Humboldt State University

Environmental Resources Engineering

McKinleyville Community Service District Waste Water Treatment Facility Renewable Energy System Project

Rachel Barry, Matt Bruder, Ryan Kaplan, Peter Seidel

Engr492 Spring 2015

Submitted May 12, 2015

Executive Summary

McKinleyville Community Service District (MCSD) is upgrading the Wastewater Treatment Facility (WWTF) to meet expected population growth, and this upgrade will involve more daily volume to treat and more energy-intensive processes such as aeration. The expected annual electricity bill will increase to approximately $155K, according to a Kennedy and Jenks analysis which assumes a $0.15/KWh average electricity rate and a 1.1388GWh expected energy use annually. MCSD is interested in offsetting this energy demand as much as possible through renewable energy systems, with the caveat that MCSD does not wish to be a net generator. Renewable Energy Consulting (REC) has been asked to assess the suitability of renewable energy systems that rely on solar radiation, wind, water motive force, biogas, biomass, and other forms of natural potential energy. REC analyzed the new WWTF plans along with other available information to determine which renewable energy-generating systems are feasible, according to a set of constraints and weighted criteria. The most feasible option was identified as a grid-tied, ground-mounted PV system. Preliminary analysis was conducted primarily with literature research for cost functions associated with specific alternatives, and simplified modeling with Excel. A preferred alternative design was identified and modeled with a combination of Microsoft Excel, System Advisor Model (SAM) by the National Renewable Energy Laboratory (NREL), and Google Sketchup.

Project constraints included laws and regulations, power consumption and generation, resource availability, space limitations, and technology availability. More specifically, renewable technologies would need to generate 5% or more of the energy demand on an annual basis to be considered for implementation, the technologies need to be commercially available, reliable, and permitted in Humboldt County, and the energy systems need to be operable by current staff without an unreasonable amount of training or certification.

Evaluation criteria include ease-of-use, ease-of-implementation, percent expected energy offset, net present value, the ratio of payback period to expected life, and expected weekly maintenance labor. Ease-of-use is a measure of how durable the technology would be at the location and how easy it would be to maintain and operate. Ease-of-implementation refers to any necessary permitting or licensing and the intensity of construction and pre-development work. Since both of these criteria are qualitative in nature, a binary system of yes/no questions was used to provide each alternative with a quantifiable score. Net present value was calculated to represent the cost to implement the alternative over the lifetime of the project. The ratio of payback period to expected life can serve as a surrogate for the risk of the investment. Maintenance labor was given a score based on the time (and money) that would go toward maintaining the technology on a regular basis. Lastly, energy offset was the percentage of the expected annual energy demand that the technology would be offsetting.

Alternatives included wind power, anaerobic digestion with biogas capture for gas engine generation, biomass steam turbine generation, ground-mounted photovoltaic (PV) systems, and a no-design alternative (as a baseline comparison). The alternatives were compared using the Delphi method that weights the criteria to determine most favorable alternative. Criteria weights were assigned based on the relative importance of the criteria as determined by REC and the client. The ground-mounted PV system was determined as the preferred alternative based on the

Delphi matrix. The following table summarizes the preliminary analyses on alternatives passing constraints (**Table 1**).

Table 1: Delphi matrix applied to preliminary alternatives

Criteria	Weight	Wind	Solar	Biomass	AD 20YR	AD 40YR	No Alternative
Net Present Value	7	-103.35	70.00	-394.43	-2749.39	-2600.34	0.00
Payback Period/ Expected Life	8	44.12	80.00	14.23	14.10	13.76	44.12
Dependability/Ease-of-Use	6	30.00	45.00	22.50	5.44	5.44	60.00
Maintenance Labor (hr/wk)	8	18.20	12.13	0.03	24.46	24.46	80.00
Ease of Implementation	8	11.20	18.67	7.00	6.22	6.22	80.00
Energy Offset	10	90.44	99.62	100.00	30.58	30.58	0.00
Net Present Value	**Total**	90.6	**325.4**	-250.7	-2699.2	-2550.5	264.1

The National Renewable Energy Laboratory's (NREL) free software, System Advisor Model (SAM), was used to design a solar PV grid-tied system with sufficient detail to imbue financial analyses. SAM allowed for several variable and parameter inputs to be used to evaluate compatible system component performance specifically in the geographical area using real solar data from the Arcata-Eureka Airport, PG&E rate schedules and granular costs related to land preparation, permitting, labor soft costs and other miscellaneous inputs. The estimated annual solar energy to be produced was calculated by SAM to be 1,138,605 kWh, with a nominal levelized cost of energy of 12.4 cents per kWh, which results in a simple payback period of nearly 13 years.

The final design is an 840 kW ground-mounted system located along the southern fence of the treatment facility. The system will occupy an area of about 2.6 acres and has a solar shading distance of about 33.3 feet. Major components include 2700 Eco Solargy Titan1000 310 Watt modules, eight Chint Power Systems 100 kW inverters (20 over the system lifetime), and 54 IronRidge ground-mounted subarrays that contain 50 modules each and are permanently tilted at 35º to the south. To make room for a system this large, the existing southern fence would need to be moved approximately 140 feet south of the existing position and a new fence would need to be erected around the panels to secure the area. The new fence line would run parallel to the arrays in the east-west direction, about 900 feet in length. This section of land would also need to be graded and cleared of trees and shrubs. Approximately 248 cubic yards of concrete would need to be poured in augured holes for the ground-mounted hardware. Construction and land preparation related events more referenced with a 2012 construction cost estimation handbook from the Gordian Group. All of these costs are accounted for in the final analysis (**Table 1Table 2**).

Table 2: Cost inputs to NREL System Advisor Model (SAM).

Input Description	Costs	Input Description	Costs
Land Clearing	$22,663	Mounting Hardware (IronRidge)	$252,261
Auger Boring	$80,919	Sales Taxes	$99,668
Fence Removal/Replacement	$66,985	PV Modules, EcoSolargy (2700)	$569,659
Concrete Estimate	$55,940	20 Inverters	$350,649
Freight	$89,274	Installation and Margin	$500,000
Wire and Conduit	$55,000	Engineering Consultation	$144,000
Permitting and connection fee	$5,000	Federal Investment Tax Credit (% installed cost)	30%

REC has concluded that installing the solar array would be exempt from Humboldt County permitting, but would require a Coastal Development Permit and a PG&E Interconnection Application. It may be necessary to seek a negative declaration to comply with CEQA. Additional inputs to the SAM software model for final design analysis are detailed in **Table 3**.

Table 3: Additional SAM Model inputs.

Description	Value	Description	Value
PV degradation Rate	0.65%/yr	Inflation Rate	2.5%
AC and DC power losses	1%; 4.93%	Real Discount Rate	5.5%
Monthly soiling loss	2%	Nominal Discount Rate	8.14%
Analysis period	25 years	Net salvage value, end of analysis period	15% installed
Sales Tax	8.50%	Contingency, % of direct capital cost:	10% of $1.97M
Insurance rate (annual, % installed cost)	0.50%	100% borrowed for 25 years, 5% rate, principal:	$2.49M
A-10 TOU Secondary Voltage PG&E rate schedule: $140/mo charge; $0.0289/kWh year-end sell rate			

An effort was made to optimize input variables according to available information and reasonable industry assumptions. SAM makes some simplifying assumptions that may alter the true cost basis and cash flow over the project lifetime. A sensitivity analysis conducted on the most influential variables is included in the full report.

Contents

Table of Contents

List of Figures

List of Tables

1. Introduction

The McKinleyville Community Service District (MCSD) is in the process of updating the Wastewater Treatment Facility (WWTF) to use state-of-the-art components. This new design will significantly increase the energy demand and costs with respect to the comparatively more passive system in place now. MCSD has retained some operational flexibility within the regime of the new WWTF design by continuing to use ponds, in order that pumping and other electrical consumption can happen outside of peak rate hours. Even with this savings, the increased expected energy consumption is a significant increase in expenses. Wastewater and water treatment processes contribute to about 3% of the overall total US consumption of energy (Eric Byous, 2012). This is mostly due to the various pumps that will need to be running to move masses of wastewater from one location to another, and also to introduce oxygen for treatment. A WWTF will usually have a considerable amount of land associated with the facility as treatment processes can require very large components. Wastewater facilities have the potential to become energy generators by optimizing facility efficiencies along with the addition of feasible renewable energy systems (Eric Byous, 2012).

Renewable Energy Consulting (REC) will analyze the potential energy demand of the new facility in order to determine optimal sustainable energy system alternatives in order that MCSD may reduce their energy expense to run the new WWTF. The projected demand for the upgraded facility according to the study done by Kennedy and Jenks is 1.1388 gigawatt-hours per year. This analysis will investigate different renewable technologies to offset this demand to the greatest extent possible. Possible renewable technology alternatives include solar panels, wind turbines, anaerobic digestion with methane capture, micro-hydropower, etc. REC will develop a set of criteria and constraints to evaluate the technologies based on their potential to meet the project's objective. The alternatives will then be evaluated using the Delphi method to determine the preferred alternative design. The final deliverable will include: component and construction specifications of the final design, construction drawings, associated costs, and a construction bid document and schedule. The report will detail the energy generation, system capacities, time of use, and preferred rate schedule. A separate permitting report and operation and maintenance manual are attached in the Appendix.

1.1 Objective

The MCSD wastewater treatment facility system components, operation and capacity will soon be upgraded in anticipation of a future population increase. System upgrades will substantially increase the power consumption when the new facility comes online in the fall of 2016, and MCSD management would like to offset the power demand with renewable sources. Given the facility setting, potential renewable sources should minimize aesthetic, noise, air quality, biological, and recreation impacts.

1.2 Setting and History

The McKinleyville WWTF is located on a 68.4 acre parcel, though only 34 acres are currently being occupied for treatment purposes, mostly for ponds. The Hammond Trail (part of the Pacific Bike Path) cuts through the parcel just to the East of the existing ponds. Much of the remaining area on the parcel is wooded and undeveloped. Hiller Park is nearby to the southeast, and mixed use, unpaved trails are to the south and west of the ponds, leading to a bluff above the bank of the Mad River. The wastewater treatment system presently has two primary and two secondary oxidation ponds, and two finishing marshes.

As of February 2015, pond 1A (an oxidation pond), is almost completely drained and dredged. The area will be filled in and the new facility components will be built here. The consulting engineering firm Kennedy and Jenks has submitted the 90% completion design documents, showing that the future components in the drained and filled area include two aeration basins, two secondary clarifiers, and an open-air biosolids storage basin. The plans indicate that the three existing polishing ponds and two polishing wetlands will remain. However, the plans also indicate that two future aeration basins may be built where polishing pond 1 (east of the planned components), and another two secondary clarifiers may be built, along with future UV disinfection system (AECOM, 2014).

The current capacity for biological treatment is 1.18 MGD and 3.3 MGD for disinfection treatment, respectively. Up to 45 million gallons of treated wastewater can be stored on site in ponds. During the winter, the treated wastewater is discharged into Mad River at the Hammond Bridge crossing. During the summer, the treated wastewater is sent to a percolation pond and pumped to a nearby 90 acre parcel that is leased to a farmer who cuts and sells the baled hay. The upgraded facility requires about 830 kilowatts of power.

2. Background and Literature Review

This section discusses renewable energy feasibility studies at similar wastewater facilities.

2.1 General Case Studies

In a 2008 study by Kennedy/Jenks Consultants, two wastewater treatment facilities in Oregon were evaluated for renewable potential. The renewable energy systems investigated in the study include: fuel cells, internal combustion engines, micro-hydro, micro turbines, solar photovoltaic, small wind turbines, and a system to increase digester gas production to use in various energy systems. These two facilities are located in the northwestern side of the state roughly 250-miles north of McKinleyville, CA. In this study, prepared for the Oregon Association of Clean Water Agencies (ACWA) and Energy Trust of Oregon, Kennedy and Jenks Consultants found that the two Oregon City WWTFs were able to benefit from a combination system consisting of a PV unit and micro turbines powered from digester methane gas (Consultants, 2008). Both facilities were able to become nearly net zero energy consumers by the addition of the combination renewable energy systems. In these combinations the turbines were both recommended first, followed by the addition of PV to help to offset most of the remaining energy demands.

In April 2007, the City of Thousand Oaks began two renewable energy projects at the Hill Canyon Treatment Plant. The first project was cogeneration with methane capture which utilized the existing anaerobic digesters. This project could generate 500 kilowatts of power, or 50% of the facility’s demand. The second project involved a 2,783 panel solar array. The array provided 15% of the facility’s energy needs and produced energy during peak demand (when energy was the most expensive). The California Public Utility Self Generation Incentive Program (SGIP) provided grants to fund both projects, totaling $2.0 million. However, both projects are owned by a third party who is knowledgeable in the technical skills to keep the system functioning. In 2014, the wastewater plant received another $1.5 million grant to offset 100% of their projected demand with an additional 360 kW of biogas energy. In all, no city funds were spent on any of the renewable systems, and the expected annual savings total $400,000 over buying from the local utility company (Vickie Montgomery, 2015).

2.2 Solar Arrays

The McKinleyville CSD wastewater treatment facility has generous land resources where photovoltaic (PV) panels could be installed. A study will need to be conducted to determine the payback period, depending on the site and scale of the system, and other parameters.

Photovoltaic solar power uses semiconductor materials to convert sunlight into electricity. Several wastewater treatment facilities use this form of solar power for their electricity consumption. The first US facility to be powered by solar energy was in Oroville, California. In 2002, the Oroville WWTF installed 5,128 ground mounted panels, which generated 520 kilowatts of power. The solar installation cost $4.5 million, even though PG&E covered half of this with a large renewable rebate. The system was installed by Sun Power and generated enough power to treat 80% of the wastewater intake (Weston, 2010).

Several WWTFs have added, or are in the process of adding, PV systems to their facility to reduce their own overall energy consumption. Santa Rosa's WWTF has installed a 1.1-MW DC PV system that saves them $152,000 per year which adds up too roughly 30% of the facilities overall annual energy demands (Wong, 2011). PV installations can be expensive as the technology is still fairly new and the mounting systems can be typically bulky. Over the past 10-years PV systems have been economically gaining momentum allowing for a slow yet steady price reduction.

Placement of PV panels is critical to recovering the most potential solar radiation available. The more panels that can be added, than essentially the more power that can be produced as energy production is a function of surface area of the panels. For WWTFs, PV panels have been place in several common places in such as sludge drying beds, open space (typically adjacent to facility), building roofs, and even over open tanks. A study in Blue Plains, District of Columbia, for a WWTF determined that the optimal places to put their PV panels was over open basins and rooftops (Wong, 2011). This particular placement is likely due to limited open space to place a PV panel farm.

2.3 Micro-hydro

In August 2013 the EPA published a document on low head hydropower from wastewater, which included several case studies and an overview of low head turbines. The first case study was for the Point Loma WWTF in San Diego, California. The plant received a $360,000 grant from the California Energy Commission and $420,000 in incentives from the State of California to go towards the energy recovery project. The new hydroelectric turbines were powered by treated wastewater that dropped 90 feet from the facility to the ocean outfall. With this amount of head, the generated power was able to supply 13,000 households (EPA U. , 2013).

Another case study involved the Kankakee Illinois Hydro Project. The project upgrades cost $3.8 million, not including the $1.0 million donated by the Illinois Department of Energy and Natural Resources. The turbines were the first in the US to run on the “siphon principle”. The design features resulted in considerably higher efficiencies, as the system was able to better adapt to variations in flow. The plant found that the design was cost effective when the energy production was applied to the base load necessary to operate the treatment plant. Another case study was analyzed of the Deer Island WWTF in Massachusetts. The hydro-generating facilities cost an estimated $7.4 million. The system consisted of two 1000 kW Kaplan turbines with 500 cfs capacity, and the available head for the site was 29 feet (EPA U. , 2013).

A micro-hydro system can also be installed on an existing water distribution network. The city of Portland, Oregon recently entered a Power Purchase Agreement for renewable energy for their in-line turbines on a water distribution pipe. The project was a joint effort between Lucid Energy and the Portland Water Bureau. The design consisted of four 42-inch turbines on one drinking water pipeline, taking up a total of 65 feet. The network is gravity-fed so no pump is required to move the water, and the energy supplied by the turbines is sold to Portland General Electric. Overall, the design cost $1.7

million, but it is capable of generating $20 million in energy over the duration of the purchase agreement. The turbines can generate an estimated 1,100 megawatt hours of electricity annually, which is enough to power 150 homes (Hickman, 2015). Some of the main advantages of installing an in-line turbine are: it makes use of existing infrastructure, it provides low-cost energy, it has minimal environmental impacts, and it is not weather dependent.

In 2009, the California Energy Commission found that in-conduit hydropower was the least expensive of several renewable technologies. The price was estimated to be about $1,968 dollars per kilowatt (KEMA, 2009). Basically, a pressure reducing turbine replaces an existing pressure reducing valve on the water distribution network. Such in-conduit systems have been implemented by the Eastern Municipal Water District in California, the City of Prescott in Arizona, and the San Diego County Water Authority in California. The San Diego project was able to install a 4.5 MW hydroelectric system, which was enough electricity to power 5,000 households. The water network entered an agreement to sell power to the local utility company and expected to pay back the micro-hydropower system in only seven years (EPA, 2014).

2.4 Wind Turbines

Wind turbines are generally feasible in areas that have a steady wind supply of adequate magnitude. Several wastewater treatment facilities are already relying on wind power generation to supply their energy needs. A WWTF in Atlantic City, New Jersey with a 40 MGD capacity is currently supplementing its energy demand with wind power. The system contains five 1.5 MW turbines, totaling 7.5 MW of power when operating at wind speeds of 12 mph or greater. This power production actually exceeds the energy demand of the facility, allowing the WWTF to make a profit by selling power to the local utility grid. In this case, the levelized cost of energy was 7.9 cents per kilowatt, while the delivered cost from the grid was 12 cents per kilowatt and was expected to rise. The upfront cost of the wind farm was $12.5 million and resulted in savings of $350,000 annually (EPA U. , 2013).

Another area that incorporated wind turbines was in the north central region of Maine. The Blackfeet Reservation, a native reservation occupying 1.5 million acres, has been pursuing renewable energy for years. The WWTF in Browning installed 10 four kilowatt turbines, which accounts for a quarter of the plant's demand. Another plant in the City of Fargo, North Dakota installed a 1.5 MW system, enough to offset 85% of the demand. The turbine's upfront cost was about $2.4 million but would save an expected $203,000 annually (Spellman, 2013).

The following data is from a study done in 2011 to find the average levelized cost of energy. It was a study done on wind turbines in the Midwest with a power rating of 1.5 MW with rotor lengths of 82.5m.

Table 4 shows the costs of parts of a wind turbine and the overall cost of implementing the project (Tegen, et al., 2015).

