Thrane Homestead Microgrid

Alex Cagle, Greg Miller, Miheer Shah
ABT 212: Path to Zero Net Energy Spring 2020

Project background

Brief History and Context

David Evans is the owner of an organic apple and pear orchard in Oregon's Hood River Valley, and has been fascinated with the idea of sustainable farming and agriculture throughout his career in this industry. David envisions a small homestead that is completely powered by renewable energy and can function off the grid. Utilizing state-of-the-art technology and designs, he hopes to support a working orchard, farm buildings and a home that make up "Thrane Homestead". His motivations primarily stem from valuing the importance of energy security and independence from the grid especially during emergencies and unexpected crises. Additionally, he is committed to demonstrating a model of self-sufficient agriculture and living to local farmers, schools and interested students through growing all your own food and using your own energy. He hopes to inspire a new generation to understand alternatives to a carbon-based energy dependence. As a UC Davis alumnus, David is interested in leveraging the resources of UCD's Path to Zero Net Energy course.

Problem Description

David has tasked us to investigate whether it is technologically and economically feasible to power Thrane Homestead with 100% renewable energy. He wants to understand all options for renewable energy, energy efficiency, electrification, and microgrid architecture, as he expects to privately fund, own and operate the solutions. Our project assumes two additional conditions from David: prioritize energy loads related to food production; and begin the first phase of the project as early as next summer. Our goal is to identify how to provide entirely renewable power and take the homestead completely off the grid. In this report we detail a microgrid design and phased implementation plan towards realizing David's vision for Thrane Homestead.

Literature Review and Background Research

Microgrid projects have been gaining traction as distributed resources and renewable energy continue to lower in price. To investigate microgrid design and projects similar to our client's goals, we performed an academic literature review and also interviewed multiple microgrid companies and locations in which microgrids have been installed. Specifically, the team investigated proposed microgrid circuit design on a residential level (Roggia et al., 2008). This literature search familiarized the team with circuit layout and design and ultimately informed our proposed system design. Additionally, this investigation allowed for the understanding of how integrated electric vehicle loads may impact circuit design and demand patterns (Roggia et al., 2008; Elsayed et al., 2015). Additionally, a review of the HOMER software used for economic feasibility and sensitivity analysis was conducted in order to assess the applicability of the software for our estimation goals for the system (Nurunnabi et al., 2015).

Upon completion of the preliminary literature review, we performed informative interviews with Heila Technologies, the controls platform behind a similar microgrid project in Napa Valley, CA. This interview gained us information on the actual implementation process of microcontrollers and control platforms for microgrids at the scale we were evaluating (10-50 kW). Specifically, this interview allowed us to understand exactly how programmable and adaptable modern microgrid controller technologies have become. Wanting to potentially add both loads and generation sources across time to the Thrane homestead microgrid, this information was specifically valuable as it gave us the confidence to explore all avenues of potential microgrid components for our client.

In addition to existing system literature review and interviews, the group also explored a range of technology options for all major components of the microgrid. Specifically, multiple solar panel manufacturers were reviewed at various price points and efficiencies for application in this grid (ReneSola LTD, SunPower LTD). Additionally, the current home energy storage market was evaluated based on integration ability, cost-effectiveness, and technical ability. While there is much discussion about the Tesla Powerwall and the Sonnen Eco home batteries, there are also many implementation benefits for utilizing a battery programmed to function with the suggested PV installation. This motivated the exploration of the SunPower Equinox battery and microcontroller system that ultimately are recommended in this analysis.

Report Structure

This report is structured into four main sections representing the four major components of our analysis: renewable resource assessment, energy demand analysis, energy balance assessment, and implementation recommendations. Within each of these sections, we describe the methodology used, the main results, sources of uncertainty, and any follow-on work that will be required.

Resource Assessment

The Thrane homestead location had three potential renewable energy sources to power the proposed microgrid: solar, wind, and conduit hydropower. Due to the variability of both wind and solar energy and the seasonal variability of hydropower availability on the site, it was anticipated that multiple renewable energy sources may be available to power the same microgrid. The group then developed detailed resource assessment of all three resources with the constraints that the technology deployed would need to be both economically feasible, residential scale (under 25 kW capacity), and deployable under local zoning and power requirements.

