EDUCATION SOLAR STATION

Designing a solar array to power an educational field station at Loup Canyon

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UEPP 471 Campus Sustainability Planning Studio
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ACKNOWLEDGEMENTS

We acknowledge that we are on the traditional lands of the sp̓aƛ̓mul̓əxʷəxʷ (Methow) and the sʔukʷnaʔqín (Okanogan) people, bands of the Colville Confederated Tribes, who have lived here since time immemorial. Original territories of the sp̓aƛ̓mul̓əxʷəxʷ people encompass the area in and around the Methow River, while territories of the sʔukʷnaʔqín extend from the mouth of the Okanogan River to the Similkameen Valley in British Columbia, Canada. Both lands were stolen through violent and unjust actions.

The implementation of this project is an opportunity to explore co-stewardship of the Loup Canyon area with the Colville Confederated Tribes. An important aspect of such co-stewardship would be to engage with and keep a consistent communicative relationship with tribal programs who would be using the site, and make sure that their visions and goals for the space are being centered throughout the course of the project.

This project was completed by Western Washington University students participating in the Sustainability Pathways Fellowship program. As a group, we would like to extend our thanks and gratitude to the experts and sponsors that helped us through this project:

Michiel Zuidweg – MZ Solar Contracting
Stacey Mathews – Owner of an off-grid tiny home in the Methow Valley
Joshua Porter – Sustainability Pathways Director, Western Washington University
Emily Davis – Sustainability Pathways Fellow, who provided many photos of Loup Canyon

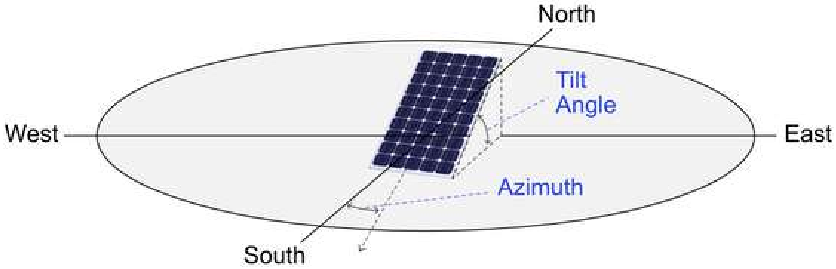
TABLE OF CONTENTS

GLOSSARY

AC – Alternating current, the current flows one way before reaching a peak, hitting zero, and going back, this is a frequency (in USA 60Hz). AC power is used in home appliances.

Amperage – A measurement of current, the number of electrons passing a given point over a measure of time.

Azimuth – The horizontal angle or direction of a compass bearing measured in degrees from North.



Orientation of Solar Panels [Diagram]. Solar Design Guide. https://solardesignguide.com/solar-panel-tilt-and-azimuth/

Battery – A source of voltage; a way to store voltage.

Circuit – A closed system with a load or resistance, a voltage source and a current.

DC – Direct current, used in batteries, the current only flows in one direction.

Energy – Power used or produced over a length of time (Kilowatt Hour, kWh).

Greenhouse Gas – A gas that traps heat inside the atmosphere (carbon dioxide, methane, nitrous oxide, fluorinated gases, plus more).

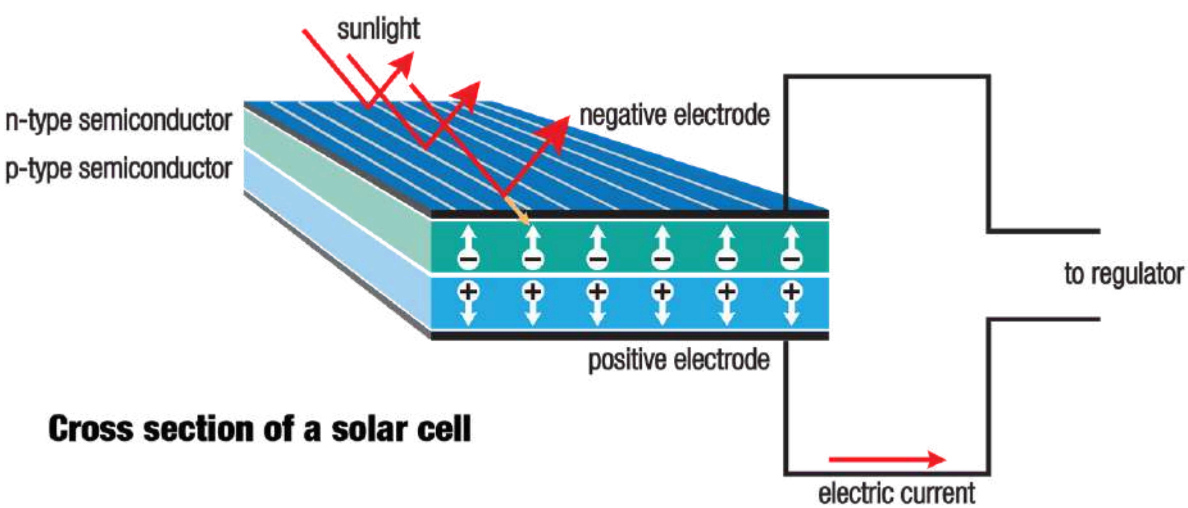
Inverter – Converts the DC power coming from the panels or batteries to AC power that can be used by appliances.

Load – The device or appliance connected to the voltage source; directly related to how much power you need. A general load on the system refers to how much power might be needed to power the system during day-to-day use.

Power – Rate at which energy is used, usually per second (kilowatt, kW).

PV – Stands for photovoltaic, refers to the process of converting light into electricity.

Solar Panel, Solar Cell – A unit composed of a positive electrode, a semi-conductor, a negative electrode and an anti-reflective coating. Photons from the sun hit the panel to create an electrical current that can power a battery. Used to collect power from the sun.



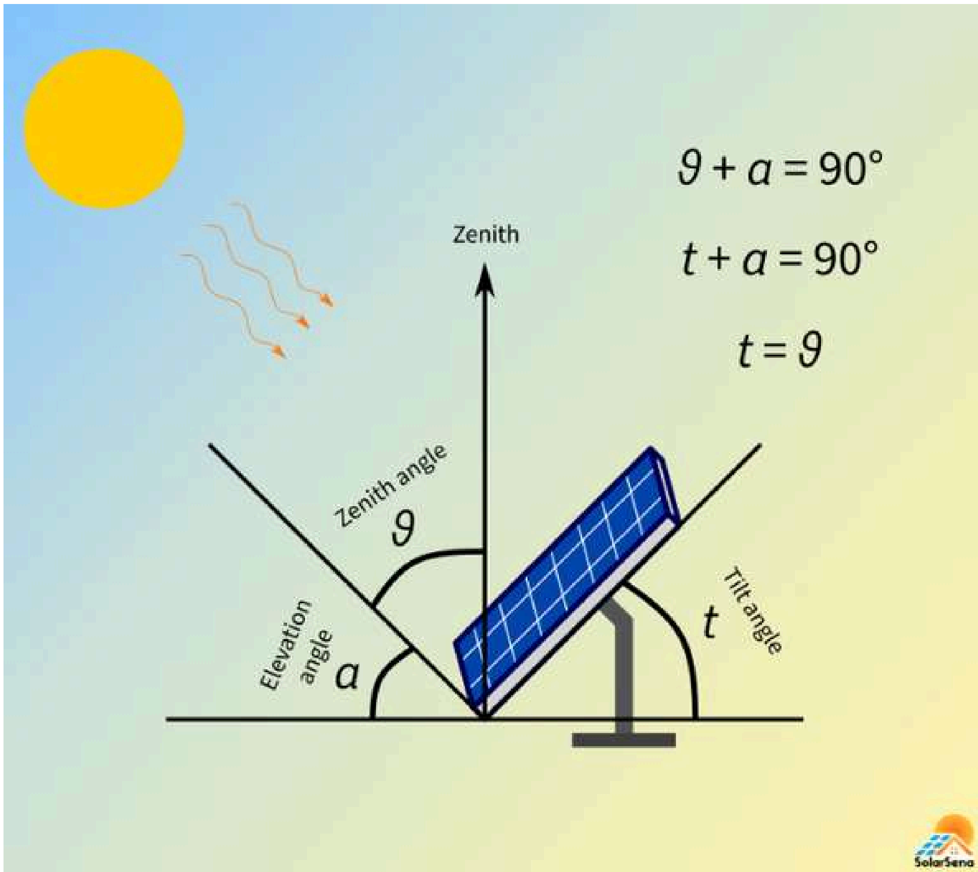
(2010) Cross section of a solar cell [Diagram]. Electrical and Electronics. https://electricalhub.tech.blog/2019/08/12/high-efficiency-solar-cells/

Sustainability – Meeting the needs of current generations without compromising the ability of future generations to meet their own needs. Has ties to many realms such as the environment, social justice, and the economy.

