Energy Management System

Deployable Prototype Documentation

Team 04

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Elevator Pitch - We created an energy management system to address the challenges associated with integrating renewable energy to local power distribution.

EXECUTIVE SUMMARY

All sources of energy production have an impact on our air, water, and land, but the magnitude of that impact varies. Because electricity consumes the majority of overall energy consumed in the United States, it accounts for a considerable amount of each individual's environmental footprint. Energy efficiency reduces the amount of fuel consumed to generate power, as well as the amount of greenhouse gases and other air pollutants produced. Renewable energy sources, such as solar, geothermal, and wind, do not contribute to climate change or local air pollution since no fuels are used. Energy storage is an essential component of decarbonization. It is possible to do so by considering the many aspects that influence the system's functioning and its capacity to react to changing energy demand. Despite being the leader in renewable energy generation, California still derives the majority of its power from nonrenewable sources. This implies that energy efficiency and other steps will continue to be required to guarantee that consumers get the most out of their electricity. To address these concerns, we suggested a design concept that mixes solar power with energy generation from local utilities.

The design idea for this project incorporated many technological study parts into various feasible device implementations. We first planned to create a battery management system, but after considering the social problem and aiming to provide a more comprehensive answer, we decided to create something centered on energy management. Our design will be based on a typical Sacramento home, utilizing data from the local power provider, SMUD. Our project will be powered by three different sources: solar power, battery storage, and utility electricity. The objective is to develop a system that can draw power from a regular 110V AC outlet by calculating the most efficient and cost-effective source at any given time.

To efficiently complete the assignment, the team collaborated and agreed on duties and deadlines based on class due dates. The features were divided into five areas by our team: power, monitor panel, green power algorithm, power source switching, and assignments and reports. These features are then subdivided into tasks and subtasks in order to allocate the work among team members in the next weeks and complete the project by the deadline. The work breakdown structure includes assignments and activities from the Fall and Spring semesters to the completion of senior design in May 2022. The project timeline is an important and necessary instrument for properly completing our work. The timeline's goal is to display a visual representation and temporal sequence of which project pieces have previously been finished and which portions must be completed before moving on to the next stages. This offers us a visual representation of which components still need to be repaired and which should be finished first. The milestones on the PERT diagram show the progress of each project component and how it will be created in chronological sequence. These critical timetable components enabled the team to effectively finish the project by the deadline.

Following the selection of a design and a contracting technique, the next stage was to investigate the possible risk associated with each device component. Because this project requires the completion of many components at the same time. We were obliged to create a Risk Matrix Table during the evaluation that illustrated 11 dangers and their possible influence on our project. This may be found on page 21 in the section IV: Risk Assessment, which is explained in depth.

We began the project testing and integration part of the course in the second semester. The project was divided into hardware and software components for each quantifiable measure on the punch list, and a deadline and team of team members were assigned to work on it. For example, the first metric concerning monitoring the smart outlet required numerous activities such as verifying sensor accuracy, timing accuracy, and wireless data transmission. As a visual assistance for understanding the testing breakdown, a timeline graphic was created. This schedule will be updated when the team completes testing, and will include each test ID, description, expected and actual findings, and a pass/fail grade. As part of the verification and validation process, we will test the system's edge cases and boundaries in order to detect bugs and catastrophic flaws and enhance the design. We conducted a market study to acquire a better grasp of the feasibility of our concept. Our market review framework is separated into four sections. The first part, Populations, Demographics, and End Users, concentrates on California customers because the state has the nation's biggest capability for generating electricity from small scale solar power.

To guarantee that our project matched the criteria given in the punch list, we developed and executed a device test strategy that assessed the independent properties of the components and compared quantifiable data to those predicted in the measurable metrics. The general purpose of testing the device is to guarantee that it fulfills the engineering standards and specifications stated by the team at the start of this project. Our prototype was tested for about two months, beginning in early February 2022 and finishing in April 2022. The results of the testing have been organized into two independent tables, one for software and one for hardware, which can be found at the end of the publication in Appendix I and Appendix II. To complete the senior design course, our project was 95 percent complete, with the hardware element completed but the software side of the project requiring a little more time.

ABSTRACT

Climate change is having a significant influence on humanity and is forcing us to reconsider how we use energy. When we burn oil, coal, and gas, we are not just meeting our energy needs; we are also contributing to the current global warming disaster. In order to adapt to this transformation, mankind must shift its energy system away from fossil fuels and toward renewable energy. Renewable energy consumption and storage have issues that must be thoroughly investigated in order to provide a cost-effective and efficient solution. To solve these problems, we designed an energy management system that includes solar panels, lithium iron phosphate batteries, relays, an inverter, voltage and current sensors, and microcontrollers. The system automatically switches between utility and battery power based on the time of day and the state of charge, in accordance with the SMUD electricity tariff plan. We have also completed additional assignments such as a work breakdown structure, market study, and risk assessment to improve the efficiency of our design technique and obtain a better knowledge of the feasibility of our project. Finally, we developed and performed a device test strategy that verifies that all individual project aspects are in accordance with the criteria given in the quantifiable metrics. The device test plan was completed concurrently with the project's full system integration, and all features were determined to be in accordance with the expectations stated at the start of the project.