Wind Resource Analysis

Given the homestead is located within a mountain valley, there was a great hope for high wind potential. The major parameters we were required to analyze for on-site wind power viability were the cut-in speed of the proposed turbine, height of the turbine and relations to local structure height requirements, and clearance needed around the turbine. Of these, limiting factors include the Hood River zoning limit of 35 ft on a turbine and a 35 ft clearance around the object (Hood River County, 2016). Higher tower heights would be able to assess more of the wind resource in the valley. Wind resources were assessed by analyzing 10m wind data from a local airport less than seven miles away. We reviewed historical wind data and averaged both monthly and daily wind loads over the most recent three-year period. In context of a small-scale wind turbine, we found that the wind necessary to meet cut-in speeds occurred very infrequently throughout the year. Specifically, a 10kW wind turbine would only generate 234 kWh/year. This is a capacity factor of 0.002 (.2%) and would not add a large measure of resiliency or generation security to the microgrid. Additionally, new 10kW wind turbines average $50,000, causing a completely unattainable payback period (over 1,000 years).

Conduit Hydropower Resource

The property also receives irrigation water from approximately May 15 through September 15 each year, which must be reduced from a supply pressure of 60 PSI to 40 PSI for distribution around the orchard. Currently this pressure is reduced using a pressure reducing valve, but the available hydraulic head could be used to power a hydroelectric turbine. There is a separate irrigation sub-main which flows under the property that has excess head that could be converted to electricity before reaching downstream farms. Power was calculated utilizing the parameters in Appendix 1 and total annual generation could reach up to 32,929 kWh during the growing season. While this is a substantial and consistent source of renewable energy, the season in which this resource is available coincides with peak solar PV production, causing an unusable amount of energy in the summer months and no renewable energy in the winter months. Additionally, there is no model for conduit hydropower within the Hood River Electric Coop and a large distribution network, over 700ft, would have to be constructed to have the conduit hydropower station connect to any type of housing sub paneling or grid distribution network. For these reasons, the group is not advising the pursuit of conduit hydropower on the property.

Solar Resource

Finally, the group assessed the potential of solar PV generation on the site. Given the large amount of acreage of the property and six applicable rooftops for installation, both ground-mounted and roof-mounted options were explored in this analysis. After conversations with David we were able to rule out ground-mounted solar and limit our analysis to rooftop solar potential. The group then assessed roof tilt angle and azimuth angle, local irradiance conditions, shading patterns, and individual roof area to identify total PV potential on the homestead. We then performed a PVWatts analysis of the given rooftops to get detailed, site-specific estimations that incorporate shading and system losses and degradation over time. This analysis found the rooftop potential capacity for this site to be 67 kW and a total annual production potential of 82,059 kWh. The generation value of kWh produced takes into consideration averaged irradiance values across the last five years.

To determine how much rated solar capacity we should install on the property, we combined information on local net metering and grid interaction permitting, available rooftop space, and cost information to determine that the optimal design would be to install a 22.7kW high-efficiency panel array on top of a singular rooftop above the tractor storage building. Local net metering and interconnection standards under the Hood River Electric Coop limit installed solar capacity for residential clients to be below 25kW. The recommended 23kW installation on a singular roof using high-efficiency SunPower x-series panels allows the client to both stay within the constraints of the local power authority and reduce the need to construct PV arrays on multiple rooftops, thus also limiting risk/maintenance costs of two systems. Total annual production for this system and daily energy production at both low and high-production portions of the year can be viewed in Appendix 2 and this demonstrates the stark variability in seasonal and daily energy production on the property.

Complete Resource Assessment

This group assessed the renewable energy potential for solar energy, wind energy, and hydropower within the constraints of a residential exclusive farm use zoning under the Hood River Electric Cooperative. After evaluating both localized resource availability and plausible technologies to be deployed, the group arrived at the conclusion that the most viable option to maintain high amounts of year-long renewable penetration to the microgrid would be a solar-only option. While the deployment of solar is well developed and estimated solar planning is an established practice, there still is uncertainty of the structural integrity of the structure we are recommending to house the PV array. A consultation with a PV contractor will be able to alleviate these uncertainties.

Energy demand analysis

Methodology

Thrane Homestead consists of several buildings with energy consuming equipment. One of our team members conducted a walkthrough to audit the demand of various loads and documented their energy sources. For equipment that did not have nameplate information, a Kill-A-Watt meter was used to compile data on the overall power drawn from each building. A home energy monitor was used to estimate the hourly energy profile. By knowing when certain loads consumed energy as well as the power drawn by the loads through the audit, energy efficiency measures targeting specific energy uses are recommended. Recommendations to electrify existing loads powered by fossil fuels are also made to utilize the available renewable energy and achieve near zero emissions. Lastly, the client anticipates adding some new loads for which efficient options are reviewed. Additional tables supporting the results are in Appendix 3-8.