Table 4: Overall Cost of Implementing a Wind Turbine (Tegen, et al., 2015)

Data Source		1.5-MW $/kW	1.5-MW $/MWh
Model	**Turbine Capital Cost**	1286	37
Model	**Balance of Station**	446	13
Market	**Soft Costs**	172	5
Market	**Market Price Adjustment**	195	6
Market	**Installed Capital Cost**	2098	61
Market	**Annual Operating Expenses ($/kW/yr)**	35	11
Market	**Fixed Charge Rate (%)**	9.5	
Model	**Net Annual Energy Production (MWh/MW/yr)**	3263	
Model	**Capacity Factor (%)**	37	
	Total Levelized Cost of Energy ($/MWh)	72	

2.5 Anaerobic Digester with Methane Capture

A WWTF that has an anaerobic digester can use the methane gas that is produced by the digestion of the biosolids to create electrical energy. This gas is incorporated into a combined heat and power system or cogeneration system which converts the thermal energy to usable power. Several WWTFs have already incorporated such systems into their design. That being said, in order for the system to be feasible, the produced gas has to be of sufficient quality.

The Ina Road Water Pollution Control Facility in Tucson, Arizona found the cogeneration system to be economically beneficial for the 25 MGD wastewater facility. Large energy consumers at the plant include the HVAC system, chilled and hot water appliances, and the digester. The cogeneration system was built in 1977 and has an efficiency of only 65%. The installed equipment include seven 650 kW Waukesha engines with heat recovery and a 950 ton absorption chiller. The system runs off of a combination of methane produced and natural gas, and has a capacity of 3,300 kW. The cost analysis showed that the levelized cost of energy is 4.7 cents per kW and results in annual savings of $1.26 million. The WWTF dries the methane gas to 37 degrees then reheats it to get rid of most of the contaminants. A plate and frame heat exchanger was superior to the tube and shell exchanger in this study (Energy, 2015). Characteristics of the gas used to run the system are production, heating value, concentration of hydrogen sulfide, and composition

Table **5**.

Table 5: Gas quality and quantity at the Tucson cogeneration facility (Intermountain Clean Energy, 2006)

Parameter	Quantity
Current gas production	350,000
Projected gas production	1,000,000
Heating value (BTU/ft3)	600
Concentration of hydrogen sulfide (ppm)	15
Composition	40.1% carbon dioxide, 0.23% nitrogen, 0.025% siloxanes

The East Bay Municipal Utility District in Oakland, California installed a similar cogeneration system, along with other energy efficiency measures to treat the 415 MGD of wastewater intake. The cogeneration system consists of three 2,368 kW generators installed in 1985. The system currently only uses two, which compromise half of the plant's demand. The system is looking to add a digester cover which would store gas at night to later be used at peak demand. In this case, the anaerobic digester with methane capture setup resulted in annual savings of $2,796,000, with a payback period between six and eight years (CEC, 2000).

2.6 Biomass with Combined Heat and Power

The Covanta Company owns seven biomass plants that generate electricity from wood waste, which collectively produce over 191 MW. The wood waste would otherwise be sent to landfills or be left to accumulate on forest floors, causing wildfires. The Burney Mountain Power Facility in Burney, California processes about 280 tons of wood waste a day, generating about 11 MW. The fuels to run the plant include tree chips, forest residue, and mill residue. A similar facility known as Mount Lassen Power in Westwood, California receives 270 tons of biomass and produces about 11.5 MW (Covanta, 2012).

One source on the web contained several different biomass case studies in California. The first was in Blue Lake, California, which is in relatively close vicinity to the McKinleyville WWTF. The system has been in operation since 1985 and generates 11.4 MW off of wood fuel. Approximately 95,000 BTU per year of fuel is burned. The facility was shut down and brought back online several times, due to changing ownerships or plant upgrades. A similar facility with an output of 28.4 MW is located in Burney, California. This system is operated by North American Energy Services and has been in service since 1989. In all, there are many case studies involving energy generation from burning biomass, particularly wood, agricultural waste, tire-derived fuel, manure, and rice hulls/straw. However, it should be noted that case studies could not be found that had a similar energy consumption as the projected consumption for the McKinleyville WWTF. The lowest plant output found was 4 MW and was operated by Sierra Pacific Industries (IndustCards, 2014).

3 Criteria and Constraints

This section provides an overview of the criteria and constraints used to determine and evaluate the design alternatives. The overview includes an overall narrative describing the criteria or constraint. Any alternative that does not meet a constraint will be discarded from further analysis. Alternatives are compared via criteria using the methods described in this section. The criteria and constraints are listed in Table 6 below.

Table 6: Criteria and Constraints.

Criteria	Constraints
1. Net Present Value 2. Payback Period/ Expected Life 3. Dependability/ Ease-of-Use 4. Maintenance Labor 5. Ease of Implementation 6. Energy Offset (by % annual demand)	1. Laws/ Regulations 2. Power Consumption/Generation 3. Resource Availability 4. Space Requirements 5. Technology Availability

3.1 Narrative on criteria

Costs and benefits are calculated as Net Present Value (NPV, sometimes called total project value or life cycle cost), as a function of capital investment, maintenance and operations, return on investment, component salvage value, and dollar value of energy offset as a percentage of annual demand. The payback period of a project is determined only if at some point the project has positive cash flow such that costs have been offset and overtaken with a net benefit. The ratio of the payback period over the expected life of the alternative will provide how quickly each alternative will be paid off compared to its life cycle. This ratio somewhat represents the risk of the investment, since a lower fraction value shows the alternative gets paid off more quickly during its life cycle. Maintenance Labor refers to the dollar amount that would typically be associated with the regulatory operations.

The more qualitative criteria can be quantified with a summation of a series of binary yes or no questions. The criterion “dependability/ease-of-use” includes considerations of equipment reliability and durability, such as materials being able to hold up to the weather conditions in Humboldt County and coastal conditions. How often the alternative needs to be operated on and maintained will affect the alternative’s ease-of-use, which includes component replacement and servicing schedules. More reliable and durable systems that require lower operational and maintenance costs are ranked higher. The criterion “ease of implementation” considers issues such as licensing (if a technology is patented), pre-construction, and permitting with respect to CEQA or any other federal, state or county standards. Alternatives that are less feasible due to a vast amount of pre-construction work are ranked lowest. The alternative that requires little or no permitting effort and has no environmental or cultural impacts is of course ranked highest. Admittedly, environmental and cultural considerations are somewhat obscured by the criterion name “ease of implementation,” and sequestered within the realm of permitting. For all purposes, environmental impact will be interpreted as expected impacts to resource areas (which includes cultural, recreational, archaeological, aesthetic or other nuisance impacts) as defined in the California Environmental Quality Act (CEQA) statutes or guidelines.

Energy produced by the renewable system in proportion to the expected energy consumed by the WWTF is an important criterion. The alternative that provides the most power output to offset the projected electricity bill sets the precedent as highest ranking.

The range of values determined for each criterion among the alternatives is normalized to a unit-less value between 0-10 with one of two simple equations. When a lower criterion unit value is preferred (as in a lower life-cycle cost and lower payback period), *Equation 1* is used to establish the normalized unit-less value. When a higher criterion unit value is preferred (higher EROI, ROI, energy offset), *Equation 2* is used. Yes or no questions for dependability/ease-of-use and ease of implementation are shown below. An answer yielding yes will result in a value of one and a result yielding no will have a value of zero. A max value for dependability/ease-of-use will be preferred while for ease of implementation a minimum value is preferred.

Equation 1: $\text{Min Value Criteria} = [(\text{best value})/(\text{actual value})] \times [10]$

Equation 2: $\text{Max Value Criteria} = [(\text{actual value})/(\text{best value})] \times [10]$

3.1.1 Questions for dependability/ease-of-use:

- Materially durable in WWTF and coastal conditions?
- Mechanically/structurally durable in stormy/rainy conditions?
- Warranty included to insure an expected life with reliable duration?
- Easy to operate (will wastewater grade 4 operator knowledge be sufficient)?
- Easy to maintain (could a licensed contractor or journeyman do the work)?
- Does the system operate continuously?
- Will the system have an energy storage component for backup or regular operation?
- If the system operates intermittently, is its energy output predictable?

3.1.2 Questions for ease of implementation:

- Is a permit, approval, inspection, waiver or variance needed from:
- A federal agency?
- A state agency?
- A regional agency or board?
- Humboldt County?
- Will a license need to be obtained to use a patented technology?
- Will pre-construction or development work be necessary? (1 for each week)

The table below provides a summary description of each criterion and mentions how it will be evaluated numerically for each alternative (Table 7).

Table 7: Criteria Description and Method of Comparison

#	Criterion	Description	Method of Comparison
1	Life-Cycle Costs	The ratio of total benefits to total costs over the project lifetime; useful for further analysis of utility.	The alternative shown to have the LCC with the highest net benefit is preferred. (Equation 2).
2	Payback Period/ Expected Life	The time required for the alternative LCC costs to be repaid by its benefits over the life cycle of the alternative.	The smaller the ratio for the alternative is preferred as it will result in the alternative with the least risk. (Equation 1).
3	Dependability/ Ease-of-use	Technology should be: durable enough to withstand conditions at the WWTF; have an expected life of reliable duration; be relatively easy to operate and maintain.	Alternative that is more dependable and easy to use will be preferred. A binary method of yes/no questions will be used to quantify the value, yes giving a 1 and no a 0. The largest value will be the preferred alternative. (Equation 2).
4	Maintenance Labor	Renewable energy systems will need some sort of maintenance associated in order to maintain efficiency.	Alternatives are given dollar values for typical annual maintenance and those with greater value are considered the less preferred.
5	Ease of Implementation	Permits required from the state or other authorities related to CEQA or other laws; intensity of pre-construction and development work; licensing of technologies.	The easier and less complicated alternative to obtain permits or satisfy regulations are preferred. A binary method of yes/no questions will be used. Smallest value will be preferred. (Equation 1).
6	Energy Offset	The amount the proposed alternative will reduce annual energy demand through PG&E.	Energy offset on an annual basis relative to expected energy demand. (Equation 2).

Criteria weights are assigned so that the Delphi Method can be used to determine the preferred alternative. Initial weights are ranked by the estimated importance of each criterion as discerned by REC and the MCSD. A chosen, or combined, weight will be the final weight used in the Delphi Matrix (Table 8).

Table 8: Weights by Criterion as Assigned by Consultant and Client.

#	Criterion	REC Engineering Consensus Weight	MCSD Staff Consensus Weight	Chosen Weight
1	Life Cycle Costs	7	7	7
2	Payback Period/Expected Life	8	8	8
3	Dependability/ Ease-of-use	6	6	6
4	Maintenance Labor	8	8	8
5	Ease of Implementation	5	>5	8
6	Energy Offset	10	10	10

The energy offset of the design alternative is considered the top priority, so this criteria outranked all of the others. Life cycle costs, payback period over expected life (or risk), and maintenance labor were all ranked about the same. Dependability and ease of implementation were not weighted as much. However, after consulting with the clients, they noted that permitting was important to them and suggested this value be increased.

3.2 Narrative on constraints

3.2.1 Laws and Regulations

Regulations for renewable technologies exist at the local, county, regional, state, and federal levels. In order to add a renewable system to the grid, certain codes and regulations must be met. For example:

a) Only California-certified PV panels can be installed in the state; similar restrictions may apply to other technologies
b) Microhydro systems emptying treated effluent to the Mad River may only operate during the wet season (October to May), provided the flow is at least 200 cfs.
c) The location may be in the airports flight zone if the wind power systems are too tall.

3.2.2 Power Consumption/Generation

The renewable technology must offset at least 10% of the annual energy bill to be considered an alternative, but no more than 100%. The McKinleyville CSD does not want to be a power generator, therefore any alternative that produces more energy than the total energy consumption will be disregarded or downsized. However, it would not be worth the time to input a renewable energy system if the energy system is only producing a small percentage of the total consumption; hence the 5% minimum.Net-metering may be an option, in which case the constraint would be that net power generation remain at or below the projected power demand by WWTF.

3.2.3 Resource/Technology Availability

Renewable energy technologies generally operate on resources that are not readily available 100% of the time. If enough of the resource was not available locally, the technology was disregarded as an alternative. In regard to specific alternatives, solar power is only feasible during daylight hours, and is concentrated in the summer months. A microhydro system could only operate if there is enough elevation head and flow available. Anaerobic digestion and methane capture may be feasible if there is enough sludge mass resource available (from WW and/or augmented by other inputs). Even then, the alternative is only feasible if MCSD is willing to augment the new WWTF plans to include the component.

Some technologies may be too difficult or too expensive to get up to Humboldt because it is such a remote location and there are transportation constraints. If the technology itself was not readily available, then it was not considered as an alternative.

3.2.4 Space Availability

The design is also constrained by the amount of space available on the parcel that can be utilized. Some of the technologies are bulky and require more area to produce more power. Solar panels for instance typically need 5-6 acres to produce 1-MW. The technology would also need to be close to the WWTF so that there will be minimal power losses. MCSD does own other parcels of land that could potentially be used for energy generation. Alternatives such as biomass fuel generation could be feasible by making use of the existing effluent irrigation arrangements during summer months. Feasibility of some alternatives may also be contingent upon the existing or projected zoning of said parcels.

3.2.5 Mature Technology

It was expected that the MCSD would not want to invest in technologies that are not yet commercially available. Case studies exist for technologies that are still in their development stages, but in order for them to be made mainstream they must pass several regulations, codes, and standards. The technology of each alternative must be developed enough for the MCSD to purchase it and not have to fabricate any of the necessary components. Wind turbines, for example, are readily available for consumers to purchase from manufacturer and dealers. All of the technologies that were not mature in their development were exempt from being considered alternatives in this analysis.

3.3 Technologies that Did Not Pass a Constraint

3.3.1 Micro-hydro on the Mad River

A run of the river micro-hydro system could be added somewhere along the Mad River with sufficient head and flow. According to a 2010 Mad River Watershed Assessment, the average flow on the river is 1380 cfs but ranges between 2000 and 5000 cfs during the wet season. How much of this flow could be diverted into the hydroelectric system would depend on the specific site location. From the same study, the gradient in the lower section of the Mad River is 12 feet/mile (Mad River Watershed Assessment, 2010). This slope would not provide a large amount of head along the river for the potential micro-hydro system. Upon closer inspection of the topography using Google Earth, no sites could be found with a significant elevation difference.

A micro-hydro system on the Mad River would be subject to a significant amount of regulation. The system may be subject to CEQA/NEPA if any environmental impacts exist. The MCSD would also have to notify the Federal Energy Regulatory Commission and the US Army Corps of Engineers and be subject to their specific regulations. The district may also have to obtain a separate water right to produce power, and may be subject to the Coastal Commission if the project falls within the coastal jurisdiction boundary. The community itself places intense scrutiny on conserving the salmonid populations, so micro-hydro on the river would face regulation in regard to preservation as well. Thus, due to the lack of available net head and the extensive regulation requirements, a micro hydro system on the Mad River was determined infeasible.

3.3.2 Micro-hydro on the Effluent Pipe

Wastewater effluent could be used as the water source for a micro-hydro system using an integrated pipeline scheme. Preliminary topographic analysis on Google Earth indicates that from the existing headwork to the Mad River, there is approximately a 50 foot elevation difference. An equalization basin could be constructed such that a relatively consistent head is maintained, in order that a micro-hydro system could make use of the treated effluent potential energy.

From the study done by Kennedy/Jenks Consultants, the projected average annual flow (AAF) at the site is 1.53 MGD (2.37 cfs), while the current average dry weather flow (ADWF) is 1.05 MGD (1.62 cfs). The current ADWF was used to size the turbine, so that the system could run year-round. A micro-hydro system on the effluent pipe would not receive much flow at all during the night hours, so it may only run for about 12 hours a day. If the turbine were to be placed at the location near the outlet to the Mad River on Fischer Road, the available net head from the headwork would be about 47 feet (using Google Earth). The estimated head loss due to friction in the 12 inch PVC pipe would be about 2 feet, making the net head 45 feet.

Although the system would have significant head, few case studies exist for a system with such small flows. The estimated power potential according to the equation below would be about 5 kW, which means only 4% of the required energy could be offset. Thus a significant amount of power could not be produced from the effluent, given the site characteristics. This low power production reveals that the alternative does not meet the constraint which states that the technology must offset at least 5% of the WWTF's utility bill.

$$P = nQdgH$$
$$where:$$
$$P\ is\ hydroelectric\ power\ (W)$$
$$n\ is\ efficiency$$
$$Q\ is\ flow\ (cms)$$
$$d\ is\ the\ density\ of\ water\ (kg/m3)$$
$$g\ is\ the\ gravitational\ constant\ (m/s2)$$
$$H\ is\ head\ (m)$$

3.3.3 Micro hydro on the Water Distribution Network

REC also looked into placing an in-conduit micro-hydropower system on the existing water distribution system. Such a system would be placed near the pressure reducing valves, which were found on the WaterCAD files. Since meter aggregation was not possible, the nearest PRV could be used, with the wire running to the WWTF's grid. PRV 7 was the closest, and had a significant pressure difference, due to the elevation difference from the water tank. The valve reduced the pressure from 100 to 70 psi, although the average daily flow, according to the WaterCAD files, was only 53 gpm. Upon inspection, REC concluded this was not enough flow for a commercially-available turbine. Thus, a micro hydropower system on the distribution network was determined infeasible.

4. Description of Alternatives

This section provides an overview of the renewable energy alternatives that passed all of the previously discussed constraints. The section provides a brief description of the basic mechanics behind the technology, associated costs and locations, and a summary of the system performance. Alternatives considered individually include wind generation, solar power, biomass fuel, and two scenarios for the installation of an anaerobic digester for the production, capture, refining and combustion of methane in a co-generator.

4.1 Assumptions Made Throughout All Systems

For all projects it was assumed that there would be a discount rate of 5% and that the utility would be saving $0.15/kW on energy consumption due to alternative offsets. Where appropriate, proposed systems have been scaled to constraints based on the capacity of the systems available and area available to the MCSD now or at full build-out of the new WWTF. All systems have been maximized, without producing more energy that will be consumed on an annual basis, in order to minimize supplemental PG&E energy. Levelized cost of energy is determined for each alternative based on the annual equivalent annuity and the total energy produced by the alternative and supplemented by PG&E, with the cost of energy and the discount rate used as previously stated.