Keyword Index

Climate Change, Renewable Energy, Non-Renewable Energy, Solar Power, Energy Storage, Energy Management, EMS, Power Distribution, Raspberry Pi, ESP32, Inverter, Relay, Solar Charge Controller, LiFePO4, Automatic power-source Switching

I. INTRODUCTION

A. Societal Problem

Climate change is already having a significant impact on the ecosystems and organisms that live in the Arctic. In addition, its increasing frequency of melting ice sheets and rising sea levels are contributing to global sea level rise. Human activity is responsible for climate change, which occurs when people burn fossil fuels and convert vast areas of land into farmland [1]. Renewable energy does have an environmental impact, although it is not as substantial as utilizing domestic electricity. Renewable energy may also help in the growth of the economy and the creation of jobs in manufacturing installation, and other areas.

Challenges existing when adapting power distribution infrastructure to renewable sources, as peak-demand hours and stability are affected. An example of this is net-zero metering, where consumers sell their excess power back to the grid. While this provides a benefit to the individual household, it forces those without the capability to subsidize new solar panel projects as costs associated with upgrade projects to handle the increased load and technology are included in the base cost [2].

Energy storage is an important area for decarbonization because many renewable energy sources suffer from intermittency. The usage of energy is also not constant and fluctuates based on the demand. This means the storage has to account for the amount of energy that needs storage, rate of charge and discharge, the economics of building and maintaining the system, and respond to changes in demand. Various sources are analyzed such as flywheels, compressed air, thermal, batteries, and pumped hydro. The specific type or combination of storage technology depends on many factors like region or cost. A method of categorizing both problems with renewable integration and the solutions to these problems is explored and can help governments meet their energy storage needs.

Renewable energy is not without drawbacks. Solar power struggles with efficiency, as even under the best conditions only 22% of energy that reaches the panel is converted to usable power [3]. Wind power is also heavily location dependent, with the potential output at a given time being highly unpredictable depending on local weather [4]. Hydroelectric power can cause flooding and is subject to fluctuations due to local conditions such as drought and heavy rain [5].

As of 2019 California was the leader in renewable energy production by overall volume, however 79.7% of power consumption still comes from non-renewable sources such as natural gas and fuel [6]. As consumers rely more heavily on electricity from their home to power their heating, appliances, and electric vehicles, adaptions must be made to existing power infrastructure to handle the increased loads.

B. Design Idea

Solar energy is one of the most plentiful energy sources on the planet, and it is a renewable energy source that can meet your home's power requirements. It is also gaining popularity these days since it may bring substantial advantages to both humans and the environment. Solar energy, unlike certain other kinds of traditional energy generation, does not pollute the air. Solar panels do not contribute to acid rain or greenhouse gas emissions by emitting carbon dioxide. On this world, the sun is the most abundant source of energy. In only one minute, it can generate enough energy to meet the world's electrical demands for a year.

We plan to create an Energy Management system that controls and monitors energy-consuming devices such as heating equipment, fans, and lighting in order to address concerns about energy efficiency, limitations of solar power due to non-peak hour operation, and variable power costs based on Time-of-Day usage rates. The solution we propose will be based on a residence in the Sacramento Area's typical power usage, scaled down for viability within the project's scope. SMUD has given typical power estimates for a Sacramento home as of January 2021 in order to build an adequate and appropriate design. The typical household uses 750 kWh per month or around 25 kWh per day. According to SMUD's energy tariffs are calculated using a Time-of-Day rating method, which means that the cost per kWh rises during peak usage hours. SMUD and other utilities acquire energy from outside sources to fulfill demand during these peak hours, which is typically produced using non-renewable and ecologically unfriendly techniques [7].

C. Work Breakdown Structure

The work breakdown structure shows the organization needed to complete all components of the project (research, design, acquiring supplies, working prototype, field testing, final report, etc) within the time frame allocated. This contains a component-by-component summary of the tasks involved in completing the design. The project is broken down into five main sections, labeled features, each with its own set of tasks and sub tasks, for a total of 35 sub tasks or work packages. The five sections the project tasks have been broken into include: Power Supplied from carbon-efficient sources, Monitor panel and load voltage and current, “Green” Power Algorithm, Power Source Switching, and Course Assignments. This division allowed us to sort and assign different tasks to team members dependent on their skill sets and availability. Furthermore, each task and subtask has been given a time frame for completion. The full table containing the tasks, subtasks, features, person assigned, and time table can be found in Appendix D.