Voltage – The pressure in a circuit that pushes charged electrons through the circuit. Measured in volts (V). Also known as electrical potential difference.

Watts – A measurement of power, or the rate at which energy is used (watt, W).

Zenith – The angle between the sun's rays and the vertical (found using an inclinometer)



(2020) Visual Representation of Zenith in Solar Panels [Diagram]. Solar Sena. https://solarsena.com/solar-elevation-angle-altitude

EXECUTIVE SUMMARY

Previous reports by Sustainability Pathways students have identified the area of Loup Canyon, which is traditionally used by the Methow and Okanogan tribes of the Colville Confederated Tribes, as an important location for educational opportunities related to environmental stewardship and placed-based learning. To have full access to the site, clean water and housing are needed for the students who will use it. This report will serve as the design and basic planning for a mobile solar microgrid that will be used to power a well pump and a tiny home field station.

Increased accessibility to Loup Canyon will provide educational and cultural stewardship opportunities for students at the Okanogan school district, Methow Valley School District, Sustainability Pathways Program, and other youth programs.

The microgrid itself will also be an important part in learning about sustainable energy options, and how off-grid living with sustainable energy can be a point of resilience in the face of climate change, especially for rural communities.

The main goal of this project is to design a solar array that will be fixed on a trailer for easy placement and removal on the site. As four college students with relatively little experience with solar power, we spent a lot of time researching, benchmarking (comparing other existing examples), surveying students about their electricity usage, and consulting with Michiel Zuidweg of MZ Solar, an expert in the field. This led us to the creation of a load profile, ultimately determining our final design of a system with five solar panels, two inverters and two batteries fixed onto a 20 foot trailer.

Our recommendations include an extensive budget to be used by Joshua Porter for construction of the mobile solar power unit, with a cost of around $18,500 – including the trailer. Our timeline for implementation takes the lifespan of the batteries and panels into consideration, as that impacts the overall budget and the importance of considering options for the reuse and recycling of old lithium batteries and solar panels to make our system design more sustainable.

One of the most important aspects of our design is our standard operating procedure. This document will educate and empower the tiny home dwellers by teaching them about their solar power system while also letting them know the specific rules they should follow to maximize power production and system lifespan. We had to make strict decisions about appliances and appliance usage that are important to communicate with future users of this system to be as cost and energy efficient as possible.

(2024) Sustainability Pathways Students at Loup Canyon [Photograph]

INTRODUCTION

According to a greenhouse gas inventory study commissioned for the Methow Valley Climate Action Plan, one of Methow Valley's primary contributors to emissions is the use of fossil fuels for the heating, cooling, and lighting of buildings (Methow Valley Climate Action Plan, 2021, p. 6). As we consider our current climate crisis and how our emissions affect our future, the switch to solar energy is one of many key factors to reduce greenhouse gas emissions and air pollution.

Off-grid infrastructure powered by solar energy is already being implemented within Washington. Okanogan County Electric Cooperative, Inc. is currently working with MZ Solar Consulting and Resilient Methow to upgrade their 20kW solar project and install a microgrid battery project nearby Winthrop's substation, while WWU's student-led Project ZeNETH is creating an off-grid, net-zero energy tiny house on campus. Additionally, our initial background research into solar energy solutions range from an off-grid tiny house in California to a mobile solar-powered water pumping system in Niger. It's clear that solar is a cleaner solution to greenhouse gas emissions that is being used both on a global scale and within our communities.

Further research into solar energy informed us that most solar energy systems have the same basic components: solar panels to capture solar energy and convert to electrical energy, inverters to convert direct current (DC) from solar panels to alternating current (AC) to power appliances, switches and safety measures for the system, batteries to store energy for later use, and appropriate wiring and connectors to tie all necessary parts together. Key factors such as solar panel tilt angle, location, azimuth, and estimates of loads became clear when considering the overall construction of the system.

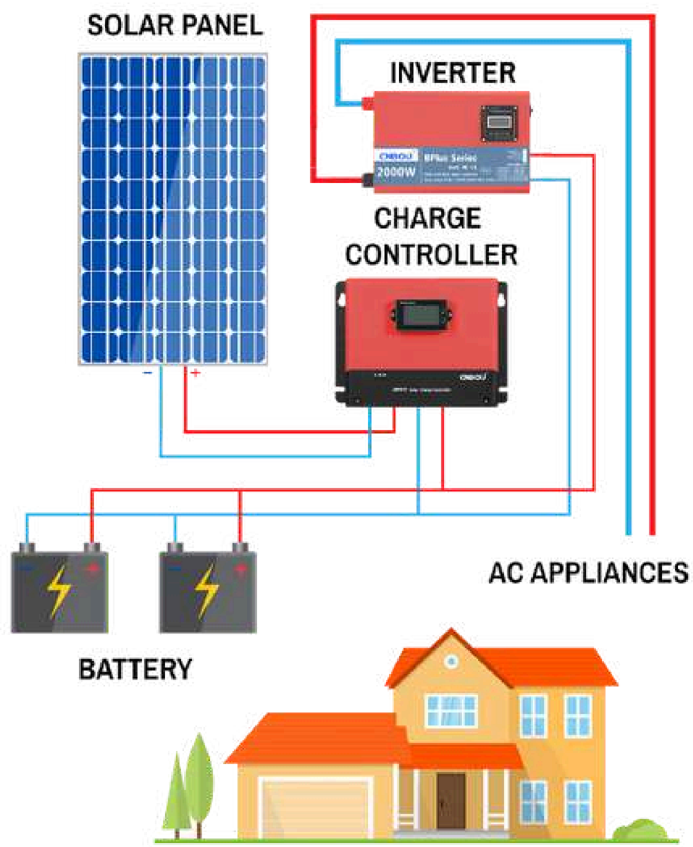


Figure 1 - a basic solar system [Diagram]. CNBOU. https://www.cnbou.com/products/what-do-i-need-for-off-grid-solar.html

STATEMENT OF NEED

The switch to solar starts with local education programs such as the Sustainability Pathways Program, directed by Joshua Porter. In conjunction with local Methow Valley high schools, the program plans to set up an education station within Loup Canyon to promote outdoor education and hands-on stewardship of the site. The ideal station includes an off-grid tiny home for students to reside in while having access to drinkable water from a nearby well. For nine months, excluding winter, students will live, learn and work within Loup Canyon.

Our job as the Mobile Solar Power Unit Team is to provide clean and renewable energy that can provide power for a water pump and multiple tiny home amenities within a reasonable budget. Much of our personal learning and project recommendations come from the experienced Michiel Zuidweg from MZ Solar Consulting. Thanks to his specialization in microgrids and solar infrastructure, we were able to create a design that is based on expert advice.

This project not only provides a cleaner solution than burning fossil fuels and builds resiliency within the valley, but it also gives a learning opportunity for students to learn the basics of living with solar energy. This coincides with the fundamental core of Sustainability Pathways: interdisciplinary ways of creating sustainability using place-based and community-based approaches.

PROJECT GOALS

We are focused on aligning our project to the UN Sustainable Development Goals to be a part of the worldwide call to action for sustainable implementation and prosperity. Specifically, three out of the seventeen goals that our solar project addresses are **affordable clean energy, clean water and sanitation, and quality education.**

This report attempts to create a feasible off-grid solar energy design within the context of an outdoor education station in Loup Canyon, while providing general concepts and ideas that can be applied to anyone wanting to implement a similar design.

Davis. E (2024) Sustainability Youth Corp at Loup Canyon [Photograph]

METHODOLOGY

To give context to our environment and the demands of the project, the team conducted background research on the basics behind solar power. Afterwards, we benchmarked two relevant cases of solar powered homes in the Methow Valley and conducted surveys among current Sustainability Pathways students to anticipate the needed energy usage the system would need to support. For additional guidance we conducted a stakeholder interview with sponsor, Joshua Porter, full interview available in the Appendix.

BENCHMARKING

Benchmarking was a valuable means for research because it allowed us to explore what systems were operating successfully in the North Central Washington geography and climate and modify them for our own application. Benchmarking gave us context for our project and helped us to simultaneously learn about solar array systems and design one. We visited Michiel Zuidweg's standard sized family home as well as Stacey Mathew's off-grid tiny home. Michiel helped us through the benchmarking process by providing us with tours of his home solar system and Stacey's off grid tiny home power system.

Stacey Mathews' solar battery set up.

