,500	Washington PBI + federal tax incnetives	$ 6,060	$ 2,025	0
	Max. size system, 3MW, unknown offtaker	$ 12,000,000	none	$ 242,400	$ 81,000	74

a *Data assume a maximum usable area of 15.2 acres.*
b Number of average American households that could hypothetically be powered by the PV system assuming 11,040 kWh/year/household.
c Job-years created as a result of project capital investment including direct, indirect, and induced jobs.
d Jobs (direct, indirect, and induced) sustained as a result of operations and maintenance (O&M) of the system.
e Assumes energy offsets local retail rate of electricity, $.08/kWh

The Community Solar program is fairly complicated. Understanding the program and developing a project will require project champions in Snohomish County government and motivated community members. The following bullets summarize program rules and project considerations:

- Community Solar subscribers have to be SNOPUD customers. This limits total possible investor pool.
- SNOPUD's obligation is to provide PBI for up to 108 kW and the program has approximately 86 kW of remaining capacity.
- Community Solar PBI is available through June 30, 2020. The longer it takes to execute a project, the more challenging the economic environment.
- The property that hosts to a Community Solar project has to be served by the utility paying the PBI.
- The rules are complicated and seem to be designed to contain size and encourage local market participation. Large national-development firms are less likely to respond to solicitations for proposals than local developers.
- At this time, it is not clear if a small Community Solar project can attract a tax equity investor for exploitation of the federal tax incentive or whether a project can be legally structured to allow this and still capture the Community Solar PBI.

Contact information for local programs and incentives is provided in Appendix F.

5.4 Job Analysis and Impact

To evaluate the employment and economic impacts of the PV project associated with this analysis, the NREL Jobs and Economic Development Impact (JEDI) models were used.[15] The JEDI models are tools that estimate the economic impacts associated with the construction and operation of distributed generation power plants. JEDI is a flexible input-output tool that estimates, but does not precisely predict, the number of jobs and economic impacts that can be reasonably supported by the proposed facility.

JEDI represents the entire economy, including cross-industry or cross-company impacts. For example, JEDI estimates the impact that the installation of a distributed-generation facility would have on not only the manufacturers of PV modules and inverters but also the associated construction materials, metal fabrication industry, project management support, transportation, and other industries that are required to enable the procurement and installation of the complete system.

For this analysis, inputs, including the estimated installed project cost ($/kW), targeted year of construction, system capacity (kW), O&M costs ($/kW), and location, were entered into the model to predict the jobs and economic impact. It is important to note that the JEDI model does not predict or incorporate any displacement of related economic activity or alternative jobs due to the implementation of the proposed project. As such, the JEDI results are considered gross estimates as opposed to net estimates.

For the Snohomish County Cathcart Landfill site, the values in Table 12 were assumed.

Table 12. JEDI Analysis Assumptions

Input	Community Solar	Maximum Size
Capacity	75 kW	3,000 kW
Placed In Service Year	2013	2013
Installed System Cost	$487,500	$12,000,000
Location	Washington	Washington

Results can be scaled for other project sizes. Using these inputs, the JEDI tool estimates the gross direct and indirect jobs, associated earnings, and total economic impact supported by the construction and continued operation of the proposed PV system.

The estimates of jobs associated with this project are presented as either construction-period jobs or sustained-operations jobs. Each job is expressed as a whole, or fraction, full-time equivalent (FTE) position. An FTE is defined as 40 hours per week for one person for the duration of a year. Construction-period jobs are considered short-term positions that exist only during the procurement and construction periods.

[15] The JEDI models have been used by the U.S. Department of Energy, the U.S. Department of Agriculture, NREL, and the Lawrence Berkeley National Laboratory, as well as a number of universities. For information on the NREL Jobs and Economic Development Impact tool, see: http://www.nrel.gov/analysis/jedi/about_jedi.html.

As indicated in the results of the JEDI model analysis provided in Appendix E, the proposed 75-kW system is estimated to support 3.2 direct and indirect jobs per year for the duration of the procurement and construction period, while a 3-MW system would support 78.1 jobs. Total wages paid to workers during the construction period are estimated to be $168,700 for 75 kW and $4,153,300 for 3 MW. The total economic output is estimated to be $432,500 for 75 kW and $10,647,300 for 3 MW. The annual O&M of a 3 MW PV system is estimated to support 1 FTE per year for the life of the system, while it is negligible for the 75-kW system. The jobs and associated spending are projected to account for approximately:

- $1,500 in earnings and $2,700 in economic activity each year for the next 25 years for a 75-kW system
- $61,700 in earnings and $108,700 in economic activity each year for the next 25 years for a 3-MW system.

5.5 Financing Opportunities

The procurement, development, construction, and management of a successful utility-scale distributed-generation facility can be owned and financed a number of different ways. The most common ownership and financing structures are described below.

5.5.1 Owner and Operator Financing

The owner/operator financing structure is characterized by a single entity with the financial strength to fund all of the solar project costs and, if a private entity, sufficient tax appetite to utilize all of the project's tax benefits. Private owners/operators typically establish a special purpose entity (SPE) that solely owns the assets of the project. An initial equity investment into the SPE is funded by the private entity using existing funds and all of the project's cash flows and tax benefits are utilized by the entity. This equity investment is typically matched with debt financing for the majority of the project costs. Project debt is typically issued as a loan based on each owner's/operator's assets and equity in the project. In addition, private entities can utilize any of federal tax credits offered.

For public entities that choose to finance, own, and operate a solar project, funding can be raised as part of a larger, general obligation bond; as a standalone tax credit bond; through a tax-exempt lease structure, bank financing, grant and incentive programs, or internal cash; or some combination of the above. Certain structures are more common than others, and grant programs for solar programs are on the decline. Regardless, as tax-exempt entities, public entities are unable to benefit directly from the various tax-credit-based incentives available to private companies. This has given way to the now common use of third-party financing structures, such as the PPA.

5.5.2 Third-Party Developers with Power Purchase Agreements

Because many project site hosts do have the financial or technical capabilities to develop a capital intensive project, many times they turn to third-party developers (and/or their investors). In exchange for access to a site through a lease or easement arrangement, third-party developers will finance, develop, own, and operate solar projects utilizing their own expertise and sources of tax equity financing and debt capital. Once the system is installed, the third-party developer will sell the electricity to the site host or local utility via a PPA—a contract to sell electricity at a negotiated rate over a fixed period of time. The PPA typically will be between the third-party developer and the site host if it is a retail "behind-the-meter" transaction or directly with an electric utility if it is a wholesale transaction.

Site hosts benefit by either receiving competitively priced electricity from the project via the PPA or land lease revenues for making the site available to the solar developer via a lease payment. This lease payment can take on the form of either a revenue-sharing agreement or an annual lease payment. In addition, third-party developers are able to utilize federal tax credits. For public entities, this arrangement allows them to utilize the benefits of the tax credits (low PPA price, higher lease payment) while not directly receiving them. The term of a PPA typically vary from 20–25 years.

5.5.3 Third-Party "Flip" Agreements

The most common use of this model is a site host working with a third-party developer who then partners with a tax-motivated investor in a special purpose entity (SPE) that would own and operate the project. Initially, most of the equity provided to the SPE would come from the tax investor and most of the benefit would flow to the tax investor (as much as 99%). When the tax investor has fully monetized the tax benefits and achieved an agreed-upon rate of return, the allocation of benefits and majority ownership (95%) would "flip" to the site host (but not until after the tax benefits are exhausted, within the first 5 years). After the flip, the site host would have the option to buy out all or most of the tax investor's interest in the project at the fair market value of the tax investor's remaining interest.

A "flip" agreement can also be signed between a developer and investors within an SPE, where the investor would begin with the majority ownership. Eventually, the ownership would flip to the developer once investors' return is met.

5.5.4 Hybrid Financial Structures

As the solar market evolves, hybrid financial solutions have been developed in certain instances to finance solar projects. A particular structure, nicknamed "The Morris Model" after Morris County, New Jersey, combines highly rated public debt, a capital lease, and a PPA. Low-interest public debt replaces more costly financing available to the solar developer and contributes to a very attractive PPA price for the site hosts. New markets tax credits have been combined with PPAs and public debt in other locations, such as Denver and Salt Lake City.

5.5.5 Solar Services Agreement and Operating Lease

The solar services agreement (SSA) and operating lease business models have been predominately used in the municipal and cooperative utility markets due to its treatment of tax benefits and the rules limiting federal tax benefit transfers from non-profit to for-profit companies. Under IRS guidelines, municipalities cannot enter capital leases with for-profit entities when the for-profit entities capture tax incentives. As a result, a number of business models have emerged as a work-around to this issue. One model is the SSA, wherein a private party sells "solar services" (i.e., energy and RECs) to a municipality over a specified contract period (typically long enough for the private party to accrue the tax credits). The non-profit utility typically purchases the solar services with either a one-time up-front payment equal to the turn-key system cost minus the 30% federal tax credit or purchase the services in annual installments. The municipality may buy out the system once the third party has accrued the tax credits, but due to IRS regulations, the buyout of the plant cannot be included as part of the SSA (i.e., the SSA cannot be used as a vehicle for a sale and must be a separate transaction).