Results

Old Barn: The walk-in freezer in the old barn is the single-largest electricity consumer on the property, using over 67% of the electricity. The current freezer is about 20 years old. Replacing the freezer with a modern, prefabricated unit would save the most energy over the long run.

Energy efficiency recommendations with low investment costs for the walk-in freezer in the old barn. See Appendix 4.

Applies to Existing / New Freezer?	Description of Efficiency Measure	Investment Cost
Existing	Seal air gaps in freezer walls/door	Low
Existing	Switch interior lights to LED lamps	Low
New	Install interior handle that allows the door to be closed when someone is inside	Low

Due to the thermal mass of the freezer, there is an opportunity to use it as a thermal battery. Thermal energy can be solar charged and stored during the day and discharged overnight. Viking Cold Solutions has a phase change material battery with a smart controller that is compatible. The manufacturer states that their solution increases the overall efficiency and load flexibility of the unit.

Lab Building: The lab building currently uses electricity for lighting, space heating, freezing samples, and other equipment. It also has a propane-powered instant water heater to provide hot water. Once more food preservation operations such as dehydrating and canning begin, these will add significant loads.

Energy efficiency recommendations with low investment costs for equipment in lab building. See Appendix 5.

Load Type	Description of Efficiency Measure	Investment Cost
Freezer	Defrost and unplug over any long periods where the freezer is not needed for storing samples	Low
Space heater	Make sure the space heaters are placed away from freezer	Low

If there is ever a greater demand for hot water, such as for hydronic soil heating at the adjacent hoop house, we would recommend replacing the current instant water heater with an electric tank water heater, which can help act as a thermal battery and maximize solar utilization.

A new load planned for the lab is dehydration and canning for orchard fruits. Canning requires a stove to provide heat for disinfection and preservation. Recommendations are detailed in Appendix 6. Together, these new operations are expected to add over 630 kWh/year.

<u>House:</u> The house consumes approximately 3,800 kWh of electricity and 400 gallons of heating oil per year. The primary energy loads are the furnace for space heating, the water heater, and the refrigerator. Many of the major appliances are 20-30 years old and should be replaced with modern versions that are ENERGYSTAR certified. The current 50-gal electric water heater, for instance, was installed in 1997 (23 years old), and consumes approximately 40% of the house's electricity (according to the home energy monitor). In order to maximize use of the onsite solar energy, these appliances should be equipped with "smart" controls that allow them to time their energy use to align with solar availability.

For space heating, the current 30 year old furnace was installed in 1990 and runs on heating oil. We recommend that the furnace be replaced with an electric air-source heat pump, which is more efficient and does not burn fossil fuels. Converting from oil to electric heating will significantly increase the amount of electricity consumed, but will decrease overall energy use and cost. To control the furnace, we recommend installing a smart thermostat with temperature sensors in critical rooms (such as the bedroom) to make sure that the necessary spaces are being conditioned to the desired setpoint.

Energy efficiency could be greatly improved through a combination of updating aging equipment and better insulating the building envelope. The largest sources of heat loss through the building envelope are the single-paned windows. These windows make up a relatively large percentage of the house's wall area and increase the amount of energy for space heating. Efficiency recommendations are detailed in Appendix 7.

<u>Greenhouse:</u> The greenhouse is only used for 3-4 months of the year in late-winter into the spring, and most energy is consumed to maintain the temperature of the space. The vent fan prevents the space from getting too hot during the day, and the propane space heater prevents the space from getting too cold overnight. Since greenhouses are inherently passive buildings, we recommend maximizing the passive features of the structure for both ventilation and heating. Details are found in Appendix 8.

The client intends to install supplemental lighting for the greenhouse so as to extend the growing period each day and increase the productivity of the greenhouse. It is recommended that this new load be an LED source utilizing photosynthetic wavelengths. In addition, a low-cost dusk-to-dawn switch installed in the electrical supply line to the greenhouse would increase the efficiency of the lighting use. TotalGrowLights offers a variety of high efficiency LED lamps fit for the purpose, such as the TotalGrow Multi-HI bar light. Supplemental lighting is expected to add about 90 kWh/year to overall consumption.