4.1.1 Alternative 1 – Biomass Combined Heat and Power System

This alternative assumes that an abundant and cheap wood waste feedstock with consistent properties is available for regular delivery. A heat exchanger runs through a combustion chamber where the biomass is burned. The heated water runs to a boiler, where it changes phase into steam, spins a turbine that in turn spins a shaft that is connected to a generator, which produces electricity. The system could also be a combine heat and power (CHP) system where the leftover heat is used to dry out some of the biomass before combustion. Biomass systems that only use the burning of biomass to produce electricity are not very efficient because a lot of energy is still left in the steam after it passes through the turbine. If the energy from the steam is captured and used to heat the CHP system is much more efficient. Implementing a CHP system can increase net savings, reduce the loss of waste heat, and lower CO_2 emissions (BIC, 2015). In a system that does not require extra heat it is not useful to capture it. In the case of the power plant it may be beneficial to use the waste heat to dehydrate the sludge and other biomasses so they will burn more efficiently. A CHP system consists of the following (Figure 1):

- Heat exchanger
- Combustion chamber
- Storage place for biomass
- Flue gas cleaner
- Chimney
- High pressure boiler
- Water piping
- Steam Turbine

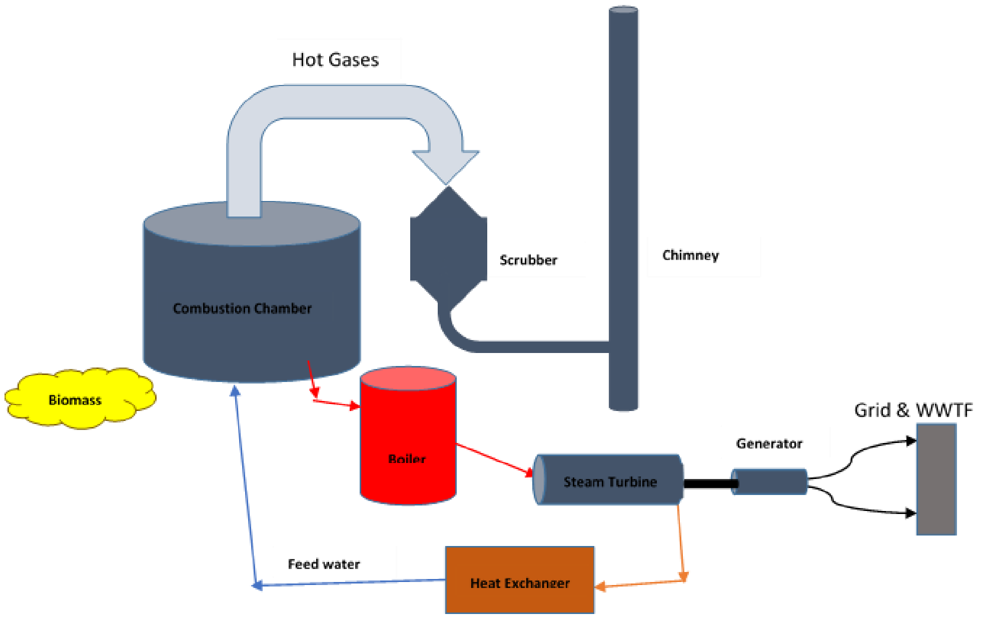


Figure 1: Diagram of a combined heat and power system for biomass.

This biomass CHP system used around 90 million pounds of biomass annually and produced around 30 GWh of electricity and 50 GWh of heat. The system under evaluation only requires around a max of 1.1388 GWh annually allowing the amount of biomass required to be drastically lower, around 3 million pounds annually. If everything performed with the same efficiencies at the new annual biomass consumption rate of 3 million pounds the CHP system would produce around 1.1 GWh of electricity and around 1.7 GWh of heat.

For the purpose of evaluation, a capital and O&M cost was determined based on the system size, the required biomass input, and an assumed salvage value. Input values are as follows:

- Running 8 hours per day, to generate 1.1388 GWh of electricity annually (Consultants, 2008), a system of approximately 390 kW capacity is necessary.
- Assuming the higher end of a cost curve, $4,000/kW capacity installed is assumed (DOE D. o., 2015), plus a 20% contingency, so a total installed capital cost of approximately $1.87 M is used.
- Operations and Maintenance costs are assumed to be a function of the installed system capacity, $91/kW (NREL, 2013). This value is assumed to cover daily operations and scheduled maintenance, for an annual cost of approximately $35,465.
- A cost of $20-30 per short ton delivered (for 20 metric tons, the largest allowable shipping container) was quoted for "wet" or "green" residual biomass, from Sierra Pacific Energy fiber products department in Anderson, CA. The range is due to seasonal supply and demand fluctuations, and $25/ton was assumed for this analysis.
- Heating value of wood fiber at 30% moisture is assumed to be 3.4 kWh/kg (Francescato, 2008)
- Using the heating value and a conservative 25% electrical conversion efficiency, an annual volume of approximately 1339 metric tons of biomass feedstock will be consumed at a cost of approximately $36,895 delivered.

These values are summarized in Table 9 and Table 10, and Table 11summarizes the performance of this alternative relative to the other alternatives.

Table 9: System costs associated with Biomass CHP Alternative

System Costs	Annual Costs	Lifetime Costs
Initial Installed Capital	-	$(1,870,684.93)
O&M	$ (35,465.07)	$ (441,973.14)
Biomass Fuel Cost	$ (36,895.00)	$ (459,793.22)
Value of Generated Electricity	$ 170,700.00	$2,127,299.31
Salvage Value at life end	-	$280,602.74
Life Cycle Cost or Benefit	-	$ (364,549.25)

Table 10: Parameters associated with Biomass CHP Alternative

System Parameter inputs	Value
System Capacity (kW)	390
Daily Energy (kWh)	3117.8
Heating Value, Woodchips (30% moisture, kWh/kg)	3.4
Total annual biomass consumed (kg)	1,338,824
Electrical conversion efficiency (%)	25%
System Life (yrs)	20
Assumed weekly O&M (hrs)	28

Table 11: Table of the criteria evaluation for Biomass system key performance metric.

Biomass Alternative	Weight	Values
Life Cycle Costs (or benefits)	7	$ (364,549)
Payback Period/Expected Life	8	3.100
Dependability/Ease-of-use	8	0.375
Maintenance Labor (hr/wk)	8	28
Ease of Implementation	5	1.143
Energy Offset (%)	10	100.0%
Annualized Cost ($/yr)	-	$29,400
Levelized Energy Cost ($/kWh)	-	$0.176

A CHP system would be useful to evaporate the moisture before combustion. If only a CHP system were used to power the new MCSD WWTF, it would be necessary to receive a 20 metric ton shipment approximately every 5 days. According to the analysis, the payback period would be 62 years without salvage value considered, so the effective cost of energy would be higher than market rate.

While the Biomass CHP alternative is sized to meet the entire electricity demand, the life cycle cost of the system is quite large since it is assumed that a great amount of O&M labor and money is required to operate, and economy of scale works against the financials for a smaller scale operation. REC estimates that significant permitting will be involved, especially with respect to the North Coast Unified Air Quality Management District. This alternative is also constrained by the operational hours. Whenever the system is on, there should be an operator onsite, and REC estimates that a maximum of four operator hours per day would need to be dedicated to the system. These hours are accounted for financially in the Life Cycle Costs, using the O&M figure as a function of kW capacity (NREL, 2013). The worst case scenario would be that operator hours will be required on-site for 4 hours per day for start-up, shut-down and any other system operations. These hours are accounted for in the criteria "Maintenance Labor (hr/wk)." Finally, although the information provided does not ascertain this, it was assumed that there will sometimes be an electricity demand by the WWTF outside of those operating hours, so the actual supplemental electricity cost from PG&E may be higher than the estimates mentioned.

4.1.2 Alternative 2 - Solar Arrays

Photovoltaic (PV) solar array systems convert sunlight into usable electrical energy. Sunlight basically excites electrons that are then moved through a closed conductive loop producing current. A PV solar system typically consists of a battery, panels, conduit, an inverter, a racking system, wires, and connectors (Figure 2).

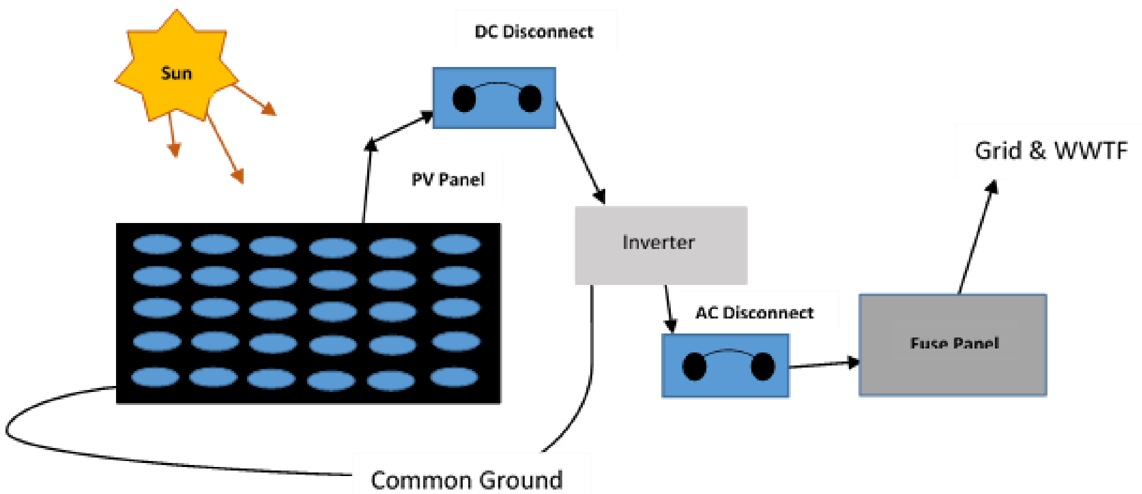


Figure 2: Schematic of simple PV system.

The battery for this particular system will be PG&E's electricity grid. The other components will need to be purchased from an appropriate supplier. The PV panels can be placed over drying beds, over clarifiers, any open land, and on south facing roofs (preferred). The panels and inverters will need to be reasonably close to the inter grid connection because there can be significant power losses associated with vast lengths of wire. For the MCSD a quick aerial assessment was made to determine appropriate places to put the PV modules (Figure 3).

Figure 3: Aerial picture with potential areas for PV installation.

PV systems for commercial applications producing around 200-kW should be in the range of $2.54 per Watt (D. Feldman, 2014). The alternative for MCSD was predesigned to use a ground mounting system built by Iron Ridge Inc., ET Solar 300-W polycrystalline PV modules, and 100-kW inverters by Chint Power Systems LTD. This particular system was theoretically designed with a price tag of nearly $1.50 per Watt and has a life cycle cost of $418,674 (Table 12).

Table 12: Table of the criteria evaluation for PV solar system key performance metric.

Solar Alternative	Weight	Values
Life Cycle Costs (or benefits)	7	$ 418,674
Payback Period/Expected Life	8	0.436
Dependability/Ease-of-use	8	0.750
Maintenance Labor (hr/wk)	8	0.066
Ease of Implementation	5	0.429
Energy Offset (%)	10	99.7%
Annualized Cost ($/yr)	-	$ 106,873
Levelized Energy Cost ($/kWh)	-	$0.094

4.1.3 Alternative 3 - Wind Turbines

Wind turbines are useful because wind is a readily available energy and can be harnessed relatively easily. A drawback for wind turbines is that in certain locations and times the wind velocity is not sufficient to spin the turbines, making a particular implementation infeasible. Wind orthogonal to the blade surface will cause them to spin and turn a shaft that is connected to a generator that produces electricity. Turbines will orient themselves correctly according to the wind direction; upwind turbines face into it while downwind turbines face away from it (DOE D. o., 2015). A wind turbine consists of the following (DOE D. o., 2015) and is shown in Figure 4:

- Blades
- Rotor
- Pitch System
- Shafts
- Brake
- Gear Box
- Generator
- Controller
- Anemometer
- Wind Vane
- Yaw Drive
- Yaw Motor
- Tower
- Nacelle

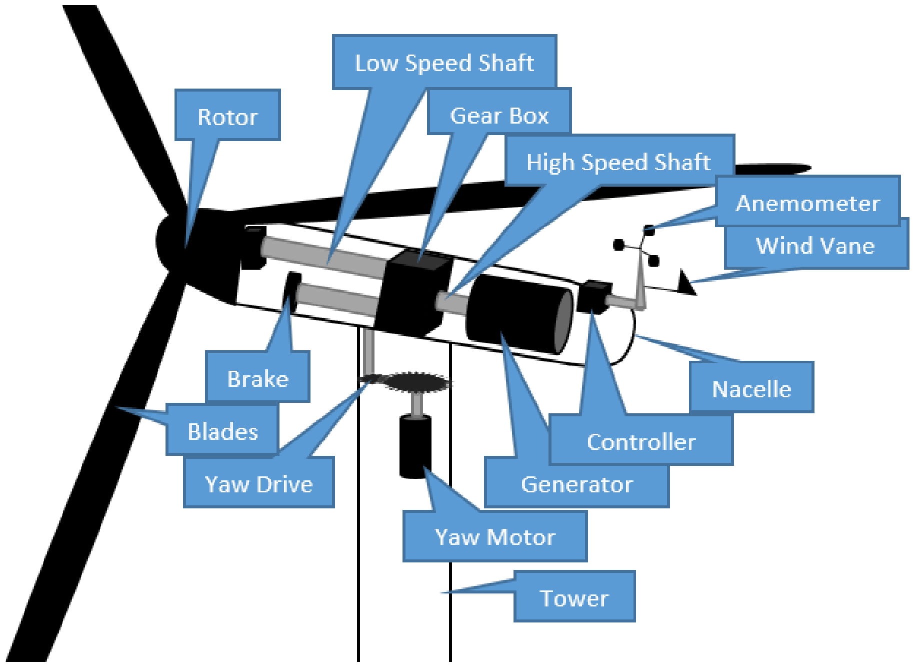


Figure 4: Wind Turbine System with Components.

Table 13: Costs of a 100 kW Wind Turbine

Cost per kWh ($/kWh)	**0.15**	**Lifetime (yr)**	**20**
Cost per MWh ($/MWh)	150	Capital Cost ($/kW)	2000
Hours in a year	8760	O&M cost ($/kwh)	0.025
1st Year O&M ($)	2,574.84	Capital Cost per Turbine ($)	200,000

A single 100 kW wind turbine would only produce approximately 9% of the total energy required by the WWTF, so a small wind farm of 10 turbines was analyzed as an alternative. Due to wind conditions in the area the turbine would only be running around 30% of the time in a year. The power curve shows that it is needed for the wind to be above 27 mph to produce the rated power of 100 kW (Figure 5).

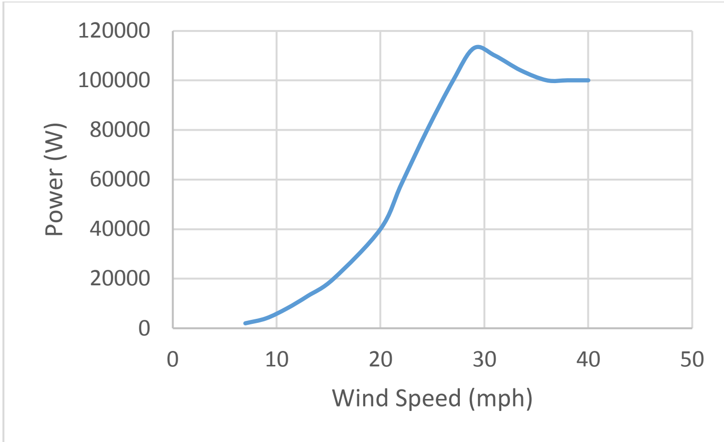


Figure 5: Power Curve for a 100 kW Wind Turbine

Based on the wind data the wind turbine will be running at a much lower efficiency than the rated 100 kW. With the small period of working availability and the low quality of the power produced during that period it was determined that a wind turbine would not pay for itself in energy offsets over its lifespan, and therefore would not be worth purchasing. The values obtained through the analysis of the wind turbine are shown below (Table 14).

Table 14: Table of the criteria evaluation for wind system key performance metric.

Scaled Wind Alternative	Weight	Values
Life Cycle Costs (or benefits)	7	$ (95,592)
Payback Period/Expected Life	8	1.000
Dependability/Ease-of-use	8	0.500
Maintenance Labor (hr/wk)	8	0.044
Ease of Implementation	5	0.714
Energy Offset (%)	10	91%
Annualized Cost ($/yr))	-	$ 24,000
Levelized Energy Cost ($/kWh)	-	$0.157

A 100 kW rated turbine was analyzed using a wind lens, which increases by a factor of 1.4 the velocity entering the turbine, making it generate more power and work at a larger variety of wind speeds. The system involving the wind lens requires smaller rotors in order to generate an equal amount of power compared to a normal 100 kW wind turbine. Including the wind lens helped improve the wind turbines energy generation but still not help it enough for the system to save money over its lifespan. More importantly for the analysis, the wind lens alternative is not an option because according to research, lenses are not commercially available for the size of system analyzed. Only wind lenses for residential, five kW systems were found during the analysis.

4.1.4 Alternative 4 -Anaerobic Digester with Methane Capture

For this system to be an option, MCSD would have to alter the future WWTF plans to include an anaerobic digester outfitted for biogas capture and the requisite supporting components for solids handling before and after digestion, and biogas refining, and then a gas-turbine or combined heat and power (CHP) generating unit. The 90% completed plans from Kennedy and Jenks show that instead of digestion, solids will be thickened passively before removal in a "biosolids storage basin." The value proposition for this combination of components is two-fold: solids are densified before removal, which saves on transportation costs; power is generated to offset some of the costs of operating the solids equipment and a significant amount of the total WWTF power demand. There appears to be enough space in the spot reserved for the biosolids storage basin that all of the components could be built in this area (Consultants, 2008).

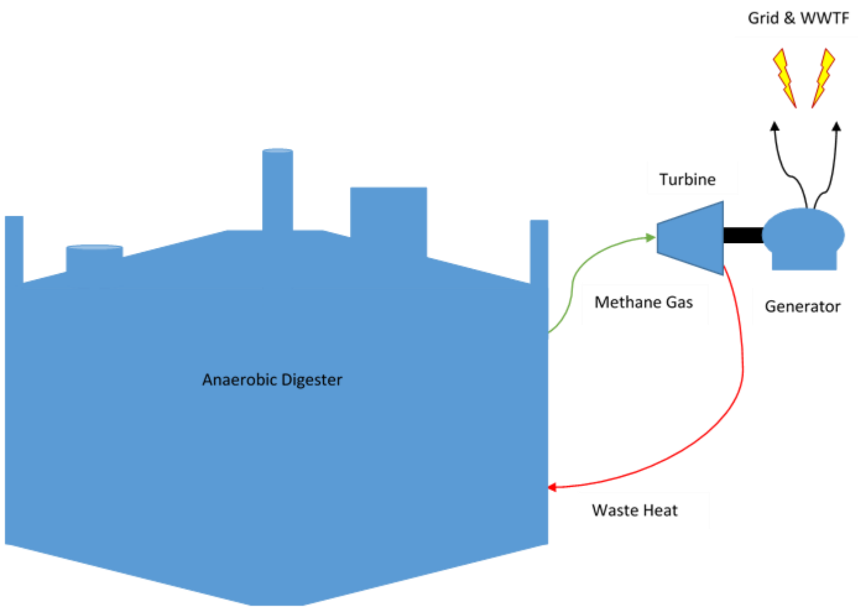


Figure 6: Cross-section detail of an anaerobic digester with a floating cover.

A typical system pumps solids from the primary oxidation tanks and secondary clarifiers (sometimes to a thickener) to a closed anaerobic digester. According to the Kennedy and Jenks plans, only solids from the two secondary clarifiers will be removed, which reduces the potential sludge mass input to the digester. The digester design can vary, but a typical design will have a floating tank lid. In an anaerobic environment, thermophilic bacteria will produce more methane than mesophilic bacteria (while also lowering the hydraulic residence time of the sludge and potentially the design volume of the tank). In either case more methane will be generated more quickly if the solids are first thickened. Anaerobic digesters are usually fitted with heat exchangers or boilers to keep the temperature warmer, and for this reason it may economically advantageous to use a combined heat and power (CHP) unit when the methane captured is combusted. But for this to occur, the methane must first be cleaned up, so that water vapor, CO_2, H_2S, SO_4, siloxanes, or any other volatiles to not reduce the quality of the fuel or its heating value, and does not pose a risk to the gas turbine material and mechanical components, or the public from the air emissions. Systems are available to desorb these volatiles and remove water vapor by using activated carbon and manipulating heat and pressure.