Similar to the SSA, there are a variety of lease options that are available to municipalities that allow the capture of tax benefits by third-party owners, which result in a lower cost to the municipality. These include an operating lease for solar services (as opposed to an equipment capital lease) and a complex business model called a “sales/leaseback.” Under the sales/leaseback model, the municipality develops the project and sells it to a third-party tax equity investor who then leases the project back to the municipality under an operating lease. At the end of the lease period, and after the tax benefits have been absorbed by the tax equity investor, the municipality can purchase the solar project at fair market value.

5.5.6 Sales/Leaseback

In the widely accepted sales/leaseback model, the public or private entity would install the PV system, sell it to a tax investor, and then lease it back. As the lessee, they would be responsible for operating and maintaining the solar system as well as have the right to sell or use the power. In exchange for use of the solar system, the public or private entity would make lease payments to the tax investor (the lessor). The tax investor would have rights to federal tax benefits generated by the project and the lease payments. Sometimes, the entity is allowed to buy back the project at 100% fair market value after the tax benefits are exhausted.

5.5.7 Community Solar/Solar Gardens

The concept of “community solar” is one in which the costs and benefits of one large solar project are shared by a number of participants. A site owner may be able to make the land available for a large solar project, which can be the basis for a community solar project. Ownership structures for these projects vary, but the large projects are typically owned or sponsored by a local utility. Community solar gardens are distributed solar projects wherein utility customers have a stake via a prorated share of the project’s energy output. This business model is targeted to meet demand for solar projects by customers who rent/lease homes or businesses, do not have good solar access at their site, or do not want to install solar systems on their facilities. Customer prorated shares of solar projects are acquired through a long-term transferrable lease of one or more panels, or they subscribe to a share of the project in terms of a specific level of energy output or the energy output of a set amount of capacity. Under the customer lease option, the customer receives a billing credit for the number of kilowatt-hours their prorated share of the solar project produces each month; it is also known as virtual net metering. Under the customer subscription option, the customers typically pay a set price for a block of solar energy (i.e., 100 kWh per-month blocks) from the community solar project. Other models include monthly energy outputs from a specific investment dollar amount or a specific number of panels.

Community solar garden and customer subscription-based projects can be solely owned by the utility, solely owned by third-party developers with facilitation of billing provided by the utility, or be a joint venture between the utility and a third-party developer leading to eventual ownership by the utility after the tax benefits have been absorbed by the third-party developer.

There are some states that offer solar incentives for community solar projects, including Washington State (production incentive) and Utah (state income tax credit). Community solar is known as solar gardens depending on the location (e.g., Colorado).

6 Conclusions and Recommendations

The site locations considered for a solar PV system in this report are feasible areas in which to implement solar PV systems. Available acreage and local utility infrastructure could potentially support up to 3 MW of PV on the Snohomish County Landfill. The original project proposal was for 5 MW, but a system of this size will not likely fit due to insufficient area of flat regions. However, site electrical loads and policy and program size limits suggest a 100-kW net-metered system or a 75-kW community solar system are more reasonable and are the most economical but still have poor project economics. The systems in these cases are likely to have paybacks periods of 25 years or more. Although a 3-MW system would fit on the site, current net-metering limits and lack of other identified off-taker make a system of this size unviable.

As summarized in Section 5, the economic analysis completed using SAM predicts a likely LCOE of $0.14–$0.28/kWh, depending on what local incentives are captured and to what degree. A 75-kW community solar project that maximizes the PBI but is unable to exploit federal tax incentives has an estimated LCOE of $0.14/kWh and a 25-year simple payback. If a project can incorporate federal tax incentives and attract a tax equity investor, Snohomish County could receive no-cost power in exchange for hosting the project. However, this scenario seems unlikely due to uncertainty over the legality of this type of project structure, the added complexity it presents, and that projects of this type were not described by local developers and utility representatives as having been done to date.

If the county is interested in pursuing a project, it should find a strong project champion within county government and expect a challenge navigating the project to completion. The next steps are to develop an internal consensus on whether the county is willing to take on a renewable energy project that is not supported by economics, decide on whether to purchase a 100-kW system or pursue a more complicated 75-kW community solar project, and then move forward with a request for proposals to see what the market will offer.

Snohomish County's enthusiasm combined with the state's high PBIs for locally manufactured modules and inverters are the two strong drivers that counterbalance the relatively low cost of electricity. This report finds that a PV system is a possible use for the site, but that project economics are unfavorable.