D. Project Timeline

The project timeline is comprised of four primary sections, divided into hardware, software, fall course assignments, and spring course assignments. The objective of this section is to lay out the work that has been completed over the course of the two semesters that encompass senior design. The main body found in section IV is supplemented by Appendix E, which includes both a Gantt chart and PERT diagram. The Gantt chart functions as a visual tool to allow quick reference to the tasks and assignments mentioned in the above section, while the PERT diagram relates these tasks in order of completion, to lay out the critical paths that will lead to the completion of the overall design project within the specified time frame. Furthermore, the tasks have been assigned a team member (or members) who will take primary responsibility for its completion, as well as an estimated time frame in hours that it will take to complete. Milestones for the fall semester in the hardware section included spot welding and soldering the LiFePO4 battery, and wiring all essential components including battery, panel, charge controller, relays, power adapter, inverter, and outlet. Software tasks include writing the majority of the software that will be running on the raspberry pi and esp32 MCU. This includes the module which pulls data from the solar radiation API, data collection from the smart outlet, code to enable wireless transmission of data, and the relay switching algorithm.

E. Risk Assessment

When it comes to building and managing an energy management system, there will be certain risks. The hazards we face stem mostly from the power supply, as we are working with a high voltage (110V), and the biggest concern for our LiFePO4 battery is that it may catch fire. Many of our components, such as the solar panel, Raspberry Pi, and MCU, were quite costly. Our main concern with the solar panel was that it would break, and because it was such a large component, we had to carry it home for most of the time because it didn't fit in the locker allocated to us in class. Another important danger element for us is burning out the MCU and Pi while connecting to other circuits and components.

Furthermore, there is a significant possibility that one or more features may not be completed on time. We'd have to test it with other features if we wanted to make sure some of the functions functioned properly. If we wanted to test switching power between our solar panel and battery pack, for example, we'd need both the hardware and the pi and code to operate properly. Our risk assessment chart has been provided to provide a visual for the reader and to illustrate our context in a legible design. These include the dangers that have been stated and are rated on a scale of one to five in terms of their likelihood of occurring and severity. So many of the risks we face are dangerous, and while some have a minimal chance of occurring, they can have a significant impact on our operation.

F. Problem Statement Revision

Early in the design process of the first semester we decided to shift our focus from a battery management system to energy management, as it better addressed the issues we have researched regarding climate change. Because energy management has more uses and larger client base, it reduces greenhouse gas emissions more than battery management. Many of the renewable energy options we investigated were beyond our project budget’s reach, so focusing on domestic energy management with solar and battery storage was more realistic. While developing our prototype, we realized there were various improvements we might have done to better our idea. This includes connecting a relay to our smart outlet to allow remote toggling of devices and scheduling of energy heavy chores was a wasted opportunity, and one adjustment we can do is to make the system more user pleasant. Another change that would appeal to a wider demographic would be in creating separate energy profiles that appeal to users outside of the demographic served by SMUD. Not all utility customers are on Time-of-Day use plans, so our system in its present state would not be a viable renewable energy solution for them [7]. Finally, a study conducted in Canada found that smart home devices such as our system can cause users to spend more time adjusting and toggling with settings than would be saved if they simply focused on responsible energy use by manually turning off their appliances [8]. By making the project more accessible to less tech-savvy customers the effectiveness of our design would increase and appeal to a wider customer base.

G. Device Test Plan

An essential component of progressing our design from the laboratory prototype to the deployable prototype over the Spring 2022 semester is the device test plan. This section of the report breaks the current device test plan, found in appendix G. of this report, into two sections; hardware and software. The hardware section covers the testing of components including voltage and current sensors, solid state relays, and the accuracy of the solar panels production compared to the expected values calculated by our solar radiation API. The software section focuses on the timing of

our data readouts, including the data from the two sensors, the solar charge controller transmission via RS485 and MQTT, and the main program on the raspberry Pi comparing production to the expected values every 30 minutes.
Furthermore, this section of the report lists the team members each of these tasks are responsible for, as well as a general timeline in which they are expected to be complete.