<u>Farm Equipment:</u> An ATV is being used on the orchard for a variety of purposes including fruit sampling, collection, towing, and plant inspection. The current vehicle is diesel powered, and should be replaced with an electric vehicle that can be charged with the available renewable energy. The rechargeable battery could even be used as an energy buffer in emergency situations such as a power outage. Eco

Charger offers such a solution, with lithium-ion and lead acid battery options. Their Dominator e-ATV uses a lead-acid battery that provides a 28 mile range with 350kg towing capacity. It achieves a 70% charge within 90 minutes via a 3 kW charger, with a total cost of approximately $11,000. Based on estimated schedules, the ATV will consume about 930 kWh/year.

The client also desires a rototiller for the orchard and growing other produce. While battery-powered cultivators are available, they are limited to 90 minutes of use, and insufficient tilling width and depth. Corded machines are capable of widths and depths upto 18”x7”. In combination with a 50-foot extension cord, this option is recommended with a reasonable upfront cost of $200. This cultivator is estimated to consume an additional 330 kWh/year.

<u>New Barn:</u> The two most significant new loads in the barn are expected to be space heating and chicken coop heating for laying hens and brooding chicks. Space heating is expected to add the greatest additional energy load to the homestead. Based on occupancy, scheduled usage and a 65-68°F set point, space heating is estimated to contribute 1500 kWh/year of new load.

Heating for chickens via high efficiency IR lamps is expected to add about 840 kWh/year of new load, assuming round the clock heating for brooders in the summer and for layers in the winter. However, this load may be significantly less, as chickens’ own body heat may be sufficient depending on how well the coop and barn envelopes are insulated.

There are two significant sources of uncertainty in the energy demand analysis. The first is the lack of detailed energy load profiles, as this analysis is based on monthly and a limited set of hourly data (collected over 2 weeks), and is currently only being collected for the house. This means that the impact of our energy efficiency recommendations are only qualitative, and restricts our analysis on how much energy demand and consumption will actually be lowered by these measures. Secondly, the new loads’ estimates are uncertain as they are based on rough projections of their usage schedule. Moreover, some of the new loads may not be implemented as the client continues to evaluate whether they are necessary (like the chicken coop heating). Therefore, estimating the impact of new loads on overall energy demand and consumption was not analyzed. The timing of implementation of the loads presents another uncertainty towards making such a determination.

Addressing these uncertainties motivates follow-on work. Hourly interval data should continue to be collected, and expanded to include all the buildings for which energy efficiency is recommended. New load demand and consumption can be better quantified as their schedules and implementation schedules are clarified. As these requirements become clearer, their impact on the amount of renewable energy and battery storage needed to meet them can be estimated more accurately.

Energy Balance / HOMER Analysis

The purpose of the energy balance analysis is to simulate the operation and performance of the microgrid, and answer questions such as: Will the solar PV produce enough energy to match existing energy demand? How well does the timing of the energy demand match with the availability of solar? During what times of the year and day might there not be enough energy? What size battery will meet the needs of the property overnight? How long could the microgrid operate off the grid?

To accomplish this analysis, we used two primary approaches: first, assessing general seasonal and diurnal trends using an excel spreadsheet model, and second, performing a more robust simulation of performance using the HOMER Grid Software.

For the Excel analysis, we first assessed the annual timescale with a monthly time step in order to identify seasonal energy trends. The solar production data was generated using PV Watts, assuming the installation of Sunpower SPR-X22-360 panels on the tractor canopy. The monthly energy demand data for the house and the farm is based on historical electricity billing data. To estimate the energy consumption of the cold storage, we estimated an annual energy consumption of 12,000 kWh, which is based on extrapolating limited meter data and reviewing several commercial refrigeration websites. We then assumed that monthly energy use would be a linear function of the average outside temperature for each month, with hotter ambient temperatures resulting in higher energy consumption.

We then assessed the daily timescale with an hourly time step for a representative June day (when solar is at its peak) and a representative December day (when solar is at its nadir). Hourly solar production was generated using PVWatts. Since hourly meter data was not available from the local utility, the hourly profiles were estimated. Since we were able to install a home energy monitor on the house circuit panel during the project, we had limited interval data on which to base the house hourly profile, but we also utilized the standard residential and commercial demand profiles suggested by the HOMER software. For cold storage, we estimated the daily demand profile based on a case study of a walk-in freezer optimized for solar production published by Viking Cold Solution. For the daily analysis, we also simulated how long the battery could supply energy if it only charged from the solar. For this, we assumed the power and capacity specifications of the Sunpower Equinox battery.

