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Assessing Renewable Technologies at Wild Mountain Cooperative

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Environmental Studies Capstone 417 Community-Engaged Research in Environmental Studies
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Executive Summary

Overview

This report is a renewable energy analysis for an intentional community, Wild Mountain, who would like to decrease their dependence on fossil fuel sources for energy. The homestead's goal is to further move toward targets of environmental sustainability and eco-justice. Our methods involved a partial energy audit recording the energy usage at the homestead, focusing on the electricity usage, and energy consumption used for heating. Three renewable energy sources were researched and evaluated to assess their viability for offsetting estimated fossil-fuel based energy usage. These three technologies are solar electricity production, methane digestion, and compost heap heating. Calculations and data synthesis were conducted to determine the best energy options for Wild Mountain. These calculations mainly centered around total energy usage, the corresponding greenhouse house emission equivalents, and inputs available at the homestead for the renewable technologies. Synthesis involved taking the calculations to construct energy production scenarios and other determinants of the data; from this recommendations are given on the viability of the renewable technologies being implemented at Wild Mountain. Significant assumptions for data, calculations, and other parts of the project are outlined in the appendices, in order to make the report's main body more concise.

Findings

Overall energy usage was found to be 145.41 mmBTUs/year of the parts of the energy usage studied. Attached to this number is the greenhouse emissions equivalents 24319.3 kg CO_2 equivalents. For organic inputs available at the homestead 35295 pounds per year is computed. Solar energy calculations focused on the number of panels necessary to produce electrical energy at certain levels of the homestead's electrical usage. A 9-panel system that would offsetting a minimum portion of the electrical use that the co-operative wanted to focus on, and a 19-panel system that covers all the known electrical usage. The methane digester depending on design could produce substantial amount of energy. Compost Heap Heating was found to have a theoretical maximum energy production of 163.8 mmBTU per year using the organic inputs available from the homestead.

Conclusions

To help conceptualize the results, scenarios involving the implementation of the renewable technologies were constructed to further analyze which renewable technologies would be more ideal in energy production and offsetting the current sources of energy. Five scenarios combined different partnerships of renewable energy and spatial heating in order to compare costs, energy production, and offsetings of current fossil fuel sources across technologies. Recommendations out of the scenario model put forth results for Wild Mountain to consider rather than ranking one scenario more ideal than the others. Other recommendations are made based on the research and results in general, from specific consideration for the technologies to energy conservation.

Introduction

The need for a nationwide transition away from fossil-fuel energy sources has never been more pressing, as anthropocentric climate change is showing its effects around the United States in a variety of ways. This year, the Western U.S. experienced one of the worst fire seasons on record due to a prolonged heat wave combined with an abrupt drop in precipitation levels. Concurrently, on the other side of the country, Texas, Florida, and Puerto Rico experienced hurricanes that caused loss of life and far-reaching destructive consequences. Scientists conclude that occurences of these calamities are exacerbated by the effects of climate change on our global environment. (Drash 2017)(Marlon et al. 2009). One of the largest drivers of this changing climate is the emission of greenhouse gases into the atmosphere, and a massive contributor to these emissions is the production of electricity to power the energy needs of our growing, technology-driven population. The current methods producing electricity are mostly derived from sources that emit greenhouse gases, either directly or indirectly. Here in Maine, electricity supplied by Central Maine Power (CMP) is produced using a medley of different methods. As of July 2017, 27.6% of produced electricity is generated by gas, 6.1% by oil, and 1.5% by coal. While the relative majority of CMP electricity is actually supplied by hydropower (48.1%), in terms of air emissions, CMP's suppliers actually emit 12.69% more yearly Carbon Dioxide (CO^2)than the New England average (908.6 lbs/MWh)(Central Maine Power 2017).

Wild Mountain Cooperative is one user of CMP's electricity. Although they have made preliminary steps towards energy independence, they still rely heavily on fossil-fuel based energy sources. Numerous scholarship indicates the need for a "bottom-up" method for approaching ways of achieving a societal transition to renewable energy sources. Community-based shifts towards alternative energy have been promoted as one method for attaining this transformation (Koirala et al. 2015). While the dominant "top-down" paradigm approach for instituting sustainable policy in the U.S. has resulted in reductions environmental and public health impacts, our country is still responsible for nearly 20% of global greenhouse gas emissions as of 2016 (Klein, Coffey 2016). One relevant scholarly article actually concluded that democratically guided energy co-operatives were the most efficient way at achieving a country-wide transformation to alternative energy, in the specific case of the Netherlands (Schoor et al. 2016). This study shows the transformative potential for small-scale community movements towards alternative energy.

One of Wild Mountain's founding goals as a homestead and permaculture farm is to remove their community and the land they occupy from a capitalist system of ownership. Engaging in subsistence farming enables this to some degree but while they are still tied to capitalist methods of energy production, the full realization of this goal becomes unattainable. Another component of Wild Mountains driving philosophy includes minimizing the impact that their intentional community has within their local ecosystem, and to a larger degree, within the environment as a whole. In line with these goals, we are investigating the potential for application of small-scale renewable energy at the homestead. We believe that the results we achieve for this project could enable Wild Mountain to be used as a model for other intentional communities looking to minimize their environmental impact through a movement away from fossil-fuel based energy sources.

Energy Audit

Methods

Our energy audit of Wild Mountain included a yearly energy-usage assessment relating to three categories: electricity, propane, and wood. We calculated total electricity use of the School House meter by considering 2016-2017 electricity bills. We assessed the electricity-usage of appliances of the Common House using kilowatt tracker-devices, with aid from our community partner Kate Boverman who contributed to the data-entry. We used the energy-data linked to appliances to estimate the overall yearly electricity use of the Common House. Kate provided us with information about yearly propane and wood usage of Wild Mountain. We gathered and organized energy-usage data for the 2016-2017 year at Wild Mountain, pertaining to the three categories, via a shared Google Sheets file. (Appendix 1, Google Sheets)

Key Energy Audit Findings: 2016-2017 Year

Electricity:
Common House (appliances): 2309.44 Kwh
School House: 4929 Kwh
Total Electricity Use: 7238.44 Kwh

Propane: 256 Gallons

Wood: 7 Cords

Overall Energy Usage: 145.41 mmBTUs/year

Energy Discussion

We believe the estimate electricity-usage calculated for the Common House is an underestimate because it did not take into account a few of the light switches and other appliances that we did not monitor with Kw trackers. We made educated estimates about the energy-use of these additional values, however, which can be seen in our spreadsheet. Nonetheless, the overall usage is to be regarded as an underestimate of actual electricity used. One noticeable result from our audit is the massive spike of consumption in the winter months at the schoolhouse meter (Figure 1). This is probably attributable to the space heaters used in the school house and other buildings attached to the meter. This is important to note because the potential implementation of solar would mean that during the months the cooperative is using the most electricity, they would be harnessing the least amount of solar energy. Another metric of note is the massive energy draw coming from the freezers located in the common house (Figure 1). A significant amount of energy conservation could be achieved if Wild Mountain were to replace these freezers. Figure 3 shows the percentage breakdown of energy produced by the three source categories. We converted the three categorical energy estimates into mmBTUs and compared them against each other as parts of an overall usage number of 145.41 mmBTUs per year. Wood contributes the overwhelming majority of this energy.

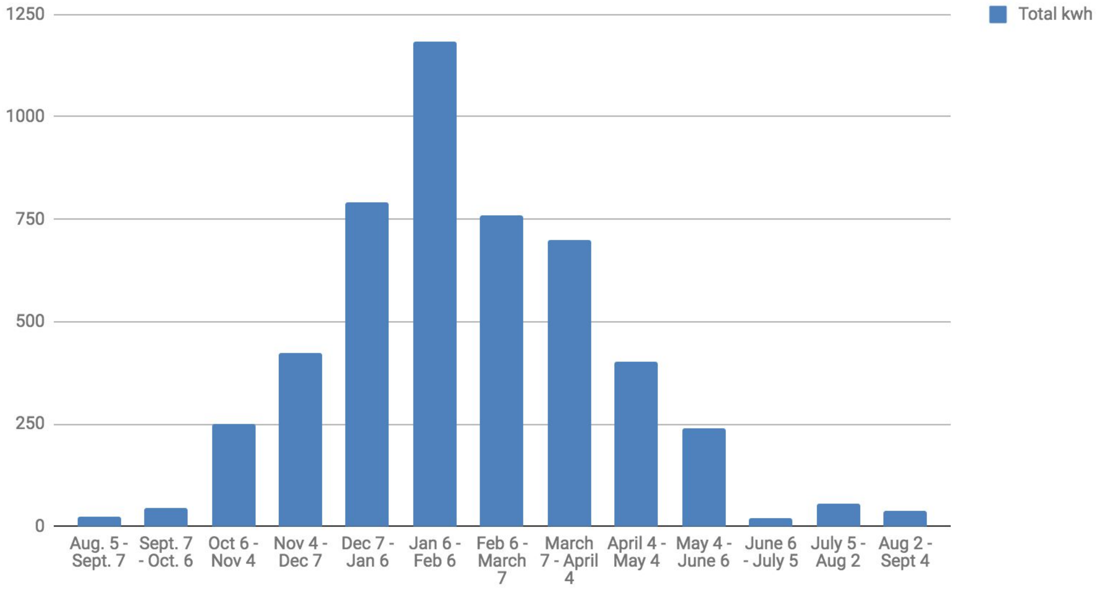

Figure 1 - Total kWh Usage/Month for schoolhouse

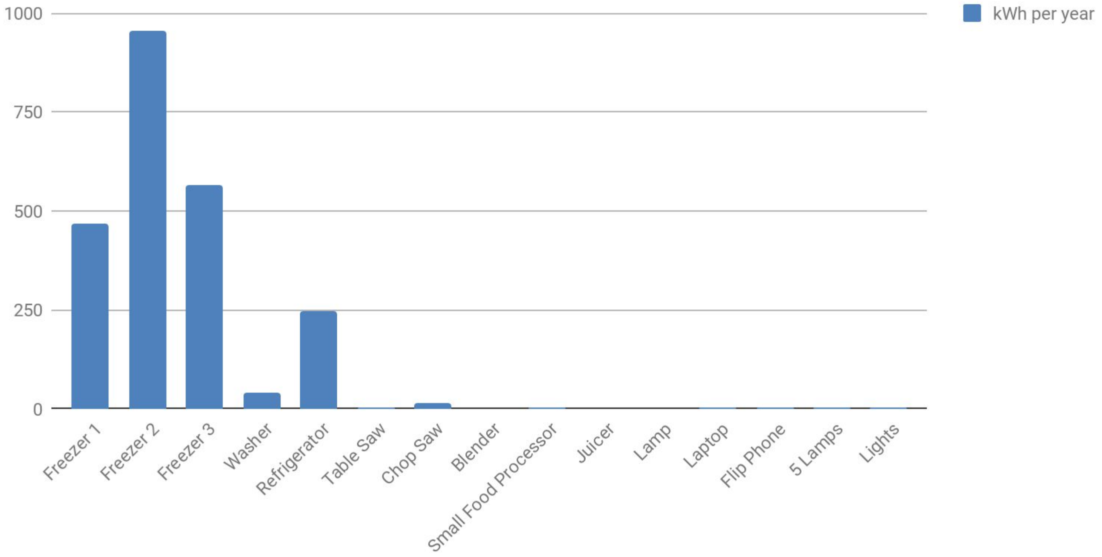

Figure 2 - kWh/Major appliance at common house

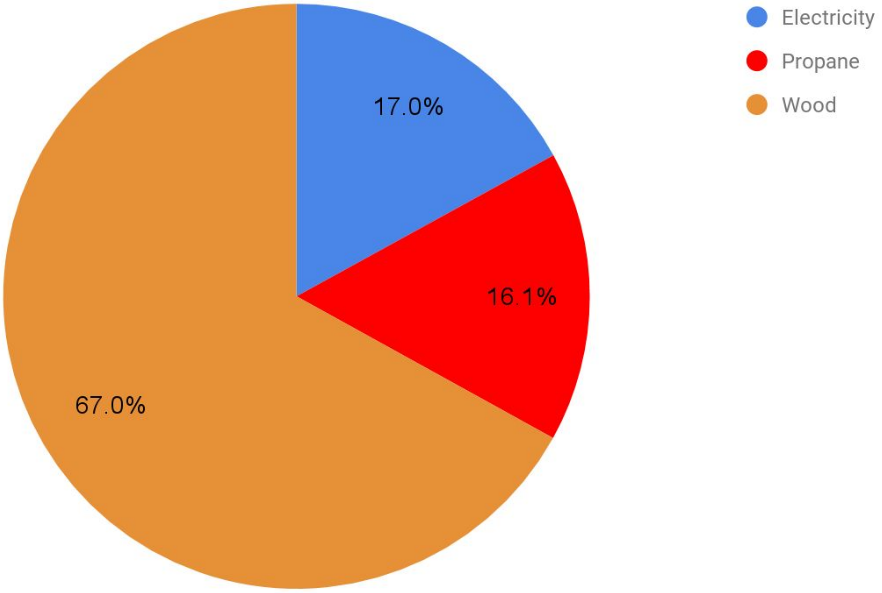

Figure 3 - Percentage of overall energy usage contributed by source categories

Organic-Material Input Findings

Intro:

In order to effectively assess the ability of a methane digester or CHH system to provide energy for Wild Mountain we conducted an analysis of the quantity of organic material inputs available for these two technologies at the cooperative. Our efforts centered on evaluating horse manure, humanure, and food waste, as these three categories appeared to be the most relevant, and easily quantifiable inputs to the two aforementioned technologies: methane digester and compost-heap heating. The results of these estimates are summarized in Table 1.