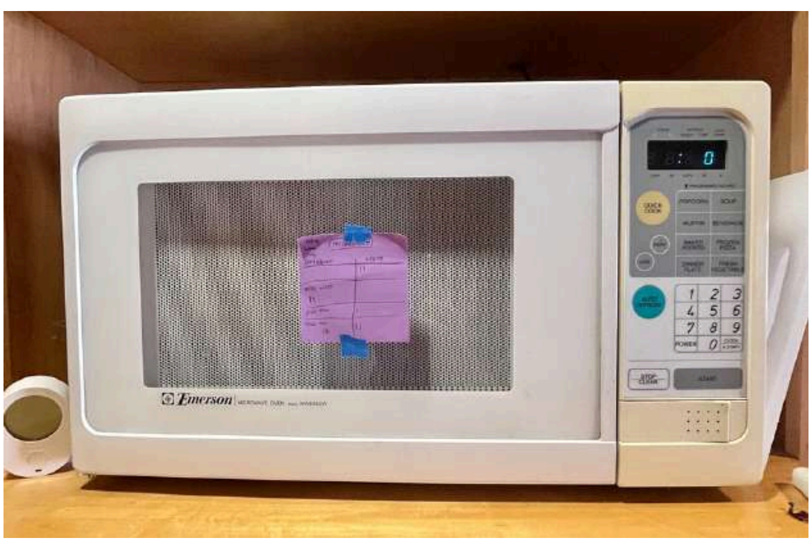
These real-world examples gave us a starting point for load usage estimation, which would dictate exactly how much power the tiny home would require. This also gave us an avenue to explore what it may look like if something goes wrong, to learn from other's mistakes, and to build resiliency for extreme circumstances. Both home visits gave our team the hands-on experience with components of a solar powered system we had not previously had, growing our confidence in understanding.

SURVEY TOOL

Surveying Sustainability Pathways students allowed us to gather specific data related to the load of the tiny home. Our survey polled common appliance use over a week, indicating if use was more likely to occur during daylight hours or night. It is important to make a distinction between daylight and nighttime use because a solar array can replenish the energy stored in batteries during daylight hours but will not be able to during nighttime.

For the survey, we posted sticky notes by each appliance that we wanted to record the use of – stovetop, oven, toaster oven, toaster, fridge, microwave, rice cooker, kettle, fan, and shower. Participants were then asked to mark a tally each time they used the item, either in the daylight or nighttime column. We then averaged the data from twelve students' living patterns across a week to predict the load of 1-2 people. Our system is based off this predicted load, which needed to be accurate and well thought out for the design to best fit the project's needs. Due to this, a follow-up survey was given to participants to understand how accurate their self-reported appliance usage was.

The overall purpose of our survey was to better understand the students who will live in the tiny home so that we could predict how much energy they would use and when they would occur. We used this information to determine the load that our system would need to handle, how much energy our batteries would need to be able to store, and what discharging the batteries throughout the day could look like.



Microwave Survey at home of Sustainability Pathways students.

RESULTS

SITE ANALYSIS

Key Takeaways:

There is a specific site location that will best serve this project (Figure B). Additionally, the solar panels on the mobile solar power unit will be southeast facing.

Trailer Location Rationale:

In July 2024, our team visited the Loup Canyon site. Taking our top four site-related project needs (Figure A) into consideration, a top candidate for trailer location quickly became evident (Figure B).

Need	Influence on Site Location
Power both a well pump and tiny home.	Must be close to well.
Preserve the site as much as possible.	Must utilize previously established roadways.
Provide easy access to backing trailer in.	Must utilize previously established roadways.
Maximize energy production.	Must avoid shaded areas.

Figure A: Site needs.

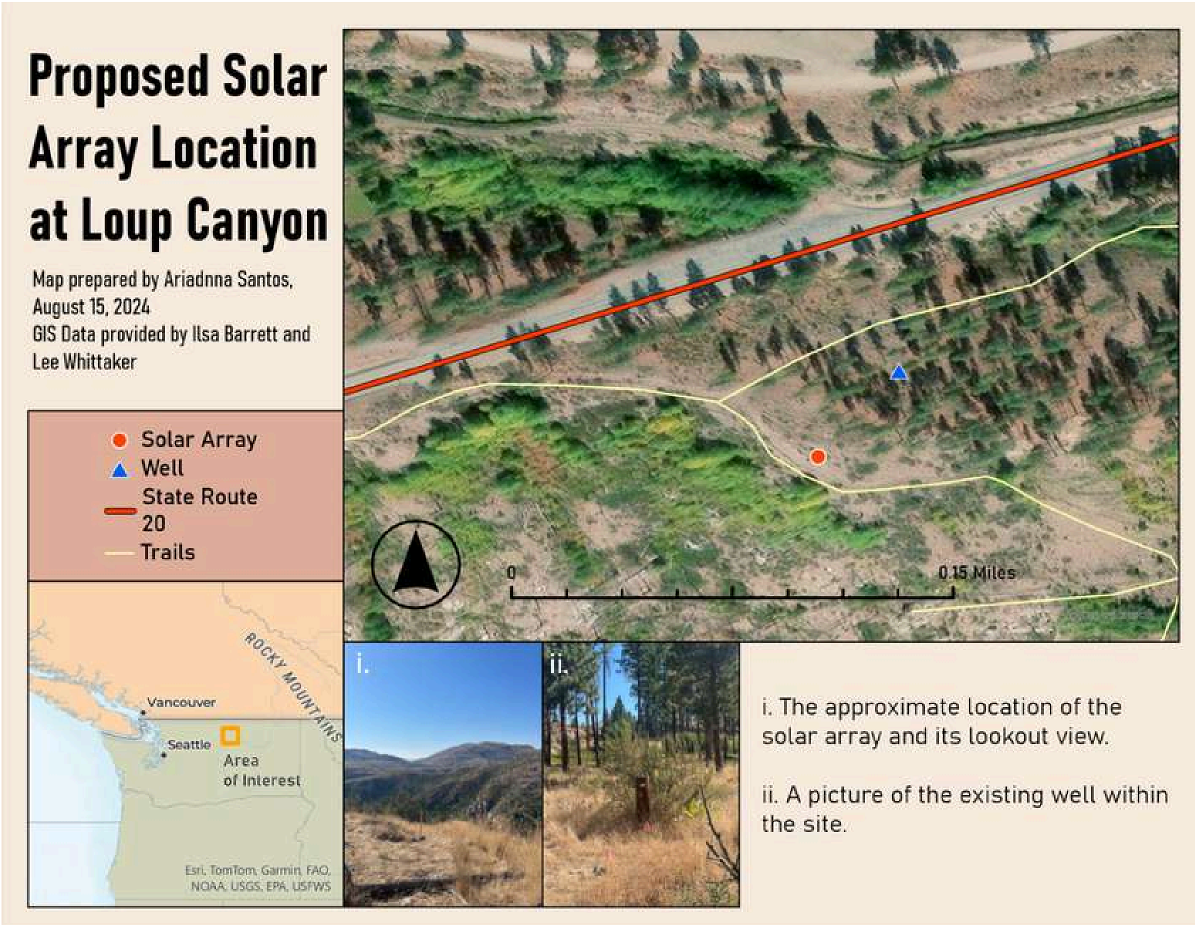


Figure B: Trailer location.

Solar Panel Direction Rationale:
In an ideal system, our panels would be facing south, where they would absorb the most sunlight possible in the northern hemisphere due to the sun's path being in the southern sky. However, given the need to avoid shading from trees and have a reasonable way to bring the trailer on site, our options were to have southeast or southwest facing panels. We determined that collecting the morning sun and storing it in the system's batteries for people's use throughout the day would be more beneficial than collecting most of the energy later in the day. Therefore, the panels will be facing in the southeast direction.

BENCHMARKING

Key Takeaways:
It is reasonable and efficient to design our system based off an existing example in the community. Given the predicted load needs of our use, our system could be half the size of this example.

½ Scale Design Rationale:
In July 2024, we visited Stacey Mathew's 200 square ft. tiny home for two (Figures C and D). This site is applicable to our project because it is an off-grid system used for a similar purpose and a similar sized home. Our conversations with Stacey about her living habits and appliance usage allowed us to compare her system needs with our system needs.

Figure C: From left to right: Stacey Mathews' system, panels, and tiny home.

Figure D: Secondary view of Stacey Mathew's solar power system.

In Stacey's tiny home, there are two people consistently living there year-round who want the option to continue growing while living comfortably. Conversely, our system will be designed to power a temporary home for one to two people to live in on and off, not including the winter months.