A simplified system schematic follows of the methane capture, combustion and heat exchanger. The diagram does not include the gas cleanup which would be necessary, and would include at least a compressor, scrubbers with adsorbent media, a blower and a dryer (**Figure 7**).

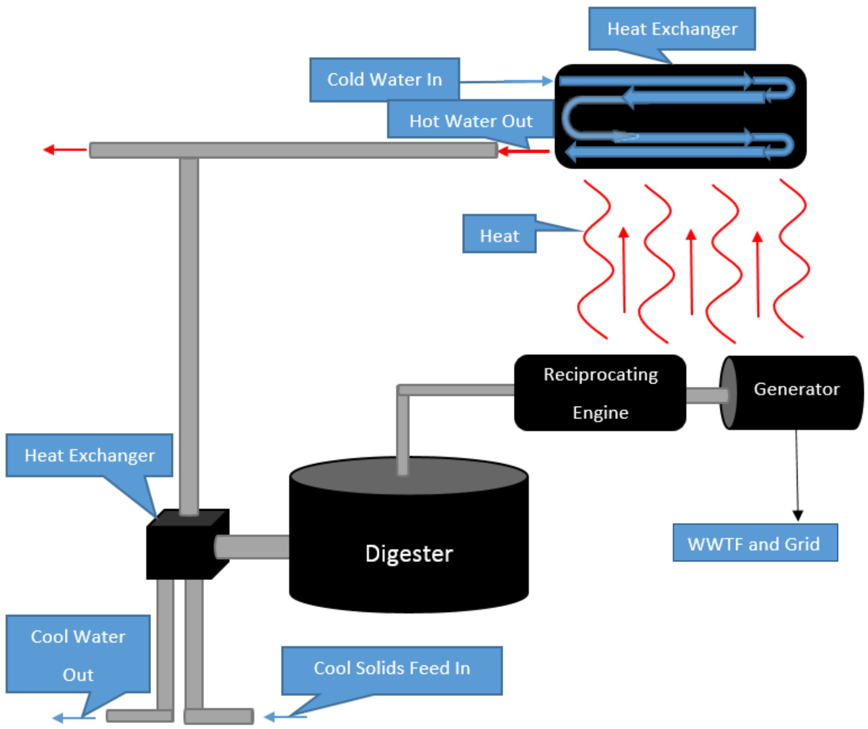


Figure 7: Schematic of a Cogeneration System using Methane Capture *(Commerce, 2011).*

Any power generated by a methane capture, refining and combustion system could only be used by MCSD at the WWTF facility, and any excess would not be eligible for a net-metering compensation. This is because the PG&E net-metering for biodigesters (NEMBIO) program is no longer taking applicants, as of December 2009 (PG&E, n.d.). That said, it is unusual for a WWTF to produce more power than is consumed in the treatment processes from methane combustion or a CHP system, even if the chemical potential energy flowing through the system far exceeds the energy consumed during treatment. A likely challenge would be to design for great enough storage to be able to run a generator on a regular schedule when pumping or other energy-intensive processes are operating.

Finally, components for solids drying and thickening are typical, especially for high-throughput WWTFs. Analysis should be conducted to determine if these would be economical. The advantage is that costs of transportation are reduced when the percent solids by volume is maximized, but energy and capital must be put into this effort.

Although inconvenient to change the ultimate build-out plans for the MCSD WWTF, this option seemed viable, especially if the digester were supplemented with food waste (which has approximately three times the chemical energy as biosludge) or perhaps brewery waste streams from around Humboldt County. Assuming the values reported by Kennedy and Jenks for influent and effluent TSS and flow rates, if an anaerobic digester, methane capture and refining system, and generator system were assembled, potentially the system could offset about 39% of the electrical energy demand (before factoring in the energy to run the digester). Over 30 years, assuming $0.15/kWh, this could add up to $1.8 M in electricity cost offset. For an analysis of potential methane production using TSS, see the appendix section.

Using this method and other information from Lin (2007), an estimate of the digester tank volume was determined to be approximately 1100 m^3. For the purpose of economic analysis, a simpler method was used, using a capital cost figure from the HSU ERE Capstone 2014 project, for a Bioferm digester with 1,107 m^3 capacity (R.P. Dunne, 2014). Another figure of $0.05/kWh was for the assumed total net cost to generate power from biogas given a plant size of between 1 and 5 MGD in moderate climates (EPA E. P., 2011). This is assuming that a rich burn engine is used in this cost estimate, and that the figure is already in net present cost. Finally, to simplify the analysis, another figure of 26 kW of electric capacity is generated continuously per 1 MGD of influent wastewater (EPA E. P., 2011). This figure was simply scaled up to determine how many hours per day a 100 kW generator can run, which is approximately 9.55 hrs/day, for a total of about 955 kWh per day. This production equates to almost 31% of the total annual expected energy demand for the new WWTP. The estimate is smaller than the figure estimated with the TSS method (Lin, 2007). Table 15 summarizes the analysis of digester alternatives at 20 and 40 years.

Table 15: Table of the criteria evaluation for AD+Methane systems key performance metric.

AD+Methane 20 yr Alternative	Weight	Values
Life Cycle Costs (or benefits)	7	$ (2,542,904.81)
Payback Period/Expected Life	8	0.25
Dependability/Ease-of-use	8	0.75
Maintenance Labor (hr/wk)	8	0.333
Ease of Implementation	5	1.286
Energy Offset (%)	10	31%
Annualized Cost ($/yr)	-	$ 367,752
Levelized Energy Cost ($/kWh)	-	$0.323
AD+Methane 40 yr Alternative	Weight	Values
Life Cycle Costs (or benefits)	7	$ (2,177,141)
Payback Period/Expected Life	8	0.25
Dependability/Ease-of-use	8	0.750
Maintenance Labor (hr/wk)	8	0.333
Ease of Implementation	5	1.286
Energy Offset (%)	10	31%
Annualized Cost ($/yr)	-	$ 311,017
Levelized Energy Cost ($/kWh)	-	$0.273

After analysis of the HSU ERE Capstone Spring 2014 projects, digesting food waste was only viable economically over the lifespan of the project when tipping fees were paid for dumping food, so that staff salaries could be paid. However, the economics of the hypothetical facilities did not assume co-location of wastewater treatment and abundant water, so the assumptions and economic parameters in the previous studies do not apply directly. Operating a food digesting system may in fact be significantly more favorable at MCSD WWTF than the locations that the previous Capstone projects had analyzed.

Preprocessing the slurried food waste, and handling of the solids post-digestion would be necessary, would be adding additional costs to the processes. It is possible to automate much of this to reduce staff labor, of course costing a bit more up front. Assuming that MCSD will not have interest in, or the staff budget support for, maintaining this sort of operation, the alternative cannot be excluded from consideration based on a resource availability constraint (either with or without food waste supplementation). It should be stated emphatically that these results do not give proper treatment to an alternative that uses a digester supplemented with food waste, but that such an alternative could satisfy both the need for MCSD to reduce its future energy demand and the need for the County to make better use of its green waste regionally.

4.1.5 Alternative 5 - No Design Alternative

The no design alternative entails that no renewable energies be added to the site. The wastewater facility would continue to solely rely on power supplied from PG&E. The cost of this energy would be about $170,820 annually, or about $2.13 million over the 20 year project lifetime.

Since the no design alternative has no upfront capital costs and no maintenance, it would require no maintenance labor, and would be dependable and easy to implement. Thus it would score well in all of these criteria. It would also offset all of the required energy, but it would have no net benefits. Given the price of energy, PG&E expenses over the 20 year period would be high, so it would score low in life cycle costs and the PG&E annual bill criteria (Table 16).

Table 16: Table of the criteria evaluation for no alternative systems key performance metric.

No Alternative (100% PG&E)	Weight	Values
Life Cycle Costs (or benefits)	7	-
Payback Period/Expected Life	8	1.000
Dependability/Ease-of-use	8	1.000
Maintenance Labor (hr/wk)	8	0.010
Ease of Implementation	5	0.100
Energy Offset (%)	10	0%
Annualized Cost ($/yr)	-	$ 170,820
Levelized Energy Cost ($/kWh)	-	$0.150

5. Analysis of Alternatives

This section provides an analysis of the alternatives that passed all of the constraints. The criteria are briefly described, followed by assumptions and weighting of the final alternatives. The subsequent Delphi matrix summarizes the overall performance of the alternatives, allowing for easy comparison. The analysis section ends with a discussion of the preferred alternative, or the optimal solution from the matrix.

5.1 Criteria and Weighting

Below is a description of the criteria for this project and the how each of them were weighted.

5.1.1 Net Present Value

The net present value (NPV) of an alternative, or the total benefits taking into account the required costs, is weighted as a 7. If the alternative does not offset 100% of the WWTF's power, this cost takes into account the cost of buying any required power from PG&E.

For this criterion, each alternative is scored on a scale from 1 - 10 according to the numeric ratio scheme displayed in the equation below. The weight allows the alternative with the highest net benefit to outscore the others. The NPV of each alternative (as previously mentioned in the Description of Alternatives section) are displayed in the table, alongside their subsequent weights.

Weight = actual/best *10

5.1.2 Dependability or Ease of Use

This criterion describes the durability of the technology and its ability to withstand conditions at the WWTF. This encompasses the reliable duration, or expected life, and the ease to which it can be operated and maintained. The criteria is rated as a six, as it is not the most important factor but it does bear considerable significance (Table 17).

Table 17: Dependability/Ease-of-Use Analysis

Dependability/Ease-of-use Questions	Wind	Solar	Biomass	AD + Biogas (20 yr)	AD + Biogas (40 yr)
Materially durable in WWTF and coastal conditions?	1	1	1	1	1
Mechanically/structurally durable in stormy/rainy conditions?	1	1	1	1	1
Warranty included to insure an expected life with reliable duration?	1	1	0	0.5	0.5
Easy to operate (will wastewater grade 4 operator knowledge be sufficient)?	1	1	0	0.5	0.5
Easy to maintain (could a licensed contractor or journeyman do the work)?	0	1	0	0.5	0.5
Does the system operate continuously?	0	0	0	0.5	0.5
Will the system have an energy storage component for backup or regular operation?	0	0	0	1	1
If the system operates intermittently, is its energy output predictable?	0	1	1	1	1
Total	0.500	0.750	0.375	0.750	0.750

5.1.3 Payback Period / Expected Life

This criterion represents the time required for an alternative's net present value (if negative) to be repaid by its benefits over the life cycle of the alternative, and is rated as an eight. Each alternative was weighted using the equation below, which allows for the alternative with the smallest ratio, or the smallest risk, to be optimal. The table below contains the risk ratios for each alternative and their accompanying weights.

Weight = best/actual *10

5.1.4 Maintenance Labor

This criterion was added to take into account the opportunity costs that would be associated with the time and money typically spent doing maintenance work on the renewable system in question. The addition of this criteria allowed for a more realistic analysis of each alternative. Maintenance labor was given a weighting value of eight, since this criterion can end up costing the MCSD money directly or indirectly. It should be noted that O&M costs are factored into the life cycle costs of all the alternatives, but that that maintenance labor criterion is purposely compiled and weighted separately.

5.1.5 Ease of Implementation

This criterion refers to the amount of permitting and licensing that the design alternative requires. This includes CEQA/NEPA and permits required at the local, regional, state, and federal levels. The criterion also describes the intensity of the pre-construction or development work by the estimated amount of time involved (Table 18).

Table 18: Ease of Implementation Analysis

Questions for ease of implementation:	Wind	Solar	Biomass	Anaerobic Digestion 20 Yr	Anaerobic Digestion 40 Yr
Is a permit, approval, inspection, waiver or variance needed from					
A federal agency?	0	0	1	0	0
A state agency?	0	0	0	0	0
A regional agency or board?	1	0	1	1	1
Humboldt County?	1	0	1	0	0
PG&E or the CPUC? (if grid-tied?)	1	1	1	0	0
Will a license need to be obtained to use a patented technology?	0	0	0	0	0
Will pre-construction or development work be necessary? (1 for each week)	2	2	4	8	8
Total	0.714	0.429	1.143	1.286	1.286

5.1.6 Energy Offset

Energy offset is a criteria that allows the alternative with the most energy production to hold more weight in the analysis of all of the systems. Energy offset was considered the largest weighting criterion since the objective of REC's analysis is to reduce MCSD's proposed electric bill.

5.1.7 PG&E Annual Bill, PG&E Project Lifetime and Levelized Energy Cost

These criteria represent the remaining expense that MCSD would need to pay at the end of the year with each alternative, the supplemental cost of energy in Net Present Value over the project lifetime, and the alternative and supplemental cost per kilowatt-hour of energy over the project lifetime, respectively. It was decided not to include these criteria in the weighting scheme because the same information is incorporated into the energy offset criterion. The information is included to aid in determining the annual equivalent annuity and the ultimate levelized cost of electricity when an alternative is implemented over its project lifetime, with PG&E supplemental bills included in the cost. The purpose of including this is to be more informative.

5.2 Delphi Matrix

A Delphi matrix was used to rank the design alternatives by how well they met the criteria. The design alternatives were evaluated for each criterion based on the scoring scheme described previously (Table 19).

Table 19: Values Calculated for each Alternative and Criteria and Derived Annual and project lifetime PG&E Electricity Bills

Criteria	**Wind (100 kW)**	**Solar**	**Biomass**	**Anaerobic Digestion 20 Yr**	**Anaerobic Digestion 40 Yr**	**No Alternative**
Life Cycle Costs (or benefits)	$(95,591)	$64,743	$(364,806)	$(2,542,905)	$(2,405,052)	$ -
Payback Period/Expected Life	25/20=1.25	11/20=0.55	62/20=3.1	63/20=3.13	64/20=3.21	1
Dependability/Ease-of-use	0.5	0.75	0.375	0.75	0.75	1
Maintenance Labor (hr/wk)	0.044	0.066	28	0.33	0.33	0.01
Ease of Implementation	0.714	0.429	1.143	1.286	1.286	0.100
Energy Offset (%)	90.5%	99.7%	100%	31%	31%	0%
PG&E Project Lifetime	$(203,505)	$(6,652)	-	$(1,477,384)	$(2,034,194)	$(2,128,795)
PG&E Annual Bill	$(16,330)	$(534)	-	$(118,549)	$(118,549)	$(170,820)

Weights were added to each of the criteria to properly evaluate each alternative (Table 20).

Table 20: Weights for each Alternative and Criteria.

Criteria	Weight	Wind (100 kW)	Solar	Biomass	Anaerobic Digestion 20 Yr	Anaerobic Digestion 40 Yr	No Alternative
Life Cycle Costs	7	-14.76	10.00	-56.35	-392.77	-371.48	0.00
Payback Period/Expected Life	8	4.41	10.00	1.78	1.76	1.72	5.51
Dependability/Ease-of-use	6	5.00	7.50	3.75	7.50	7.50	10.00
Maintenance Labor	8	2.28	1.52	0.00	0.30	0.30	10.00
Ease of Implementation	8	1.40	2.33	0.88	0.78	0.78	10.00
Energy Offset (%)	10	9.04	9.96	10.00	3.06	3.06	0.00

The weights for each criteria were then multiplied by the scores each alternative to determine the optimal alternative (Table 21).

Table 21: Scores for Each Alternative and Criteria and Total Scores.

	Scores						
Criteria	Weight	Wind (100 kW)	Solar	Biomass	Anaerobic Digestion 20 Yr	Anaerobic Digestion 40 Yr	No Alternative
Life Cycle Costs	7	-103.35	70.00	-394.43	-2749.39	-2600.34	0.00
Payback Period/Expected Life	8	44.12	80.00	14.23	14.10	13.76	44.12
Dependability/Ease-of-use	6	30.00	45.00	22.50	5.44	5.44	60.00
Maintenance Labor	8	18.20	12.13	0.03	24.46	24.46	80.00
Ease of Implementation	8	11.20	18.67	7.00	6.22	6.22	80.00
Energy Offset (%)	10	90.44	99.62	100.00	30.58	30.58	0.00
	Total	90.6	**325.4**	-250.7	-2699.2	-2550.5	264.1

6 Preferred Alternative

REC has come to the conclusion based on the evidence stated above that the MCSD's preferred option would be to install a PV solar system. Using the criterion and weights in the Delphi Matrix, Solar ranked the highest with a value of 318.4. The next most preferable alternative was to maintain the status quo with PG&E. Wind power ranked third, with a levelized cost of energy higher than relying solely on PG&E. Biomass ranked a distant fourth, in large part due to the high expected O&M costs and the consistent annual fixed cost of feedstock. Anaerobic digestion with biogas capture is not viable as an energy generation scheme because the large total capital cost to build the digester, install a biogas capture and cleaning (and storage) system, the reciprocating engine installation, and the associated engineering fees to redesign the new WWTF plans are not justified by the meager expected energy generation. Sensitivity analysis shows that even if a methane capture and generation scheme could produce 100% of energy demand, the levelized cost of energy would still be higher than the PG&E status quo.

In the following sections, analysis of the ground-mounted, grid-tied PV system will commence using the NREL software, “System Advisor Model” (SAM). Inputs, parameters and outputs are much more detailed and granular. An iterative process was used to produce the most cost-efficient model, and the system components were cross-checked for availability with major suppliers to ensure the system would be buildable.

6.1 SAM Model

The National Renewable Energy Lab (NREL) has developed the System Advisor Model (SAM) which estimates the performance and cost of a grid-connected renewable energy system. The system is actually an accumulation of models developed at NREL, the University of Wisconsin, Sandia National Laboratories, and select other organizations. The model's predictions are based on installation and operating costs, and design parameters that are inputted by the user. Such design parameters include the project location, system equipment, installation cost, operating cost, and any financial or incentive assumptions. For weather and performance data, SAM relies on online databases such as OpenEI U.S. Utility Rate Database and NREL Solar Prospector to help gather input variable values.

The program allows the user to do a sensitivity analysis of the various input variables to become more confident in the result. For example, if the user was unsure of the exact labor cost, the model could make a graph to show how altering this input would affect the payback period. The simple user interface allows the user to change variables with ease and get re-calculated results quickly. In regard to performance, SAM calculates the system's electricity production over the course of a year, using hour by hour predictions. Performance is also measured with standard metrics such as total annual output and capacity factor. In regard to finance, SAM analyzes cash flows over a specified period to provide financial metrics such as net present value and payback period.

SAM uses the LK scripting language, which the user can use to manipulate scripts to control simulations. The model can also be linked to Excel to export data and graphs. After starting SAM and selecting the technology type and financing option, the model will automatically choose the appropriate internal financial and simulation models that correlate to the project (Paul Gilman, 2012)

7 Analysis of Preferred Alternative

The analysis of the preferred design alternative consists of a description of all of the components of the design, including all structural and electrical equipment necessary. The analysis also includes a detailed discussion of important system locations, pre-development work, and system costs. This system will be capable of producing nearly over (800 kW) at peak sun exposure.

7.1 Location

The WWTF is located at 1656 Sutter Road off of highway 101 in between School Rd and Murray Rd exits. The PV system will be located along the southern fence of the property, nearest to the playground area (Figure 8).