	Estimate pounds per year	Average pounds per day
Horse Manure	32,000	87.67
Humanure	375	1.03
Food Waste	2,920	8

Table 1 - Organic matter inputs available at Wild Mountain

Ecological Footprint

Intro:

The energy usage audit was conducted by gathering data on homestead's energy usage with bills, the homestead's estimates on energy usage habits, evaluating major and smaller electrical devices and appliances with kill-o-watt readers, and sample measurements of biomass. Calculations were done using the numbers gathered by the previous data collection methods mentioned. First overall electrical energy use was calculated, and other numbers gathered on propane and biomass usage. Then using these numbers, equations were derived to translate the usage numbers into CO2 equivalents derived from carbon dioxide, methane, and nitrogen dioxide gases. (Excel Sheet, Energy Audit)

	GHG ecological footprint - yearly totals (kg CO2 eq.)
Electricity (Schoolhouse bill and Common House appliances	2848.48
Propane	1437.7
Wood	20033.1
Sum/total	24319.3

(Excel Sheet, Energy Audit)

Table 2 - Summary of CO2 Equivalents

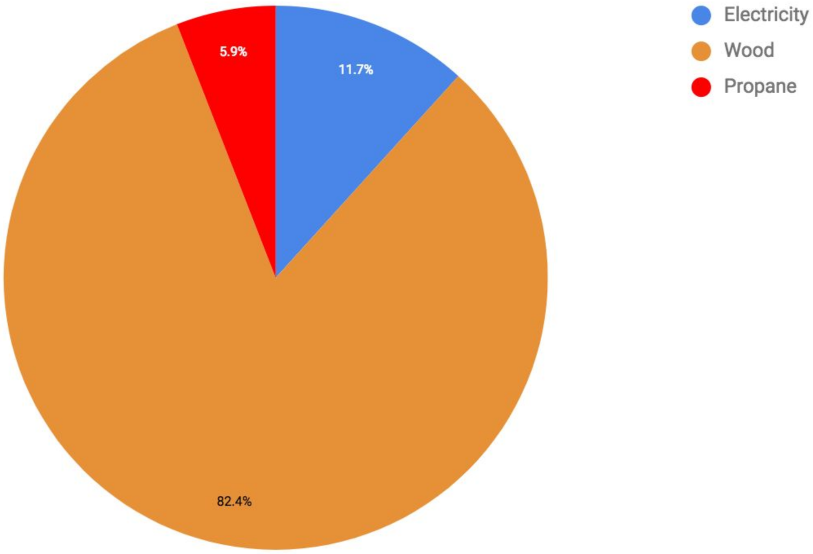

Figure 4 - CO2 equivalents for Co-Op Energy sources

Discussion:

To put this overall cooperative CO2 footprint of 24,319 (20 metric tons) into perspective, as of 2015, the average Americans contribution to carbon emissions was 21.5 metric tons (Kinhal 2015). Wood constitutes the overwhelming majority of the cooperatives CO2e emissions (Figure 5). However, it is important to take into account that wood is a renewable resource and trees sequester carbon as they grow and age. Therefore, when deciding which categories to prioritize offsetting, electricity and propane would come before wood as they are non-renewable energy sources.

Solar

Introduction:

The use of solar power from photovoltaic cells for electricity generation is relatively common throughout the United States and Maine. They have become increasingly more affordable as a renewable energy option. In the last fifteen years, Maine and New Hampshire's leading installer of grid-tied solar power, ReVision Energy, has established over 6,000 solar energy systems in Northern New England. (SolarReviews, 2017) Wild Mountain Cooperative previously had experts on solar power installation determine an ideal location for an array on their property. There is already a wiring system in place to convey the potential power to the newly constructed schoolhouse. Our primary aim within the investigation of solar is to report the number of panels required to fully cover electricity needs at Wild Mountain Cooperative, as calculated during our energy audit. We also convey the square-footage on the ground this solar array-size would occupy. We also discuss the smallest possible array size that could be installed, understanding that this information may be useful give financial and spatial limits. Finally, we discuss our findings regarding the ecological footprint of the production and installation of a solar array. We have aimed to compare the environmental cost of this renewable energy alternative to

Wild Mountain Cooperative's current convention approach of receiving electricity from Maine Central Power via the grid.

Methods:

We used information about panel-dimensions and energy-output from personal communication with ReVision Energy staff to complete calculations of sizing, square-footage. We used basic multiplication and trigonometry to calculate the area of solar arrays of different sizes, as well the area these arrays cover on the ground. We used information on ReVision Energy's online website to report on the price of various sized solar array systems. We used information from personal communication with ReVision Energy staff regarding a solar-system sizes and corresponding inverters, as well as standard payback time period of installation costs. solar calculator and geometrical math in order to see how many panels were need and could be installed on the pre-evaluated land on the homestead.

Results:

We found that 19 ReVision Energy panels would cover one hundred percent of Wild Mountain's electricity needs for the Common House appliances and the School House meter.

According to information from a personal communication with ReVision Energy staff members, a 19-panel (6 Kw) system would produce 8,366 kWh per year, which would cover the calculated 7,238 kWh required per year. ReVision Energy staff suggested that a 9-panel (2Kw) system represents the smallest-sized array that can still operate with an inverter that can equally be used with arrays up to 19-20 panels in size. Therefore, we propose the installation of a 9-panel system as an option in the following graphs and tables. We suggest that Wild Mountain install 19 panels to cover all of their electricity needs, or to install 9 panels initially, perhaps adding more panels to the system over time. (Revision Energy staff, 2017) (PVWatts Calculator, n.d.)

	19 panel solar	9 panel solar
Installation cost comparison (dollars)	13,766	6,888

Table 3 - Cost for installation of 19 panel and 9 panel systems

	19 panel solar	9 panel solar
Cost per kWh (dollars)	0.137	0.168

Table 4 - Cost per kWh of 19 panel and 9 panel systems

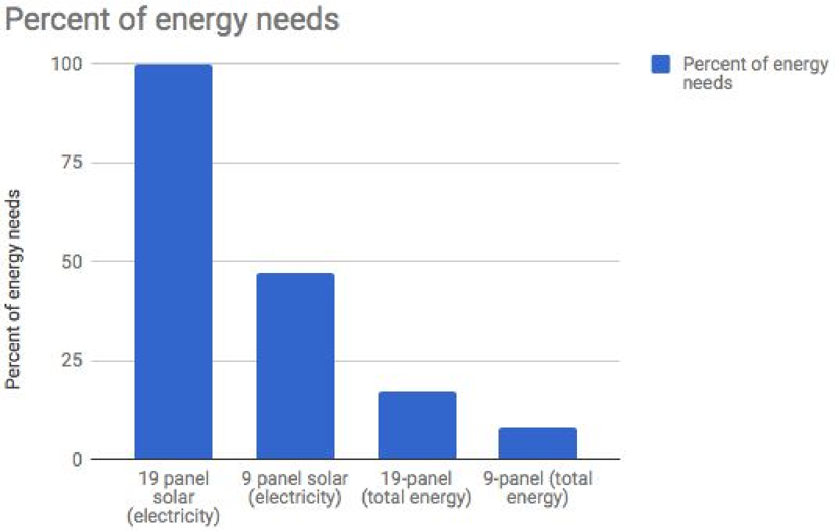

Figure 5 - Percent of the electricity and total energy usage solar systems would meet (electricity, biomass, and propane).

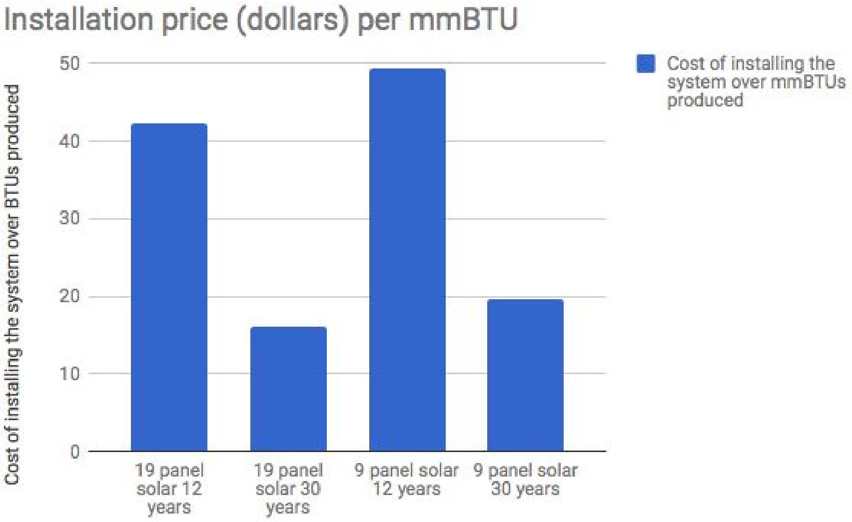

Figure 6- Price (in dollars) of a 19 or 9 panel system per mmBTU production, in reference to a 12 year or 30 year financing period.

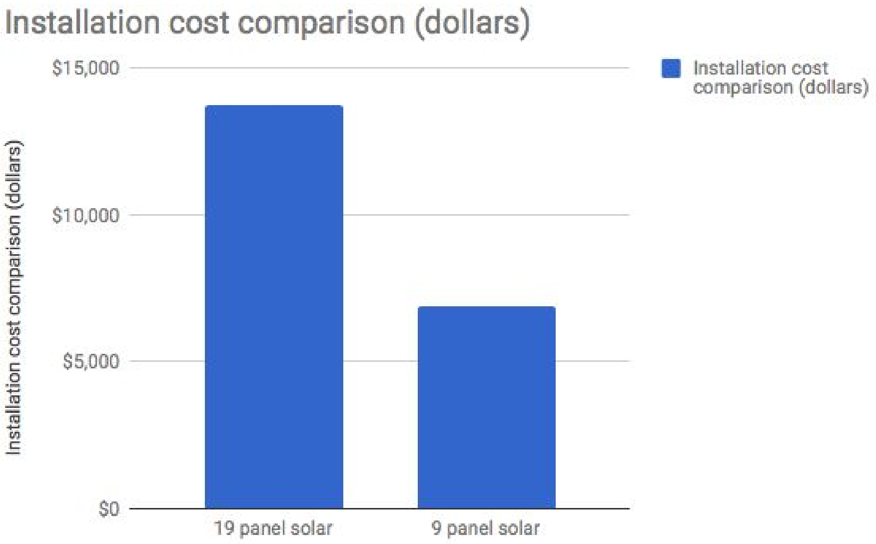

Figure 7 -Installation costs of a 19 solar panel system and and 9 panel system.

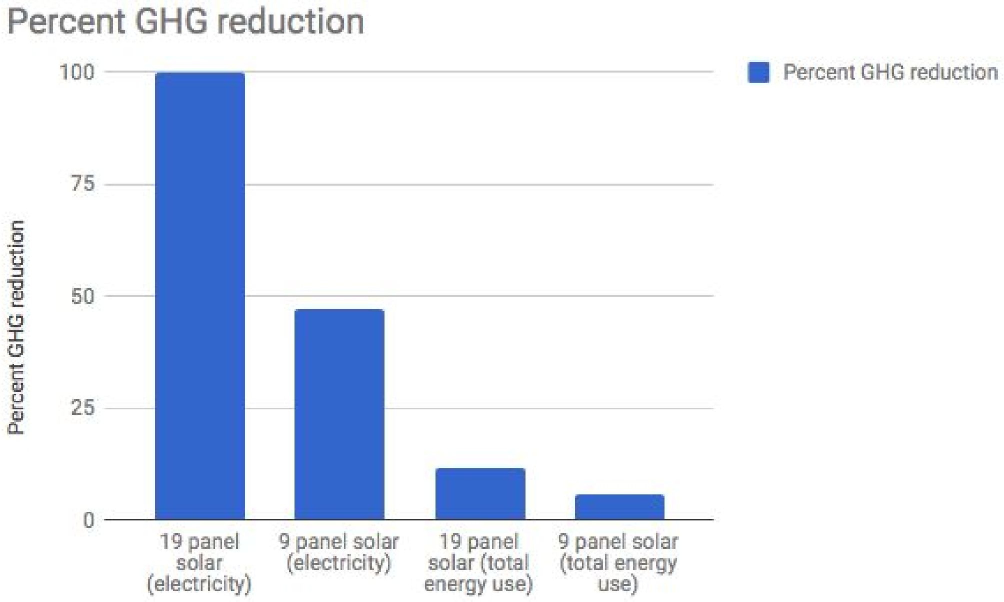

Figure 8 - Percentage of greenhouse gas emissions reduced by the energy production of the 19 and 9 solar panel systems.