These differences, combined with professional advice from Michiel Zuidweg, led us to understand how our model could be based on a scaled-down version of Stacey's system. Details about key components in the mobile solar power unit and how the ½ scale applies are described in Figure E.

Component	Specifications	# Stacey Has	# We Need	Reasoning
Solar panel	~400W, bifacial, monocrystalline	2x 5 in series	1x 5 in series	½ scale applies
Battery	LiFePO4 51.2V100Ah-5120Wh	4	2	½ scale applies
Inverter	5kW Stackable 48V 240VAC 100A 450VDC Off-Grid	2	2	Second inverter allows for system growth

Figure E: Key system components and 1/2 scaling.

LOAD ANALYSIS

Key Takeaways:

There is a set list of appliances that the mobile solar power unit will need to support. Recorded wattage ratings for appliances, frequency of usage, and time of day they were used provide quantitative proof that scaling down a system like Stacey Mathews' to half the size would be sufficient. A load of 8,675 watts represents a generous estimate of power used per day for our tiny home's use.

Appliance List Rationale:

A stakeholder interview with Sustainability Pathways Director Joshua Porter (found in the Appendix) in addition to an interview with Stacey Mathews, who has experience with living in a tiny home, led us to decide on a finalized list of appliances that the system will need to power. We then used a wattmeter to measure the watts that each appliance requires while in use. We also researched into secondary sources for appliances that we were not able to directly measure ourselves, such as the mini split and water heater. The appliances and the corresponding amount of power required in watts are described in Figures F and G. Note that some appliances, such as fridges, cycle on and off. Due to this, we researched into the average "running power" required for this appliance, instead of the full amount of power required each time the fridge cycles on.

Load Estimate Analysis:

We decided which appliances would reasonably be in use while people were out of the tiny home during the day at school/work/practicum to establish a baseline power need (Figure F). We also decided which appliances could all be used at once (within reason, although representative of a more extreme case than usual) to establish a maximum power need (Figure G).

In typical day-to-day use, this means that the tiny home would need a minimum power supply of 89 watts, and a maximum of 8,675 watts (Figure H). With a scaled down version of Stacey's system, we would have 10,000 watts maximum available to us at any given time if the batteries were fully charged (due to 2 5-kWh batteries).

The maximum estimated typical power use (8,675 watts) is below 10,000 watts, which means our proposed system could support the tiny home and well pump. 8,675W is also close enough to 10,000W that we can ensure that the batteries will most likely be properly discharged (used) in day-to-day use while not fully reaching 0%, which preserves their health.

It is important to note that both the low-end range and high-end range of using absolutely every single appliance in the tiny home at once exceeds the 10,000W max that our proposed system could provide (Figure H). While the chances of a tiny-home dweller doing this are very slim, it is possible. Because of this, we developed a standard operating procedure (covered in the Recommendations section) to educate tiny home dwellers how best to utilize the system throughout the day to ensure that they do not run out of power.

APPLIANCE	WATTS
Computer (charging)	200
Phone (charging)	25
Lamp	10
10 gallon water heater (tank)	1500-2500
Mini split heat pump	500-1500
LED ceiling light x 8	80
Merv 13 (HEPA) air filter	32
Box fan	106
Toaster oven	1412
Water kettle	1400
Apartment fridge	52
2 burner induction stovetop	1544
Oven	2000-3000
Rice cooker/pressure cooker	415
Well pump	750
Wifi router	5

Figure F: Baseline power need.

APPLIANCE	WATTS
Computer (charging)	200
Phone (charging)	25
Lamp	10
10 gallon water heater (tank)	1500-2500
Mini split heat pump	500-1500
LED ceiling light x 8	80
Merv 13 (HEPA) air filter	32
Box fan	106
Toaster oven	1412
Water kettle	1400
Apartment fridge	52
2 burner induction stovetop	1544
Oven	2000-3000
Rice cooker/pressure cooker	415
Well pump	750
Wifi router	5

Figure G: Maximum power need.

USE	WATTS
lowest use -- no one home	89
maximum reasonable to use all at once	8,675
all appliances -- low range	10,031
all appliances -- high range	13,031

Figure H: Range of loads required to power the tiny home and pump.

PV WATTS CALCULATOR

Key Takeaways:

Our optimal solar panel tilt angle, or the angle between the ground plane and panel, is 28 degrees. Using this tilt angle, our system is estimated to produce 2,677 kWh/yr. For the months of February through October (9 months in operation), the amount of energy produced will average about 267 kWh/month or 8.91 kWh/day. Note that as the months and thereby the amount of sunlight change, the amount of energy produced will change.

Optimal Panel Angle Rationale:

PV Watts Calculator is a source provided by the National Renewable Energy Laboratory that calculates estimated solar power production given many factors such as system size, panel type, geographic location, and time of year (PV Watts Calculator, 2023). We used this resource to test different panel tilt angles and find the one that gave us the largest kWhs (energy) per year. The optimal panel angle and associated energy production are highlighted in Figure I.

Tilt Angle	kWh/Yr	Feb-Oct kWh
36	2,677	2,396
35	2,679	2,399
34	2,680	2,402
33	2,680	2,403
32	2,681	2,405
31	2,681	2,406
30	2,680	2,406
29	2,679	2,406
28	2,677	2,407
27	2,675	2,406

Figure I: Optimum solar panel tilt angles and their associated energy production.

Figure I highlights the key finding that while a tilt angle of 31 degrees would result in the most kWh/yr produced, a tilt angle of 28 degrees would result in the most kWh produced in the operating months of February through October. Therefore, a panel tilt angle of 28 degrees is suggested for this design, although anywhere from 27-32 could be sufficient.

We recommend that the panels be on a fixed frame, meaning that they are not adjustable throughout the year. This is because given our estimated energy needs and months of operation, fixed panels will generate enough energy for the tiny home and well pump. Creating an adjustable frame is unnecessarily complex, could lead to parts breaking, and could require more parts/increase costs.

Solar Production Monthly Breakdown:
The estimated amount of energy produced per month according to the PV Watts Calculator is shown in Figure J. This data allowed us to calculate an average energy production of 8.91 kWh/day from February through October. The lowest amount will be 148 kWh/month in February, or about 5.23 kWh/day. The highest amount will be 368 kWh/month in July, or about 11.87 kWh/day. Note that this is a very large range – the high is more than double the low. This means that behaviors and habits surrounding power may need to flex with the seasons.

Month	Solar Radiation (kWh / m^2 / day)	AC Energy (kWh)
January	1.81	97
February	3.09	148
March	4.35	225
April	5.79	282
May	6.66	321
June	7.02	325
July	7.88	368
August	6.77	317
September	5.39	250
October	3.41	171
November	1.87	95
December	1.48	79
Annual	4.63	2,678

Figure J: Energy generated by proposed system by month of year, courtesy of https://pvwatts.nreal.gov/.

PV Watts Calculator as Proof of Concept:
We utilized data and observations collected during an onsite analysis of Michiel Zuidweg and Stacey Mathews' respective solar powered homes, as well as appliance usage surveys taken by current Sustainability Pathways students (as described in Methodology and detailed in Appendix) to create an estimate of energy use for each hour of the day.

This energy use is visualized by hour of day and specific appliance in Figure K. Take note that Figure K represents a high-end extreme – where someone is taking a hot shower, using the rice cooker, and using the oven for a long period of time, in addition to many more daily uses.

The main takeaway from Figure K is that there will be a constant draw on the system. As expected, loads increase during the hours someone is inside the tiny home. An appliance to take note of is the oven (medium green) – just using it for one hour makes up the most substantial load placed on the system throughout the day. The water heater (orange) also makes up a substantial portion of the load placed on the system throughout the day.

Appliances such as air filtration (red) and fridge (light green) can be used all day because they require much less energy, thus placing a smaller load on the system.

Figure L details how this visual aid was created – taking things such as time per use, Wh (energy) per use, and times used throughout one day into account for each appliance. The key takeaway from Figure L is that the overall load placed on the system on this day (once again, representing an extreme use case) is 11.038 kWh.