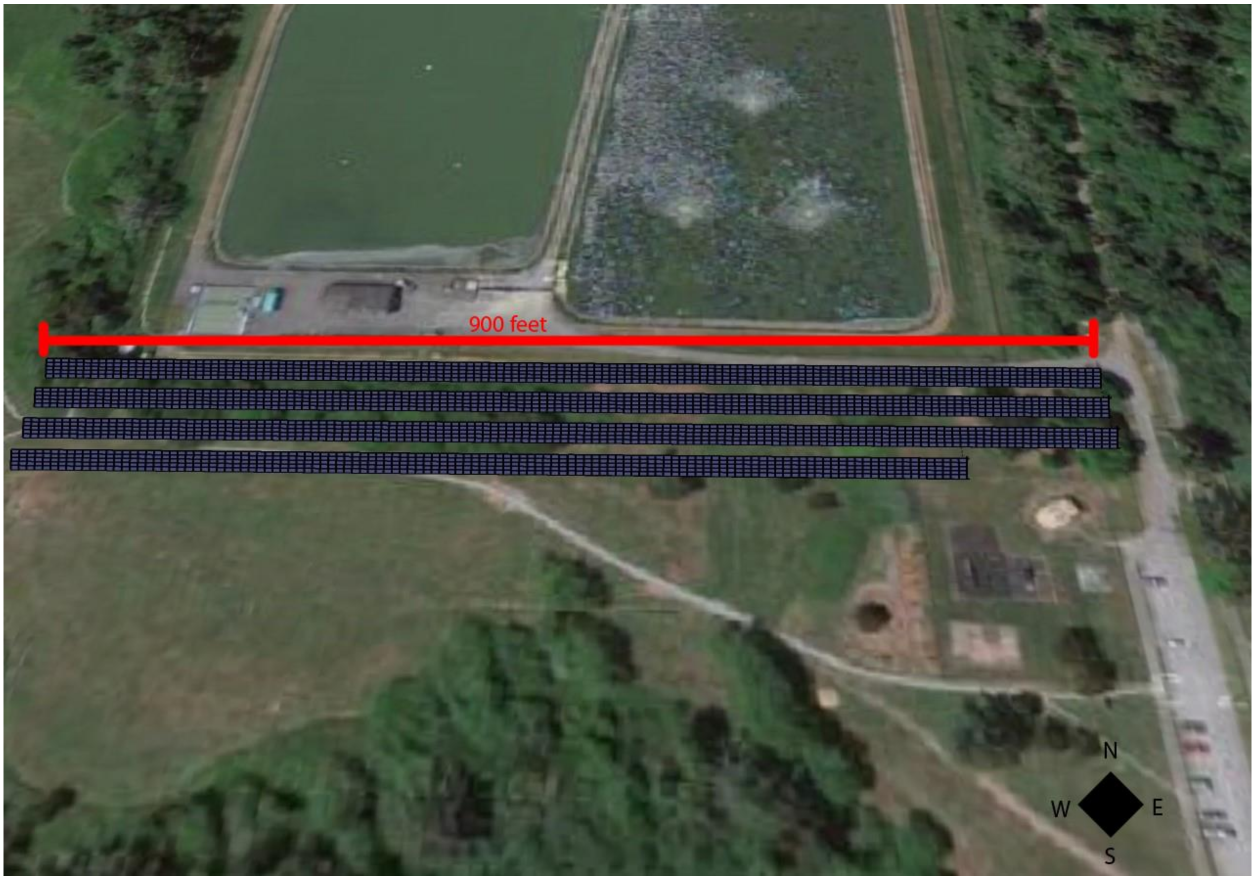


Figure 8: Arial view of MCSD WWTF and Image of proposed tilted PV array locations

This location is well-suited for a solar farm because it has little shading and is not in the way of the MCSD's layout or potential plan for the area. Placing the panels in the front for the public to see would enhance their appreciation of the MCSD for its commitment to environmental welfare. Also, the system is expected to have very little environmental impact at this location and it is close to the grid, which minimizes the length of wire and conduit necessary. However, the panels would slightly overlap the existing trail by the southwest corner and some shrubs and small trees would need to be removed in order to use this proposed area.

7.2 Land Preparation

A few measures will need to be taken to prepare for the installation of the panels. The southern fence will need to be extended linearly about 1650 feet to make room for the panels. An additional fence would need to be erected to encase the panels themselves. Also, approximately two acres of underbrush and trees will be removed on the south side of the WWTF, according to an assessment with Google Earth measurement tools on the site area. The removal of this vegetation is expected to have relatively little environmental impact. In regard to land surface, the area would need to be graded and approximately 100 cubic yards of soil will need to be excavated.

7.3 SAM Inputs

SAM required many different inputs to run a simulation. If the information needed was not inherently available, the group either left the default value or made an educated assumption based on relevant data. None of the assumptions made would result in significant changes in the model's output. The following table displays several of the SAM inputs.

7.4 Rate Schedules

REC did a sensitivity analysis with the different rate schedules in SAM. The model showed that having a constant 130 kW load and an A-10 rate schedule would result in the greatest savings. Contingencies with the A-10 and E-19 schedules with different loan rates, the availability of the NEM contract and FITC are considered later in Section 7.8.5.

7.5 Analysis of Different Solar Options

The SAM Model has several internal databases containing modules and inverters from different manufacturers. REC determined several modules fit the characteristics of this project, so they were all considered as potential alternatives (Table 22). The economic analysis shows that the EcoSolargy modules had the lowest total cost, so these panels were chosen for the final design.

Table 22: Economic analysis of different solar alternatives

Metric	ET Solar	EcoSolargy	Suniva	Kyocera
Annual Energy (kWh)	1,138,399	1,138,605	1,130,632	1,138,195
Capacity factor (%)	15.7	15.5	15.6	15.5
First year (kWhAC/kWDC)	1,374	1,359	1,370	1,356
Performance ratio	0.87	0.86	0.87	0.86
Levelized cost (nominal), (¢/kWh)	12.78	11.69	14.00	14.21
Levelized cost (real), (¢/kWh)	10.13	9.26	11.09	11.26
Electricity cost without system	$162,118	$162,118	$162,118	$162,118
Electricity cost with system	$20,049	$20,063	$20,329	$20,047
Net savings with system	$142,069	$142,055	$141,789	$142,071
Net present value	$356,069	$480,865	$223,337	$193,848
Payback period (years)	13.3	12.2	14.5	14.8
Initial cost	$2,747,832	$2,489,264	$3,011,440	$3,083,758

7.6 System Design

A typical grid-tied commercial photovoltaic (PV) system consists of solar panels, disconnects, wires, inverters, mounting racks, conduit, and several other miscellaneous electrical connecting devices. All of the electrical components must be UL listed in order to comply with US standards. UL stands for Underwriters Laboratories which is a safety standard for most electronic components. All of the solar systems components of this design are accepted by the California Energy Commission (CEC), so that they can legally be installed in California. The PV system design for the McKinleyville Community Service District (MCSD) has been broken down into sections labeled as panels, mounting system, inverter, miscellaneous components, location, and costs. The specifications of the major components of the PV system are described in detail below. Other small components include: connects, disconnects, switches, fuses, diodes, and power boxes.

7.6.1 Panels Specifications

Solar panels rely on sunlight interacting engineered materials to convert photons into electrical energy that can be then transferred to intended loads. The PV panels that have been analyzed for this project are EcoSolargy Titan1000 310W, rated at peak power output of 310W and 15.50% efficiency (Table 23).

Table 23: List of electrical specifications for the EcoSolargy Titan1000 310 Watt Panel.

Peak Power (P_{max})	**310W**
Module Efficiency	15.50%
Maximum Power Voltage (V_{mp})	38.40V
Maximum Power Current (I_{mp})	8.08A
Open Circuit Voltage (V_{oc})	46.00V
Short Circuit Current (I_{sc})	8.82A
Power Tolerance	0 to +5W
Maximum System Voltage	DC 1000V
Nominal Operating Cell Temperature	45∓2℃

These particular panels are polycrystalline and contain 72 individual cells in series. They can be purchased from ecosolargy.com for $0.68 per watt which is a pallet price. These panels have a 25-year performance guarantee plus a 10-year workmanship guarantee. They can be shipped with 21 panels on a pallet and the pallet can then be placed on a shipping container to be delivered. These panels are certified as California approved and will meet the state’s requirements.

Given the analysis of solar energy available in the region, the specifications of the components and the location and tilt of the modular arrays, the entire system would need approximately 2,700 solar panels to try to offset the fully rebuilt WWTF system expected annual energy demand of 1.1388 GWh. The panels are arranged together in groups 50 panels per ground mount subarray. To meet the power specifications of the inverter analyzed, panel wiring will be slightly different from the mounting system arrangement. There will be 54 subarrays that will be arranged into a larger array, and eight inverters each are fed by a series of interconnected subarrays.

7.6.2 Mounting System Specifications

An Iron Ridge ground mounting system was chosen to contain the solar panels into 54 subarrays each containing 50 panels. A schematic of the mounting components can be found in the Appendix. The project requires 54 repeats of subarrays that each contain 50 panels, requiring 648 piers that will need to be put vertically into the ground. The amount of concrete required per pier is 0.22 yd3, cumulatively 141.38 yd3 for the system. For this foundation, Iron Ridge specifies a 12 inches diameter hole to be dug with a minimum depth of 78 inches for each pier. Then the minimal volume of excavated soil is just under 141.35 yd3. The length of framing pipe required for this project, given size of the piers and cross rails, is approximately 13,492.5 f t. The total cost of the mounting system is about $246,996, which is broken down to $0.30/watt, given the price of all of the described components (Table 24).

Table 24: List of components and costs for ground mounting system by Iron Ridge Inc. (Appendix).

Item No	Description	Price
XR-1000-204A	XR1000, Rail 204" (17 Feet) Clear	$132,192.00
70-0300-SGA	SGA Top Cap at 3"	$42,120.00
29-7001-000	SGA Rail Connector at 3"	$38,880.00
29-4000-002	WEEB Grounding Lug (WEEB-LUG-6.7)	$10,800.00
29-7000-101	4-pack, Mid Clamp (C) 2.25", Mill	$9,720.00
29-4000-001	WEEB Compression Clip (WEEB-DMC)	$6,804.00
29-7000-157	4-pack, End Clamp (C) 1.57", Mill	$6,480.00
	Total Price	**$246,996.00**

7.6.3 Inverter Specifications

The inverter converts the DC output from the panels to AC output that supplies the grid. Relevant specifications of the chosen Chint CPS SC100KT-O/US-480 inverter are displayed in the table below. Six inverters will be needed, at a cost of approximately $17,500 each. They are have an expected lifetime of 10 years (Solar, 2015), but the manufacturer offers a standard warranty of just five years (Table 25).

Table 25: Inverter components (Appendix)

Component	Value
Maximum Input Power (kW)	110
DC Voltage Range (V)	300 - 600
Nominal Power (kW)	100
Maximum Efficiency (%)	96.8
Width/Height/Depth (mm)	1200/1850/880
Weight (lb)	1984

7.6.4 Conduit and Wiring inside Conduit, different sized gages

The panels being set up in subarrays of 5X10 and is going to require eight inverters to handle the power produced by the 2700 panel system. Six out of the eight inverters are going to be connected with 35 strings while two inverters with have 30 strings. A string is 10 panels connected in series to one another. When panels are connected in series the voltage of the wire adds the voltages. In parallel the amperage of the system gets added, not the voltage. A string of 10 panels in series has a voltage of 460 V and an amperage of 8.82A, which is the short circuit amperage of the panels. A diagram of a 5X10 subarray is shown in Figure 9 demonstrating how the wires would be connected in series to create a string and how five strings would be connected in parallel and connected to the inverter. The black and red wires in the figure are the wires in parallel, the blue being the wiring in series, green is the grounding wire. The wire to connect the panels in series was not considered as it comes with the panels and will not require more wiring. The wire to ground each of the panels is going to be small and was not considered as a cost as it would be minimal.

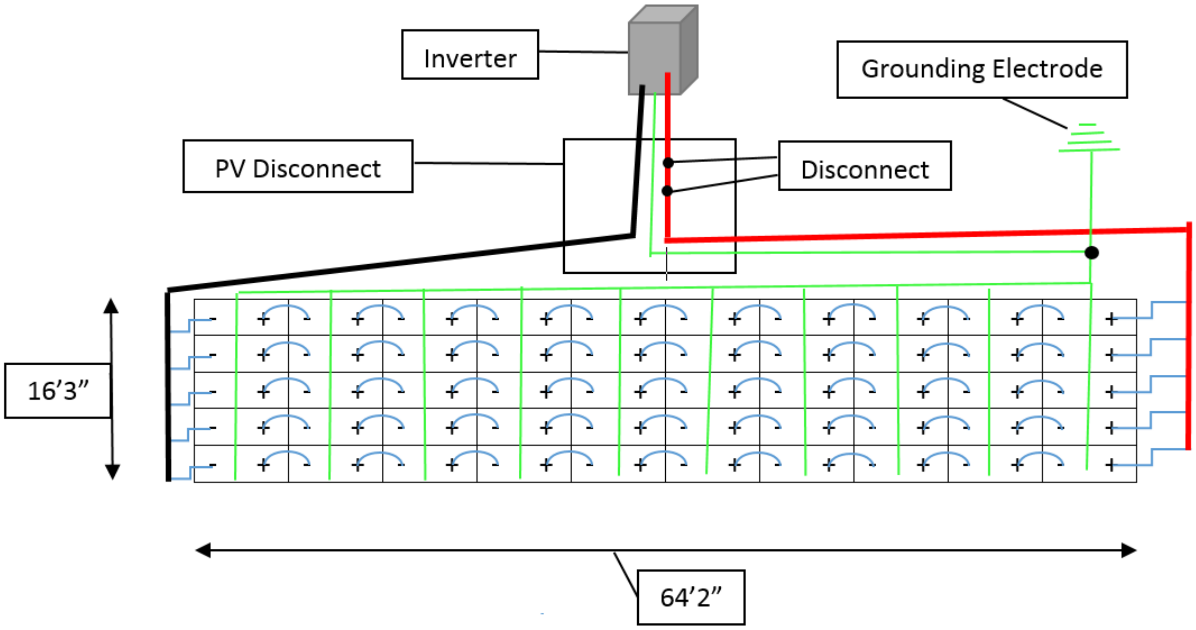


Figure 9: Wiring Configuration

Each inverter has 4 lines that it can intake allowing the 35 or 30 strings to be split up to reduce the amperage per wire entering the inverter. The six inverters that need to have 35 strings will have three lines that have nine strings and one line that will have eight strings. The two other inverters that have 30 strings will have two lines with eight strings and two lines with seven strings. All lines going in to the inverter will have the same voltage of 460 V, but the lines with nine strings will have an amperage of 79.38 A, 8 lines 70.56 A, and 7 lines 61.74 A.

The six inverters with 35 strings will require 1,306.68 feet of wire per inverter resulting in a total of 7,840.08 feet. All of the wire required for these inverters will be 2 AWG copper wire to accommodate for the amperage and the distance of wire. The two inverters with 30 strings will require 908 feet of wire resulting in a total of 1816 feet. The line of 7 strings will only require 4 AWG copper wire while the line with 8 strings will require 2 AWG copper wire. With this these two inverters will have a total of 1,160 feet of 4 AWG wire and 656 feet of 2 AWG wire.

All of these inverters need to be connected to the grid at the current metering locations. The inverters output is going to be a three phase wire and will require a large 1/0 AWG copper wire to handle the power that is being supplied to the grid from the inverters. The length of the wires from the inverters to the grid metering locations was determined to be roughly 3,000 feet. With all three of the different types of wire that are required for this project the total wiring cost is going to be $54,325.05. A pricing breakdown and length of wires is shown in Table 26

Table 26: Prices and Total Cost of Wiring

Wire	Price ($/1000 ft)	Length (ft)	Cost ($)
2 AWG	$ 4,050.95	8,496.08	$ 34,417.20
4 AWG	$ 3,327.83	1,160	$ 3,860.28
1/0 AWG	$ 5,349.19	3,000	$ 16,047.57
Total		12,656.08	$ 54,325.05

If it is decided to use no 4 AWG wire, with the 2 AWG being used instead, then the total cost of wiring would be increased by almost $1,000 to result in a total of $55,163.87. It may be beneficial to use the 2 AWG copper wire in case it is decided to increase the size of the system so the wire would not have to be replaced. All of the wiring costs analyzed also include the conduit prices for that wire and were obtained from the Humboldt State construction task catalog. The voltage drop was calculated over the distance of the wire based on the resistance, current, and voltage through the wire. This voltage job was determined to be less than 5% over the entire system and was used in the SAM model.

7.6.5 System Performance

Preferred alternative system performance and financials are summarized in the following main numeric figures.

•System Design Output: 837.3 kW

•Annual Energy (first year): 1,138,605 kWh

•Levelized Cost (nominal): 11.69 ¢/kWh

• Engineers Estimate of Costs Net Savings with System: $142,055

•Net Present Value: $480,865

•Payback Period (simple): 12.2 years

•Initial Cost: $2.489 Million

This section details the economics behind the design, including capital costs, costs of energy, lifetime benefits, etc. Final costs take into account the permitting costs and the labor costs associated with the transport and installation of the system.

Additionally, the system energy output, based on solar availability in McKinleyville from the Arcata-Eureka Airport, and considering the resistance and other losses, is modeled in **Figure 10**. The figure assumes that the system is brought online and grid-connected with a NEM contract with PG&E on March 1st. Data analysis of the SAM output determined that this scheduling would make the most economic sense for MCSD, given that NEM credits that expire at the end of contract year are reimbursed at just $0.0285/kWh (PG&E, 2014).