The main finding of the seasonal energy analysis, included in Appendix 9, is that there will be a large amount of solar overgeneration in the summer months (which will need to be exported to the grid), and there will be a slight undergeneration in the darkest winter months, which will require grid imports.

The main finding of the hourly analysis, included in Appendix 10, was that in the summer months, the solar plus battery storage would allow the system to run completely off grid for extended periods. In the middle of winter, however, if there were a grid outage, the system would only be able to supply energy to critical homestead loads for 15 hours per day.

However, one of the main sources of uncertainty is the magnitude of the cold storage energy demand and the seasonal patterns. Our research was unable to find any reliable data about the annual energy demand or demand profiles of walk-in freezers, and developing a bespoke model was beyond the scope of this analysis, especially since the client had not yet fully determined the specifications of the future cold storage system. Once this system is designed, a more robust estimate could be developed. In addition, the energy demand profiles were based on historical data and did not include adjustments for any of the efficiency recommendations or additions of new load, which were not included due to the uncertainty of the temporal profile of these strategies.

Using HOMER Grid, we performed a more robust analysis of system performance and economics under various assumptions about equipment cost, lifespan, and discount rate. We fixed the solar array size at 22.7 kW, but allowed the simulation to select the number of batteries. For our sensitivity analysis, we evaluated the following parameters:

- Solar cost of $2.83 per watt and $3.60 per watt, which is the range of costs that we have seen for SunPower systems
- Battery lifespan of 10 years and 15 years, which reflects the range of lifespans we have seen for these batteries
- Discount rates of 0%, 2%, and 8%, which represent scenarios for whether the client needs to borrow money to implement the project or not
- Net metering with full retail rate sellback and with 4 cent per kWh sellback
- Four scenarios with a single randomly-occurring 24 hour grid outage per year

The optimal microgrid recommended by HOMER included a single battery and achieved an annual renewable fraction of 86.5%, which represents the amount of time that the system would be operating off-grid. The levelized cost of energy (LCOE) varied widely based on the assumptions:

Scenario	Discount Rate	Battery Life (years)	Solar $/W	Net Metering	LCOE
Best case	0%	15	$2.83	7 cents	9.7 cents
Realistic	2%	10	$3.60	7 cents	13.1 cents
Worst case	8%	10	$3.60	4 cents	21.9 cents

Once the client receives actual cost quotes and has more information about the energy load profiles, this simulation can be run again to determine more accurate costs and system performance.

We also allowed HOMER to choose the solar size and battery quantity to achieve various levels of renewable percentage. This suggests that there are alternate approaches to achieving the same renewable fraction as our recommendation, as well as the costs for trying to achieve higher renewable fractions. These estimates will be sensitive to the load flexibility and energy efficiency outcomes, which we were not able to simulate.

Alternative systems, assuming “realistic” case (2% discount rate, 10 year battery life, $3.60/W solar cost, and full retail net metering):

Renewable %	Solar kW	Battery qty	LCOE	Initial Capital
86.5%	17.2	2	17.5 cents	$49,000
90.0%	20.1	2	16.5 cents	$56,000
93.0%	25.0	2	15.3 cents	$67,000

Recommendations & Conclusions

Phased Approach

We estimate that the total upfront capital required to implement this project is approximately $150,000. While various incentives, described below, will reduce this upfront cost, a significant portion of these incentives come in the form of tax credits, which may take several years to fully recoup. The client has not specified a budget, so it is possible that he does have the capital to implement all of our recommendations at once, but we have also specified a phased approach in case it is necessary to spread the investment over several years. This phased approach is driven mostly by the upcoming sunsetting of the federal investment tax credit for renewable energy projects.