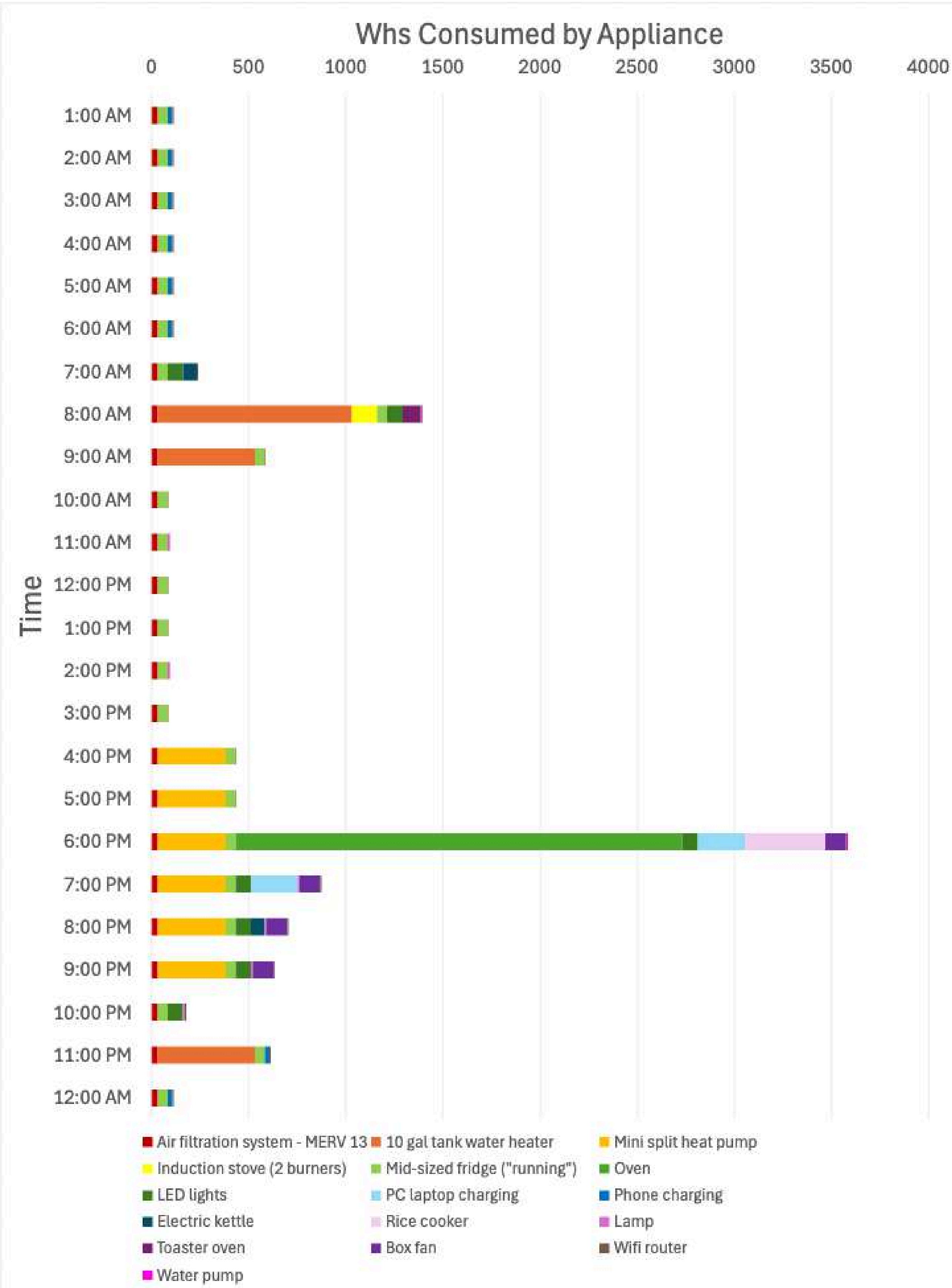


Figure K: Load estimate by appliance and hour of day: representing a high end extreme.

Appliance	**Time per Use (min)**	**Whs per Use (watts x time)**	**Times Used**	**Total Whs in 1 day**	**kWhs**
Air filtration MERV 13	60	32	24 (constant)	768	0.768
10 gal tank water heater	20	666.67	3	2000	2
Mini split	60	350	6	2100	2.1
Induction stove (2 burners)	10	129	1	129	0.129
Mid-sized frige ("running")	60	52	24 (constant)	1248	1.248
Oven	60	2300	1	2300	2.3
LED lights	60	80	7	560	0.56
PC laptop charging	60	240	2	480	0.48
Macbook charging	60	125	0	0	0
Phone charging	60	25	8	200	0.2
Electric kettle	3	70	2	140	0.14
Rice cooker	60	415	1	415	0.415
Lamp	60	10	4	40	0.04
Toaster oven	4	94	1	94	0.094
Box fan	60	106	4	424	0.424
Wifi router	60	5	24 (constant)	120	0.12
Water pump	1.6	5	4	20	0.02
TOTAL				11038	**11.038**

Figure L: Load related data used to create Figure K.

Note that the hypothetical total kWhs required from Figure L (11.038 kWh) exceeds the average production of 8.91 kWh/day. However, if the hypothetical person had not used the oven (the most power demanding appliance), their energy consumption would be reduced to 8.70 kWh. They could then use the stovetop to cook a quick dinner, bringing their total up to 8.83kWh, which is below the average limit of 8.91kWh.

This shows that while the system will be able to support day-to-day use, it will also serve as a learning opportunity for those living in it. Energy is not endless; if tiny home residents are not careful, they will run out.

Months with lower production, like February and October, will require more care from the people living in the tiny home to make sure they do not run out of power. Fan use, air conditioning, and showering could likely be reduced during these months, resulting in a naturally lower load placed on the system.

A SolMan Classic at the Entertaining Abode tiny house [Photograph]. The Tiny Project. https://tiny-project.com/going-solar-in-a-tiny-house/

FINAL DIAGRAM OF SOLAR ARRAY DESIGN

Line Drawing:

Figure M is an electrical line drawing of the final design. Figure N refers to Figure M, detailing which major components are present, how many there are of each component, and how the components work together.

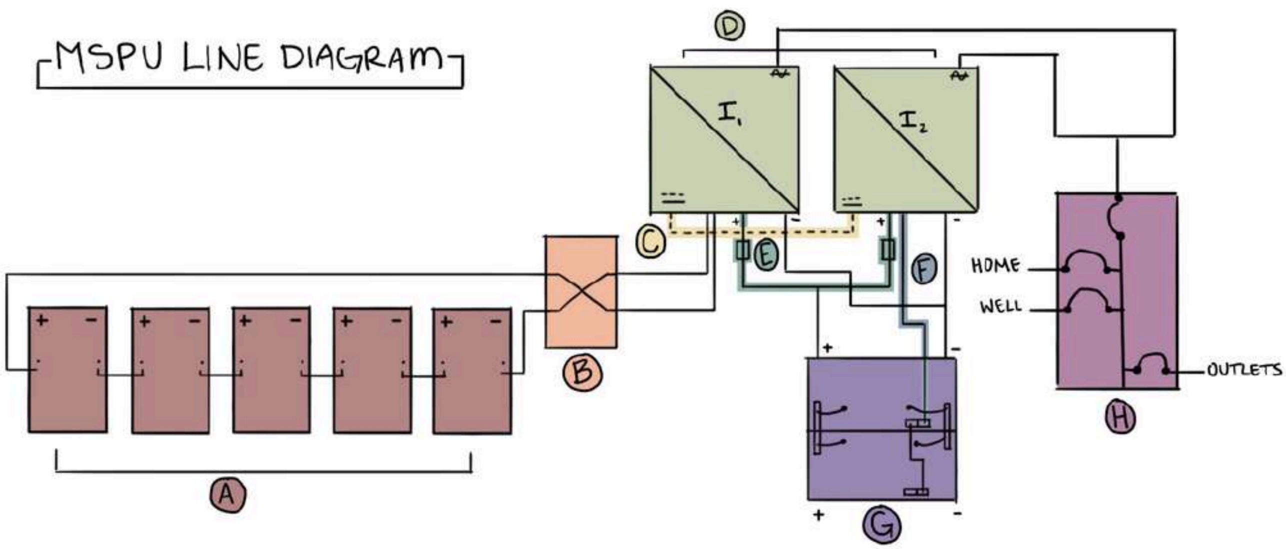


Figure M: Final line drawing of Mobile Solar Power Unit design.

#	Component	Purpose
A	5x ~400W bifacial monocrystalline panels	Collects solar energy
B	DC disconnect	Safety feature to interrupt DC current in emergencies
C	Inverter parallel communication cable	Allows inverters to communicate
D	2x off-grid inverter	Converts AC to DC and DC to AC
E	DC circuit breaker – positive line	Safety feature – detects overload and short circuits
F	Primary inverter -> primary battery communication cable/connect	Gets energy to batteries
G	Battery bank, holds 2x LiFePO4 batteries 51.2V100Ah-5120Wh	Stores energy
H	Electronic switch	Controls flow of electricity to different areas/for different loads

Figure N: Components and component purposes as detailed in Figure M.