Appendix A. Provided Site Information

Figure A-1. Aerial view of site

Source: Snohomish County Public Works

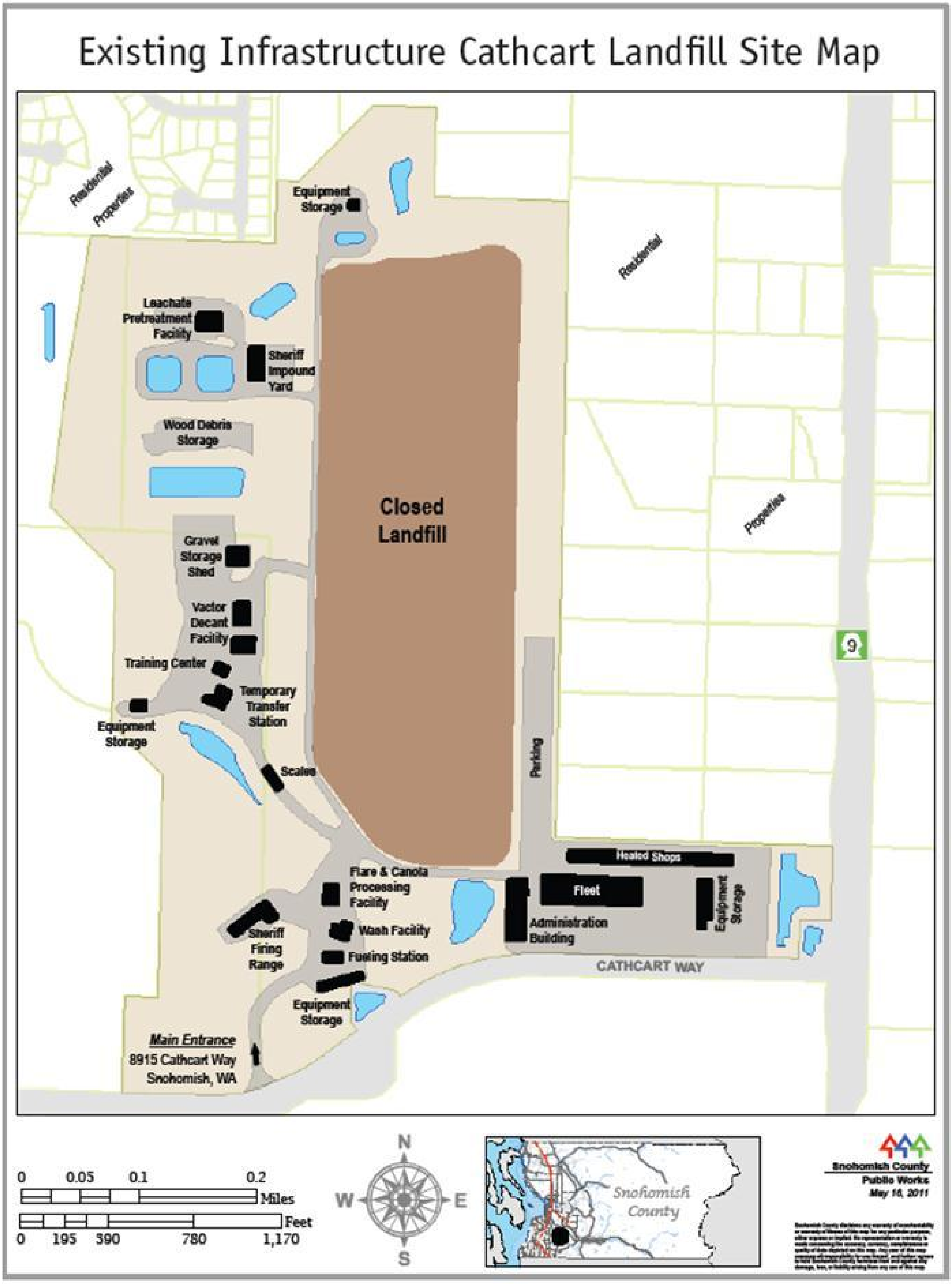

Figure A-2. Existing infrastructure site map

Source: Snohomish County Public Works

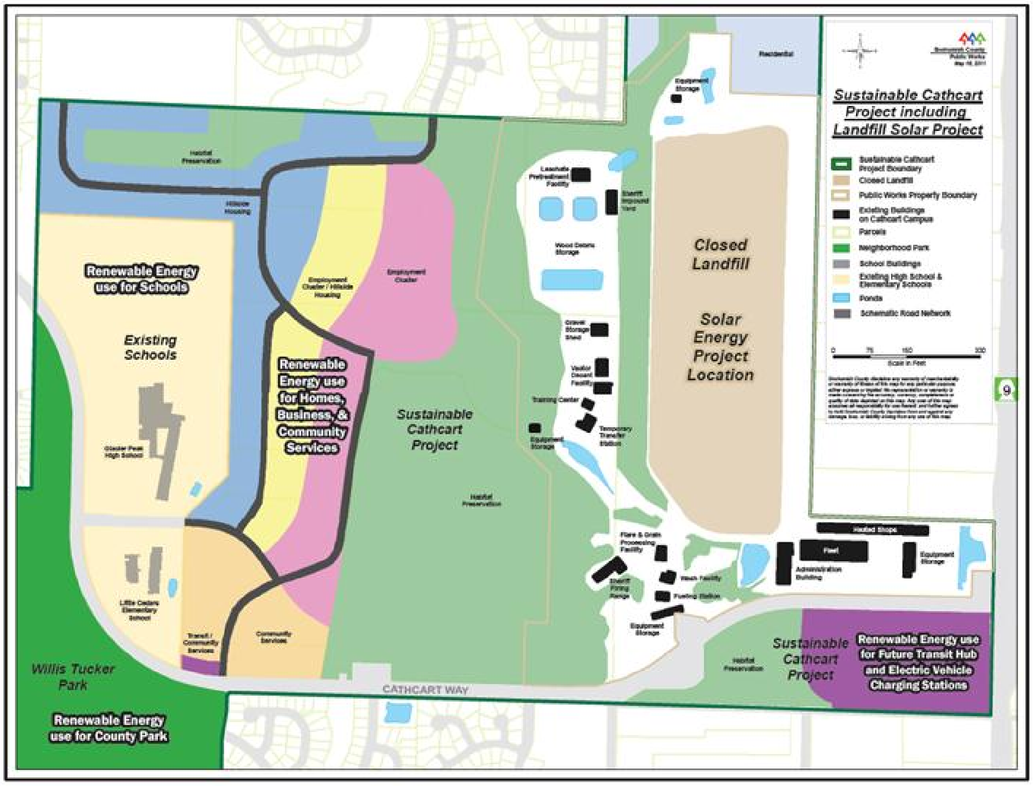

Figure A-3. Sustainable Cathcart proposed project

Source: Snohomish County Public Works

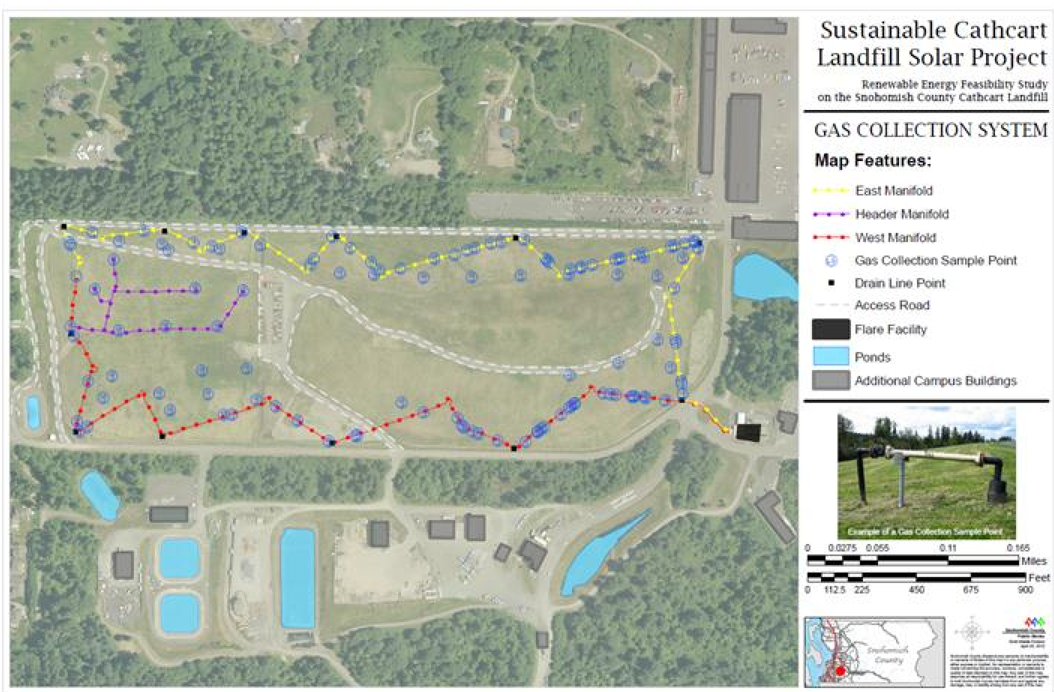

Figure A-4. Gas collection system at Snohomish County Landfill

Source: Snohomish County Public Works

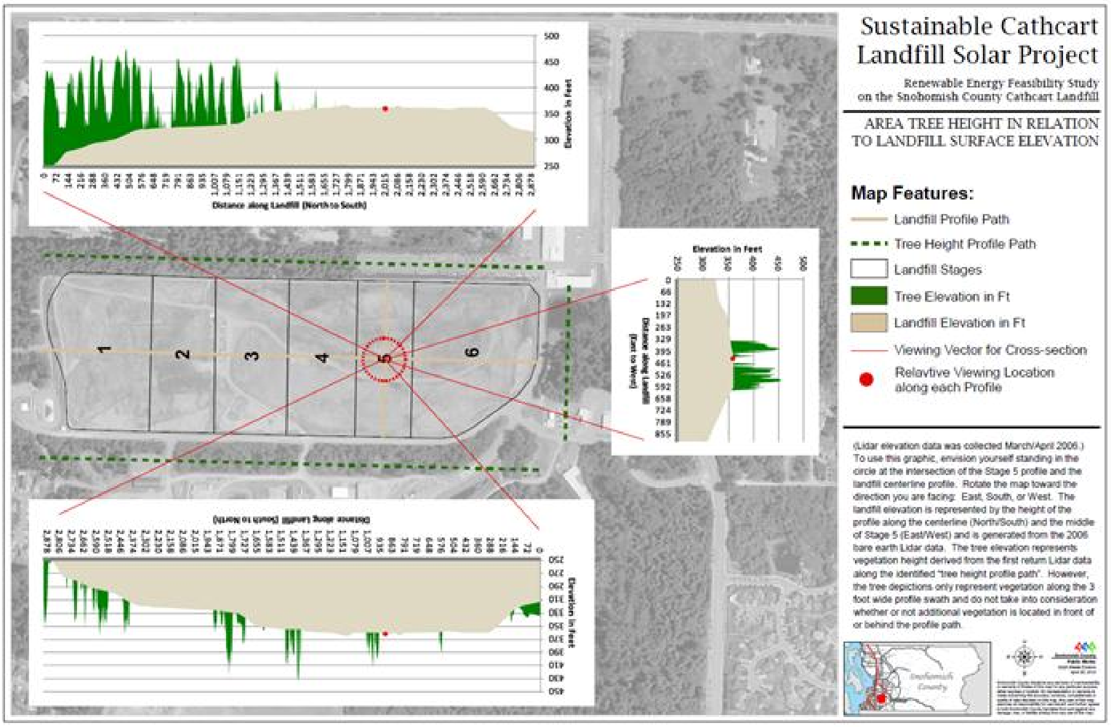

Figure A-5. Tree height in relation to landfill elevation

Source: Snohomish County Public Works

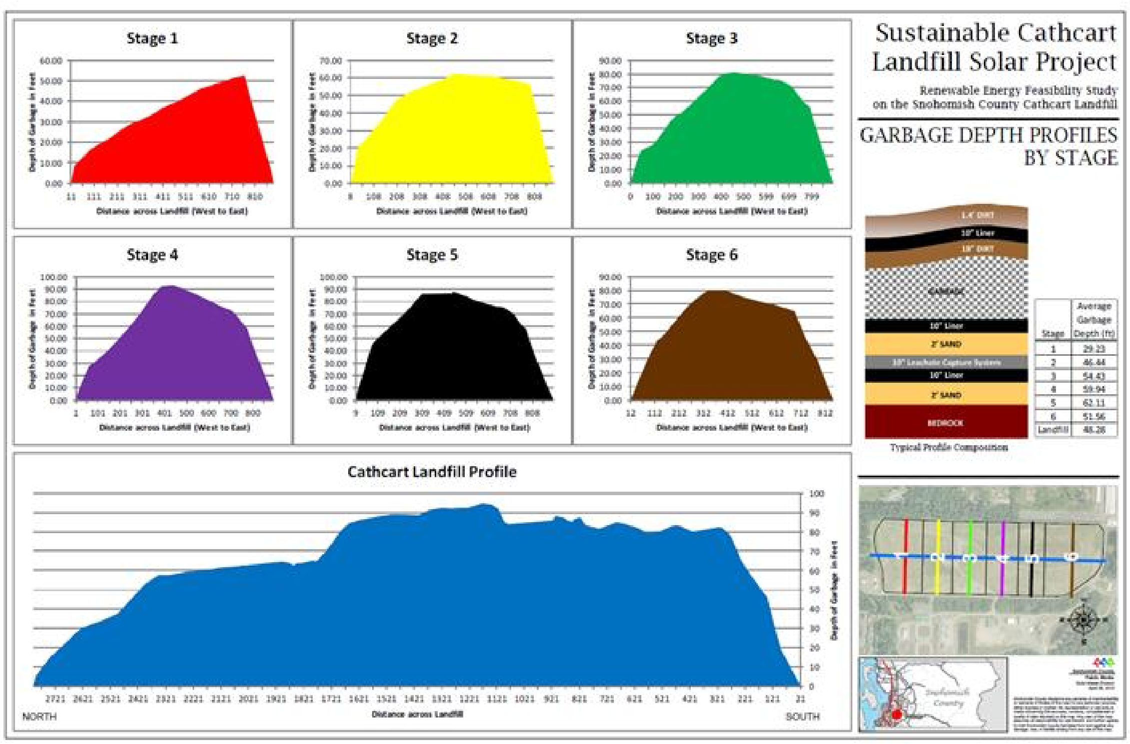

Figure A-6. Garbage depth profiles

Source: Snohomish County Public Works

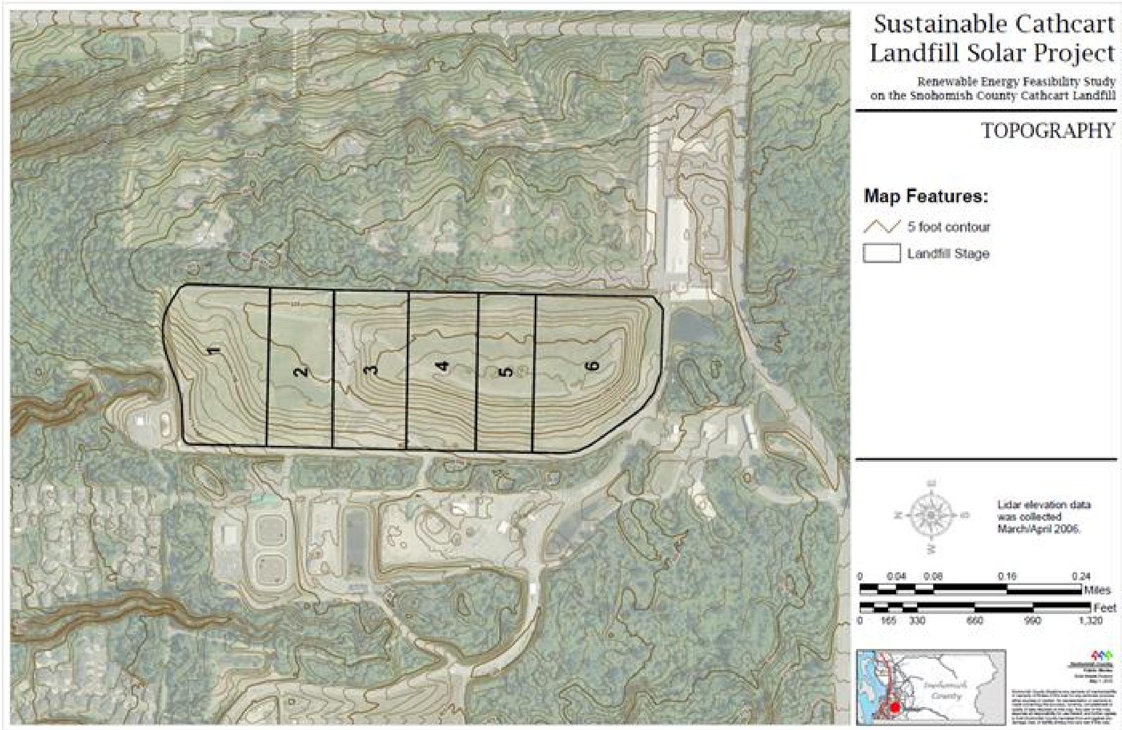

Figure A-7. Snohomish County Landfill topography

Source: Snohomish County Public Works