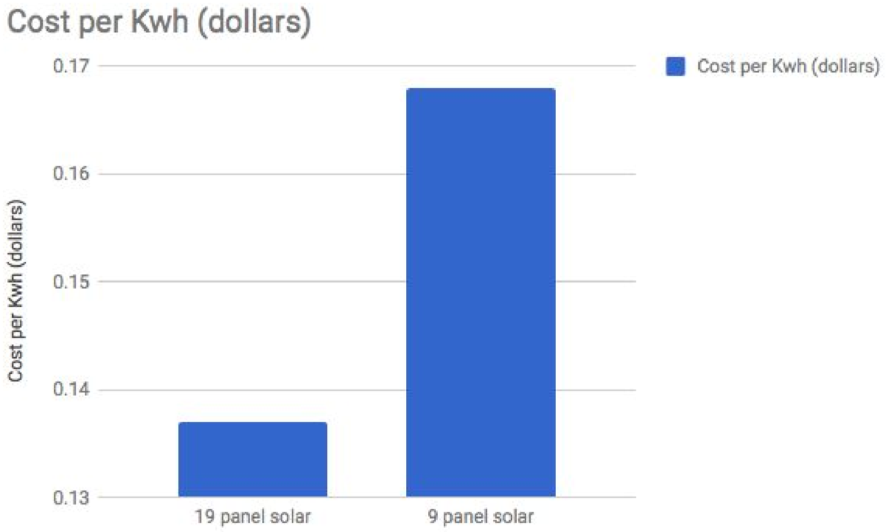

Figure 9 - Cost per kWH comparison between 19 and 9 panel systems.

Size of the solar array

A 6 kW system would be required for one hundred percent coverage of Wild Mountain Cooperative's current electricity use. A 6 kW system represents 19 panels, and would produce 8,366 kWh per year according to an online solar calculator of the National Renewable Energy Laboratory (PVWatts Calculator, n.d.). Wild Mountain Cooperative used 7,238 Kwh of electricity during the 2016-2017 year, as stated in our energy audit. The 6kW system of 19 panels would cover 1,000 kWh above their need. However, any smaller system would fall below their need, such as a 5kW system, which would yield 6,972kWh/year according to the solar calculator.

Square footage of the array:

Our findings reveal that a 19-panel array has an area of 3,480 square feet.
The panels would occupy 199.83 square feet on the ground. This area represents the rectangle on the ground that the angled solar array would cover. Assuming that the calculated length of 19-panel solar array, 760 inches (63.3 feet), is correct, this sized array would likely be too large to situate at the previously designated location adjacent to the schoolhouse. We judge the calculated area as unrealistically large, however. We recommend that Wild Mountain Cooperative consult with ReVision Energy about the square footage of this array, and about the best location for it.

It seems more likely that a 9-panel, 2 kW, system would fit well in the designated location. Our findings reveal that a 9-panel array has an area of 165 square feet, and occupies 94.65 square feet on the ground. (Appendix 1)

Cost Analysis

We estimated the price of these solar-array systems using information about cost on an online source by Revision Energy. The cost of a 19-panel system was found to be $13,776, after accounting for the 30 percent tax credit. Given a 12-year payback period, described as typical by ReVision Energy staff, the cost per month would be $95.67 if distributed equally over this period. The full cost of a 9-panel system would be $6,888. (SolarReviews, 2017) (Revision Energy staff,

2017) Although these cost estimates include both the solar array itself, as well as the cost of installation, we reason that these prices are represent underestimates.

Discussion

In talking to Kate, our community partner, we understand that installing solar panels will be a challenge for Wild Mountain Cooperative financially. Therefore, installing a smaller system of 9-panels initially may be most ideal. ReVision Energy will follow up with required permitting. (ReVision Energy staff member, 2017) ReVision staff members assert that many homeowners installing solar arrays will establish a small number of panels, and add panels to the array at a later date in order to cover more of their total electricity use. One financial drawback to this approach of adding panels to small initial array is that the 30 percent tax incentive applies only the first time panels are installed. Another finding is that there is financial incentive to install an array within the next couple of years given that this incentive, which reduces the installation of a solar array through a federal tax reduction of 30 percent on the installation-fee, is scheduled to decrease to perhaps 26 percent in 2020. (Revision Energy staff, 2017)

Analysis of Ecological Footprint of Solar

In *How Bad Are Bananas?* Berners-Lee suggests that investing in solar panels for electricity at one's home saves 50 tons of CO2 equivalents over the course of a lifetime.

Ecological Footprint and Financial Payoff of Solar Panels

In *How Bad Are Bananas?* Berners-Lee estimates the financial payback of household renewables. He approximates that "in the U.K. it will cost you 10,000 euros ($15,000) to get a set of panels installed that is capable of providing you with 18,000 kilowatt-hours per year. Once you have taken account of income from the tariff, your sales to the grid and reductions to your grid electricity bill as well as annual maintenance costs, Chris think you can make a return of 730 euros ($870) per year. This figure suggests a financial break-even after 14 years" (Berners-Lee, 2011, pp.131). Berners-Lee also estimates "that the 10,000 euros ($12,000) you spend is half on the kit and half on the installation. To give the carbon sums their very best possible chance, I'll generously overlook the footprint of installation and use the lowest plausible figure I can take from my input-output model for the manufacture of the panels: 0.47 kg CO2 e per dollar spent. That gives the panels a footprint of 3.5 tons. If we assume the electricity generated all replaces output from coal-fired power-stations rather than the grid average, then the carbon savings per year is about 1.8 tons, and you'd pay back the carbon [of the panel-footprint] in about 2 years" (Berners-Lee, 2011, pp.132)

Nunez further explores the ecological footprint of solar panels, considering both the extraction of natural resources and the processing of those resources for their manufacture. The creation of solar panels requires chemicals including sodium hydroxide and hydrofluoric acid. The process also uses both water and electricity, and involves greenhouse gas emissions. The source of energy for the electricity used for the manufacturing process – often coal – determines how large a silicon-based cell's carbon footprint. The manufacturing process also produces waste. Another consideration regarding the ecological footprint of solar panels is the lack of places to recycle defunct panels. Recoverable materials, such as precious metals within the panels, usually go to waste. (Nunez, 2014)

Methane Digester

Intro

Small household methane digester have been used across the globe, with innovative designs mainly created in countries other than the United States. Methane digesters in the United States are most commonly employed on large-scale farms, especially dairy farms, as well as at sites with large industrial or municipal organic waste such as sewage treatment facilities. A methane digester is a technology that involves the decomposition organic-material, mixed with water, within a sealed oxygen-free container. Methane digester designs can be either above-ground or below ground. We explored the possibility of using the minimally-used septic tank at Wild Mountain as a container for a methane digester container for digestate. This design-technique has been implemented and explored by others, although its construction appears more complicated than implementing self-constructed and pre-manufactured digesters above-ground. (Mush 2017)

Biogas Production Prediction for a Design at Wild Mountain

We calculated daily biogas production of HomeBiogas System and two other digester-designs using an equation from the International Renewable Energy Agency. (See Appendix, Methane Digester Section, for detailed calculations)

Digester-designs analyzed to assess potential quantity biogas production, assuming daily input of current feedstock types and amounts, at Wild Mountain:

1. HomeBiogas system (A pre-manufactured design advertised and for sale. Volume: 1.5 cubic meters) (HomeBiogas System, 2017)
2. Green Monster Design (A digester fermenter developed in South Africa. Volume: 2.5 cubic meters)
3. ACME portable assembly biogas plant (an on-site assembled biogas plant developed in China. This design differs due to its pyramid-shape, and its rubber-like material rather than plastic or metal cylinders for oxygen-free containment of digestate. Volume: 3-50 cubic meters) (Villacreses, 2015)

Considering all of the methane digester about which we learned, the three specific models above represent designs that would be ideal for the climate, the scale, and the available organic-inputs at Wild Mountain. They are also models for which the volume of the digestate container was given in the descriptions, which facilitated our calculation of biogas production.

Biogas production findings; daily biogas produced (See Appendix, Methane Digester Section, for detailed calculations)

HomeBiogas system: 0.97 cubic meters

Green Monster Design: 16.4 cubic meters

Small-sized ACME Design: 1.95 cubic meters

Medium-sized ACME Design: 16.3 cubic meters

Recommendation

We recommend that Wild Mountain revisit the International Renewable Energy Agency's biogas production estimation equation when the volume size and the volatile solids content (which will vary according percentages of humanure, horse, manure, and food waste inputs) of the digester they decide to build or to establish becomes clear.

Methane Digester Background and Considerations for Design, Operation, and Maintenance

The Process of Methane Digestion

Methane digestion is a controlled biological process that produces a gas composed of mainly methane and carbon dioxide from organic waste. The waste-inputs, which most frequently include animal manure and food-waste, decompose in a sealed, oxygen-free container. Plant matter adds to the production of biogas, and waste grease and food waste are among the substances that yield the highest amount of biogas (Woughter 2017) Mesophilic digesters, those with a "middle" temperature range of 95-97 degrees Fahrenheit, are most common and effective for small-scale cases. (M. Richardson, personal communication, October 15, 2017) Abigail Woughton writes that target temperature for small-scale anaerobic digesters of New York is 100 degrees Fahrenheit. Waste-material in a digester ideally has a 4-8 percent solids-content. (M. Richardson, personal communication, October 15, 2017)The amount of time for biogas production depends on the Hydraulic Retention Time (HRT), which relates to how long the digestate material remains in the tank.

General types of methane digester / analyzing best digester type for Wild Mountain

Abigail Woughter describes two types of anaerobic digesters she views as well-suited for small farmers of the Northeast United States. The first type, called a plug-flow system, involves no moving parts, whereas the second type, called a mixed system, contains "moving parts for stirring and mixing influent as it is digested." While a plug-flow system processes manure, a mixed system does well at processing both manure and food waste (Woughter 2017). While there are various mixing methods, the Lewiston-Auburn treatment plant uses an electric pump-mixer, pulling some of the liquid out of the digester and injecting it at high pressure through nozzles that create a vortex action. (M. Richardson, personal communication, October 15, 2017)

Biochemical functioning of methane digesters

Mac Richardson (Superintendent, Lewiston-Auburn Wastewater Treatment) recounted that anaerobic digestion – unlike an aerobic system – relies on "2-3 sets of organisms doing 2-3 sets of things." There are a group of organisms called "acid formers" that break down degradable organics into organic acid, and there are a group of organisms called "methane formers" that take those organic acids and convert them into methane and carbon dioxide. In order to ensure that these crucial organisms remain present in the digester, and to assess gas quality, the Lewiston Auburn wastewater treatment plant monitors alkalinity, sulfuric acid, and volatile acids two or three times a week. If these organisms fell short, a noticeable change in gas production for a small-scale digester would be obvious. (M. Richardson, personal communication, October 15, 2017)

Ensuring Gas Quality

The quality of gas produced by methane digesters can be improved by removing the moisture content. The Lewiston-Auburn wastewater treatment facility uses a condensate trap for this purpose. The operators at the plant remove hydrogen sulfide (because if combined with moisture this could turn into dangerous sulfuric acid) and silica compounds (that come from feeding the digester substances such as lotions, and deodorants. Is the removal of any of these chemicals required for small-scale household digesters that plan to use the gas for cooking and/or heating rather than electricity generation? Small scale digester designs that we have examined indicate that the removal moisture is necessary, whereas other chemicals are apparently not a concern.

Different Designs

"How efficient a digester is at producing biogas is dependent on the ability of the system to maintain a consistent temperature." Abigail Woughton suggests a model of anaerobic digester for small-scale farm use in New York state. She suggests a design for heating the digester tank by including a series of stainless steel vessels within it through which warm water is pumped to heat the material in the digester. Woughton also describes other heating methods such as "exterior heat exchangers and hot water boilers that heat the material before it enters the mixing compartment of the digester." (Woughter 2017)

Anaerobic Digestion for Small-farmers of New England

The majority of methane digester use in the United States occurs on large-scale dairy farms includes equipment that processes tons of waste, produces thousands of Mwh of electrical energy, and thousands of tons of liquid fertilizer. (Barstow's Dairy Farm and Bakery, n.d.) Woughton suggests that creative reuse of materials, such as septic tanks and grain bins, is valuable for the success of small scale digesters.

A Specific Case

Volunteers in Technical Assistance describe a specific anaerobic digester design that produces enough gas for a family of six, and depends on a steady, daily input of manure. This digester produces 4.3 cubic meters of gas per day, and depends on the daily input from eight cattle and six humans. The digester tank holds about seven cubic meters in a cylinder that is 1.5 by 3.4 meters. It has a gas cap that is 1.4 meters in diameter and 1.5 meters tall. The cost estimate of this digester in US in 1979 was 145-800 dollars. This writer suggests that if people plans to implement a digester pit, they locate it far from a source of drinking water. The writer recommends planning for slurry storage – both for input waste-material and the resulting effluent for fertilizer. The writer recommends installing a digester in a site with plenty of exposure to the sun. "Each person produces an average of 1 kg of waste per day; therefore, six people times 1 kg per person times 0.05 cubic meter/kg = 0.30 cubic meter gas." (Volunteers in Technical Assistance 1980)

Prefabricated Digesters

There are small household anaerobic digesters for sale online that United States citizens can order, one is called the HomeBiogas System that processes both animal waste and food scraps. The advertisement draws attention to the design's quick assembly, low maintenance, durability, and convenient use at a price of $990. The biogas generated is expected to be used for cooking. The advertisement itself claims that the system produces up to 2 hours of cooking gas every day. There is a greenhouse-like covering that also serves as a wind-breaker over the system. There are weights over the gas-holder that create pressure that makes gas flow into a house without any electricity. Waste is thrown into an inlet, travels down a pipe, and arrives inside the digester. Inside the digester, there are bacteria that produce the biogas. The gas accumulates, rises to the top of the container, and exits through the gas outlet. Within the gas outlet, there is a special filter through which the gas moves before getting into the gas bag. There is a pipe opening at the very bottom to empty the waste in the digester after it has been used, which serves as great fertilizer. The site suggests that homeowners pour about 3-4 liters a day of food scraps, animal waste, and water. Likewise, 3-4 liters a day of fertilizer is taken out of the digester through the outlet tube.The site advises situating the digester where it has maximum sunlight for heat during the winter. The gas pipe is narrow; at the start of the pipe, close to the digester system, a branch of piping for the accumulated and extracted water to drain. The pipe continues and branches in two directions – two pipe lines traveling to two different kitchens.