Implementation:
Figures M and N can be used in conjunction with our suggested site location, solar panel tilt angle, bill of materials (found in Budget), implementation timeline (found in Recommendations), and the standard operating procedure document (found in Recommendations) to continue into the construction phase of this project. More details on each component's specific type and rating can be found in this report's Budget section.

Please note that this system has two inverters, which means it is designed for potential growth. A second solar panel array can be added to expand the system and allow it to support more loads.

System flow for current use:
Panels → Inverter 1 → loads.

System flow for expanded system:
Panels → Inverter 1 + Inverter 2 → loads.

Construction on solar panel [Photograph] anotoliy_gleb. Adobe Stock

RECOMMENDATIONS

Since this report serves as a design for Joshua Porter to implement for the Sustainability Pathways program, many of our recommendations are about which/how many parts to include in the unit. The rationale behind part type/amount can be found in the Results section, and detailed specifications and amounts for each part can be found in the Budget section.

Note that while our job is not to determine what the tiny house should look like on the inside, the power system that we designed may dictate some of those choices. That said, we have general suggestions for some of the appliances, keeping both the tiny home's needs and projected power usage in mind (Figure N). To check if an appliance can be supported by our solar array, we recommend double-checking the appliance's wattage is like the wattage rating listed in Figure F from the Load Analysis section in Results.

Example Solar Trailer [Photograph]. Transportable Solar Power - https://www.nstsolar.com/trailer-mounted-solar-power-sources/

Appliance	Recommendation
Water heater	10-gallon, tank
Fridge	Apartment sized (10-18 cubic feet)
Well pump	1 HP, 240V

Figure N: tiny home appliance recommendations.

IMPLEMENTATION AND TIMELINE

Implementation:

1. Apply for grants and funding.
2. Purchase and order the parts necessary to build the mobile solar power trailer.
3. Hire a professional technician to do the necessary wiring and technical work of getting the system together in an array.
4. Involve the Career Technical Education program from the Okanogan and Methow Valley School District in the construction of the racking and attaching everything to the trailer.
5. Bring the trailer to the site and have people use it (water pump and eventually tiny home).
6. Gather data via surveys of people who use the well for water and those who live in the tiny home. What's working and not working for them? Plan to work with a solar professional such as Michiel Zuidweg if sizing up the system is necessary (for example, adding a battery).
7. Reflect on the standard operating procedure: is it helping people live in the tiny home more successfully while also educating them about solar? Surveys can be used to gather this information.
8. Continue maintenance and part replacement as the project continues. When there is a system that is settled on as working well, expansions and upgrades can occur.

Timeline:

We hope to see the implementation process occur within the next year. Once sufficient funding is acquired to pay for the parts, the high school students could begin construction on the trailer whenever Joshua Porter and Sustainability Pathways are ready to add the education station to Loup Canyon. From there, people would continue to live in and utilize the system, adding to it if necessary.

Our batteries should last 10 to 15 years if they are charged and discharged regularly. Please note that charging and discharging the batteries is important in supporting the longevity of the system. People utilizing this station will have to monitor battery health and must inform others if current batteries are inefficient and need to be replaced. They can be recycled at a relevant recycling facility. The closest location for this would be the Home Depot in Omak, where lithium batteries can be recycled through their Call2Recycle program.

The panels have a life of about 25 to 30 years if they are cared for properly. When they are no longer providing sufficient power to rely on, they should be replaced. It is still very difficult to recycle solar panels, but there are a few options. They can be recycled at specific facilities (closest to the Methow is in Seattle), reused for things such as electric bikes or car chargers that need less reliable and constant power, or returned to the manufacturer. Hopefully by the time these panels need to be replaced, there will be better options for recycling and reuse.

Davis E. (2024) [Photograph].

STANDARD OPERATING PROCEDURE

During the creation of our load profile, we realized that making concrete decisions about power usage within the tiny home would be the best way to practice sustainability, save money, and educate the tiny home dwellers. This allowed us to scale down our system from Stacey Mathews' example.

To ensure that the tiny home dwellers can live comfortably and not run out of power, some of the appliances in the tiny home will require specific usage patterns, such as the shower/water heater, oven, heat split and appliance charging. The batteries, inverters and panels will also need monitoring and maintenance to continue working most effectively. We condensed these requirements into a standard operating procedure that can be used by the dwellers of the tiny home as a guideline to the mobile solar power system. Hopefully, this document will be a general introduction to how to maintain any off-grid electrical system, an educational experience for those who live there, and a helpful tool to keep the system working efficiently.

Standard Operating Procedure – Solar Powered Tiny Home

Batteries and Inverters:
The inverters come with a screen that shows how much energy is flowing through and being used by the system and how much power the batteries have. Using the WIFI you can download the Growatt ShinePhone app to track how much each appliance is using within the home and use that to determine how much energy is left to use.

Solar Panels:
The panels should have monitoring as they can accumulate dust or wildfire smoke easily, which can significantly improve their efficacy. Checking on them occasionally will be good enough and if you notice a lot of dust, you can simply wipe them with some clean water and a soft rag.

Showers and Water Usage:
The water heater is only 10 gallons, which is just enough for a short shower (5-10min, 10 min maximum). It will also take a lot of power to heat up the water for an entire shower, so make sure you are showing during daylight, preferably in the morning or right when you return for the day. If you must shower at night, be prepared to have it be the last thing you do and to then not have more power until daylight.

Cooking Meals:
If you choose to use a lot of electricity at night, you may not have enough to cook breakfast in the morning. Be smart about when you cook meals and how much you cook at once. You may want to prep a lot during the weekend to have prepared for the week. Or plan to grill/use the camp stove to cook when you don't have as much power.

Charging Appliances:
If you can charge your appliances during the day while you are gone at work that would be ideal so that the batteries can be discharged, and so there is sufficient power to charge them. If you need them during the day charge them when you get home while it is still sunny out, so you don't use up your limited nighttime supply charging devices. Work on charging appliances only as much as you need them and unplugging them once they are done charging.

Mini Split:
It will be best practice to leave the AC on during the day while you are gone so that the batteries are still being exercised. Set it around 72-74 degrees before you leave, and you are welcome to turn it down further when you get home and are using the house. It's always best to check your battery health to make sure that you have enough power to sufficiently cool the home.

MONITORING AND EVALUATION

IMPORTANCE OF MONITORING AND EVALUATION

The success of our project depends on its resiliency towards disturbances and general wear and tear, its efficiency in supporting a tiny home and a water pump, and its accomplishment in teaching residents how to live within an off-grid energy system. Our project for creating an off-grid solar system aids with providing outdoor education and stewardship of Loup Canyon; therefore, the growth of students using the Loup Canyon education station will also factor in project success.

In broader ways of thinking about success, providing an off-grid solar power station can lead to future creation of off-grid housing units that can be provided to the community in case of extreme disturbances such as wildfires, which cause displacement. Not only can it provide a basis for future off-grid housing, it can also be another step towards increasing solar energy usage within Methow Valley. Access to dependable energy is especially important within rural areas where expanding the main grid is not financially feasible. Tracking success within the broader context of the community is important when thinking about the possible impacts we could make as individuals, groups, and organizations working together.

Much of this data can be gleaned with follow-up surveys tailored to students living within the tiny home and educational leaders such as Joshua Porter, who is implementing this project. Below are some example questions that can be asked to monitor the project after its implementation. We recommend doing these surveys once or twice per education program, to track progress and efficiency.

EVALUATION SURVEY QUESTIONS

Possible survey questions for students include the following. We recommend doing these surveys monthly or bimonthly to check in with tiny home residents:

- On a scale of 1-5, with 1 being extremely uncomfortable and 5 being extremely comfortable: how would you rate the experience of living/working here? Any comments or questions?
- How comprehensive and understandable is the standard operating procedure? What things need to be clarified?
- How often did you check the battery life of the system? Solar Panels? Are there any questions/concerns about the longevity of either unit?
- If you checked battery life, how was it done? Did you use the inverter screen/Growatt ShinePhone App/something else?
- On a scale of 1-5, with 1 being no experience and/or knowledge and 5 being plenty of experience and/or knowledge: how would you rate your knowledge about solar energy and its relation to sustainability before you resided here? After you resided here?
- What is the best part of living here? What is the worst part about living here?
- Are there other amenities that would make living here more comfortable?
- Do you think there are limitations to the current system?

Possible survey questions for educational directors and solar panel system implementers include the following. We recommend doing these surveys once every education program to record design success and current progress:

- How easy was it to implement this design? What are some things that were hard during the building process, and what could be clarified?
- How many students initially lived here on this site? How has this number grown after three months? One year? Two years? Five years?
- Would you say this project helped the stewardship and monitoring of Loup Canyon? Are there more students that can work and live on site due to the project?
- Do you think this is a design that can be easily transferred to other off-grid units? Have there been instances where this design has been used elsewhere?
- Has this site been used for other purposes besides being an education station?