There are three main types of incentives available: state rebates, federal tax incentives, and net metering. At the state level, the Energy Trust of Oregon offers many rebates, incentives, and assistance for implementing energy efficiency and renewable energy projects, but unfortunately they only serve customers of Portland General Electric and Pacific Power, and not customers of any of the rural electric coops. However, Oregon also has a solar + storage rebate of up to $7,500 that is available for all Oregonians. At the federal level, the Investment Tax Credit (ITC) can be claimed for 26% of the capital cost basis of the microgrid. However, the ITC drops to 22% in 2021, and disappears completely in 2022. The project can also claim bonus depreciation in combination with the ITC, which will allow the client to depreciate 100% of the depreciable basis of the project in the first year of the project. The final incentive is net metering, which allows the client to sell excess solar energy back to the grid at the retail rate of electricity. In HREC territory, any excess credit at the end of the year will be credited at the wholesale rate, which is about 4 cents per kWh.

Given the upcoming phase out of the ITC, we recommend that the first phase should build the solar + storage microgrid, which would be followed in subsequent years by investments in efficiency and electrification. While the microgrid might not operate optimally in the first couple of years, it would minimize project cost and allow the system to be tweaked over time.

Phase I: Solar+Storage / Microgrid Controls Recommendations

Given the current structure of the ITC, the group recommends the building out of the solar, storage, and microgrid controllers before any other measures. Specifically, we recommend the purchasing of 63 SunPower X22-360 panels (total capacity of 22.7kW_p). These panels utilize the highest efficiency of commercially available PV panels (22.7%) and allow for the entire system to be constructed on a singular rooftop. Cost estimates for these panels and associated balance of system technologies is approximately $3.60/watt, bringing the PV system cost to $81,720 before credits and incentives. As opposed to providing a range of solar PV panel options at various price points, it is estimated that the price of building out the necessary structural and balance of system components for an additional roof would end up causing a non-economic outcome.

In addition to the solar PV array, we recommend the purchasing of a singular SunPower Equinox battery pack. This 13 kWh/ 6.8kW battery system integrates seamlessly with the recommended solar PV array for simple and user-friendly load management. Additionally, this system has integrated microcontrollers connecting the solar array, battery, inverters/circuit busses, and metered subpanel. The additional cost of this battery, microcontrollers, and balance of system technologies will be approximately $18,280. This system also comes with a preinstalled software and app platform that will store detailed energy production and load demand throughout the whole system. With this level of in-depth knowledge and control of both the loads and production, we can identify the critical loads on the farm circuit to power in islanding mode. Of equal importance is the ability to alter these critical loads throughout certain times of the year.

The client can then also use this detailed energy consumption and generation information to better inform phase II implementations of additional loads and efficiency measures. In addition to informing the second phase of implementation, this software allows for instantaneous visualization of energy data on any smartphone or tablet, allowing David to use the system as an educational device as well. He can demonstrate in real time exactly how much energy they are consuming on site and also how much more or less energy they are producing.

Phase II: Efficiency / Load Flexibility Recommendations

Given that the walk-in freezer represents 67% of the current energy consumption of the homestead, we recommend investing in a more efficient freezer that can significantly reduce this. Meanwhile for the existing unit, Viking Cold Solutions offers a thermal battery that can charge during the day when solar is plentiful, and discharge to the freezer overnight, reducing the grid-source electricity. An initial estimate from the company reveals approximately $230/year in savings for a 100 square foot freezer, which equates to replacing 25% of grid energy with energy from installed solar panels.

Next we recommend investing in energy efficiency for other homestead energy loads, with specific recommendations found in the Energy Demand Analysis section and Appendices 4-7. The client considers farming related activities a priority, therefore energy efficiency in the old barn, lab building and greenhouse should be targeted first.

Consistent with this prioritization, we recommend investing in electrified equipment to replace current fossil-fuel consuming machines as technology becomes available. These include the ATV, rototiller, dehydrator and canning stove, supplemental greenhouse lighting, and new barn space heating. Chicken coop heating should be investigated further to determine whether improved insulation could substitute for heating lamps.

Investing in energy efficiency at the house is the lowest priority identified by the client. The house is also the smallest contributor to the energy consumption footprint of the homestead, and thus energy efficiency measures here would have the lowest impact compared to the rest of the homestead. Specific recommendations can be found in Appendix 7.