Methane Digester Results

Figure 10 assumes that HomeBiogas System is implemented, and replaces propane by 42 percent. The 42-percent replacement assumes that the digester produces the estimated 0.97 cubic meters per day. As shown, it meets a negligible amount of total energy needs. Additionally, we researched the costs and benefits of incorporating a spatial heating system for use in conjunction with the digester. These results are shown in Figure 11, they are seen to be impractical as cost outweighs the benefit of use of biogas for heating.

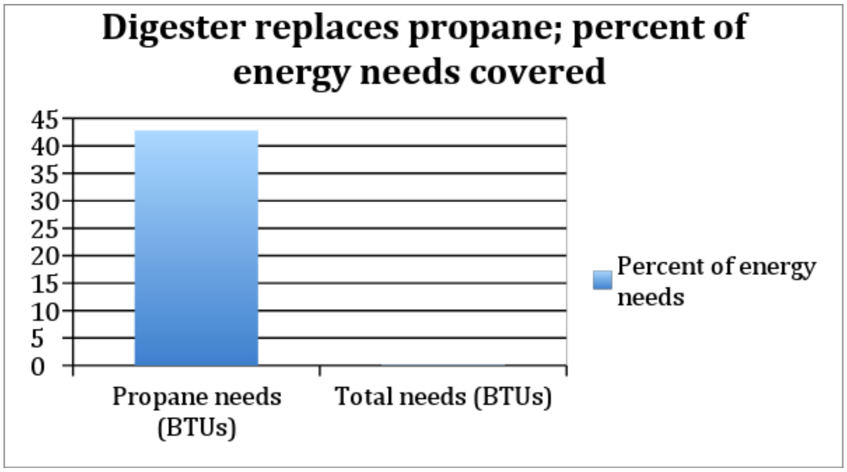

Figure 10 - Digester replaces propane, percent of source and total needs met

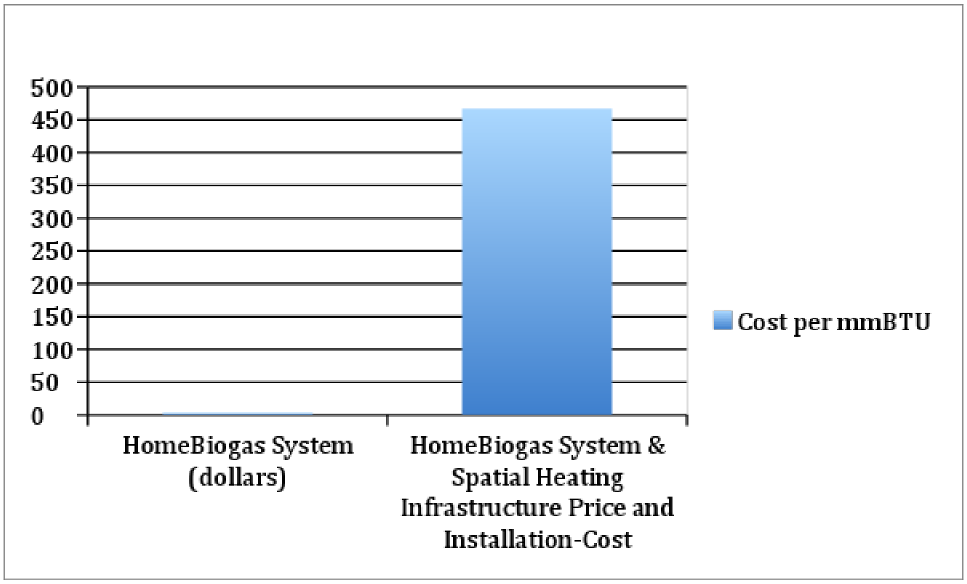

Figure 11 - Cost per mmBTU using biogas to power spatial heating system

	Installation Cost Comparison (dollars)
HomeBiogas System	950
HomeBiogas System & Spatial Heating Infrastructure Price and Installation Cost	14,020

Table 5 - Cost comparison between implementation of solely Homebiogas system, and the digester with spatial heating infrastructure

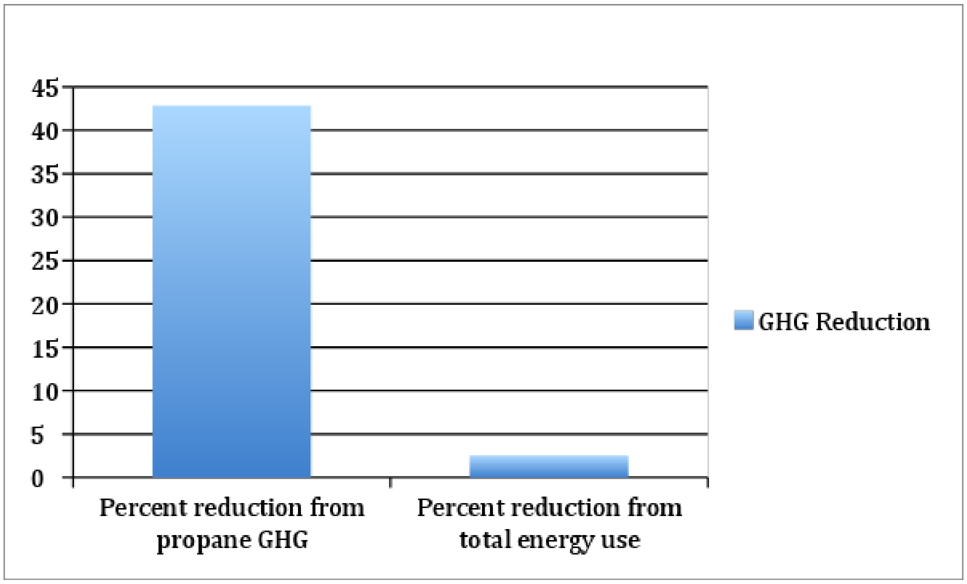

Figure 12 - Digester reduction from propane GHG compared to total energy use

Discussion:

The amount of gas produced from a small household methane digester could easily replace Wild Mountain's propane-use for their stove and hot water heater.

Assuming that propane and biogas are equivalent – their propane demand of 0.003 cubic meters (0.7 gallons) per day represents a much smaller value than the 0.97 cubic meters (256 gallons) of gas per day they would produce with HomeBiogas System digester design.

According to multiple sources, the heating values of propane and methane or biogas differ significantly. While the heating value of propane is 2,500 Btu per cubic foot, the heating value of methane biogas is 600-1,000 Btu per cubic foot. This data suggests that the 0.003 cubic meters (0.7 gallons) of propane Wild Mountain currently uses each day would have to be replaced by more than double the amount of biogas. Suppose that Wild Mountain would need 2.5 times as much biogas as propane, which represents a scenario in which the heating value of biogas is 1,000 Btu per cubic foot -- the high-end of the range. In this case, Wild Mountain would need 0.0075 cubic meters (1.75 gallons) of biogas per day. This figure represents 0.5 percent of the daily biogas production from HomeBiogas System digester. Coverage of stove cooking and water-heating needs represents only a tiny fraction of the biogas that would be produced from a digester, even taking into account the discrepancy between propane and biogas heating values.

Compost Heap Heating

Introduction:

Compost heap heating is a renewable energy resource where the user harnesses the natural process of decomposition and methane production within a mound or heap consisting of organic materials. There are three methods for extracting heat from composting. The most rudimentary is direct utilization of compost vapor, most applicable and viewed in the form of greenhouses as they benefit from the use of the heat and carbon dioxide produced. A second approach is to capture the latent heat through a compost vapor and condenser-type heat exchanger. This method is most common at large-scale commercial composting sites as extensive investment in infrastructure is needed. The third method of energy capture hydronic heating through conduction in the pile itself. This is the method most applicable to Wild Mountain and is what our research focused around. The hydronic heating/conduction method was pioneered by the French scientist Jean Pain in the 1960s-70s through a method where he coiled plastic piping within a cylindrical heap of compost and captured the resultant heat (Smith et al. 2016). Although examples on a replicable industrial scale are relatively scarce, through our research we have found numerous instances of scaling similar to Wild Mountain. Compost heap heating is also unique in the fact that it has the lowest estimated ecological footprint out of our researched technologies, therefore we believe that is has real potential for implementation.

Methods:

While researching this renewable technology, we looked for examples on a comparable scale and with similar inputs to Wild Mountain. We systematically researched various iterations and types of compost heap heating systems found in scholarly literature online, and in how-to manuals with step-by-step instructions. Within this research we specifically sought out; the amount of energy potential, need for inputs, and perceived ability to construct this technology without outside help.

Assumptions:

Our first primary assumption inherent in this research we conducted is that the model for a potential compost heap heating design at Wild Mountain would be able to produce the theoretical heat discussed in our results section, and therefore offer a viable alternative (or supplement) to their current systems of heating.

Iterations:

All of the methods of compost heap heating follow a similar formula; a compost pile is constructed and insulated, plastic tubing is coiled throughout, and the energy produced by decomposition is utilized through heating of water (Figure 13) . In all instances, the heap is placed close enough to the intended site of use to minimize heat loss, yet far enough away that the relative size doesn't impose on that building.The scales and the exact methods for using the heat produced vary throughout individual iterations, some designs are even made to capture the biogas produced in the top of the heap. We hope to give a broad picture of the variety of heaps that have been constructed.

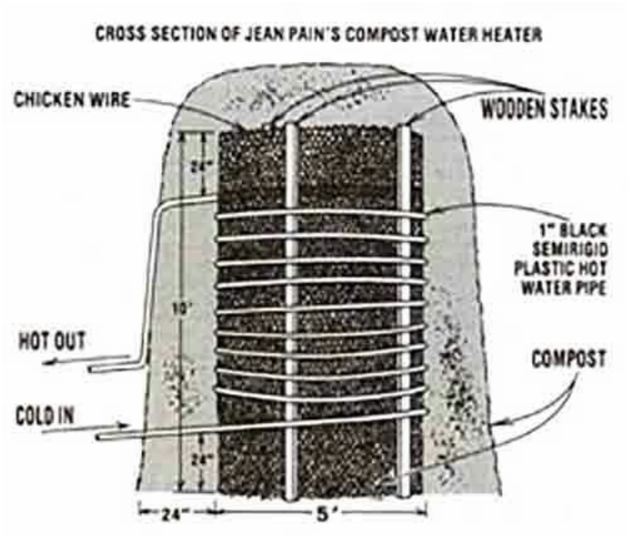

Figure 13- Diagram of Jean Pains compost heap heating system (Ogden, Mother Earth News 2017)

1. Jean Pain Method

As we have mentioned before, the French scientist Jean Pain really pioneered the hydronic compost heap system. He experimented extensively with different heap styles and compost ingredients with the aim of creating usable energy for his farm, and improving forest health. He created a heap with 50 tons of composted material and reported temperatures of up to 140 degrees fahrenheit, heating his 1000 square foot home and providing hot water at a rate of four liters per minute. Pains heaps were recorded to produce heat for up to 18 months, after which the decomposed material could be used as fertilizer. (Sjoberg 2013)

2. Small Farm Scale - Massachusetts

This size of compost heap heating system was the most common that we found through our research. Numerous iterations exist where the inputs come from an individual home or small farming community that also did most of the construction by themselves. A first example we found was a heap in Massachusetts called the Potwine Neighborhood heap. The creators of this pile kept detailed logs of its heat output over the course of a New England winter. Their smaller scale compost heap recorded a production of 6 mmBTUs during this time period and was used to heat a greenhouse. Overall it recorded heat production for 18 months. (Spade 2014)

3. Community Scale - Oregon

The Kailash eco-village in Portland, Oregon created a larger scale compost heap heating system in 1996. They created a 28 cubic yard (18.2 ton) heap covered by a greenhouse in a rectangular pattern. Consistent hot water was produced at a temperature of 90-130 degrees fahrenheit for the 18 months that this heap was functional. They reported that it fulfilled all their water heating needs for a family of 5 during this time. Additional compost was added multiple times throughout this period though, and as the heap was located inside a greenhouse it was easily accessible for maintenance. (Ersson 1996)

Inputs

Sources give varying estimates of an ideal carbon:nitrogen ratio needed in the creation of a compost heap. Literature suggests to aim for a 1:1 “brown to green ratio” to achieve an ideal carbon to nitrogen ratio of around 25-30:1 (Trautman 1996). In the context of Wild Mountain, this would mean adding an equal amount of wood chips to compostable material produced on site. For our hypothetical purposes, we decided to estimate maximum energy output using the amount of compostable material produced for half the year. It must be acknowledged that this ratio of inputs varied wildly throughout researched variations. Some examples just used wood chippings as their only composted material (Spade 2014), while others merely utilized what was produced from garden scraps. There would be a possibility of producing a large amount of heat using either of these methods if Wild Mountain wished to simplify the construction of a heap.