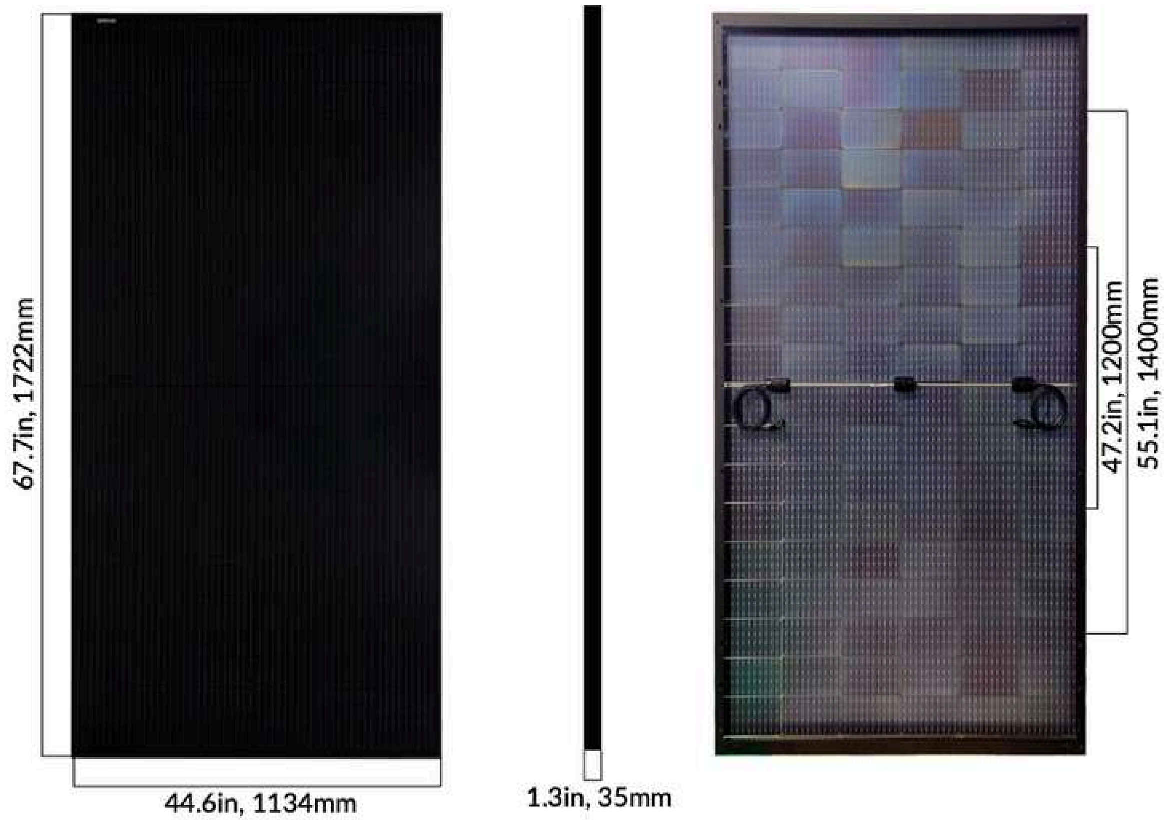
BUDGET

Item	Suggested Product	Suggested Retailer
a.	EG4 LifePower4 Lithium Battery | 48V 100AH | Server Rack Battery | UL1973, UL9540A | 5-Year Warranty	Signature Solar
b.	Battery Racking and Security Subject to Contractor Decision	Local Hardware Suppliers
c.	Flexible Branch Pair | MC4-Style	Signature Solar
d.	Breaker/Load Center Subject to Contractor Decision	Local Hardware Suppliers
e.	Growatt 5kW Stackable Off-Grid Inverter | SPF 5000US | UL 1741	Signature Solar
f.	IMO DC Disconnect Rooftop Isolator Switch | 4 Pole | 2 String	Signature Solar
g	Misc. Electric Components Subject to Contractor Decision	Local Hardware Suppliers
h.	Determined by Retailer	N/A
i.	Aptos 440W Bifacial Solar Panels (Black) | Up to 550W with Bifacial Gain | DNA-120-BF10-440W	Signature Solar
j.	Solar Racking/ Strut Subject to Contractor Decision	Local Suppliers
k.	Growatt 5kW Split Phase Transformer | ATS 5000T-ES	Signature Solar
l.	Wayne Upgraded 1 HP Cast Iron Convertible Well Jet Pump (21-26 GPM Expectation)	Local Hardware Supplier
m.	Subject to Contractor Decision	N/A

Figure O: Product list for mobile solar power station project.

Mobile Solar Power Unit Materials Budget				
Component	Specifications	Budgeted Cost Per Unit	Quantity	Budgeted Cost
a. Battery	5.12 kWh	$1,400	2	$2,800
b. Battery Racking and Security		$500*	1	$500
c. Branch Connector		$13	1	$13
d. Breaker/ Load Center		$500*	1	$500
e. Inverter	5kW Stackable 48V 240VAC 100A 450VDC Off-Grid	$900	2	$1,800
f. Isolator Switch		$90	1	$90
g. Misc. Electric Components		$500*	1	$500
h. Shipping		$500	1	$500
i. Solar Panels	~400W, bifacial, monocrystalline	$380	5	$1,900
j. Solar Racking/ Strut		$1000*	1	$1,000
k. Transformer	5kW Split Phase	$329	1	$329
l. Waterpump	1 HP	$500	1	$500
m. Trailer	20 feet (panels 44.6 inches wide x 5), flatbed, 2 axels	$4,000	1	$4,000
n. Labor	electrcian for 8 hrs a day, 3 days	$3,000	1	$3,000
Subtotal				$17,432
Contingency (7%)				$1,220.24
Total				$18,652
*estimated placeholder cost				

Figure P: Budget for mobile solar power unit project.



Suggested Product i. Aptos 440W Bifacial Solar Panel Measurements, courtesy of signaturesolar.com

Stacey Mathew's double inverter system that is to be utilized in our system

GRANTS, REBATES AND INCENTIVES

Renew America's School Grant – funds upgrades at K-12 schools, specifically in high-need communities, recipients often have about 4 different upgrades planned

Solar Deployment Grant Program – funds the deployment of solar projects in WA that will deliver environmental/economic developments

Rural Clean Energy Innovation – supports and funds research and implementation of clean energy to rural communities in Washington

Outdoor Learning Grants Program - funds outdoor educational experiences for students in Washington public schools

Solar System Energy Sales Tax Incentives – a Washington sales tax exemption for purchasing machinery, equipment and installation of solar energy

Federal Solar Investment Tax Credit – federal tax credit worth 30% of your total solar expenses

E. Davis, [Photograph] (2024)

UNITED NATIONS SUSTAINABLE DEVELOPMENT GOALS

The solar array, tiny home and water pump will create accessibility to the Loup Canyon site by allowing more educational, research and restoration projects to happen. Our design and the opportunities it provides are closely linked to three of the United Nation's Sustainable Development Goals (SDGs), connecting us to the worldwide call for a more sustainable future. The goals are markers created as indicators of global sustainability. Actions that fall under these goals or meet the targets can have wide-reaching implications on a global scale or can simply impact a smaller community. The three goals and associated targets that align most closely with our project are as follows:

SDG 7: **Affordable and Clean Energy** – Ensure access to affordable, reliable, sustainable and modern energy for all.

- 7.3 - Increase the share of renewable energy in the global energy mix.
- 7.a - Enhance international collaboration to facilitate access to clean energy research and technology, including renewable energy, energy efficiency and advanced and cleaner fossil-fuel technology, and promote investment in energy infrastructure and clean energy technology.

Our mobile power system is designed with solar power which is one of the most accessible and affordable forms of renewable energy available to the average homeowner. Our system will provide reliable renewable power to future tiny home residents. Our system will also educate tiny home residents on solar power while allowing them to experience what it would be like to live off-grid using sustainable energy sources.

***SDG 6*: Clean Water and Sanitation** – Ensure availability and sustainable management of clean water and sanitation for all.

- 6.1 - Achieve universal and equitable access to safe and affordable drinking water for all.

The baseline goal for this project is to power a well water pump at the top of Loup Canyon to be used by students working there This will provide access to clean and potable water within Loup Canyon. The solar powered pump will pull clean water out of the preexisting well, which will be more accessible for students than their current option of filtering water from the stream at the bottom of the canyon.