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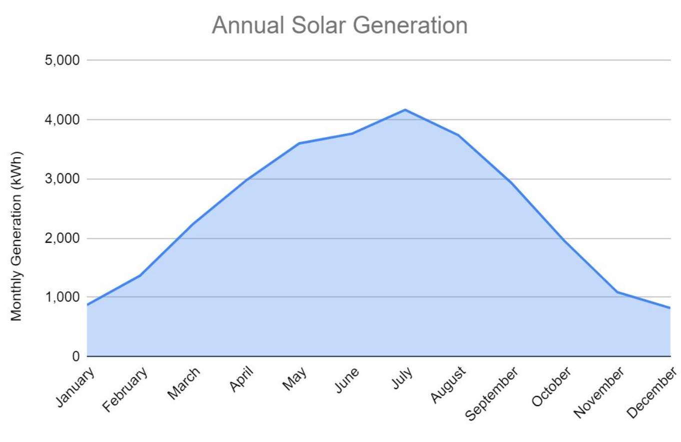
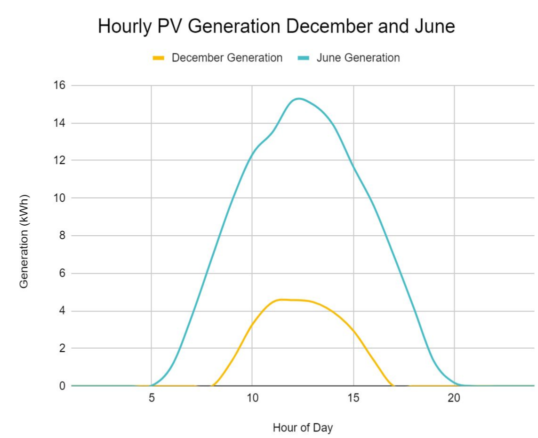
Appendix

Appendix 1: Hydropower potential calculation parameters

Site	Orchard Irrigation Supply	Irrigation Sub-main
Pipe Diameter	6”	12”
Flow Rate	250 GPM	750 GPM
Irrigation Season	May 15 - Sept 15	April 15 - Sept 30
Available head	20 PSI / 14 m	20 PSI / 14 m
Available Power	2.2 kW	6.5 kW
Maximum daily production	52 kWh	156 kWh
Maximum annual production	6,471 kWh	26,458 kWh

Appendix 2: Solar energy daily and annual load profiles





Appendix 3: Breakdown of types of energy used by each building

Building	Electricity	Space Heating	Water Heating
House	Yes	Heating Oil	Electricity
Old Barn	Yes	N/A	N/A
Office/Garage	Yes	Electric	N/A
New Barn	Yes	Electric	N/A
Lab	Yes	Electric	Propane
Greenhouse	Yes	Propane	N/A
Hoop House	No	N/A	N/A
Tractor Shed	No	N/A	N/A

In addition, farm equipment runs on gasoline and diesel, while wind machines run on propane.

Appendix 4: Energy efficiency recommendations for walk-in freezer

Applies to Existing / New Freezer?	Description of Efficiency Measure	Investment Cost
Existing	Cracked door seals should be replaced with magnetic ones to ensure a tight seal	Low
Existing	Switch interior lights to LED lamps	Low
Existing	The large air gap where the refrigerant tube enters the unit should be sealed	Medium
Existing	The gap in the roofing near the freezer exposes it to sunlight and should be sealed	Medium
New	Install interior handle that allows the door to be closed when someone is inside	Low
New	Install interior plastic curtains to minimize heat transfer when the door is open	Medium
New	Install thick/high-R wall panels	Medium
New	Properly size the freezer to meet minimum needs	High

Appendix 5: Energy efficiency recommendations for lab building

Load Type	Description of Efficiency Measure	Investment Cost
Freezer	Defrost and unplug over any long periods where the freezer is not needed for storing samples	Low
Space heater	Make sure the space heaters are placed away from freezer	Low
Lighting	Replace fluorescent lighting with LED lamps	Medium

Appendix 6: New load recommendations for equipment in lab building

Load type	Requirements / Capabilities	Examples	Cost
Dehydration	Electric Approx. 160L carrying capacity Adjustable timer & heat settings	Weston Pro-2400 Model 28-0501-w[1] Cabela's Commercial-Grade Dehydrator[2]	$450 - $550
Canning	Electric coil / induction stove 21 quart capacity Sufficient width for efficient heating	Vollrath 120V, 1800 Watt Countertop Induction Range[3] Zavor PRO Induction Black 15 in. W Non-Stick CookTop 1 Element[4] Cadco Single Burner 1500 Watts Hot Plate[5]	$130 - $350