Cost Associated:

Although this technology is relatively cheap when compared to our other researched renewable energies, compost heaps of the scale appropriate to Wild Mountain have an estimated cost of 600-1200 dollars (Appendix 1). This can vary though based on the integrative complexity the user wishes to harness the heat with. At a minimum; raw materials, piping, and some sort of pump must be purchased. On the other side of a spectrum, full integration into a building infrastructure would further require a water tank, more piping, heat sensors, and potentially a spatial heating system.

Conclusions:

From our research, we have concluded that a compost heap heating system produces a maximum of 1000 BTU/Hour/Ton, for up to 6 months. Iterations have produced heat for as long as 18 research has noted that 6 month lifespan is more accurate for maximum heat production. Water heating potential is seen to max around 155 degrees fahrenheit and achieve a 6 month average of around 130 in an efficient system (Gorton 2012). Our estimates put Wild Mountains yearly inputs at 18.75 tons of compostable material produced in a year, using this number we conclude that a maximum production of heat in a compost heap for Wild Mountain would be 163.8 mmBTU per year. This number is completely theoretical however, and relies on the assumptions that the heap would be maximizing heat production the entire year. A more likely scenario would entail the heap producing a high amount of heat for half a year and then dropping off energy production (See Figure 14). We recommend that Wild Mountain collect their inputs over the summer months and then construct a heap in the fall, letting it produce heat over the winter. Output of energy could be tracked and based on this experiment, further iterations of a compost heap could be made with potential integration into house/heating infrastructure.

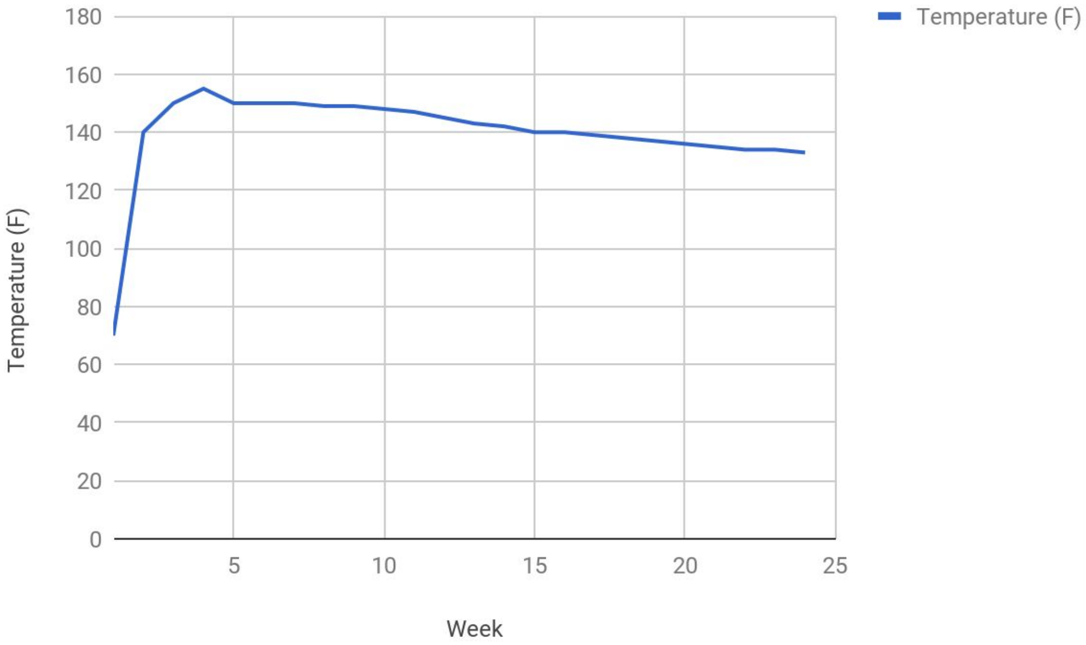

Figure 14 - Estimated water heating potential of compost heap for a 6 month period

Further Research:

This report lays out different variations of a hydronic compost heap heating system. In all of the variations the; scale, inputs, maintenance, and heat production vary drastically. We hope to have given a broad overview of the variety of iterations possible. Wild Mountain might consider seeking out the help or advice from the creators of a compost heap in order to gain further information before building their own.

Recommendations for Wild Mountain

Scenarios

We assume that Wild Mountain will implement some sort of solar array as they already have the conduit set up and have had an ideal site scoped out. Therefore our hypothetical scenarios rely on the assumption that solar will become an integral part of the energy supply for the cooperative. For our scenario discussion we have provided five different frameworks of energy pairings.

In the first four of these we present the implementation plans and foreseen results of the cooperative using solar power and then either methane digester or compost heap heating. In two of these four we assess the benefits and costs of including a spatial heating infrastructure to use with the CHH system or methane digester. With the fifth scenario we present a hypothetical implementation of solar, methane digester, spacial heating, and compost heap heating. This scenario is seen to be the most theoretical out of all five and the least realistic in terms of relative cost and energy gain because organic inputs are split between methane digester and a compost heap. If Wild Mountain wanted to assess the relative benefits/drawbacks of both organic-matter input technologies at the same time this scenario would reflect the estimated cost of that.

Five Scenarios for the Implementation of Renewable Alternatives

Scenario	System Components of Scenario	Electricity	Cooking	Hot Water	Space Heating
S1	Solar + CHH	X		X	
S2	Solar + Methane Digester	X	X		
S3	Solar + CHH + Spacial Heating	X		X	X*
S4	Solar + Methane Digester + Spacial Heating	X	X		X*
S5	Solar + Methane Digester + CHH + Spacial Heating	X	X	X	X*

Table 6 - Scenario attributes

Discussion:

S1 - Establishing a solar array would cover nearly 47 percent of electricity needs with 9 panels, and 100 percent with 19 panels. The compost heap would generate hot water, replacing an estimate of three quarters of current propane at Wild Mountain.

S2 - The same calculations in S1 for solar hold true in S2. Assuming the use of HomeBiogas System with Wild Mountain's organic feedstock inputs of horse manure, humanure, and food waste, the methane digester would generate biogas to cover an estimate of 42 percent of total propane needs for cooking and hot-water heating.

S3 - In S3, we assume all of the biogas generated from the methane digester will be used for spatial heating exclusively to offset the current CO2 eq. from wood, rather than to offset any propane for hot-water heating and cooking. This scenario depends on the implementation of spatial heating infrastructure. The spatial heating system would cost more for S4 than S3 because of the need for a boiler to burn biogas in S3. We pose this as a scenario to represent the possibility of using biogas for spatial heating, despite the small potential of spatial heating from aforementioned biogas produced by HomeBiogas System with Wild Mountain's in-puts. Spatial heating from biogas would cover only about one percent of the mmBTUs currently required using wood-stove heating. (Appendix, Methane Digester Section)

S4 - In S4, we assume that the compost heap heating would be used to deliver hot water to showers, sink, and laundry. In addition, it would be used for spatial heating to offset greenhouse gases from wood via a hydronic heating system of baseboard radiators and piping lining the Common House. We believe that there is a high probability that a compost heap could entirely replace wood-heating using this type of infrastructure. The need for experimentation with a compost heap at Wild Mountain over winter is necessary, and S2 would be best suited for such a project. However, our results indicate that it would be worth the cost, energy-production, and GHG offsets to implement spatial heating infrastructure along with a compost heap and not with a methane digester.

S5 - This scenario is seen to be the most hypothetical and unrealistic out of all four. Particularly because the organic inputs of methane digester and compost heap heating would be split between the two technologies. If Wild Mountain wanted to experiment with both at the same time to see their relative benefits and drawbacks, this scenario could make sense.

Other recommendations based on these scenarios:

We suggest using that an initial compost-heating system be used to heat water. Perhaps spatial heating infrastructure could be implemented within a small space for the trial, rather than established for the entire Common House building. There is a need to personally assess the temperature of the water generated by the compost heap, and whether this temperature can be maintained throughout a winter at a consistent rate.

Cost Analysis for Spatial Heating

We estimate the cost of a hydronic radiation spatial heating system (including a boiler, piping, and hydronic baseboard radiators lining the two floors of the Common House) plus the cost for installation to be $13,070. (Appendix, Scenarios, Graph Calculations)