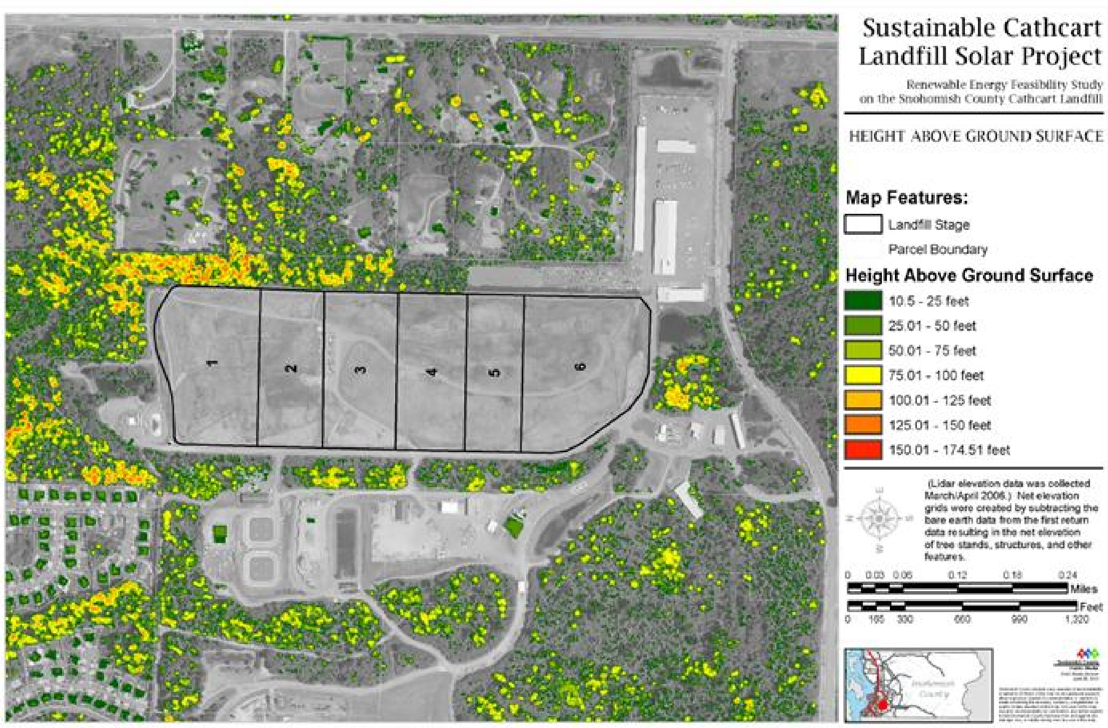

Figure A-8. Height above ground surface map

Source: Snohomish County Public Works

Appendix B. Assessment and Calculations Assumptions

Table B-1. Cost, System, and Other Assessment Assumptions

Cost Assumptions			
Variable	**Quantity of Variable**	**Unit of Variable**	
Cost of Site Electricity	0.08	$/kWh	
Annual O&M (fixed)	20	$/kW/yr	
Inverter Replacement (Year 15)	250	$/kW	
System Assumptions			
System Type	**Annual energy kWh/kW**	**Installed Cost ($/W)**	**Energy Density (W/sq. ft.)**
Ground Fixed	1,010	$4.00	4.0
Assumptions & Conversions			
	1 acre =	43,560 ft^2	
	1 MW =	1,000,000 W	
	Ground utilization	90% of available area	

Appendix C. Solar Access Measurements

5/23/2012 11:12 – South end of landfill, edge of top

Panel Orientation: Tilt=48° -- Azimuth=180° -- **Skyline Heading=178°**
Solar Access: Annual: 97% -- Summer (May-Oct): 100% -- Winter (Nov-Apr): 93%