[1] https://www.meatprocessingproducts.com/west-28-0501-w.html
[2] https://www.cabelas.ca/product/94811/cabelas-160-litre-commercial-grade-food-dehydrator
[3] https://www.grainger.com/product/VOLLRATH-120V-44X019
[4] https://www.homedepot.com/p/Zavor-PRO-Induction-Black-15-in-W-Non-Stick-CookTop-1-Element-124704/306607439
[5] https://www.grainger.com/product/CADCO-12-1-4-x-14-x-4-1-8-1500-Watts-11U510

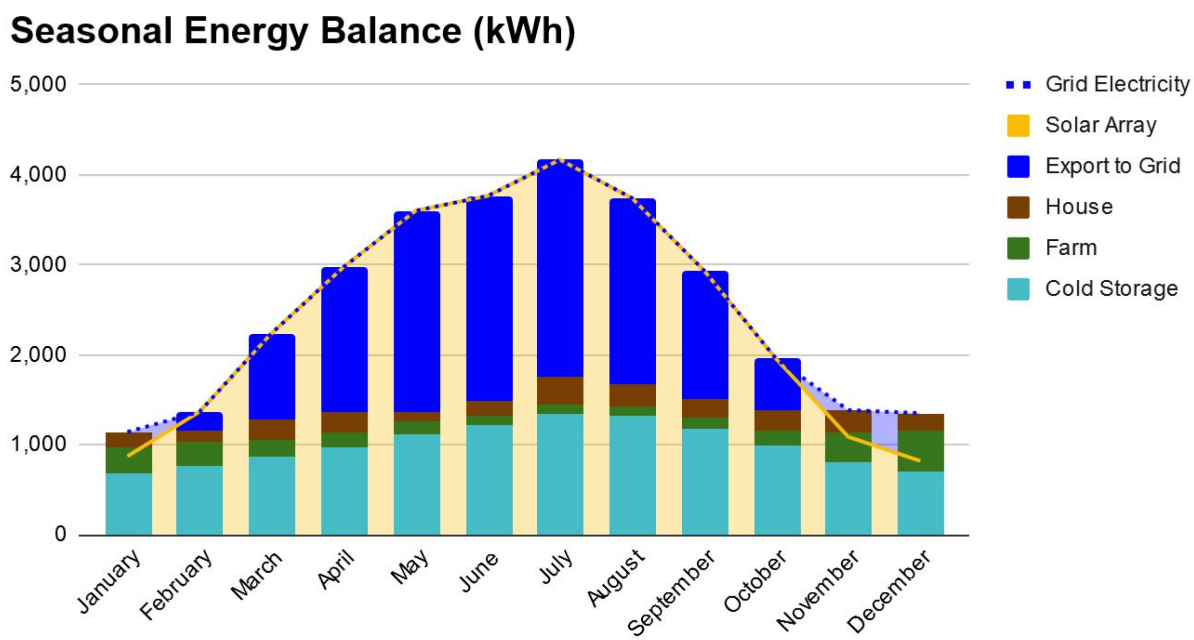
Appendix 7: Energy efficiency recommendations for house

Load Type	Description of Efficiency Measure	Investment Cost
Space heating	Replace windows with modern double or triple-paned ones	High
Water heating	Switch to low flow high pressure showerheads, water efficient dishwashers, and water efficient clothes washers	Medium
Water heating	Replace water heater with one that uses hybrid electric heat-pump design, is ENERGYSTAR certified, has smart controls to maximize available renewable energy, and uses a well-insulated tank capable of providing thermal storage	High
Refrigerator	Replace current 22 year old unit with modern, ENERGYSTAR certified, top-mount refrigerator	High
Oven/Stove	Replace 34 year old unit with modern induction stove	High
Washing machine	Replace 19 year old unit with modern ENERGYSTAR and WaterSense certified machine	High
Clothes dryer	Use line drying	Low
Dishwasher	Replace 15 year old unit with modern ENERGYSTAR and WaterSense certified machine	High

Appendix 8: Energy efficiency recommendations for greenhouse

Load Type	Description of Efficiency Measure	Investment Cost
Ventilation	Install autovent for the roof, and open the door vent during daytime	Medium
Ventilation	Place thermostat at center of greenhouse and at plant height	Low
Ventilation	Replace fan with one that doesn’t draw power when “off”	High
Heating	Place barrels of water under plant trays, at least on south side	Medium
Heating	Use electrically heated mats with thermostat control under plant trays for localized heating	High

Appendix 9: Seasonal energy balance



Appendix 10: Hourly energy balance