Graphs Comparing Scenarios 1-4

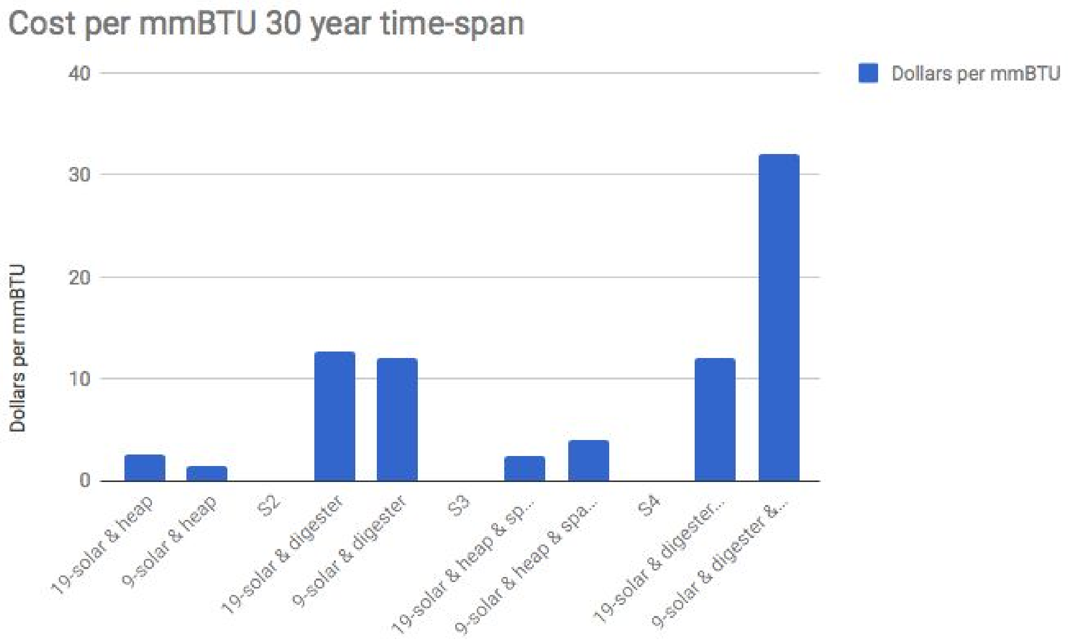

Figure 15 - Comparison of scenario cost per mmBTU over 30 year timespan

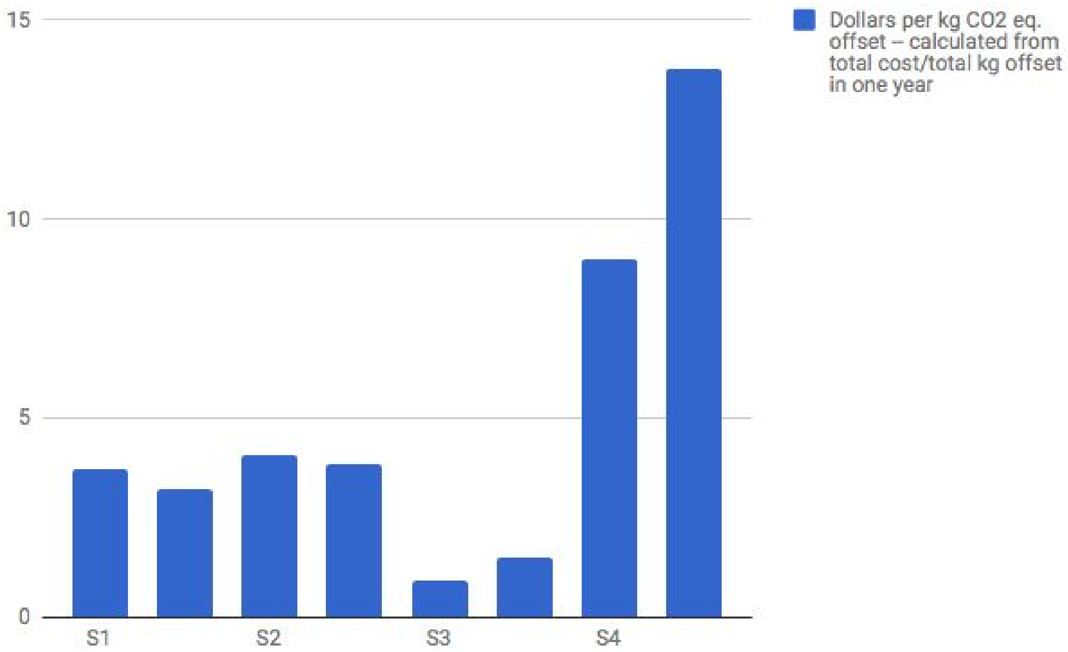

Figure 16 - Dollar/kg of Co2 offset

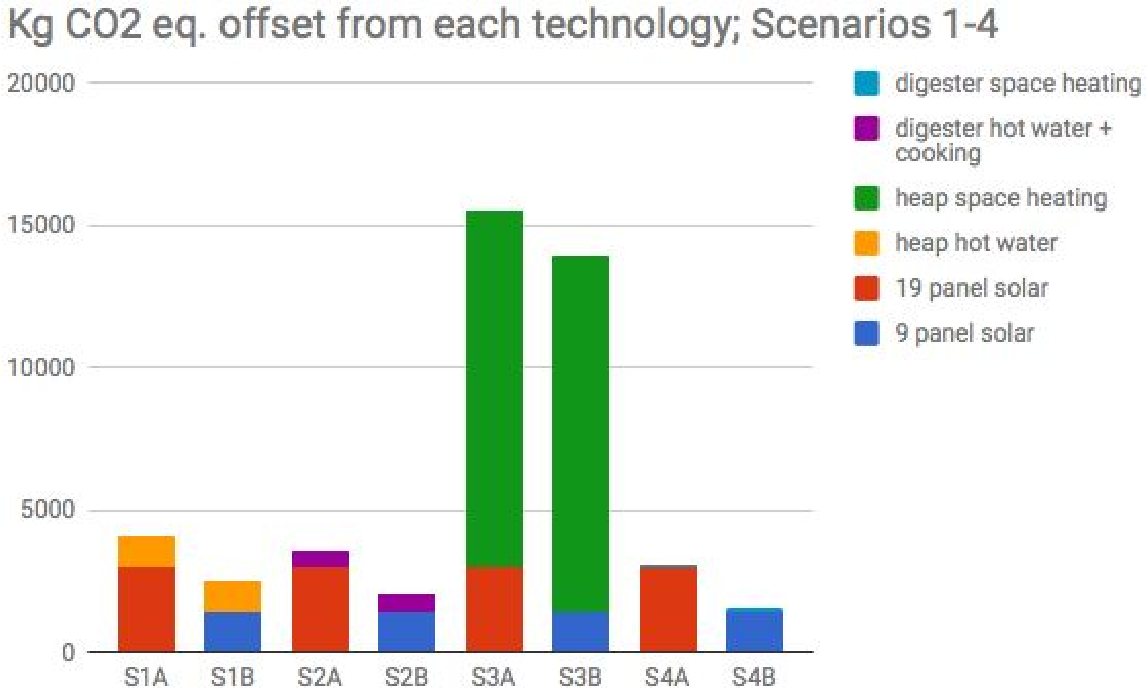

Figure 17 - CO2 Equivalents offset breakdown by technology

Discussion cont…

Each scenarios is divided into A and B options to represent the implementation of 19-panels (A) or 9-panels (B). One of the most obvious findings this graph portrays is that investment in spatial heating infrastructure paired with the use of compost heap heating would replace all of Wild Mountain's greenhouse gas emissions from wood – which represents an enormous amount of kg of CO2 eq. offset. We understand that this number may over-estimated, especially given that temperature to which the compost heap could heat water using Wild Mountain's type and quantity of organic materials is relatively unknown. In contrast, the greenhouse gas offsets from spacial heating paired with the methane digester is extraordinarily small. Scenario 4 (A and B) assumes that all of the biogas produced from HomeBiogas digester is stored over the course of warmer months, and is burned for spatial heating during the winter. As previously noted, this approach replaces only about one percent of the mmBTUs (heat) from wood upon which Wild Mountain currently relies.

General Recommendations

Figure 18- Placement recommendations of renewable energy technology on Wild Mountain property. Solar panels location is the black box, compost heap location the green circle, and the methane digester the red rectangle.

A recommendation that comes out of the data, is advising Wild Mountain to think about and do more energy conservation and energy efficiency actions, as mentioned briefly in the energy audit section. At the beginning of this project, Wild Mountain had already taken an example action of replacing an old refrigerator with a new one (the new one being one of the appliances studied), which most likely will reduce energy usage in this regard. This particularly relevant with the results of the electrical usages of the homestead's freezers and how much they use in comparison to other appliances (Figure 2). Replacing of appliances are regarded more towards energy efficiency. The homestead should also consider new ways to reduce overall energy usage, as even though energy efficiency can save larger percentages of energy, conservation can still help reduce overall use of energy and have a more immediate impact (Gardner and Stern 2008).

This report in general should be apart of the overall transition plan of the homestead, a piece in the overall though process. Especially at this time as Wild Mountain is already undertaking plans of more energy efficient building infrastructure, as well already have thinking about reducing greenhouse emissions as evident by this report. A more thorough energy audit should be conducting at all energy usage and fossil-fuel based activities in the operation of the homestead. This would allow for an even larger analysis of what could the highest area of energy usage and emissions, and consider more ways to reduce these metrics. Other renewable technologies: wind, electrical heating, other biomass technologies, and so forth should be considered and compare across the board to see which individually and which in combination would have the greatest impact.

Other recommendations include communicating and partnering with other homesteads like the exemplified ones through this report in discussion or in sourcing of literature numbers and other knowledge. This community can be a very valuable in helping Wild Mountain experiment and implement the renewable energy technologies. Also using grant from environmental and homestead organizations/foundations to fund some of these renewable energy implementation by incorporating education and opening up to the surrounding community.

List of Tables and Figures

Report Body Figures

Body Tables

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Appendix 1: Summary of Calculations

Energy Audit:

<u>Yearly mmBTUs for each energy-source category</u>
Electricity: 24.7
Propane: 23
Wood: 97
Total: 145.41

(24.7/145.41) *100 = 16.99 percent
(23.38/145.41) * 100 = 16.99 percent
(97/145.41) * 100 = 66.95 percent (See Google Sheet for Energy Audit)

Organic Inputs:

Horse Manure:
A 2,000-pound draft horse produces 16 tons of manure per year (LSUAgCenter, 1914)
A 500-pound pony produces 4 tons of manure per year (LSUAgCenter, 1914)

Horse manure produced yearly at Wild Mountain:
16 tons (3) + 4 tons = 52 tons
Manure is only available during the winter months when horses are confined at Wild Mountain.
52 tons / 2 = 26
We assume 10 tons of losses
<u>16 tons/year</u>
or 32,000 pounds

Humanure:
The total for humanure production in a given year is
4 gallons of humanure weighs 20 pounds Wild Mountain (Excel Sheet; Biomass)
4 gallons = 20 lbs.
1 gallon = 5 pounds
50 gallons + 25 gallons = 75 gallons on average per year (Excel Sheet; Biomass)
75 * 5lbs/gallon = 375 pounds of humanure per year
375/365 = 1.03 pounds of humanure per day

Food Scraps:
Wild Mountain produces 4 gallons every 3-4 days (Excel Sheet; Biomass)
About 8 gallons per week
About 1.14 gallons per day
1 gallon of food waste weighs 7 pounds (Conversion Factors, n.d.)
1.14 * 7 = 8 pounds per day
365 * 8 = 2,920 pounds of food waste per year

Solar:

According to ReVision, 3.3 panels supplies one Kw.
"In Maine, one kw (3.3 panels) will produce about 1,250 kwh per year. You buy kwh from the utility . . . And that's a south array in great sunshine" (Revision Energy Talk)

Calculation:
Calculating the number of panels (the system size) required for covering one hundred percent of Wild Mountain Cooperative's annual electricity use
Wild Mountain Cooperative's total electricity use during the 2016-2017 year was 7,238.43583 Kwh.
3.3 panels/1250 kWh per year = x panels/7238.43583 Kwh per year
x = 19.109 panels to cover one hundred percent of electricity usage
Rounding: 19.1 panels to 19 panels

If a 1 kW system is 3.3 panels, what Kw system does 19.1 panels represent?
19.1 / 3.3 = 5.8 kW
Rounding: 5.8 kW to 6 Kw

According to an advanced solar calculator, a 19 panel (6 kW) system in Portland, ME facing directly south, angled at 35 degrees would yield 8,366 kWh per year.

Calculating the percentage of Wild Mountain Cooperative's electricity usage that ReVision Energy's smallest installed system (~9 panels) would cover.
3.3 panels/1250 kWh per year = 9 panels/(x) Kwh per year
x = 3409.09 Kwh per year

If a 1 Kw system is 3.3 panels, what Kw system does 9 panels represent?
9/3.3 = 2.73 Kw
Rounding: 2.73 Kw to 3 Kw

3,409.09 represents what percent of 7,238.43583 -- the total annual electricity usage?
(3,409.09/7,238.43583) * 100 = 47 percent
9 panels would cover 47 percent of the total electricity usage
There would be 3829.35 remaining Kwh to cover.

Calculating the number of panels (system size) required for covering electricity use of solely the Common House appliances, and solely the School House needs

Common House appliances: 2309.435383 Kwh
3.3 panels/1250 kWh per year = x panels/2309.435383 Kwh per year
x = 6.10 panels
Rounding: 6.1 panels to 6 panels

If a 1 Kw system is 3.3 panels, what Kw system does 6 panels represent?
6/3.3 = 1.82 Kw
Rounding 1.82 Kw to 2 Kw

Wild Mountain would require 6 panels (2 Kw system) to cover the electricity usage of appliances of the Common House.

School House: 4929 Kwh
3.3 panels/1250 kWh per year = x panels/4929 Kwh per year
x = 13.01 panels
Rounding 13.01 panels to 13 panels

If a 1 Kw system is 3.3 panels, what Kw system does 13 panels represent?
13/3.3 = 3.93 Kw
Rounding: 4 Kw

Note: Wild Mountain would require 13 panels (4 Kw system) to cover the electricity needs of solely the School House

Solar Graph Calculations

Graph A

Percent of total need
Electricity represents 17 percent of total energy need in mmBTU
9 panels represents 47 percent of this need
.47 * 17 = 7.99

Graph B

19-panel system
12-year payback period
1 Kwh = 3412.14 BTU
19 panels produce 100,392 Kwh in 12 years
100,392 Kwh * 3,412.14 = 342,551,558.88 BTUs in 12 years
= 342.6 mBTUs
Cost of installation over BTUs produced: $13,766 / 342.6 mBTUs = 42.2

30-year lifetime period
8,366 Kwh * 30 = 250,980 Kwh in 30 years
250,980 Kwh * 3412.14 BTU = 856,378,897.2 BTUs in 30 years
= 856.4 mmBTUs
Cost of installation over BTUs produced: $13,766 / 856.4 mmBTUs
= 16.1

9-panel system
12-year payback period
9 panels produce 40,909.08 Kwh in 12 years
40,909.08 * 3,412.14 = 139,587,508 BTUs in 12 years
= 139.6 mmBTUs
Cost of installation over BTUs produced: $6,888 / 139.6 mmBTUs = 49.3

30-year lifetime period
3,409.09 Kwh * 30 = 102,272.7 Kwh in 30 years
102,272.7 Kwh * 3,412.14 BTU = 348,968,770.578 BTUs in 30 years
= 348.9 mmBTUs
Cost of installation over BTUs produced: $6,888 / 348.9 mmBTUs = 19.7

Graph D
<u>19-panel system</u>
Produces 8,366 Kwh per year
Wild Mountain requires 7238.44 Kwh per year
100 % GHG reduction from electricity
11.7 % GHG reduction from total emissions (comprised of emissions from electricity, propane, and wood)

<u>9-panel system</u>
Produces 3,409.09 Kwh per year
3,409.09 Kwh is what percent of 7,238.44 Kwh?
(3,409.09 / 7,238.44) * 100 = 47.10 %
A 9-panel system would cover 47 % of Wild Mountain's total electricity needs
NOTE: this math goes elsewhere in appendix

7,238.44 Kwh = 2,976.47943 kg CO2 eq. (See Excel chart for calculation, electric bills)
3,409.09 Kwh from 9 panels in 1 year = 1401.833 kg CO2 eq.
(1401.833 / 2,976.47943) * 100 = 47.1 %
A 9-panel system reduces Wild Mountain's GHG from electricity by 47 %
Total CO2 eq. from all energy use = 24,319.410222 kg CO2 eq. (See Excel chart graphs and graphing info)
(1401.833 / 24,319.410222) * 100 = 5.76 %
A 9-panel solar array would reduce Wild Mountain's total GHG emissions by 5.8 %

Graph E
<u>19-panel system (installation within the next two years)</u>
Cost: $13,776
Cost per Kwh during the 12-year payback period
19 panels produce 8,366 Kwh per year
Payback period: 12 years
8,366 *12 = 100,392 Kwh
100,392 Kwh/ $13,766 = 1 Kwh/$(x)
100,392 x = 13,766
x = $0.137

<u>9-panel system</u>
Cost of a 9-panel system: $6,888
Cost per Kwh during the 12-year payback period:
9 panels produce 3,409.09 Kwh per year
3409.09 * 12 = 40,909.08 Kwh
40,909.08 Kwh / $6,888 = 1 Kwh / $(x)

40,909.08 x = 6,888
x = $0.168

Note: Cost per Kwh for 18 plus years after the 12-year payback period, assuming zero maintenance costs = $0 per Kwh
These calculations also assume that panels are purchased and installed prior to 2020 when the 30 percent federal tax credit is expected to change to 26 percent.

Price per unit of fuel (kJ from Maine Central Power electricity) calculation
The price of 1 Kwh (and 1 kJ) of electricity varies month to month according to the figures on Wild Mountain Cooperative's bills from Maine Central Power.
We are calculating an average price per Kwh and per kJ based on the total Kwh and total price for the 2016-2017 year.