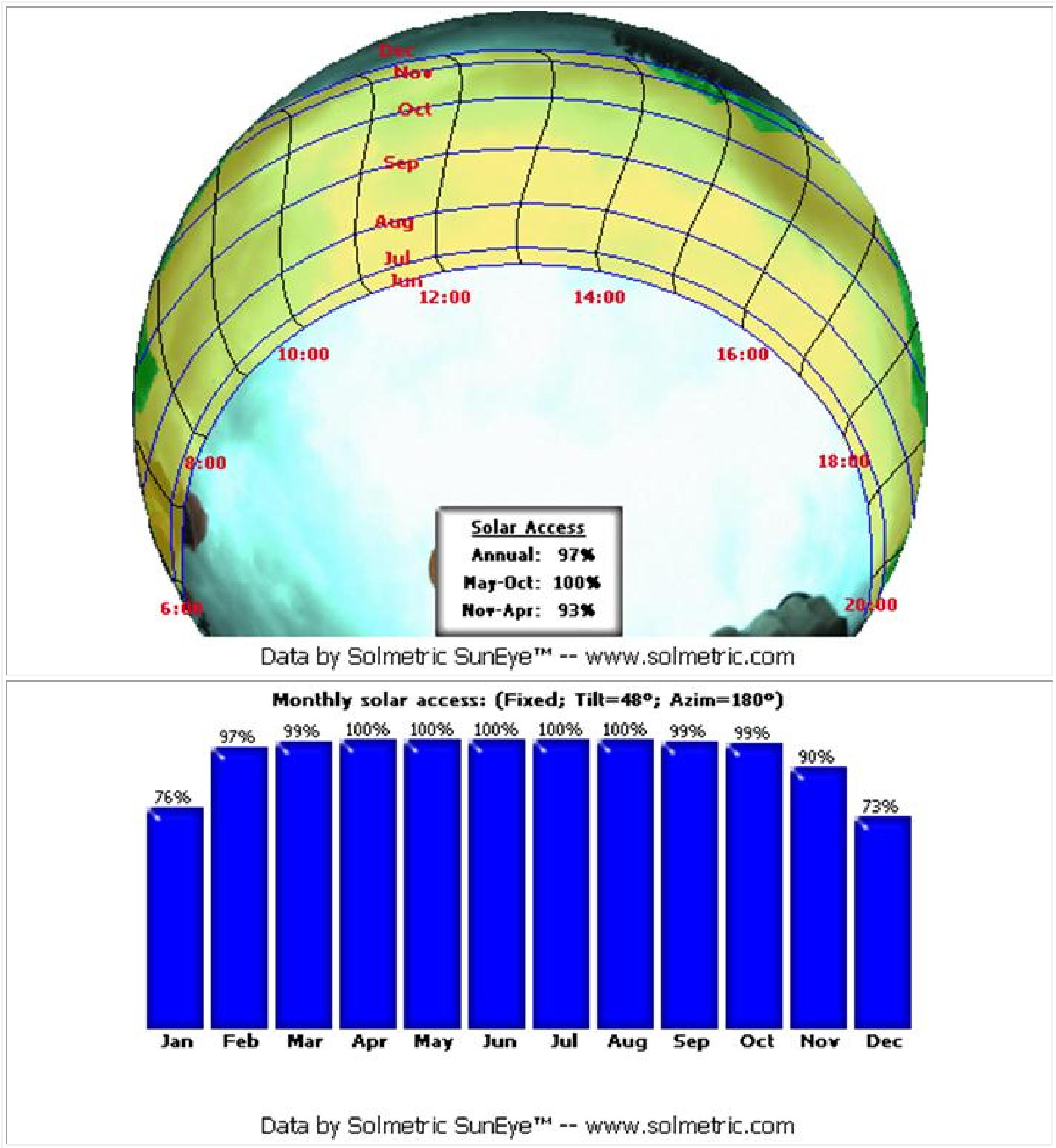

Figure C-1. Solar access measurements for south end of Snohomish County Cathcart Landfill PV site, at top edge

5/23/2012 11:12 – South edge of landfill, about 30 ft from edge

Panel Orientation: Tilt=48° -- Azimuth=180° -- **Skyline Heading=183°**

Solar Access: Annual: 99% -- Summer (May-Oct): 100% -- Winter (Nov-Apr): 96%

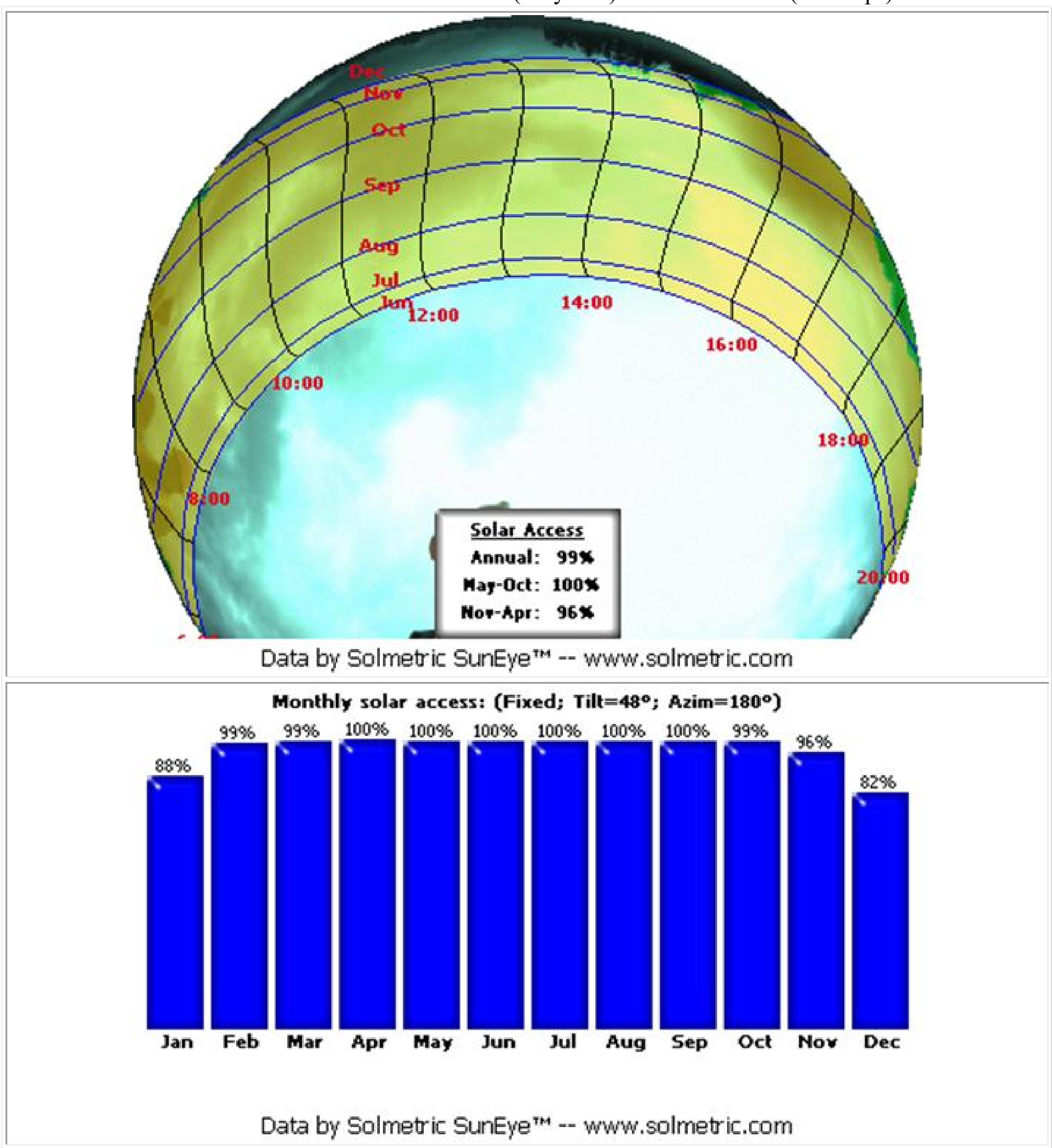

Figure C-2. Solar access measurements for south edge of Snohomish County Cathcart Landfill PV site, 30 feet north from edge

5/23/2012 12:15 – Landfill center, adjacent to cars on landfill

Panel Orientation: Tilt=48° -- Azimuth=180° -- **Skyline Heading=172°**
Solar Access: Annual: 95% -- Summer (May-Oct): 97% -- Winter (Nov-Apr): 92%

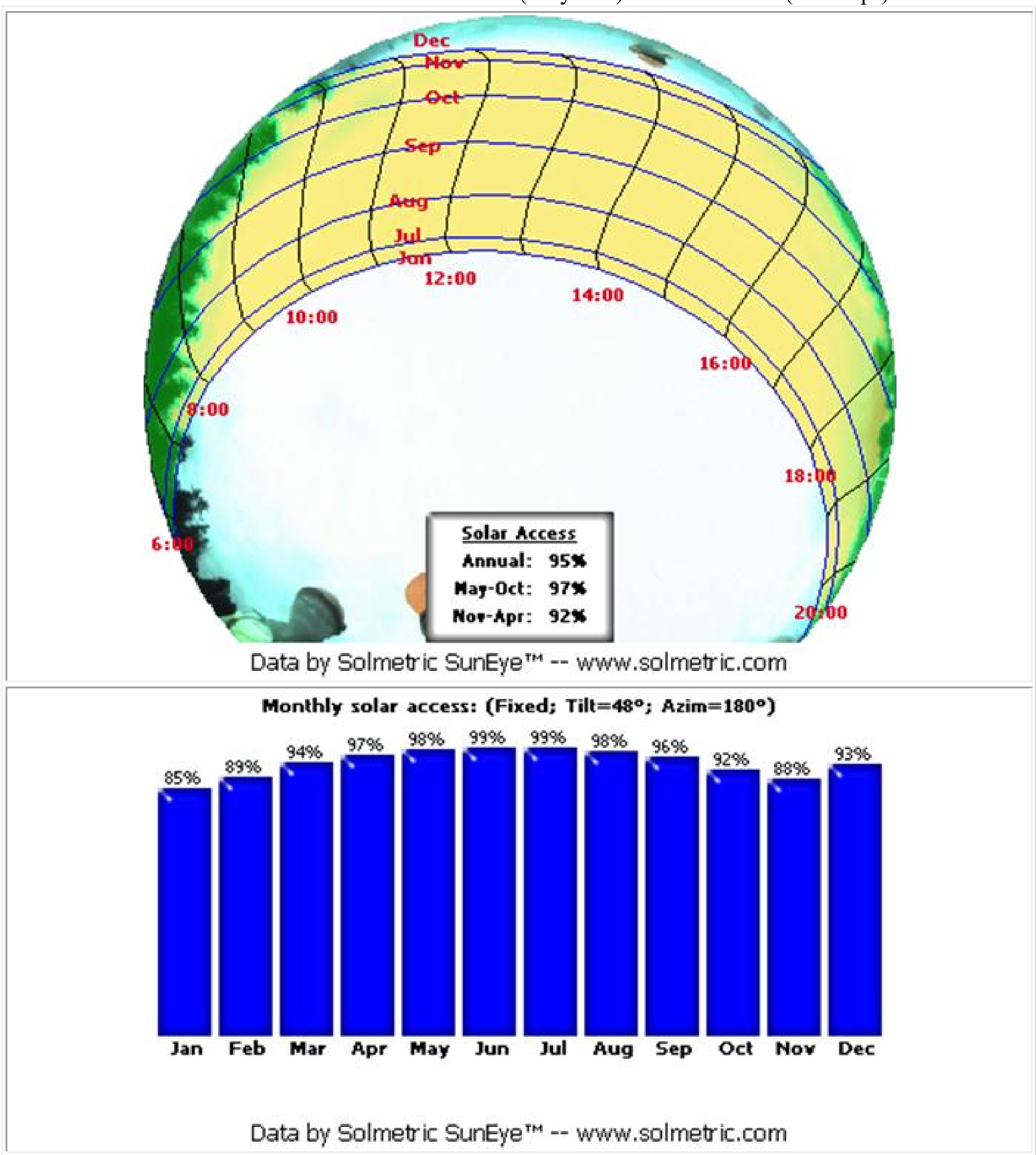

Figure C-3. Solar access measurements for center, adjacent to cars, on Snohomish County Cathcart Landfill PV site