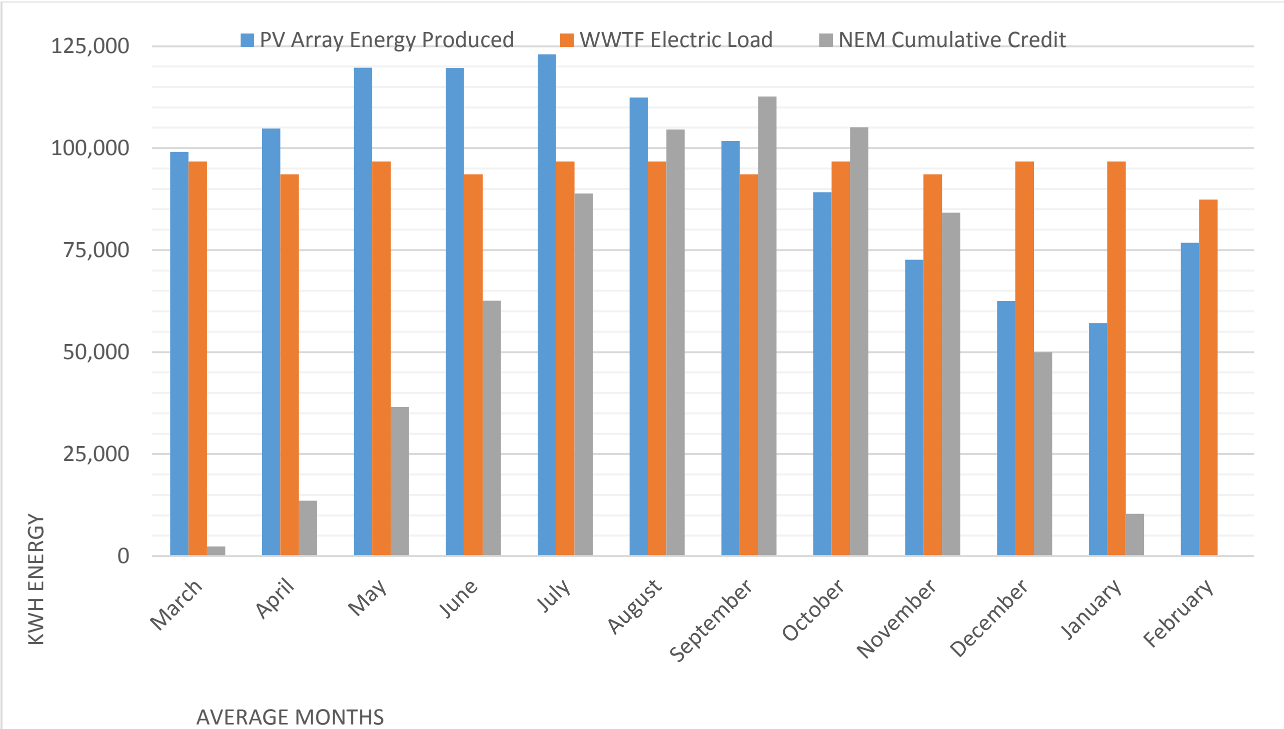


Figure 10: Typical monthly PV system performance, constant energy demand and NEM credits

7.7 Financial and Economic Assumptions

Major assumptions include the eligibility of MCSD and its financing partners for the Federal Investment Tax Credit (FITC), and the inclusion of Net Energy Metering (NEM). Both of these assumptions have limited time spans. The FITC expires at the end of 2016, and most likely will not be renewed by Congress. The FITC is a 30% tax credit for efficiency and renewable energy projects. The renewable energy project at the MCSD WWTF would be eligible with the right financing structure, likely a Limited Partnership (LP) or a Limited Liability Corporation (LLC). REC is aware that MCSD would prefer not to enter into a Power Purchase Agreement. More favorable terms are possible under an LP or LLC with a financier, especially if MCSD can secure a subsidized loan from the State of California. Subsidized loans under the name “PON-13-401” are available to “special districts” at a 1% rate for both bond and non-bond loan agreements for projects including renewable energy generation (CEC C. E., 2015).

The project at MCSD WWTF would definitely be eligible for Net Energy Metering, but time is running out to get the system online. The California Public Utilities Commission (CPUC) requires energy providers in California to make NEM available to new systems for up to 5% of the grid capacity, and after this capacity is reached, providers are no longer obligated to make this agreement available to customers with grid-tied renewable energy systems. As of May 2015, approximately 2.5% of the PG&E grid capacity has been met with NEM, but because solar installations are increasing so quickly, it is expected that by summer 2016, this capacity may be reached (Arnie Jacobson PE, 2015).

The renewable energy system that REC has modeled has positive net present value and a reasonably short payback period, even without the FITC incentive. This conclusion was confirmed with a sensitivity analysis. However, REC did not expect NEM to have a short time window. Therefore, it is in the interest of MCSD to move quickly to approve this project, make available bidding documents, specify in contractual agreements that the system be online by March 1st, 2016 (per the results in Section 7 about TOU and Rate Schedules)

7.8 Upfront Costs

All of the upfront costs for the design are described in detail below. The following table

7.8.1 Permitting

The cost of permitting was expected to be near $5,000. The WWTF is exempt from county permitting, and fees associated with the Coastal Development Permit are waived for public entities. Some of the PG&E interconnection fees are waived as well, so it seems that the only permitting fees come from the this interconnection and the costs to cover CEQA/NEPA documentation. Additional details of the permits and what they entail, and other miscellaneous expenses, can be found in the attached permitting report (Appendix).

Gordian Group- HSU Construction Task Catalog

- Labor
    - The contractor hired to install the panels must have an A, B, C-10, or C-46 license to be solar certified. Several quotes were obtained from local contractors to find the most economic installation option. Only local contractors were considered due to the MCSD's commitment to community welfare.
- Concrete
    - The Ironridge manufacturing company specified the amount of concrete that was needed for the specified mounting system. The price of the concrete itself, the associated transportation, and labor costs were calculated using HSU's Construction Task Catalog from the Gordian Group.
- Fence Replacement
    - The construction task catalog also provided pricing for the fence replacement. This provided the upfront cost, including labor, to move the fence and install a new fence around the panels.
- Land Clearing and Auger Boring
    - The pricing for land clearing and auger boring were, again, taken from the construction cost catalog for HSU.
- Construction
- Freight

Table 27: Capital cost inputs for SAM.

Description	Cost
2700 EcoSolargy Panels	$569,659
Construction & Margin	$500,000
20 Chint Inverters (over lifetime)	$350,649
Mounting Hardware	$252,261
Contingency (10% direct)	$197,245
Engineering Cost	$144,000
Land Clearing and Auger Boring	$103,582
Sales tax on components	$99,668
Freight (PV modules, inverters, mounting hardware)	$89,274
Fence Replacement	$66,985
Cement Pilings (materials & labor)	$55,940
Wire & Conduit	$55,000
Grid Interconnection Fee	$5,000
Approximate Total	$2,489,263

7.8.2 Engineering Costs

The engineering consulting fees were estimated to be about $36,000 per consultant, assuming a billing rate of $200/hour and 180 hours per consultant. This totaled approximately $144,000 for the REC team.

7.8.3 Sales Tax

A sales tax of 8.5% was assumed to calculate the total tax for the PV modules, inverters, and mounting hardware. These item costs were quoted from companies in various municipalities in California, so the baseline state tax was assessed for modeling purposes.

REC estimated that annual operation and maintenance costs consisted of wiping down the panels and period inspections and replacements. Cleaning the panels and area around them was expected to be completed monthly. The SAM Model assessed an annual supplemental PG&E bill according to the demand charges which are based on the highest average demand over 15 minute period for every month. The demand charge during the winter is $8.00/kW and during the summer is $16.23/kW (PG&E, 2014). This is in addition to the $140 monthly fixed fee.

The federal investment tax credit (FTIC), 30% of the installed costs, was included for the model of the preferred alternative. At the end of 2016 the FITC will reduce to 10% REC assume that the project will be completed in enough time to take advantage of the credit. REC includes a section with contiguities below based off of the applicability of tax credits for public agencies. There are various mechinisms for these agencies to qualify for the tax credit, by partnering with a third party (e.g. LLC , LP, or public-private partnerships).

There is currently a huge market for used solar panels. Although they are no longer operating at prime efficiencies, the panels can still produce a significant amount of energy. REC estimated a salvage value worth 15% of the initial capital cost of the panels, which may prove to be an overestimate given the ongoing development and economic effectiveness of solar panels (Table 28).

Table 28: List of extra costs.

Description	Cost/Benefit
O&M Annual Costs	$(10,000)
PG&E Supplemental Bill	$(20,063)
Salvage Value	$373,390
Federal Investment Tax Credit	$746,779

7.8.4 Cash Flow

Figure 11 shows cash flows of the preferred alternative, which takes into account a 5% loan on the entire installed capital cost, the 30% tax savings rebate after the first year, interest and principal payments annually, annual operations and maintenance, value of electricity savings, and annualized payback. For reference, cumulative payback and expenses are included, as well as a debt balance. Cash flows reference the modeled inflation rate of 2.5%. The cumulative payback corresponds to the payback period previously cited.

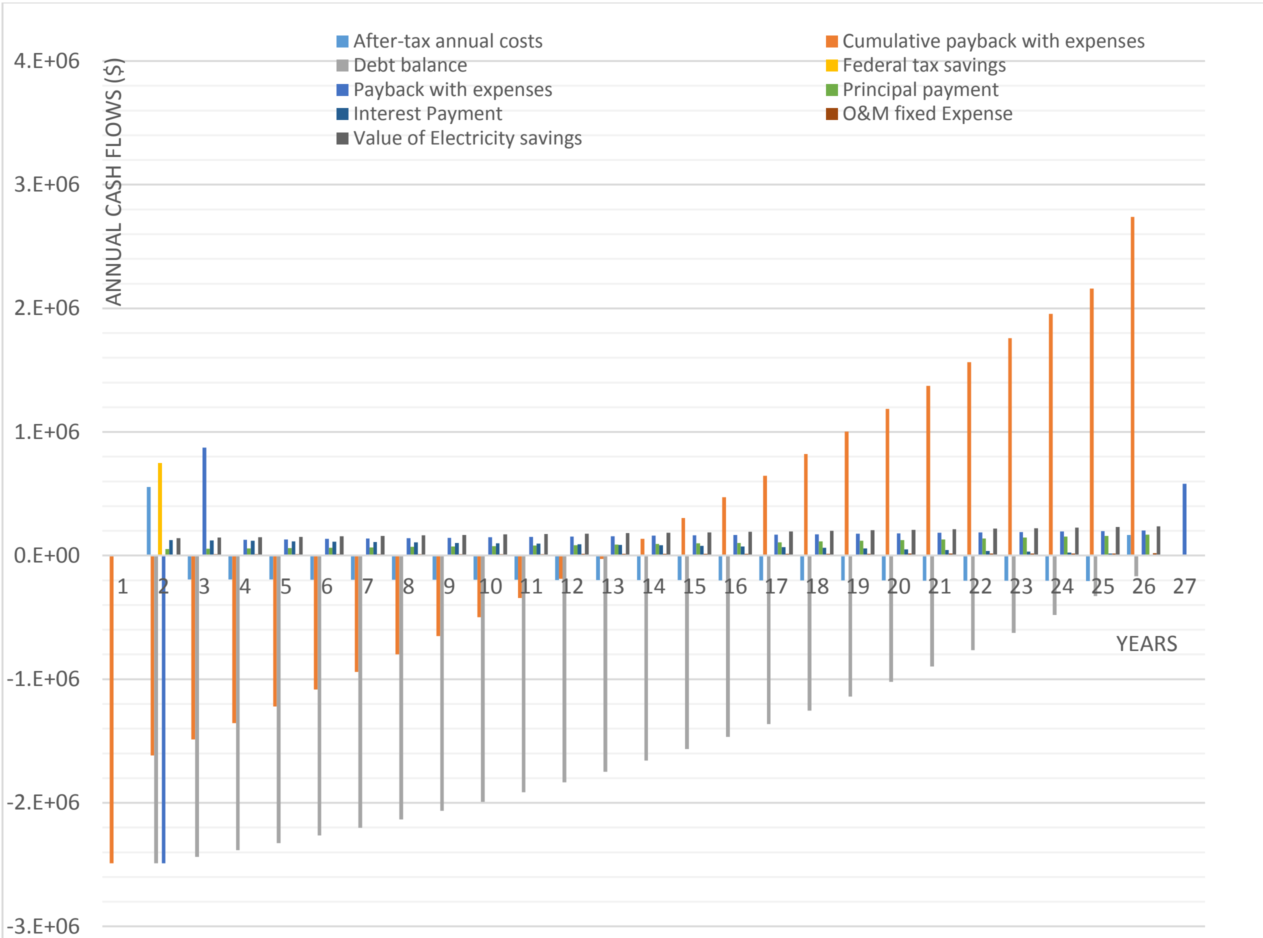


Figure 11: Cash flow of preferred alternative.

7.8.5 Contingencies

A 10% contingency fee was also included, consisting of other miscellaneous costs not formally addressed in the economic analysis.

The Monthly AB 327 Net Energy Metering (NEM) Program Limit Report, with data updated as of April 2015, shows that NEM Installations and Applications in Queue total 3.04%, where the total available MW cap is 5% of 48,177 MW (or 2409 MW) . The report states that 946.6 MW are still available for new NEM grid connections. There were 4,774 applications for a total of 43.6 MW requested in April 2015 (PG&E, 2015).

These numbers demonstrate that new grid-tied net-metered PV systems are coming online very quickly. Arne Jacobsen (HSU professor and Schatz Lab researcher) when consulted suggested that it is quite possible that the 5% cap will be met by the summer of 2015, or possibly sooner. REC's analysis had been assuming that NEM would be available as an option for most of the analysis. Another assumption

In light of the diminishing prospects to secure a NEM agreement and the limited availability of the FITC, REC prepared several variations of the preferred alternative, changing the loan term and percent rate, the presence or absence of a NEM agreement and the Federal Investment Tax Credit, and the PG&E rate schedules.

Each of the following tables with E-19 Schedules have in common the overview outputs from SAM shown in Table 30, regardless of the loan rate, loan term, and availability of the FTIC incentive. One major difference is that for this contingency analysis, REC assumes that there will be an electric load of 20 kW and 260 kW during approximately peak and off-peak hours, respectively for a total daily demand equivalent to the final preferred alternative. The daily demand schedule model is included in the Table 29. It should be noted that the SAM model intrinsic assumptions are not completely reliable for the net present value when NEM is not applied, for both the E-19 and A-10 rate schedules. SAM does not include adequate documentation to interpret the output when NEM is not applied. Time-of-Use and demand charges are not applied, but neither are the energy deficits not met by the PV system and met by PG&E. Therefore, the net present value when NEM is not applied appears more attractive than it will actually be. However, it is possible that with very careful scheduling of electricity demand around the PV system power output, extra fees can be avoided, regardless of rate schedule and net energy metering. All other factors considered, the A-10 rate schedule with net energy metering and the FITC is the most favorable, as the tables below confirm. Finally, the EECA state-subsidized loan for 1% is the most affordable loan available. REC has found that the final preferred alternative would qualify for these loans. A blank EECA loan application for non-bond loans has been included in the appendix.

Table 29: Altered demand schedule for E-19 contingency analysis.

Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Load (kW)	260	260	260	260	260	260	260	20	20	20	20	20	20	20	20	20	20	20	20	20	260	260	260	260

Table 30: SAM outputs given

Metric	With NEM	Without NEM
Electricity cost without system	$ 193,244	$ 193,239
Electricity cost with system	$ 76,520	$ 114,605
Net Savings with system	$ 116,723	$ 78,634
Initial Cost (100% financed)	$ 2,489,675	
Capacity factor	0.155	
Annual Energy (kWh)	1,138,605	
First year kWhAC/kWDC	1,359	
Performance Ratio	0.86	

Table 31: E-19 Rate Schedule with 1% EECA loan rate over 20 year term, with and without FITC and NEM

Loan Term (years)	20			
Loan Rate (%)	1%			
Loan Source	EECA			
Federal Investment Tax Credit	30%		N/A	
NEM (Yes or No)	Y	N	Y	N
Levelized cost (nominal)	7.10	7.10	13.16	13.16
Levelized cost (real)	5.63	5.63	10.43	10.43
Net present value	$ 666,775	$ 196,438	$ (23,922)	$ (494,259)
Payback period	14.9	22.0	20.2	NaN

Table 32: E-19 Rate Schedule with 3.7% private loan rate over 20 year term, with and without FITC and NEM

Loan Term (years)	**25**			
Loan Rate (%)	3.70%			
Loan Source	Private			
Federal Investment Tax Credit	30%		N/A	
NEM (Yes or No)	Y	N	Y	N
Levelized cost (nominal)	9.63	9.63	15.68	15.68
Levelized cost (real)	7.63	7.63	12.43	12.43
Net present value	$ 379,055	$ (91,282)	$ (311,642)	$ (781,979)
Payback period	14.9	22.0	20.2	NaN

Table 33: E-19 Rate Schedule with 5% private loan rate over 20 year term, with and without FITC and NEM

Loan Term (years)	**25**			
Loan Rate (%)	5.00%			
Loan Source	Private			
Federal Investment Tax Credit	30%		N/A	
NEM (Yes or No)	Y	N	Y	N
Levelized cost (nominal)	11.69	11.69	17.75	17.75
Levelized cost (real)	9.26	9.26	14.06	14.06
Net present value	$ 143,853	$ (326,484)	$ (546,844)	$ (1,017,181)
Payback period	14.9	22.0	20.2	NaN

A similar analysis was conducted with the A-10 TOU Secondary rate schedule to vary the loan rate, loan term, applicability of the FITC credit, and the presence or absence of the NEM agreement. The following tables show results of the net present value, levelized costs, and payback period given 1% EECA state-subsidized loans and 3.7% and 5.0% private loans. As previously, other outputs are not affected significantly.

Table 34: One percent loan rate on A-10 rate schedule.

Loan Term (years)	**20 yrs**			
Loan Rate (%)	1%			
Loan Source	EECA			
Federal Investment Tax Credit	30%		N/A	
NEM (Yes or No)	Y	N	Y	N
Levelized cost (nominal)	7.1	5.8	13.16	13.16
Levelized cost (real)	5.63	4.6	10.43	10.43
Net present value	$ 1,003,701	$ 1,271,740	$ 313,118	$ 433,169
Payback period	12.2	11.3	16.6	15.6

Table 35: Three point seven percent loan rate on A-10 rate schedule.

Loan Term (years)	**25 yrs**			
Loan Rate (%)	3.7%			
Loan Source	Private			
Federal Investment Tax Credit	30%		N/A	
NEM (Yes or No)	Y	N	Y	N
Levelized cost (nominal)	9.62	9.63	15.68	15.68
Levelized cost (real)	7.63	7.63	12.42	12.42
Net present value	$ 716,029	$ 835,921	$ 25,445	$ 145,497
Payback period	12.2	11.3	16.6	15.6

Table 36: Five percent loan rate on A-10 rate schedule.

Loan Term (years)	**25 yrs**			
Loan Rate (%)	5%			
Loan Source	Private			
Federal Investment Tax Credit	30%		0%	
NEM (Yes or No)	Y	N	Y	N
Levelized cost (nominal)	11.69	11.69	17.74	17.74
Levelized cost (real)	9.26	9.26	14.06	14.06
Net present value	$ 480,865	$ 600,718	$ (209,718)	$ (89,667)
Payback period	12.2	11.3	16.6	15.6

8 References

AECOM. (2014). *Technical Feasibility Study for Photovoltaic Systems DC Water Blue Plains Advanced Waste Water Treatment Plant.* Blue Plains.

Arnie Jacobson PE, P. (2015, May 7). HSU Professor . (REC, Interviewer)

BIC, B. I. (2015, Mar 4). *Combined Heat and Power*. Retrieved from Biomass Innovation: http://www.biomassinnovation.ca/CombinedHeatAndPower.html

CEC. (2000, Nov. 14). *Success Story East Bay Municipal Utility Distric*. Retrieved from California Energy Commission: http://www.energy.ca.gov/process/pubs/ebmud.pdf

CEC, C. E. (2015). *Energy Efficiency Financing*. Retrieved from California Energy Commission: www.energy.ca.gov/efficiency/financing/index.html

Commerce, S. J. (2011). *Environmental Outlook*. Retrieved from Daily Journal of Commerce: https://www.djc.com/news/en/12033594.html?action=get&id=12033594&printmode=true

Consultants, K. (2008). *Final Energy Independence Project.* Eugene: Kennedy/Jenks Consultants.

Covanta. (2012, May). *Other Renewable Energy Projects: Wood Biomass Facilities*. Retrieved from Covanta Inc.: http://www.covanta.com/facilities/other-renewable-energy.aspx

D. Feldman, G. B. (2014). *Photovaltaic System Pricing Trends.* DC: US DOE.

Davis, M. L. (2010). *Water and Wastewater Engineering.* New York: McGraw-Hill.