School House (2016-2017)
Total Kwh: 4929
Total Joules: 17,744,400,000
Total kJ: 17,744,400
Total cost: $872.7

4929 Kwh / $872.7 = 1 Kwh / $(x)
4929 x = $872.7
x = $0.17705 per Kwh of electricity

17,744,400 kJ / $872.7 = 1 kJ / $ (x)
17,744,400 x = 872.7
x = $0.000049182 per kJ of electricity

Calculation
School House total kJ (2016-2017): 17,744,400
Common House appliances total kJ (2016-2017): 8,313,967.38
Total kJ (2016-2017): 26,058,367.38
$0.000049182 per kJ of electricity
$0.000049182 * 26,058,367.38 kJ = $1281.6

Check: $0.17705 * 7,238.43583 kWh = $1281.6

Electricity from Maine Central Power versus solar cost comparison over 30 years
Wild Mountain pays $1281.6 to Maine Central Power per year, assuming that electricity use is the same each year as 2016-2017.
If Wild Mountain Cooperative continued to pay Maine Central Power for electricity for the next twelve years, the cumulative price would be $1281.6 *(12) = $15,379.23.
If Wild Mountain continued to pay Maine Central Power for the next 30 years, the cumulative price would be $1281.6 *(30) = $38,448.

If Wild Mountain Cooperative installed a 19 panel (6 Kw) system, they would pay ReVision Energy $1,148.04 each year for 12 years. The full cost over 12 years would be $13,776.
Since electricity from solar would be free after the 12-year pay-off period, the full cost over the course of 30 years would still be $13,776.

Solar array prices after 2020 calculation
26 percent federal tax credit
Calculation:
0.26 * 19,680 = 5116.8
19,680 - 5116.8 = $14,563.2

Monthly payment over 12 years
14,563.2 / 144 = $101.13

Square footage of the array calculation
One ReVision Energy panel is 40 inches wide by 66 inches tall.[1]
Area of one panel: 40*66 = 2,640 square inches = 18.3 square feet
A 19-panel, 6 kW, system has a width of 40(19) = 760 inches and a height of 66 inches.
760 * 66 = 50,160 square inches = 3,480.28 square feet

A 9-panel system would has a width of 40(9) = 360 inches and a height of 66 inches.
360 * 66 = 23,760 square inches = 165 square feet

Assumption: Panels are aligned next to each other with no space between them.

Square foot on the ground calculation
We used trigonometry to calculate the height of the rectangle (area) the panels cover on the ground

35-degree angle
Hypotenuse: 66 inches
Sin (35) = x/66 inches
x = 37.86 inches
Solar array length is 760 inches
37.86 inches * 760 inches = 28,773.6 square inches = 199.82 square feet for a 19 panel array

37.86 inches * 360 inches = 13,629.6 square inches = 94.65 square feet for a 9 panel array

Cost Comparison

Cost to install a 9-panel (2 kW) system after accounting for the 30 percent tax credit is $6,888

Methane Digester

The equation used for predicting biogas production:

$G = (Y * Vd * S) / 1000$ (IRENA, 2015)
G is the biogas production in cubic meters per day
Y is the yield factor based on temperature and feedstock retention time, average temperature being about 50 degrees and retention time being between 21-25 days
Vd is the digester volume in cubic meters
S is the initial concentration of volatile solids in the feedstock

The great majority of the mathematical work for this equation centered on finding “S.”
The calculations involved finding the percentage of volatile solids in each feedstock (organic-input) type (horse manure, as well as what percentage of these inputs would be included in the daily-inputted feedstock given our organic-input audit, was taken into about.

Wild mountain uses an average of 0.7 gallons of propane per day.

1 cubic meter is about 264.2 US gallons

An anaerobic digester size of 2 cubic meters most closely matches Wild Mountain’s propane-usage of 0.7 gallons per day.

Question: Is the energy-yield of propane and digester-biogas equivalent?

However, I expect that Wild Mountain would like to use more digester-biogas than 0.7 gallons per day. In a scenario in which digester-biogas covers all of Wild Mountain’s heating and cooking -- currently provided by a combination of electricity, wood, and propane -- the gas-usage per day is significantly higher.

Wild Mountain might use biogas from anaerobic digestion for heating and cooking, as well as the effluent (digestate-material) for fertilizer for their gardens.

Calculations
https://www.afdc.energy.gov/fuels/fuel_comparison_chart.pdf
This source states that propane heating value is 84,250 Btu/gallon

https://www.engineeringtoolbox.com/heating-values-fuel-gases-d_823.html
This source states heating values for biogas versus propane
Methane: 23811 Btu/lb
Propane: 21564 Btu/lb

“Biogas . . . it’s heating value is around 600 BTU per cubic foot” (Addison, n.d.)

Biogas Replacement at Wild Mountain; Scenario Assessment

Scenario 1: Biogas replaces propane
for cooking and hot water heater
Wild Mountain uses an average of 0.7 gallons of propane per day for their stove and hot-water heater.
The heating value of biogas is about 600 BTU per cubic foot*

Heating value of propane 2,500 Btu/cu ft. and for methane 1,000 Btu per cubic ft.(Bartok 2004)

The below calculations are important for calculating the variable "S" in the equation for methane digester biogas production

S = the initial concentration of volatile solids in the slurry in kg/cubic meter (IRENA, 2015)

Calculating Volatile Solids

Horse Manure
87.67 pounds of horse manure available per day (on average)
For horse manure, total solids (TS) = 20% of total weight of feces = 17.53 pounds per day
Volatile solids (VS) = 80% of TS = 14.02 pounds per day
14.02 is what percent of 87.67?
(14.02 /87.67) * 100 = 15.99
Horse manure has a 15.99% VS concentration

Humanure
5.15 pounds of humanure available per day (on average)
For humanure, total solids (TS) = 27% of total weight of feces = 1.39 pounds per day
Volatile solids (VS) = 92% of TS = 1.28 pounds per day
1.28 is what percent of 5.15?
(1.28/5.15) * 100 = 24.85
Humanure has a 24.85% VS concentration

Note: Another source states that human feces have 25-45 percent VS content. The fact that the calculated VS content above is close to the low end of this source's range gives more reason to believe its accuracy. (Schuster-Wallance C.J., et al., 2015)

Food Waste
8 pounds of food waste available per day (on average)
Considering an average of the percentage from fruit, vegetable, and grain food waste, volatile solids (VS) = 37% of total food-waste weight (IRENA, 2016)
(.37) *(8) = 2.96 pounds per day
What percent is 2.96 of 8?
(2.96/8) * 100 = 37 % VS concentration

<u>The amount of waste in cubic meters per day</u>
Horse manure
One gallon of horse manure is 8.3 pounds (Rutgers, 2017)
1 cubic meter = 264.2 gallons
8.3 * 264.2 = 2192.86 pounds per cubic meter
1 kg / 2.2 lbs. = (x) /2192.86 lbs.
2.2 x = 2192.86
x = 996.75 kg
There are 996.75 kg of horse manure per cubic meter
Horse manure has a 15.99% VS concentration
15.99% of 996.75 = ?
0.1599 * 996.75 = 159.38

For horse manure, S = 159.38 kg/cubic meter

Humanure
1 gallon of Wild Mountain's humanure is 5 pounds
1 cubic meter = 264.2 gallons
5 * 264.2 = 1321 pounds per cubic meter
1 kg / 2.2 lbs. = (x) /1321
2.2 x = 1321
x = 600.45 kg
There are 600.45 kg of humanure per cubic meter
Humanure has a 24.85% VS concentration
24.85% of 600.45 = ?
0.2485 * 600.45 = 149.03
For humanure, S = 149.21 kg/cubic meter

Food waste
I gallon of food waste weighs about 7 pounds (Conversion Factors, n.d.)
1 cubic meter = 264.2 gallons
7 * 264.2 = 1849.4 pounds per cubic meter
1 kg / 2.2 lbs. = (x) /1849.4
2.2 x = 1849.4
x = 840.64 kg
There are 840.64 kg of food waste per cubic meter
Food waste has a 37.% VS concentration
37% of 840.64 = ?
.37 * 840.64 = 311.63
For food waste, S = 311.03 kg/cubic meter

<u>Quantity of material inputs for methane digester and compost heap heating at Wild Mountain calculations</u>

Horse Manure
Wild Mountain has 3 horses and 1 pony
A 2,000-pound draft horse produces 16 tons of manure per year (LSUAgCenter, 1914)
A 500-pound pony produces 4 tons of manure per year (LSUAgCenter, 1914)

Horse manure produced yearly at Wild Mountain:
16 tons (3) + 4 tons = 52 tons

Manure is only available during the winter months when horses are confined at Wild Mountain.
52 tons / 2 = 26
We assume 10 tons of losses

16 tons per year
32,000 pounds per year
32,000 pounds horse manure in one year/ 365 = 87.83 pounds per day

Humanure
4 gallons of horse manure weighs 20 pounds Wild Mountain (Excel Sheet; Biomass)
4 gallons = 20 lbs.
1 gallon = 5 pounds
375/365 = 1.03 gallons of humanure per day (on average)
1.03 gallons * 5 = 5.15 pounds of humanure per day (on average)
50 gallons + 25 gallons = 75 gallons on average per year (Excel Sheet; Biomass)
75 * 5 = 375 pounds of humanure per year

Food Waste
Wild Mountain produces 4 gallons every 3-4 days (Excel Sheet; Biomass)
About 8 gallons per week
About 1.14 gallons per day
1 gallon of food waste weighs 7 pounds (Conversion Factors, n.d.)
1.14 * 7 = 8 pounds per day
365 * 8 = 2,920 pounds of food waste per year

Total input to digester per day: **100.82 pounds**
(87.83/100.82) * 100 = 87.12 %
Horse manure would be 87.12 % of total daily waste input to a methane digester
(5.15/100.82) * 100 = 5.12 %
Humanure would be 5.12 % of total daily waste input to digester
(8/100.82) * 100 = 7.93 %
Food waste would be 7.93 % of total daily waste input to digester

VS concentrations
For horse manure, S = 159.38 kg/cubic meter
For humanure, S = 149.21 kg/cubic meter
For food waste, S = 311.03 kg/cubic meter

159.38 *(.87) = 138.66
149.21 * (.05) = 7.46
311.03 * (.08) = 24.88

Calculating the average VS content in daily input waste-material
138.66 + 7.46 + 2.4,88.24 = 172.0035
The average VS concentration is 172.0035 kg/cubic meter

The average initial volatile solids concentration of the input at Wild Mountain would be **172 kg/cubic meter**

Biogas Production Prediction; Little Green Monster Design
G = (Y * Vd * S) / 1000
G is the biogas production in cubic meters per day
Y is the yield factor based on temperature and feedstock retention time, average temperature being about 50 degrees and retention time being between 21-25 days
Vd is the digester volume in cubic meters
G = (3.79 * 2.5 * 172) / 1000

G = 16297 / 1000
G = 16.297
Little Green Monster Digester would produce 16.297 cubic meters of biogas per day
1.62 * 365 = 591.3 cubic meters of biogas per year

Biogas Production Prediction; ACME portable assembly plant design -- sizes small and medium
Small: 3 cubic meters digester volume
G = (Y * Vd * S) / 1000
G = (3.79 * 3 * 172) / 1000
G = 1,955/ 1000
G = 1.956

The small size ACME portable assembly plant would produce 1.95 cubic meters of biogas per day

Medium: 25 cubic meters
G = (Y * Vd * S) / 1000
G = (3.79 * 25 * 172) / 1000
G = 16297 / 1000
G = 16.30
The medium size ACME portable assembly plant would produce 16.30 cubic meters of biogas per day

Biogas Production Prediction; HomeBiogas System; pre-manufactured biogas digester for sale now made in Israel (HomeBiogas 2017)
G = (Y * Vd * S) / 1000
G = (3.79 * 1.5 * 172) / 1000
G = 977.82/1000
G = 0.97
HomeBiogas System would produce 0.97 cubic meters of gas per day

Sources used for TS and VS percentages of total waste-weight in the process of calculating “S” for the production equation:

Spatial Heating Calculations

Length of required baseboard for spatial heating of the Common House calculations

Wild Mountain uses a combination of hardwood for the woodstove in the Common House, including ash, oak, and maple.
Assumption: The amount of wood they burn is comprised of an equal amount of ash, oak, and maple.
mmBTUs per cord
Ash: 23.6
Oak: 25.7

Maple: 24
Average mmBTU per cord: 24.333

24.333 mmBTU per cord of wood (Straus et al. 2012)
Wild Mountain uses 4 cords of wood to heat the Common House over winter per year
24.333 mmBTU * 4 = 97.73 mmBTU
Wild Mountain requires 97.73 mmBTU (97,730,000 BTU) to heat the Common House over winter each year.

Assumption: Wild Mountain burns wood from November-March (5 months)
Calculating an *average* of BTUs required per hour:
There are approximately 151 days in 5 months
97,730,000 BTU / 151 days = 647,218.54 BTUs per day
647,218.54 BTUs / 24 hours = 26,967.44 BTUs per hour
During the winter season, Wild Mountain requires 26,967.44 BTUs from wood *on average* to heat the Common House.

The Common House is 30 by 37 feet, which equals 2,200 square feet. There are two floors. One foot of baseboard can produce an average of 585 BTU/hour at a pump rate of 1 gallon per minute when the average water temperature is 180 degrees F (Keith 2011).