5/23/2012 12:34 -- 45deg52'3"N, 12deg7'6"W (East edge)

Panel Orientation: Tilt=48° -- Azimuth=180° -- **Skyline Heading=179°**
Solar Access: Annual: 98% -- Summer (May-Oct): 99% -- Winter (Nov-Apr): 96%

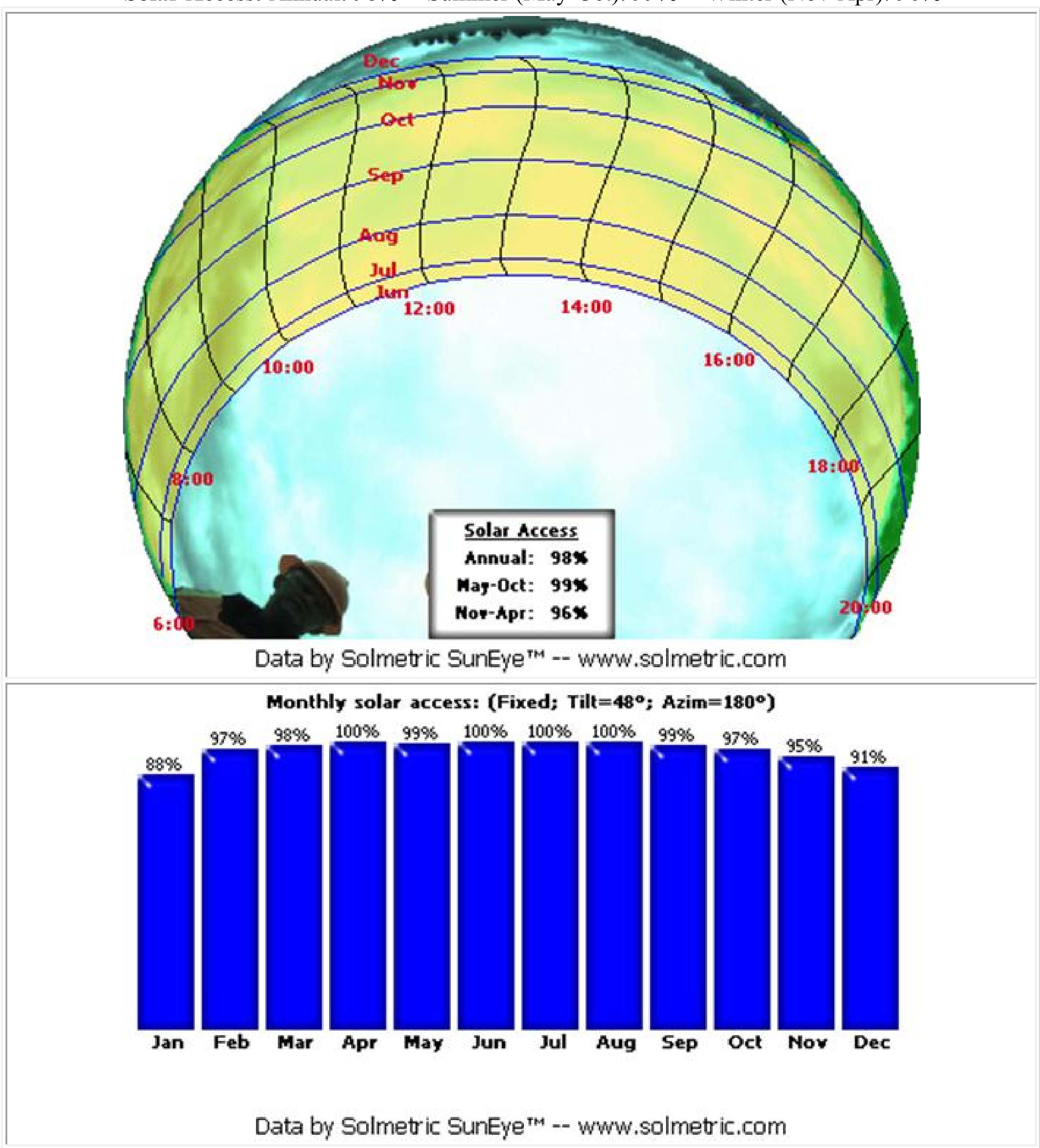

Figure C-4. Solar access measurements for east edge of Snohomish County Cathcart Landfill PV site