DOE. (2011). *Biomass for Electricity Generation*. Retrieved from Whole Building Design Guide: http://www.wbdg.org/resources/biomasselectric.php

DOE, D. o. (2015, Mar 2). *EERE*. Retrieved from Energy: http://energy.gov/eere/wind/inside-wind-turbine-0

Energy, I. C. (2015, May 11). *Ina Road Water Pollution Control Facility.* Retrieved from Clean Energy Application Center. US Department of Energy: http://www.midwestchptap.org/profiles/ProjectProfiles/InaRoad.pdf

EPA. (2014, Aug. 11). *Region 9*. Retrieved from US EPA: http://www.epa.gov/region9/waterinfrastructure/technology.html

EPA, E. P. (2011). *Opportunities for Combined Heat and Power at Wastewater Treatment Facilities:Market Analysis and Lessons from the Field.* DC: US EPA.

EPA, U. (2013). *Renewable Energy Fact Sheet: Low-Head Hydropower from Wastewater.* DC: US EPA.

Eric Byous, B. G. (2012). Solar Energy for Water and Wastewater Utilities: Step-by-Step Project Implementation and Funding Approaches. US EPA: James Horne, US EPA Office of Wastewater Management.

Explained, S. E. (2015, Apr 2). *Solar Electricity*. Retrieved from Electricity Forum: http://www.electricityforum.com/solar-electricity.html

Francescato, L. Z. (2008). *Wood Fuels Handbook: Production | Quality Requirements | Trading.* Retrieved from AEBIOM: http://www.aebiom.org/IMG/pdf/WOOD_FUELS_HANDBOOK_BTC_EN.pdf

Hickman, M. (2015, Jan. 28). *Portland Hydropower Project into Underground Water Pipelines.* Retrieved from MNN: http://www.mnn.com/earth-matters/energy/blogs/portland-hydropower-project-taps-into-underground-water-pipelines

IndustCards. (2014, Oct. 11). *Biomass Power Plants in California*. Retrieved from Powerplants Around the World: http://www.industcards.com/biomass-usa-ca.htm

Lin, S. (2007). *Water and Wastewater Calculations Manual, 2nd Ed.* New York: McGraw-Hill.

NREL. (2013). *Analysis/Tech*. Retrieved from National Renewable Energy Laboratories (NREL): http://www.nrel.gov/analysis/tech_lcoe_re_cost_est.html

Paul Gilman, A. D. (2012). *System Advisory Model SAM 2011.12.2.* DC: NREL.

PG&E. (2014). *Electric Schedule A-10: Medium General Demand-Metered Services.* San Fransico: Pacific Gas and Electric Company.

PG&E. (2015, May 12). *Net Energy Metering and Tracking*. Retrieved from Pacific Gas and Electric Company: http://www.pge.com/en/mybusiness/save/solar/nemtracking/index.page

PG&E. (n.d.). *Net Energy Metering for Biogas Digester Generators*. Retrieved from PG&E: http://www.pge.com/en/b2b/newgenerator/netenergymetering/biogasnem/index.page

PG&G. (2015). *Electric Rule No. 21: Generating Facility Interconnection.* San Fransico: Pacific Gas and Electric Company. Retrieved from www.pge.com

R.P. Dunne, I. K. (2014). *Anaerobic Phased Solids for Loca Food Waste Managment.* Arcata: Humboldt State University Environmental Resources Engineering Capstone Design .

Solar, C. (2015). *Products*. Retrieved from Civic Solar: http://www.civicsolar.com/product/chint-cps-sc100kt-ous-480-100kw-inverter

Spellman, F. (2013). *Water & Wastewater Infastructure: Energy Efficiency and Sustainability.* Boca Raton, FL: Taylor & Francis.

Stillwater Sciences, C. o. (2011). *Mad River Watershed Assessment.* Eureka.

Tegen, Lantz, Hand, Maples, Smith, & Schwabe. (2015). *2011 Cost of Wind Energy Review.* DC: NREL.

Vickie Montgomery, C. R. (2015, May 12). *The Hill Canyon Wastewater Treatment Plant (HCTP)*. Retrieved from City of Thousand Oaks: http://www.toaks.org/government/depts/public_works/sewer/hill_canyon_treatment_plant/hctp.asp

Weston, M. (2010, Oct. 2). *General News*. Retrieved from Oroville MR News: http://www.orovillemr.com/general-news/20101002/sunshine-pays-off-solar-savings-helps-in-patching-sewer-pipes

Wong, S. (2011). *Tapping the Energy Potential of Municipal Wastewater Treatment: Anaerobic Digestion and Combined Heat and Power in Massachusestts.* Massachusetts: Massachusetts Department of Environmental Protection.

WRR. (2010). *100kW Wind Turbine Generation*. Retrieved from Wind Energy Resources: http://wind-energy-resources.com/wer_100kw_wind_turbine.html

9 Appendix

9.1 Appendix A: Supplemental Calculations

Methane capture from Anaerobic Digestion using TSS for analysis

Kennedy and Jenks assumes that the input TSS will be approximately 221 mg/L, and the post-treatment maximum effluent TSS is 15 mg/L. Then according to Lin (2007) (SD Lin), the potential chemical energy from AD gases is approximately 11.558 MBTU/day. Note that this figure is based on unrefined AD gases, and that the total caloric value would not change significantly upon dehydrating and refining the gases to natural gas quality, though the energetic density would be improved so that a higher heating value may be obtained.

The following calculations are adopted from Lin (2007) (S.D. Lin).

TSS removed is:

Average Annual TSS (2,857 lb/day) X (453593 mg/lb) / (AAF=1.53 MGD X 1 L/3.7854 gal) - (monthly average effluent TSS = 15 mg/L) = 206 mg/L TSS daily

Estimating VSS in raw sewage removal, assuming VSS/TSS=0.75:
VSS removed = (206 mg/L) X (0.75) = 154.5 mg/L

Now estimate VSS in the sludge reduced 65%:
VSS reduced = (VSS removed) X (0.65) = 100.425 mg/L

Now calculate volatile solids (VS) reduced in 1.53 MGD of sewage:
VS reduced = [(1.53 MGD) X (8.34 lb) / (Mgal X mg/L)] X (VSS reduced) = 1281.6889 lb/day

Estimate daily gas production for 1.53 MGD of sewage, assuming 15.0 ft^3/lb of VS:
Gas produced = (15.0 ft^3/lb) X (VS reduced) = 19,225.3335 ft^3/day

Now, assuming a caloric value for VS (biogas) of 22,400 KJ/m^3, the potential BTU/day from biogas production:
(Gas Produced) X (1 m^3/35.314667 ft^3) X (22,400 KJ/m^3) X (0.94781712 BTU/KJ) = 11558230.3 BTU/day

Now, the best energy conversion option for the scale in question appears to be a reciprocating engine, like the GE Jenbacher model with 330 kW output, which can achieve an electrical conversion efficiency of 36%, with 44% of the potential chemical energy converted to high grade heat, and the other 10% lost. So, first assuming no losses in total caloric value after refining the biogas to approximately the influent natural gas standards required by the reciprocating engine model, the facility can optimistically expect an electrical output of 1219.46 kWh/day with a value at $0.15/kWh of $182.92/day. Assuming a 30 year life of all systems involved with methane production and energy conversion, a $1.8M electricity cost can be offset.

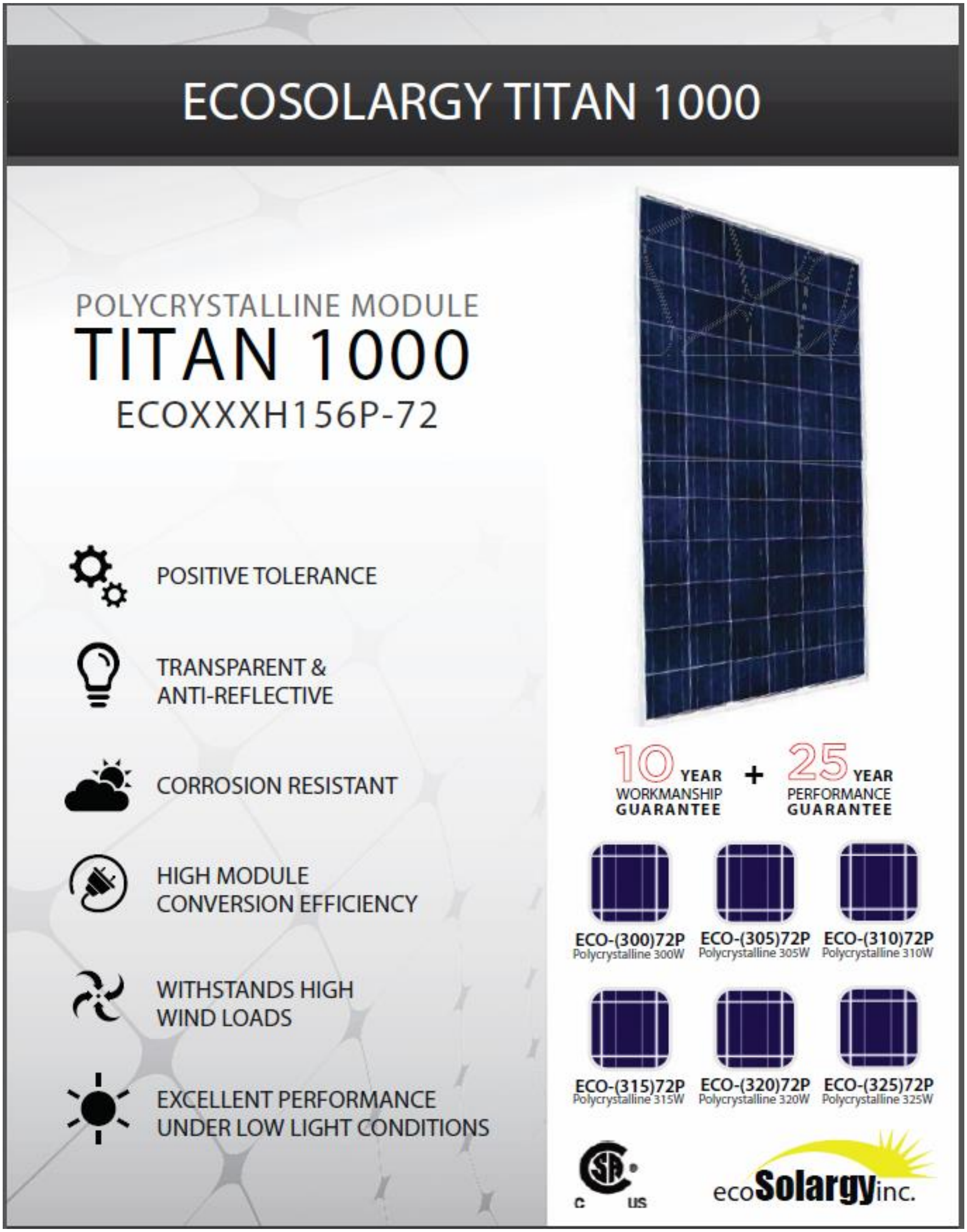
Potential electricity output = (Biogas potential chemical energy = 11558230.3 BTU/day) X (n=0.36) X (1 kWh/3412.1416 BTU) = 1219.4578 kWh/day

Potential cost offset = (Potential electricity output = 1219.4578 kWh/day) X ($0.15/kWh) = $182.92/day

Note that different values were used based upon available literature for the alternatives analysis section with respect to this alternative.

9.2 Appendix B: Technical Specification Documents

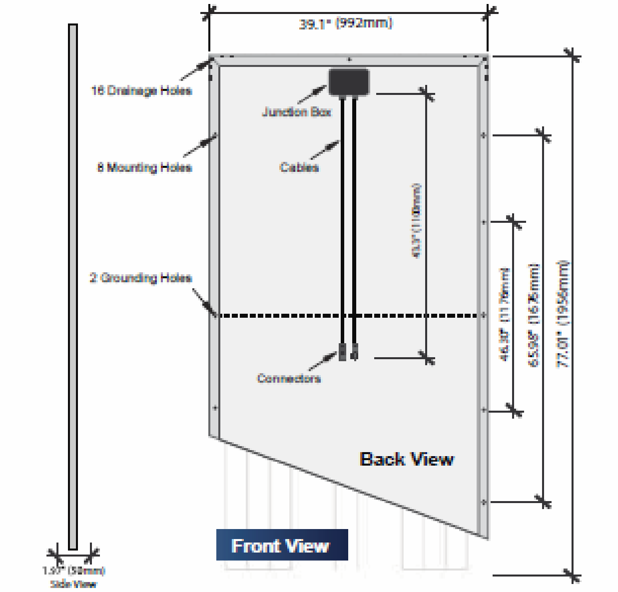
9.2.1 PV Module Specifications



TITAN 1000 ECO(XXX)H156P-72

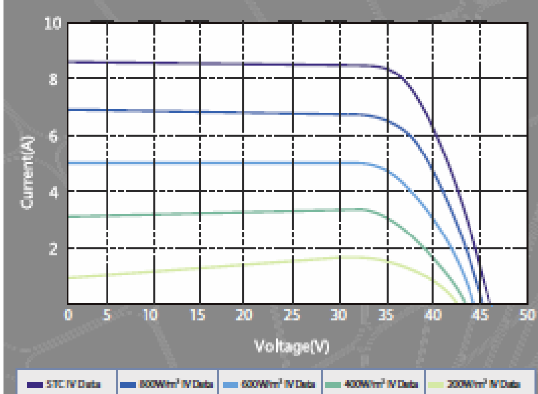
POLYCRYSTALLINE MODULE

DIMENSIONS OF PV MODULE TITAN ECO(XXX)H156P-72



CURRENT-VOLTAGE & POWER-VOLTAGE CURVE

Efficiency	up to 15.50%
Wattage	up to 325W
Warranty	25 Years



Values at Standard Test Conditions (STC) = Irradiance: 1000W/m²
Air Mass: 1.5, Module Temperature 77°F (25°C)

SPECIFICATIONS AND DATA

Panel Dimensions	77" x 39.1" x 1.97" (1956mm x 992mm x 50mm)
Weight	59.5 lbs (27kgs)
Cells	72 x Polycrystalline 6"x 6" (156mm x 156mm)
Glass	1/8" (3.2mm) Tempered Glass
Frame	Anodized Aluminum Alloy; Color: Silver
Junction Box	IP Rated Junction Box with Bypass Diodes
Cable	4mm² solar cable (RHW AWG #12)
Connector	(MC4-Type) PV Plug Connectors
EVA	EVA
Backsheet	TPT
Modules per Pallet	21 Panels

TEMPERATURE COEFFICIENTS

Nominal Operating Cell Temperature (NOCT)	45±2°C
Temperature Coefficient of ISC (α)	0.06%/°C
Temperature Coefficient of VOC (β)	-0.30%/°C
Temperature Coefficient of Pmax	-0.43%/°C

PERMISSIBLE OPERATING CONDITIONS

Operating Temperature	-40°F to +185°F (-40°C to +85°C)
Maximum Hail Diameter @ 43Mph (80km/h)	Up to 1" (25mm)
Wind Impact	≤2400 Pa
Snow Impact	≤5400 Pa

ELECTRICAL DATA

Model	Pmax (0+5W)	Vmp	Imp	Voc	Isc	Max System Voltage	Standard Test Conditions
ECO300H156P-72	300W	37.60V	7.98A	45.60V	8.68A	1000V	Irradiance: 1000W/m² AM: 1.5 Temperature: 77°F (25°C)
ECO305H156P-72	305W	38.00V	8.03A	45.80V	8.75A		
ECO310H156P-72	310W	38.40V	8.08A	46.00V	8.82A		
ECO315H156P-72	315W	38.80V	8.13A	46.20V	8.89A		
ECO320H156P-72	320W	39.10V	8.19A	46.40V	8.96A		
ECO325H156P-72	325W	39.50V	8.23A	46.60V	9.02A		

8835 Research Drive, Irvine, California 92618
T: 877.808.4213 F: 888.442.7144 E: information@ecoSolargy.com W: www.ecoSolargy.com

CAUTION: READ ALL INSTRUCTIONS BEFORE HANDLING, INSTALLING, & OPERATING THIS PRODUCT
Technical Specifications & Data are subject to change without prior notice, contact ecoSolargy for latest data.

9.2.2 Inverter Specifications

CHINT POWER

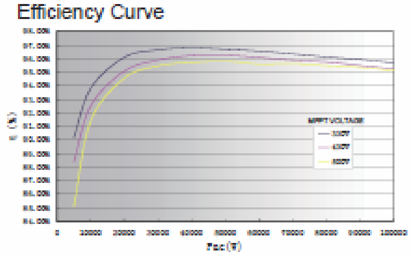
Datasheet

100kW Grid-tied PV Inverter for North America

The CPS SC100KT-O/US-480 grid-tied PV inverter is designed for the North America market. The output is designed with a built-in transformer to allow direct connection to low voltage grid. The inverter achieves a 96.8% max efficiency with low loss magnetic materials, advanced MPPT control and variable structure SVPWM controls to minimize the power loss.

The inverter enclosure is rated NEMA 3R for outdoor applications and its compact design minimizes the space required for installation. It also features film-type capacitors, enhanced DSP control, comprehensive protection functions and advance thermal design to make the whole system highly reliable.