There is currently a wood stove on the first floor and second floor of the Common House.
Assumption: Each floor requires an equal amount of BTUs.
26,967.44 BTUs / 2 = 26,967.44 BTUs per hour *for each floor*

585 BTU * (x) = 26,967.44 BTU
x = 46.1 feel
Wild Mountain needs *approximately* 46 feet of baseboard on each floor to heat the Common House during winter.
Total feet of baseboard / piping required: 92 feet

Analyzing the potential of a methane digester to replace energy-needs from propane and wood at Wild Mountain; Calculations

<u>How many BTU is generated from HomeBiogas system per day?</u>
Biogas heating value: 600-1,000 BTU per cubic foot (Addison, n.d.) (Bartok, 2004)
Average value: 800 BTU per cubic foot
1 cubic meter = 35.31 cubic feet
800 * 35.315 = 28,252 BTU per cubic meter

2.
<u>Wild Mountain Propane Needs</u>
Wild Mountain uses an average of 0.7 gallons of propane per day for their stove and hot water heater, which compiles over one year to equal 256 gallons. (Excel Sheet; Oil and Gas Use)
Wild Mountain uses 23.38 mmBTU per year
Wild Mountain uses 0.064 mmBTU per day = 64,000 BTU per day (Excel Sheet; Oil and Gas Use) (EPA, 2014)
Wild Mountain uses 64,000 BTU per day

3.

<u>Could a methane digester replace propane?</u>

0.97 cubic meters of gas per day from HomeBiogas System (Appendix calculations for biogas production)

0.97 * 28,252 BTU = 27,404.44 BTU per day from HomeBiogas System

27,404.44 BTU * 365 = 10,002,620.6 BTU per year from HomeBiogas System

(27,404.44 / 64,000) * 100 = 42.8 percent

The BTUs from biogas produced by HomeBiogas system represents about 42.8 percent of the BTUs required for current propane (gas-for-heating) needs

4.

<u>Could a methane digester cover wood heating?</u>

Our calculations indicate that HomeBiogas System would produce 0.97 cubic meters of biogas per day, which is equivalent to 27,404.44 BTU per day.

BTUs for the Common House required from wood per year: 97.332 mmBTU (Excel Chart Biomass)

Wild Mountain burns wood for approximately 5 months per year, which is equal to about 151 days

97,332,000 BTU / 151 days = 644,582.78 BTU used per day (on average)

644,582.78/24 = 2,685,762 BTU from wood during colder months is used per hour (on average)

HomeBiogas System produces 27,404.44 BTU per day

27,404.44 BTU / 24 hours = 1,141.85 BTU per hour

27,404.44 BTU would be available for baseboard heating if the average methane biogas production per day (0.97 cubic meters) was burned in a fuel tank to provide heat through a system of baseboards.

There are 647,218.54 BTUs required per day from burning wood to heat the Common House during winter. (See Appendix L)

(1,141.85 / 2,685,762 * 100 = 0.043%

The average BTUs generated daily from HomeBiogas System represents 0.043 percent of the BTUs currently required for wood-stove spatial heating

Storage-for-future-use scenario

Using biogas storage from HomeBiogas System

27,404.44 BTU per day * 365 days = 10,002,620.6 BTU in a year from HomeBiogas system

10,002,620.6 BTU / 151 days = 6,624.52 BTUs available from HomeBiogas System each day during colder months (on average, and assuming storage throughout the year)

644,582.78 required BTU compared with 6,624.52 BTU available from HomeBiogas digester

(6,624.52/644,582.78) * 100 = 1.028 %

If Wild Mountain stored the biogas produced from HomeBiogas System throughout the year, and used it solely for spatial heating during the winter, 1.028 % of the currently-required BTUs for heating with wood would be replaced.

Compost Heap Heating

Estimation of Energy produced from Hydronic Compost Heap Heating System

6 Month Pilot Project/Experiment

1000 btu/hr/ton of compost maximum (Gorton 2012)
Operating under assumption that full efficiency may not be possible.
1000 btus/hr/ton * 24/hrs/day * 7 days/week * 52 weeks/year = 8,737,000 btu/yr/ton maximum heat produced from compost heap

8.736 mmbtu/yr/ton of compost (maximum)

18.75/2= 9.3765 tons of wood chips, and an equivalent amount of compostable material

18.75 ton pile of compost = maximum hypothetical size Wild Mountain could produce

Left producing energy for a year, 18.75 x 8.736 = 163.8 mmbtu/year maximum energy yield.

30 year theoretical energy yield (temporal comparison scale) = 30 x 163.8 = 4914 mmbtus/30 years

Cost Estimate:

Woodchips 525lbs/yd^3 x 4.5 yards (dumptruck load) = 2362.5 pounds per load = 1.18 tons

9.37 tons (woodchips needed for CHH) / 1.18 tons = 7.94 (8) truck loads of wood chips for compost heap

$25/Delivery to Wild Mountain x 8 = $200
100 feet of ¾" black plastic pvc piping in heap =$100 (United States Plastic Corp.)
Water Pump $100-150 (Depending on usage) (Home Depot)
Water Tank $400-500 (optional)
Temperature Sensor $20-50 (optional)
Piping to Home $100
Square hay bales = 20 x $4 = $100

Min Cost: 200+100+100+100+100 = $600

Max Cost:200+100+150+500+50+100+100 = 1200

Average of $900

30 Year cost estimate (for scenario calculation purposes)

30 x (300)= 9000
3 x (900)= 2100

= 11,000
Assuming replacement of all organic inputs each year of 30. Replacement of infrastructure every 10 years

Scenarios

Graph 1 Calculations (Scenarios)

Dollars per BTU
1100 dollars for a compost heap sustained over 30 years
$13,776 for a 19-panel solar array
$6,888 for a 9 panel solar array

A 19-panel solar array produces **856.379 mmBTUs** in 30 years (Appendix Solar Graph Calculations)
A 9-panel solar array produces **348.969 mmBTUs** in 30 years
Compost heap at Connor's designated size would produce an estimate of 4,914 mmBTUs in 30 year

<u>19-solar + heap</u>
$14,876/5,770.4 mmBTU = $(x)/1 mmBTU
x = **$2.58 per mmBTU over a 30 year time period**

<u>9-solar + heap</u>
$7,988/5,262.97 mmBTUs = $(x)/1 mmBTU
x = **$1.52 per mmBTU over a 30 year time period**

Graph 2 Calculations

S1
Total propane use in a year produces 1437.72 kg CO2 eq.
Assumption: ¾ of propane goes towards heating water and ¼ goes towards fuel for stove-cooking
0.75 * 1437.72 = 1078.29 kg CO2 eq.

In this scenario, in which the compost heap provides exclusively hot water, 1078.29 kg CO2 eq. are offset

19-panel + heap
$14,876/ 2976.479 kg CO2 eq. + 1078.29 kg CO2 eq.
total offset CO2 eq.: 4054.8 kg CO2 eq.

Total cost by total kg offset from solar and heap
$14,876 / 4054.8 kg CO2 eq. = $(x) / 1 kg CO2 eq.
x = $3.69/kg CO2 eq.

9-panel + heap
$7,988/1401.83 kg CO2 eq. + 1078.29 kg CO2 eq.

Total cost by total kg offset from solar and heap
$7,988/ 2479 kg CO2 eq. = $(x) / 1 kg CO2 eq.
x = $3.2/kg CO2 eq.

S2

Graph 3 Calculations
S1

19-panel
CO2 equivalent offset with a 19-panel system
Wild Mountain's electricity use per year produces 2976.479 kg CO2 eq., and all of this would be offset by a 19-panel solar system
Total kg CO2 eq. offset: 2976.479 kg CO2

9-panel
CO2 equivalent offset with a 9-panel system
Covers 47 % of electricity needs
0.47 * 7238.44 = 3402.07 Kwh in on year
This represents 1401.83 kg CO2 eq. (See Excel Chart; Electric Bills)
Total kg CO2 eq. offset: 1401.83 kg CO2 eq.

Graph Calculations

Yearly BTUs from all energy sources (electricity, propane, wood) at Wild Mountain
BTUs for electricity calculation
Appliances and School House represents 7238.44 Kwh per year (Excel Sheet Electricity Bills)
1 Kwh / 3412.14 BTU = 7238.44 Kwh/(x) BTU
x = 24,698,570.66 BTU per year for electricity

23,381,000 BTU per year from propane (Excel Sheets, Oil and Gas Use)
4 cords represents Common House is 97,332,000 BTU (97.332 mmBTU) per year (Excel Sheets; Wood)

Total BTUs FOR ALL ENERGY CATEGORIES (in one year: 24,698,570.66 + 23,381,000 BTU + 97,332,000 =
145,411,579.66 BTU

Total BTU from HomeBiogas System in one year: 10,002,620.6 BTU
(145,411,579.66 /178,899,920,829.79) * 100 = 0.083 percent
The total BTUs from HomeBiogas digester represents 0.083 percent of their total energy needs

Assumptions: sum of BTUs for electricity for School House plus Common House appliances, wood use only in the Common House, and total propane use

Graph B; Methane Digester Technology -- Cost per BTU
HomeBiogas System produces 10,002,620.6 BTU per year
Cost of Home Biogas System (the pre-assembled technology): $950
I couldn't find an estimated life expectancy of the system. I am assuming 30 years.
10,002,620.6 BTU * 30 = 300,078,618 BTU

300,078,618 / $950 = 1 BTU / $(x)
300,078,618 x = 950
x = $0.000003165837 per BTU
$3.17 per mmBTU

Appendix Graph B
Methane Digester Technology + Spatial Heating Infrastructure – Cost per BTU

Boiler cost: $2,500-10,000
Middle value (estimate cost): **$6250**
Baseboard radiators (3-8 feet a piece): $100-500
Middle value (estimate cost): $300 per 5 feet
Amount of baseboard radiators/piping required: 92 feet (Appendix L)
About 90 feet required
90/5 = 18
18 five-foot length baseboards required
18 ($300) = **$5,400**
New piping: $1.25-2.5 per foot
Middle value (estimate cost): $2 (rounding)
90 feet of piping (plus an estimate of 20 feet for traveling from the boiler and upstairs, instance) = about 110 feet of piping required
110 feet ($2) = **$220**
Estimate: 20 hours to install
Labor costs vary by the plumbing or heating contractor, but the national average is 50-70 dollars per hour
Middle value (estimate cost): $60

$60 * 20 = **$1200**
Total estimate price for spatial heating infrastructure plus installation cost:
$6250 + $5,400 + $220 + $1200 = $13,070

HomeBiogas digester + spatial heating infrastructure and installation cost: $950 + $13,070 = $14,020
300,078,618 BTU / $14,020 = 1 BTU / $(x)
300,078,618 BTU x = 14,020
x = $0.000467 per BTU
$467 per mmBTU

Appendix Graph D; GHG Reduction Calculations
There are 1,437.72 kg CO2 eq. per year from propane use at Wild Mountain

Percent of reduction of greenhouse gas emissions from propane
Propane emissions represent 3% of total greenhouse emissions

42.8 percent of total annual propane use is offset
Total propane use per year is 256 gallons (Excel Sheet; Oil and Gas Use)

0.428 * 256 = 109.7 gallons offset
109.7 offset gallons represents 616.09 kg CO2 eq. offset (Excel Sheet; Oil and Gas Use)

Total current kg CO2 eq. per year from propane: 1437.72
(616.09/1437.72) * 100 = 42.85 % GHG offset of propane GHG
Total CO2 eq. from all energy use in one year = 24,319.410222 kg CO2 eq. (See Excel Chart)
(616.09/24,319.410222) * 100 = 2.53 % GHG offset from all energy sources (of electricity, propane, and wood)

Appendix 2: Assumptions

Energy Audit

1.We assume that in our estimates of the household appliances we arrived at a reasonable estimate for overall electricity consumed at the common house.

Ecological Footprint

1.We assume that averaging numbers for Ash, Oak and Maple when looking at mmBTU/Kg wood, lbs/cord, and kg CO2/cord, will give us a representative sample of Wild Mtn's overall wood consumption of the three types used.

2. We assume that the numbers for CO2 equivalents for N2O and CH4 pulled from our EPA source will give us numbers comparable to our other primary source used for the wood emission calculations. although the Futuremetrics source gave us Kg Co2 emitted, it did not contain N2O or CH4 literature numbers

Inputs

1.We assume that the numbers for relative input weights given by our sources were reasonable estimates for overall mass.

2.We assume that the amount of horse manure produced yearly given by our sources was an accurate amount. Additionally, that our estimate of losses over the summer months is accurate.

Solar

Our calculation of the number of panels and square footage of the array depend on the assumption that panels are pointed directly south, and are positioned at a 35-degree angle. We used the Portland Maine as the location for the solar array for the online solar-calculator, as this city was the closest to Greene, Maine that the website enabled.

Methane Digester

We assume that the estimated volatile solids percentages are correct, and that the used-equation for biogas production is accurate. We recommend that Wild Mountain re-visit calculations for biogas production when they develop a better idea of digester volume and percentages of types organic inputs.

Compost Heap Heating

Our calculation of the theoretical maximum energy yield of a compost heap at Wild Mountains input volume is assumed to be accurate. The actual heat produced may vary considerably though based on efficiency of design, ingredient composition, and other environmental factors.

Spatial Heating

The cost-information for spatial heating used for the scenario graphs within the "Recommendations" section assumes that the spatial heating cost corresponding with compost-heap-heating and methane digester use is the same. This assumption is inaccurate given that a boiler/furnace would be required for burning biogas to then circulate pumped hot-water-or-air through a system of pipes and hydronic baseboard radiators in the case of a methane digester, whereas only a piping system (without any boiler) would be required in the case of compost heap heating.