Appendix D. Results of the System Advisor Model

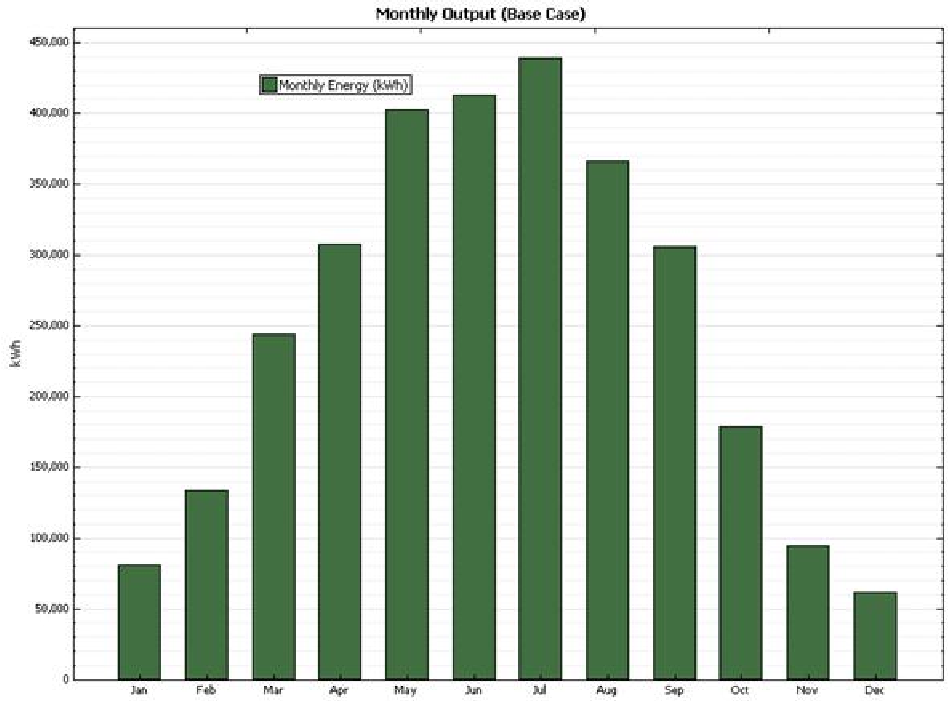

Figure D-1. Monthly energy produced from 3-MW system, fixed-tilt

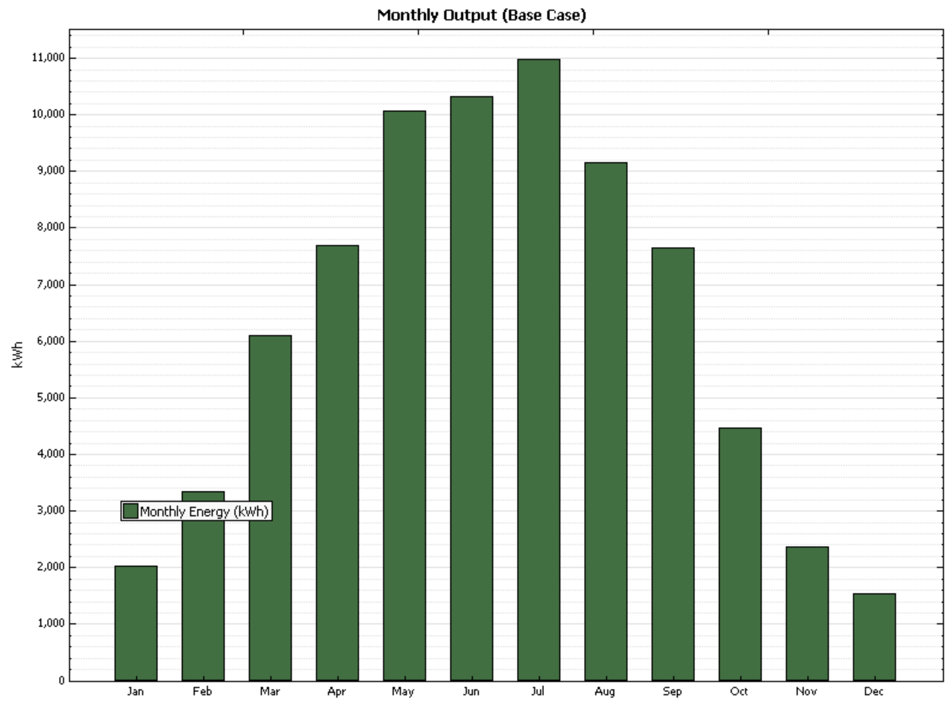

Figure D-2. Monthly energy produced from 75-kW system, fixed-tilt

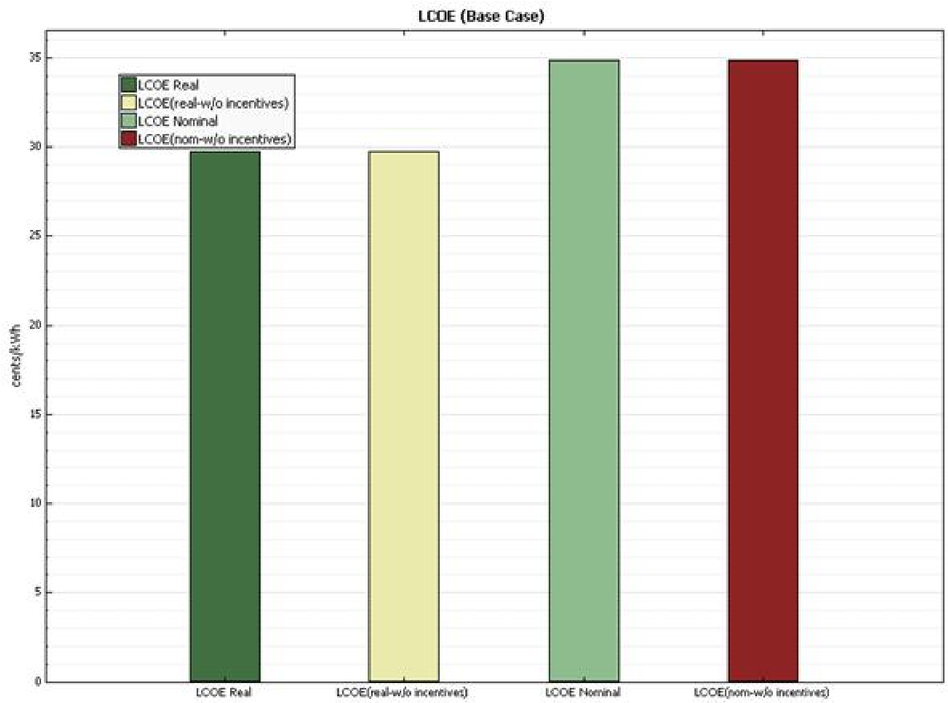

Figure D-3. Levelized cost of energy, no PBI

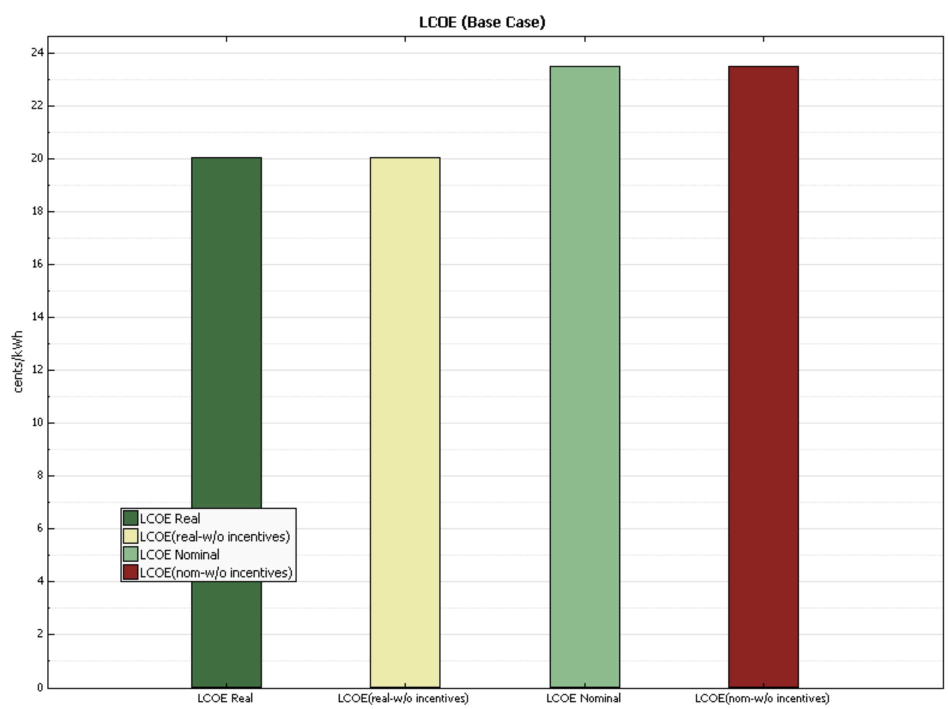

Figure D-4. Levelized cost of energy with PBI of $0.30/kWh for 6 years (base Community Solar program)

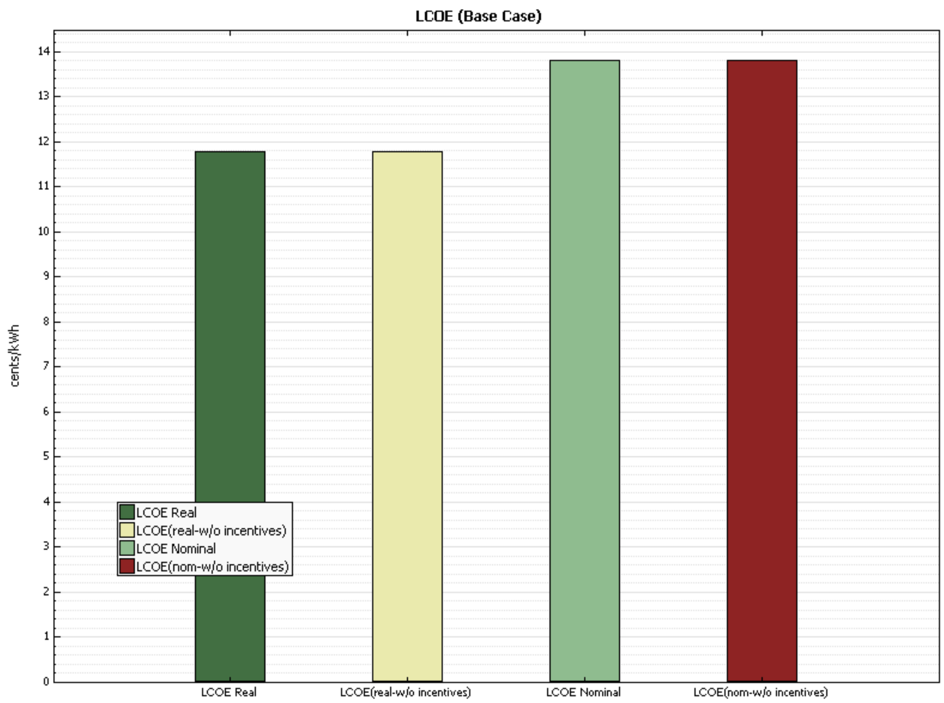

Figure D-5. Levelized cost of energy with PBI of $1.08/kWh for 6 years (Washington inverters)

Appendix E. Results of the JEDI Model for 75-kW Community Solar and Site Maximum 3-MW System

Table E-1. JEDI Model Fixed-Tilt Project Data Summary for 75-kW Community Solar

Project Location	WASHINGTON
Year of Construction or Installation	2013
Average System Size - DC Nameplate Capacity (KW)	75.0
Number of Systems Installed	1
Project Size - DC Nameplate Capacity (KW)	75.0
System Application	Utility
Solar Cell/Module Material	Crystalline Silicon
System Tracking	Fixed Mount
Total System Base Cost ($/$KW_{DC}$)	$6,500
Annual Direct Operations and Maintenance Cost ($/kW	$25.00
Money Value - Current or Constant (Dollar Year)	2012
Project Construction or Installation Cost	$487,500
Local Spending	$225,169
Total Annual Operational Expenses	$58,425
Direct Operating and Maintenance Costs	$1,875
Local Spending	$1,725
Other Annual Costs	$56,550
Local Spending	$0
Debt Payments	$0
Property Taxes	$0

Table E-2. JEDI Model Fixed-Tilt Project Data Summary for 3-MW Site Maximum Size Project

Project Location	WASHINGTON
Year of Construction or Installation	2013
Average System Size - DC Nameplate Capacity (KW)	3,000.0
Number of Systems Installed	1
Project Size - DC Nameplate Capacity (KW)	3,000.0
System Application	Utility
Solar Cell/Module Material	Crystalline Silicon
System Tracking	Fixed Mount
Total System Base Cost ($/$KW_{DC}$)	$4,000
Annual Direct Operations and Maintenance Cost ($/kW	$25.00
Money Value - Current or Constant (Dollar Year)	2012
Project Construction or Installation Cost	$12,000,000
Local Spending	$5,542,616
Total Annual Operational Expenses	$1,467,000
Direct Operating and Maintenance Costs	$75,000
Local Spending	$69,000
Other Annual Costs	$1,392,000
Local Spending	$0
Debt Payments	$0
Property Taxes	$0