***SDG 4*: Quality Education** – Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all.

- 4.3 - Ensure equal access for all women and men to affordable and quality technical, vocational and tertiary education, including university.
- 4.4 - Substantially increase the number of youth and adults who have relevant skills, including technical and vocational skills, for employment, decent jobs and entrepreneurship.
- 4.7 - Ensure that all learners acquire the knowledge and skills needed to promote sustainable development, including, among others, through education for sustainable development and sustainable lifestyles, human rights, gender equality, promotion of a culture of peace and non-violence, global citizenship and appreciation of cultural diversity and of culture's contribution to sustainable development.

The Loup Canyon site will serve as an educational tool for the Okanogan School District, Methow Valley School District, and the Sustainability Pathways Program. The increased access that the water pump and tiny home will provide will allow more class groups to visit the site and use it as a real-world example of ecological restoration, maintenance and monitoring of a solar power system, trail work and environmental stewardship.

LARGER THEMES AND SYSTEM THINKING

This solar power project incorporates global sustainability goals by making a hard-to-reach natural area accessible to more people for educational purposes. It will provide exposure to different facets of sustainability, empowering more students to enter sustainability fields.

The solar power system can also be used to power a tiny home, which over time will cost less money than other housing options in the valley. The Sustainability Pathways Program works hard to remove the cost of rent as a barrier to student participation. If the amount the program must pay to house its students decreases, the program may take on more students.

At its core, our mobile solar power unit project is an example of how off-grid sustainable power systems can support resiliency within communities, especially ones susceptible to natural disasters such as the Methow and Okanogan Valleys. As climate change continues to increase, the rate of fires in North Central Washington will also increase. Fire in the summer and heavy snow in the winter are common causes of power outages in grid systems. Our solar power system is connected to its own personal grid, allowing it to continue functioning in the face of a grid power outage. This builds up climate resiliency in communities and allows them to continue to thrive in the face of increased natural disasters due to global warming.

Campbell, T. Flames from a controlled burn [photograph], Adobe Stock

CONCLUSION

The main goal of this project was to design a solar array that would provide improved access to the Loup Canyon education site in the Methow Valley. This solar array can be used to power both a pump, which provides access to potable water, and a tiny home which doubles as a field station/education station for work and learning in the canyon. Our array will have five panels, two inverters and two batteries. The array will be located on a 20-foot trailer so that it can be taken to and from the site as needed as an extra safety measure for the system.

The longevity of the batteries and panels is especially important to us when keeping the sustainability of the system in mind. To maintain the health of the batteries, they will need to be charged and discharged (used) regularly. This will be important for students living in the house to know, as they will be the ones monitoring it. Additionally, the standard operating procedure will be important in teaching tiny home dwellers how to maintain and measure longevity and sustainability. During the winter when the solar array is not being used, the trailer will be stored in another facility. Storage for the trailer during the winter months is not ideal for battery life but will prevent vandalism and overall damage to the system due to weathering and cold temperatures.

Our overall budget for this design, which aims to be both user and budget friendly, comes to $18,652. This total includes shipping costs, a 7% contingency and an estimate of labor costs for an electrician for the final assembly. In our research, we also found a few grants that could be particularly helpful in paying for the cost of this system. Three such grants include: the Solar Deployment Grant Program, the Rural Clean Energy Innovation grant, and the Outdoor Learning Grant Program.

Methods such as conducting a stakeholder interview, closely consulting with Michiel Zuidweg of MZ Solar, benchmarking two similar systems, performing site analysis, and creating a detailed load profile with survey input were essential to our design process. This report, which details those methods, can serve as a resource for those who plan to create their own off-grid renewable energy system. Load profiles will differ from home to home, but the overall steps and methodology would be beneficial to do no matter the situation.

We encourage high school CTE programs and other programs interested in solar to engage with construction of solar arrays. Our consultation with Michiel Zuidweg helped us realize that we did not have to understand every detail about solar energy to be able to design a system that met our needs. The fact that our team of four people with limited background in solar energy was able to come up with this design in under ten weeks can inspire others to learn about and be interested in solar energy/renewables, instead of seeing it as a scary or exclusive discipline.

Solar team visiting with Stacey Mathew. Photo courtesy of Michiel Zuidweg

APPENDIX

APPENDIX A: Stakeholder Interview with Joshua Porter – Research Associate & Director of Sustainability Pathways

During the initial research process and familiarization, we conducted a stakeholder interview with Joshua Porter, the main sponsor of the mobile solar power unit. He has a unique vision for the future of students at Loup Canyon and how they will utilize the space. Here were the most useful answers we gathered from our interview with him.

How do you wish to see the Loup Canyon site being used in 5 years? 10? 50? Who do you see maintaining the site and tiny home?

- Currently- 2 high schools use the space, Omak high school 1 day per year, the sustainability youth corps, and WWU Sustainability Pathways
- In five years – increase the number of groups that use it and increase the number of days by double. Have a number of ways for sustainability and engagement with the space. Water access, bathrooms. Shelters for disturbances, gathering, camping. Maintenance over 5 years: gaining a clear partnership with Colville Confederated Tribe for co-stewardship of the property. Future full-time WWU Sustainability Pathways staff member in charge of maintenance, contract locally if needed.
- 10 years – Double group space again, more structures. Deeper engagement, specifically for tribal programs. Goal of collaboration with Colville Confederated Tribes for co-stewardship. Up to a full-time staff person to operate and maintain the mobile solar panels.

How do you feel about a tank vs tankless water heating system? Michiel and Stacey recommend propane for this, how would you feel about that? The main draw of the water heater would be the shower; how luxury do you envision this being?

- We were hoping for a smaller tank, but electric.
- In the end if there is an appliance that tips the scale, we could do without it.
- I would rather not do propane. Filling it, having natural gas; being more renewable and safer would be ideal. Having students being able to use it for 8 months is ideal, however scaling is mobile.
- Having a grill outside works. We could do propane for that. As an "emergency" option, not the go-to.
- On-demand water pump does not work well. The team was thinking that 5 gallons would work, but it would require that students living in the tiny home would do 5 minutes showers. The team is able to make suggestions to students for how to live within a solar-powered tiny home system. There are ideas for possible doing an outdoor shower or using a Coleman camp stove.

In an ideal world where anything is possible, what do you hope to achieve with this project?

- Increasing access to Loup Canyon for all sorts of youth and student groups. Potable water. Some sort of student housing. Tiny home enables student housing or field office capabilities.
- Prototype/model for mobile microgrid that can power other tiny homes, not just in education.

Will one or two students be living in the tiny home? What will their days look like while they are living there? Will any other students be camping nearby for field work at times?

- It could be anyone living in a tiny home. This tiny home is not only for field work students.
- Maximum would be two students. If we are looking at 8-9 months use (not in winter), they would mostly be working four days a week and not be around the tiny house a lot, and possibly one weekday where they are around the house. Evenings, weekends, mornings are where most use would be.
- We could factor in the occasional guest for our design.
- If there is a significant difference between one or two students, we could make the recommendation to do either or.
- Our trailer is probably half of eONE square footage.

APPENDIX B: Results from Methodology Survey

Average of all Households/person/day	Day	Night	Total
Stovetop	0.753968254	0.082539683	0.836507937
Oven	0.097619048	0.052380952	0.15
Toaster Oven	0.420634921	0.074603175	0.495238095
Toaster	0.095238095	0	0.095238095
Fridge/Freezer	1.678571429	0.5	2.178571429
Microwave	0.178571429	0.221428571	0.4
Ricecooker	0.133333333	0.014285714	0.147619048
Kettle	0.504761905	0.042857143	0.547619048
Fan	NA	NA	NA
Shower	0.395238095	0.285714286	0.680952381

Figure Q: Average number of uses for each appliance per person per day over one week.

A key takeaway from the methodology survey is that the average person tends to use less appliances than we first predicted. The highest use appliances are the stovetop, the shower, and the kettle.

However, the survey shows that these appliances were used less than one time per day on average. There are a couple of factors that could have contributed to this. One factor would be underreporting. While this is possible, we did have post survey discussions with all participants to understand where their reporting may have fallen behind/how accurate they thought they were. A second factor could be that the weather was hot at the time the survey was conducted, and most people don't enjoy cooking when it is that hot outside. This most likely led to more "cold" meals like cereal, sandwiches, salads, etc. being prepared. A third factor could be that survey members were very busy with school and work, leading to limited time to cook – once again resulting in meals like cereal, sandwiches, and salads. Note that factors two and three will most likely be present for the people who will be using the mobile solar power unit, so this data could represent them accurately.

We used the values from the Methodology Survey as a baseline, and then overestimated a bit to inform our loads estimation (seen in Results) to provide flexibility within the system.

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