Efficiency Curve



High Efficiency

- Max. efficiency of 96.8%, CEC efficiency of 96.0%
- High speed and precise MPPT algorithm
- Patented SV PWM control technique with precise thermal design to achieve high efficiency over wide load range

Broad Adaptability

- NEMA 3R (IP44) Rain proof & Ice / Sleet proof enables indoor/outdoor application
- High altitude application
- Multi communication interface: RS485, Ethernet
- Reactive power adjusting and active power derating (optional)
- Integrated ground fault detector interrupt
- Integrated AC/DC surge protection
- Negative grounded (positive grounded as an option)
- Wide MPPT range enables flexible stringing

High Reliability

- Design for reliability
- Comprehensive protection functions
- Enhanced DSP control system
- Advanced thermal design, with variable speed fans
- Anti-Islanding protection
- Special designed low frequency transformer
- Redundant controller for system protection
- Ground-fault detection and interruption circuit

Dimensions

C US

FC This device complies with part 15 of the FCC Rules

CHINT POWER

Datasheet

Technical Data

DC Input	
Max. DC Voltage	600Vdc
MPPT Voltage Range	300-600Vdc
Max. DC Power	110kWp
Max. Input Current	350A
Max. Number of Input Circuits	4
AC Output	
Output Power	100kW
Nominal Output Voltage	480Vac, Three-phase
Grid Voltage	422-528Vac
Nominal Grid Frequency	60Hz
Current THD	<3%
Power Factor	>0.99
System	
Max. Efficiency	96.8%
CEC Efficiency	96.0%
Ingress Protection	NEMA 3R (IP44)
Stand-by Consumption	<40W
Operating Temperature Range	-20°C - +60°C / -4°F - +140°F
Cooling	Variable speed cooling fans
Humidity	0-95%, non-condensing
Altitude	2000m (derating from 1500m)
Display and Communication	
Display	LCD
Communication	RS485, Ethernet (optional)
Mechanical Data	
W×H×D	1200×1850×880 (mm) / 47.2×72.8×34.6 (in)
Weight	900/1984 (kg/lb)
Certificates	
Standard & Codes	UL1741, CSA-C22.2 NO.107.1-01, IEEE1547, FCC part15
Warranty	
Standard	5 years
Option	Up to 20 years

SHANGHAI CHINT POWER SYSTEMS (North America) Inc.
700 International Pkwy, Suite 102, Richardson, TX 75081
Tel : +1-925-570-1463
Mail : EdHeacox@chint.com
Web: www.chintpower.com

9.2.3 Ground Mount Hardware Specifications

Project Report

IRONRIDGE
Solar Mounting Made Simple

Project Details

Name kasdjfh
Module Eco Solargy: ECO-(310)72P
Dimensions 39.1" x 77.0" x 2.0"
Tilt 35°

Date 2015-04-30
Total Modules 2700
Total Watts 837,000

Load Assumptions

Wind Exposure B
Wind Speed 100 mph
Snow Load 0 psf

Foundation Requirements

Type Concrete
Hole Diameter 12"
Min. Hole Depth 90"

SubArray Requirements

Pipe Size 3"
Diagonal Bracing No

Foundation Loads

Shear 1,532
Moment 3,830
Uplift -970

Project Layout

SUBARRAY DETAILS

SUB ARRAY	CONFIG	REPEATS	PIERS	MODULES / PIER	CANTIL.	EDGE CLEAR.	EW PIER SPAN	NS PIER SPAN	AREA
1	5x10	54	648 (12x54)	4.17	1' 4"	4"	12' 4"	9'	16' 3" x 3465' 5" (16' 3" x 64' 2") x 54
	TOTAL PIERS		648				TOTAL AREA		878' 10" x 3465' 5"

SUBSTRUCTURE

SUB ARRAY	REPEATS	SOUTH PIERS	SOUTH PIER PIPE [ABOVE/BELOW]	NORTH PIERS	NORTH PIER PIPE [ABOVE/BELOW]	CROSS PIPES	CROSS PIPE LENGTH	TOTAL LENGTH
1	54	324 (6x54)	7' 6" [2' 6" / 5']	324 (6x54)	12' 9" [7' 9" / 5']	108 (2x54)	64' 2"	13492' 5"
TOTALS		324		324		108		13492' 5"

CONCRETE

VOL/PIER	NO. PIERS	TOTAL VOL
0.22 yd³	x 648	141.38 yd³

3rd Party Substructure Materials

Subarray	Repeats	Piers	South Piers	North Piers	Cross Rails	Total
1	54	54 x 12 (648)	324 x 7' 6" (2430')	324 x 12' 9" (4131' 6")	108 x 64' 2" (6930' 11")	13492' 5"
					Total Pipe	**13492' 5"**

Bill of Materials

Part No.	Description	Spares	Qty.	MSRP Ea	Price
XR-1000-204A	XR1000, Rail 204" (17 Feet) Clear	0 Edit	1080	$122.40	$132,192.00
70-0300-SGA	SGA Top Cap at 3"	0 Edit	648	$65.00	$42,120.00
29-7001-000	SGA Rail Connector at 3"	0 Edit	2160	$18.00	$38,880.00
29-4000-002	WEEB Grounding Lug (WEEB-LUG-6.7)	0 Edit	1080	$10.00	$10,800.00
29-7000-108	4-pack, Mid Clamp (G) 2.5", Mill	0 Edit	1080	$9.00	$9,720.00
29-4000-001	WEEB Compression Clip (WEEB-DMC)	0 Edit	3240	$2.10	$6,804.00
29-7000-204	4-pack, End Clamp (G) 1.97", Mill	0 Edit	540	$12.00	$6,480.00
				Total Price Ext	**$246,996.00**
				Price/ Watt	**$0.30**
				Total Weight	**25809 lbs**

US prices only

IronRidge makes no representation or warranty, either express or implied, of any kind with respect to this software or its contents (such as product information, recommendations, applicability, descriptions or prices) including, but not limited to, merchantability and fitness for a particular purpose, how current it is, its accuracy, its completeness, product availability, its security or that defects will be corrected.

9.3 Appendix C: Construction Manual

In order to make the project feasible and apply to the current net metering system with PG&E, the MCSD needs to apply for the program as soon as possible. The program is about to reach its application cap limit, so MCSD's application must be filed with urgency before the net metering option expires. The solar design would probably still be feasible, but would be much less attractive financially. Once that is done, all of the other permits need to be obtained in order to get the approval to go forward and start with construction. REC assumed that the CEQA/NEPA paperwork would take around five months to go through the filing process and get approval. The Coastal Commission and the PG&E permits can be complete concurrently with the CEQA process. Both the Coastal Commission and PG&E permits were assumed to take two months. Once the approval from CEQA has been received, land clearing, including tree removal and fence removal, can be started and should take two weeks. After the land is cleared, it will need to be graded, allowing for holes for the mounting system to be drilled and trenches for the wiring to be started. Wiring is expected to take another three weeks. Installing the mounting system and filling the holes with concrete after the poles have been installed was estimated to take about a month. After the mounting system has been installed the panels added, which will take approximately two months taking 2 months. The wiring should be added alongside the panel additions to the greatest extent possible. Overall, the entire construction process is expected to take 38 weeks or 9.5 months without holidays. Based on weather conditions in Humboldt County, it is very possible that construction will be delayed in the winter months, elongating the duration of the project. If the process begins at the end of May with no delays, then REC estimates that the project will be finished and online mid to late May of 2016. This results in a total timeline of almost an exact year. A breakdown of the construction schedule is shown in Table 37 and shown in a Gantt chart in Figure 12.

Table 37: Construction Schedule Break Down

Task	Duration (days)	Start	Finish
Apply for PG&E Net Metering Program	7	5/21/2015	5/29/2015
CEQA Document and Permitting	140	5/29/2015	12/10/2015
Coastal Commission Permitting	56	6/5/2015	8/21/2015
PG&E Permitting	56	6/12/2015	8/28/2015
Land Clearing	14	12/10/2015	12/29/2015
Grading , Drilling Holes, Trenching	21	12/29/2015	1/26/2015
Construction of Mounting System	28	1/26/2016	3/3/2016
Installing Panels	56	3/3/2016	5/19/2016

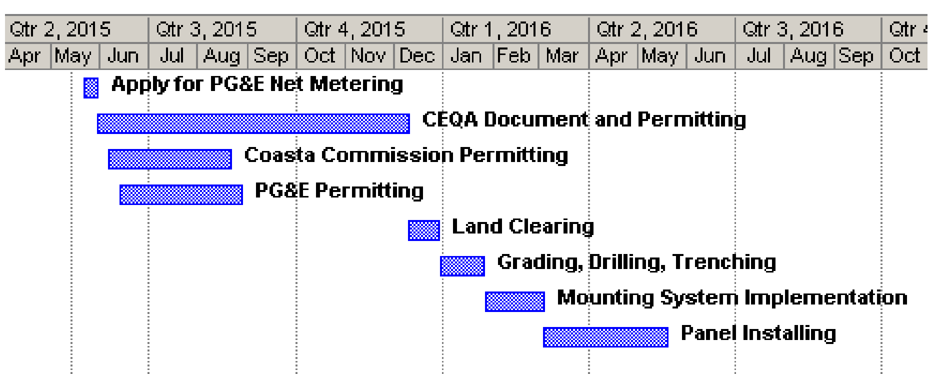


Figure 12: Gantt chart of Construction Schedule

9.3.1 System Advisor Model (SAM) Program Output

System Advisor Model Report

Photovoltaic System	838 DC kW Nameplate	Arcata Airport, CA
Commercial	$2.97/W Installed Cost	40.98 N, -124.1 E GMT -8

Performance Model

Modules	
EcoSolargy ECO310H156P-72	
Cell material	Multi-c-Si
Module area	1.9 m²
Module capacity	310.3 DC Watts
Quantity	2,700
Total capacity	837.7 DC kW
Total area	5,238 m²

Inverters	
Chint Power Systems America: CPS SC100KT-O-US-480	
Unit capacity	100 AC kW
Input voltage	330 - 500 VDC DC V
Quantity	8
Total capacity	800 AC kW
DC to AC Capacity Ratio	1.05
AC losses (%)	1.0

Four subarrays:	1	2	3	4
Strings	68	68	67	67
Modules per string	10	10	10	10
String voltage (DC V)	384.0	384.0	384.0	384.0
Tilt (deg from horizontal)	35	35	35	35
Azimuth (deg E of N)	180	180	180	180
Tracking	fixed	fixed	fixed	fixed
Backtracking	-	-	-	-
Rotation limit (deg)	-	-	-	-
Shading	no	no	no	no
Soiling	yes	yes	yes	yes
DC losses (%)	4.9	4.9	4.9	4.9

Performance Adjustment	
Annual	no
Year-to-year decline	0.65
Hourly factors	yes

Annual Results (in Year 1)				
GHI kW/m²/day	3.9	3.9	3.9	3.9
POA kW/m²/day	4.0	4.0	4.0	4.0
DC kWh from subarray	317,840	317,840	313,170	313,170
Net to inverter	1,199,000 DC kWh			
Gross from inverter	1,150,000 AC kWh			
Net to grid	1,138,000 AC kWh			
Capacity factor	15.52			
Performance ratio	0.86			

Financial Model

Project Costs	
Total installed cost	$2,489,675
Salvage value	$373,451

Analysis Parameters	
Project life	25 years
Inflation rate	2.5%
Real discount rate	5.5%

Project Debt Parameters	
Debt fraction	100%
Amount	$2,489,675
Term	25 years
Rate	5%

Tax and Insurance Rates	(% of installed cost)
Federal income tax	0%/year
State income tax	0%/year
Sales tax	0%
Insurance	0.25%/year
Property tax (% of assess. val.)	0%/year

Incentives	
Federal ITC	30%
Federal Depreciation	None
State Depreciation	None

Electricity Demand and Rate Summary

Annual peak demand -130 kW
Annual total demand -1,138,800 kWh
Pacific Gas & Electric Co
Fixed fee: $140/month
Monthly fixed TOU demand charge $0
Monthly fixed demand charge $0
Tiered rates with three or more rates

Results	
Nominal LCOE	11.7 cents/kWh
Net present value	$480,600
Payback period	12.2 years

Commercial | Flat Plate PV | Simple Efficiency Module Model | Sandia Inverter Database

System Advisor Model Standard Report generated by SAM 2015.1.30 on Thu May 14 03:57:20 2015 1 / 3

9.4 Appendix D: Extra Documentation

9.4.1 Construction Bid

Request for Construction Proposal for Ground-Mounted PV System Installation for Mckinleyville Wastewater Treatment Facility

Bid Information

Overview
The Mckinleyville Community Service District (MCSD) is seeking a construction firm to install an 840 kW capacity photovoltaic system at the Mckinleyville Wastewater Treatment Facility. MCSD has the design for the PV system, including location, component specifications, as well as electrical connections.

Goals
The installation must be in compliance with all applicable electrical and building codes. The project must be under contract with the licensed contractor by August 1, 2015. Renewable Energy Consultants have determined that the PV system must be online and grid-connected by March 1st, 2016 to establish a "true-up date" that will make the best use of net energy metering (NEM) credits and avoid high energy costs during months with lowest solar exposure should NEM credits not extend to those months.

Statement of Work
The contractor must demonstrate experience in the installation of PV ground mount systems. This experience must involve, but is not limited to, the elements described below.
Grading and subterranean supports

- Properly grade the chosen area where the PV system will be locations. Grading includes removal and grubbing of underbrush and trees, and potentially adding infill soil.
- Using an auger to bore 12"-diameter holes to a depth of 78" for the cement pilings to support pole mounts.
- Removing excavated soil
- Filling auger holes with cement and aligning poles in parallel and correct planar orientation (see diagram)

Mechanical Installation

- Inspect all of the materials (PV modules, mounting hardware and inverters) for defects or manufacturing flaws; contact the distributor if warrantied materials need replacement.
- Install the mounting rack system according to the attached schematic
- Install the solar modules securely on the mounting hardware
- Install the inverters beneath the mounting hardware according to the schematic

Electrical Installation

- Install transition boxes to connect the exterior wires to the conduit
- Properly ground the electrical equipment
- Wire the solar panel arrays in series and parallel according to the schematic included
- Connect the series/parallel combination PV module subarrays to the inverters as shown in the included schematics

Other Steps

- Clean up the work site area
- Demonstrate to MCSD staff that the system is complete and functional
- Train the staff in the routine operation and maintenance of the system

System Overview

Total capacity
840 kW (837.734 kW nameplate capacity)
System Specifications

- PV modules
- Number and type: 2700 PV modules, EcoSolargy Titan 1000 series, model ECO310H156P-7
- Dimensions: 77" x 39.1" x 1.97" (1956mm x 992mm x 50mm)
- Includes: $4mm^2$ solar cable (RHW AWG #12)

PV Module Provider:
Ben Marchak, Wholesale: ben.marchak@ecosolargy.com
(949) 769-2706
17500 Redhill Ave. Unit 140, Irvine CA 92614
Note that the wholesale contact quoted $0.68/Watt for the system size (>2000Panels)

PV Module Performance

- P_{max} = 310W
- V_{mp} = 39.40V
- V_{oc} = 46.00V
- Efficiency: 15.50%
- I_{sc} = 8.82A
- I_{mp} = 8.08A

PV Installed Location:
Just south of the existing McKinleyville Wastewater Treatment Plant

Minimum Mandatory Contractor Qualifications
Licensing: A, B, C-10, C-46
Minimum Experience: 5+ years in solar PV installation
Location: Must be local
References: Must provide information on similar PV projects with addresses, names, and contact information

Bid Submittal Information

Contact Information
Mckinleyville Community Services District
Mailing Address: PO Box 2037
Mckinleyville, CA 95519
Phone: (707)839-3251
Fax: (707)839-8456
Email: mscd@mckinleyvillecsd.com
Important Dates
Mandatory Bid Meeting – July 20, 2015 at 5 pm at MCSD Conference Room
Questions Due – August 1, 2015 by 5 pm (by mail or email)
Bids Due – August 30, 2015 by 5 pm (by mail or email)
The bid submittal should contain the sealed bid and cover letter describing the contractor's qualifications. No bids will be accepted after the date and time listed above. MSCD reserves the right to reject any bids. Illegible or incomplete bids will not be evaluated.

Contract Award

The final bid will be awarded to the contractor that meets all of the qualifications set forth. If several potential contractors are equally competitive in their qualifications, the bid will be awarded to the lowest bid. All decisions are final unless the contractor chooses to reject the offer.

9.4.2 Operation and Maintenance

Operations & Maintenance Manual

Ground mounted solar photovoltaic (PV) systems typically consist of a type of solar panel, an inverter capable of handling the power output of the system, a racking or mounting structure for the panels to reside on, electrical components, and the area where the system will be built. Below a table has been constructed to display the typical O&M of a PV system.

Table 10.4.2.1: Table of recommended operational maintenance for the MCSD WWTF.

Equipment	Description	Action
PV Panels	Inspect panel surfaces for accumulation of debris	Clean surface with appropriate cleaner.
	Inspect panel surfaces for cracks or breaks.	Replace damaged panels ASAP
	Inspect panel wires and wire connections for breaks/damage	Repair and/or replace
Inverter(s)	Inspect ventilation regimen	Clean or replace filter
	Inspect wires and connections	Repair and/or replace damaged
	Verify unit is functioning	Replace if not functioning
	Observe for irregular operation temperatures	Replace
Mounting System	Inspect for damaged components	Repair and/or replace
Electrical Components	Wear and tear	Replace as needed
	Inspect for burns, physical damage, loose connections, or hot spots.	Tighten and/or replace
	Check for warning light or sounds	Repair and/or replace
Landscape	Verify vegetation level are acceptable	Send in the goats.

9.4.3 Permitting

Permitting Report

This section outlines the permits needed for the proposed development, including associated applications and inspections. Each permit overview includes a brief description of what the permit consists of, how long it will take to implement, and any related costs.

Coastal Development Permit

According to the Public Resources Code, all new development under public works must be reviewed by the California Coastal Commission (PRC Section 30606). The application for the coastal development permit and all supplementary documentation must be filled out. The application is lengthy but requires no filing fee, according to Government Code Section 6103.

The CDP requires the following supplemental material to accompany the application:

- Proof of the applicant's interest in the property
- Assessor's parcel map
- Copies of local approvals
- Stamped envelopes to property owners within 100 feet of the property lines of the project
- Stamped envelopes to all other parties known to be interested in the proposed development
- Location map
- Two sets of all applicable plans
- Copy of environmental documents (Negative Declaration, Environmental Impact Report/Statement) and any responses
- Verification of all other permits, permissions or approvals

If the development is in an area of high geologic risk, a geology and soils report is also required. According to the Permit Streamlining Act, the lead agency has 30 days to inform the applicant of the permit application's completion. The agency can also request a resubmission, which begins the 30 day period again. A responsible agency has 180 days after the application's completion to approve/disapprove the permit. The local agency's approval/denial of the permit can be appealed within 10 days (PRC Section 30603(c)). Overall, the permit application is expected to take a few months to process, which does not include the time required to put the application together. The link to the permit application can be found below. The North Coast Coastal Commission can be reached at (707)826-8950 for more information about the permitting process.

Coastal Development Permit Application: http://www.coastal.ca.gov/cdp/CDP-ApplicationForm-nc.pdf

CEQA/NEPA

The proposed development is not exempt from the California Environmental Quality Act (CEQA). Since environmental impacts would be minimal, a Negative Declaration or Mitigated Negative Declaration

(MND) can be filed by the lead agency. An initial study must be completed within 30 days of the submission of the project application, which determines which type of environmental document must be completed (PRC Section 21080.2). An MND must be published for public review for at least 21 days. Once a final MND is adopted, which can take up to 180 days, the agency can file a Notice of Determination, which adds another 30 day period for legal challenge. Overall, the permitting process is expected to take about 6 months.

A MND requires knowledge of the potential impacts of the proposed development, as well as mitigation measures to address these issues. The most important environmental impacts from this design project would be the grading required. Trees can be planted elsewhere to potentially mitigate this problem. However, MCSD may find that a Negative Declaration may prove to be more suitable.

PG&E Interconnection Application

To connect to the grid, the client must get permission from the utility provider and file an interconnection application. For PG&E, this process has several steps. In the engineering review phase, the client must file Form No 79-974, or the Interconnection Application for Non-Export or Certain Net Energy Metered (NEM) Generating Facilities, along with all supplementary documentation. The application is divided into four major sections: application type and contact information, generating facility information, generator information, and supplementary documentation. This documentation includes a site plan, single line diagram, transformers/transfer switch/protective relay documentation, and customer authorization. The application takes about 15 days to process, and may be submitted on the PG&E website. A supplemental form (No 79-998) is also required for net-metered facilities after the application submittal, although the form is very short.

The final inspection requires engineering approval, a signed-off building permit, a copy of declarations page of home owner insurance, and the NEM Agreement Form (No 79-978). In this case, MCSD is not required to provide a building permit, as no county permits are required for a wastewater treatment facility. PG&E is required to perform the final inspection within 30 days after the application is submitted. PG&E will approve the interconnection within three business days of notifying the customer. Since the WWTF is an NEM generating facility, MSCD will not have to pay for the interconnection request fee, the supplemental review fee, or the distribution or transmission network upgrades. They do have to pay for the interconnection cost, which is $150/person-hour (PG&G, 2015).