Table E-3. JEDI Model Fixed-Tilt Local Economic Impacts Summary for 75 kW Community Solar

	Jobs	Earnings	Output
During construction and installation period		**$000 (2012)**	**$000 (2012)**
Project Development and Onsite Labor Impacts			
Construction and Installation Labor	0.7	$44.4	
Construction and Installation Related Services	0.9	$37.6	
Subtotal	1.6	$82.0	$135.4
Module and Supply Chain Impacts			
Manufacturing Impacts	0.0	$0.0	$0.0
Trade (Wholesale and Retail)	0.1	$9.0	$26.5
Finance, Insurance and Real Estate	0.0	$0.0	$0.0
Professional Services	0.2	$10.4	$35.5
Other Services	0.3	$27.5	$94.7
Other Sectors	0.4	$5.1	$17.5
Subtotal	1.1	$52.0	$174.3
Induced Impacts	0.5	$34.8	$122.9
Total Impacts	**3.2**	**$168.7**	**$432.5**
		Annual	**Annual**
	Annual	**Earnings**	**Output**
During operating years	**Jobs**	**$000 (2012)**	**$000 (2012)**
Onsite Labor Impacts			
PV Project Labor Only	0.0	$1.0	$1.0
Local Revenue and Supply Chain Impacts	0.0	$0.3	$1.0
Induced Impacts	0.0	$0.2	$0.6
Total Impacts	**0.0**	**$1.5**	**$2.7**

Notes: Earnings and Output values are thousands of dollars in year 2012 dollars. Construction and operating period jobs are full-time equivalent for one year (1 FTE = 2,080 hours). Economic impacts "During operating years" represent impacts that occur from system/plant operations/expenditures. Totals may not add up due to independent rounding.

Table E-4. JEDI Model Fixed-Tilt Local Economic Impacts Summary for 3-MW Site Maximum Size Project

	Jobs	Earnings	Output
During construction and installation period		**$000 (2012)**	**$000 (2012)**
Project Development and Onsite Labor Impacts			
Construction and Installation Labor	16.9	$1,093.4	
Construction and Installation Related Services	22.2	$924.3	
Subtotal	39.1	$2,017.7	$3,333.2
Module and Supply Chain Impacts			
Manufacturing Impacts	0.0	$0.0	$0.0
Trade (Wholesale and Retail)	3.6	$221.3	$652.9
Finance, Insurance and Real Estate	0.0	$0.0	$0.0
Professional Services	5.3	$255.0	$874.1
Other Services	7.8	$676.5	$2,331.0
Other Sectors	9.9	$126.3	$431.3
Subtotal	26.7	$1,279.0	$4,289.3
Induced Impacts	12.3	$856.6	$3,024.8
Total Impacts	**78.1**	**$4,153.3**	**$10,647.3**
		Annual	**Annual**
	Annual	**Earnings**	**Output**
During operating years	**Jobs**	**$000 (2012)**	**$000 (2012)**
Onsite Labor Impacts			
PV Project Labor Only	0.7	$41.8	$41.8
Local Revenue and Supply Chain Impacts	0.2	$12.7	$41.4
Induced Impacts	0.1	$7.2	$25.5
Total Impacts	**1.0**	**$61.7**	**$108.7**

Notes: Earnings and Output values are thousands of dollars in year 2012 dollars. Construction and operating period jobs are full-time equivalent for one year (1 FTE = 2,080 hours). Economic impacts "During operating years" represent impacts that occur from system/plant operations/expenditures. Totals may not add up due to independent rounding.

Table E-5. JEDI Model Fixed-Tilt Detailed PV Project Data Costs Summary for 75-kW Community Solar

	WASHINGTON	Purchased	Manufactured
Installation Costs	**Cost**	**Locally (%)**	**Locally (Y or N)**
Materials & Equipment			
Mounting (rails, clamps, fittings, etc.)	$437,613	100%	N
Modules	$4,806,068	100%	N
Electrical (wire, connectors, breakers, etc.)	$498,954	100%	N
Inverter	$714,749	100%	N
Subtotal	$6,457,384		
Labor			
Installation	$1,093,418	100%	
Subtotal	$1,093,418		
Subtotal	$7,550,802		
Other Costs			
Permitting	$50,525	100%	
Other Costs	$1,116,611	100%	
Business Overhead	$3,282,061	100%	
Subtotal	$4,449,198		
Subtotal	$12,000,000		
Sales Tax (Materials & Equipment Purchases)	$0	100%	
Total	$12,000,000		

Table E-6. JEDI Model Fixed-Tilt Detailed PV Project Data Costs Summary for 3-MW Site Maximum Size Project

	WASHINGTON	Purchased	Manufactured
Installation Costs	**Cost**	**Locally (%)**	**Locally (Y or N)**
Materials & Equipment			
Mounting (rails, clamps, fittings, etc.)	$437,613	100%	N
Modules	$4,806,068	100%	N
Electrical (wire, connectors, breakers, etc.)	$498,954	100%	N
Inverter	$714,749	100%	N
Subtotal	$6,457,384		
Labor			
Installation	$1,093,418	100%	
Subtotal	$1,093,418		
Subtotal	$7,550,802		
Other Costs			
Permitting	$50,525	100%	
Other Costs	$1,116,611	100%	
Business Overhead	$3,282,061	100%	
Subtotal	$4,449,198		
Subtotal	$12,000,000		
Sales Tax (Materials & Equipment Purchases)	$0	100%	
Total	$12,000,000		

Table E-7. JEDI Model Fixed-Tilt PV System Annual Operating and Maintenance Costs for 75-kW Community Solar

	Cost	Local Share	Manufactured Locally (Y or N)
Labor			
Technicians	$1,125	100%	
Subtotal	$1,125		
Materials and Services			
Materials & Equipment	$750	100%	N
Services	$0	100%	
Subtotal	$750		
Sales Tax (Materials & Equipment Purchases)	$0	100%	
Average Annual Payment (Interest and Principal)	$56,550	0%	
Property Taxes	$0	100%	
Total	$58,425		
Other Parameters			
Financial Parameters			
Debt Financing			
Percentage financed	80%	0%	
Years financed (term)	10		
Interest rate	10%		
Tax Parameters			
Local Property Tax (percent of taxable value)	0%		
Assessed Value (percent of construction cost)	0%		
Taxable Value (percent of assessed value)	0%		
Taxable Value	$0		
Property Tax Exemption (percent of local taxes)	0%		
Local Property Taxes	$0	100%	
Local Sales Tax Rate	6.50%	100%	
Sales Tax Exemption (percent of local taxes)	100%		
Payroll Parameters	**Wage per hour**	**Employer Payroll Overhead**	
Construction and Installation Labor			
Construction Workers / Installers	$21.39	45.6%	
O&M Labor			
Technicians	$21.39	45.6%	

Table E-8. JEDI Model Fixed-Tilt PV System Annual Operating and Maintenance Costs for 3-MW Site Maximum Size Project

	Cost	Local Share	Manufactured Locally (Y or N)
Labor			
Technicians	$45,000	100%	
Subtotal	$45,000		
Materials and Services			
Materials & Equipment	$30,000	100%	N
Services	$0	100%	
Subtotal	$30,000		
Sales Tax (Materials & Equipment Purchases)	$0	100%	
Average Annual Payment (Interest and Principal)	$1,392,000	0%	
Property Taxes	$0	100%	
Total	$1,467,000		
Other Parameters			
Financial Parameters			
Debt Financing			
Percentage financed	80%	0%	
Years financed (term)	10		
Interest rate	10%		
Tax Parameters			
Local Property Tax (percent of taxable value)	0%		
Assessed Value (percent of construction cost)	0%		
Taxable Value (percent of assessed value)	0%		
Taxable Value	$0		
Property Tax Exemption (percent of local taxes)	0%		
Local Property Taxes	$0	100%	
Local Sales Tax Rate	6.50%	100%	
Sales Tax Exemption (percent of local taxes)	100%		
Payroll Parameters	**Wage per hour**	**Employer Payroll Overhead**	
Construction and Installation Labor			
Construction Workers / Installers	$21.39	45.6%	
O&M Labor			
Technicians	$21.39	45.6%	

Appendix F. Contact Information for Local Incentives and Programs

Contact information for SNOPUD renewable program manager is:

Leslie Moynihan
Renewables Program Manager
Snohomish County PUD
(425) 783-8289
LGMoynihan@snopud.com
www.snopud.com

Contact information for Washington State PBI incentives (called the "Renewable Energy Cost Recovery Incentive Payment Program") details are:

Phil Lou
Washington State University
Extension Energy Program
PO Box 43165
905 Plum St SE Bldg #4
Olympia, WA 98504-3165
(360) 956-2132
loup@energy.wsu.edu

Beth Mills
Washington State Department of Revenue
6500 Linderson Way SW
Suite 102
Tumwater, WA 98501
(360) 705-6642
bethm@dor.wa.gov
http://dor.wa.gov