H. Market Review

By conducting a market review for the viability of our product, we identify a few key factors. This section is broken into four sections, namely, population demographics and end users, competitive environments, feature comparison, and SWOT analysis. We identify the primary demographic of systems such as our as higher income housing, primarily in neighborhoods with large populations of White and Asian homeowners. An important note from this analysis however is that these statistics have been trending down, as technology increases and prices become more affordable, solar has become more affordable to a much wider demographic of potential consumers. From competitive environment we have determined that a viable market near to Sacramento is the Bay Area, where they pay a minimum of 51.4$ more per kWh than the average for the entire United States [9]. Three primary competitors have been identified as well, namely Siemens, Bluesky Energy, and smart home providers such as google nest [10] [11]. By comparing and contrasting the key features and intended users of these products we have identified what makes our project unique, and therefore viable as a standalone product. Finally, the SWOT analysis focuses on analyzing the strengths, weaknesses, opportunities, and threats. Some of the notable findings from this section include the different areas of experience our group members have, including experience in the solar industry.

I. Testing Results

The testing period for our prototype lasted around two months, beginning in early February 2022 and ending in April 2022. Throughout this procedure, team member 2 set out to gather valid and relevant data on each of our self-assigned unique characteristics. We were instructed to reflect on the learned information and testing data and submit it in the second half of this report's Section IX (Deployable Prototype Status). Any adjustments we deemed were necessary to the testing procedure or the prototype itself were noted. The results of the testing have been put into two separate tables, one for software and one for hardware, which may be found in Appendices A and B at the conclusion of the documentation

J. End of Project Documentation

Concluding the research, design, and implementation of the energy management system, the team found that the project and course overall expanded upon the skills we have learned throughout our time at Sacramento State. Sections such as the work breakdown structure and risk assessment were vital components of laying out a foundation with which we could effectively complete the design by the assigned deadlines. The teamwork aspect forced us to grow as a group, learn each other’s skills and areas of interest, and cater to those skills to increase the efficiency with which we built and complete the deployable prototype. We also learned a great deal about time management, as well as how common it is to underestimate the amount of time an objective will take to complete when it is being done for the first time. With the experience and knowledge we have gained over the past two semesters the implementation of a similar type of design by the team could be created more efficiently, as well as be more cost effective.

II. SOCIETAL PROBLEM

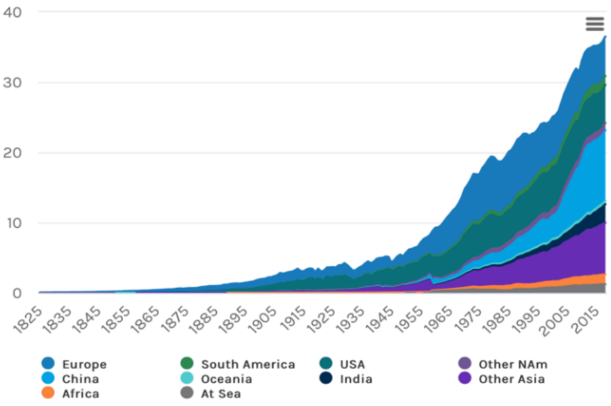
A. *First Semester Interpretation of the Societal Problem*

1) *Energy Sources Relating to Climate Change*

For over a century, burning fossil fuels has provided us with the energy needed to propel our cars and keep our home and business running. Despite the damage they do, coal, oil and gas still provide for the majority of our energy needs. Fossil fuels are produced when fossilized remains of plants and animals are used to make them [1]. But there are a lot of disadvantages that happen while burning fossil fuel that are really bad for the climate.

a) Water Pollution: The growth of coal mining, hydraulic fracturing, and oil and gas production poses various threats to our water supplies. These activities can lead to the release of acidic runoff into streams and wetlands, as well as contaminate water sources. [1]

b) Emission: Long before they are burned fossil fuels create hazardous air pollutants.



Source: Carbon Dioxide Information Analysis Center (CDIAC), Global Carbon Project (GCP)

Figure 1. Carbon Dioxide Output Analysis by Region [12]

The Global Carbon Project noted that fossil-based CO2 emissions have reached 36.6 billion tons in 2018, and in 2019 it reached 37.8 billion tons. Over the past decade, land use change and oceans have absorbed about 9.3 billion tons of CO2 [12].

c) Global Warming: Fossil fuels are responsible for global warming. When they are burned, they contribute to the climate change caused by greenhouse gas emissions.

Fossil fuels are responsible for a wide range of greenhouse gas emissions. These include mercury and sulfur dioxide. When burned, these emissions contribute to the development of air pollution and global warming.[1]

Nuclear energy has been used as a clean energy source. However, it is not a clean energy source and its environmental impacts are significant. Nuclear power plants do not release greenhouse gases when in operation. During its lifecycle, nuclear emissions are equivalent to that of wind and solar energy.

Nuclear power facilities emit no greenhouse gases when in operation, and throughout the length of its lifecycle, nuclear emits around the same amount of carbon dioxide-equivalent emissions per unit of energy as wind, and one-third of the emissions per unit of the emissions per unit of electricity as solar.

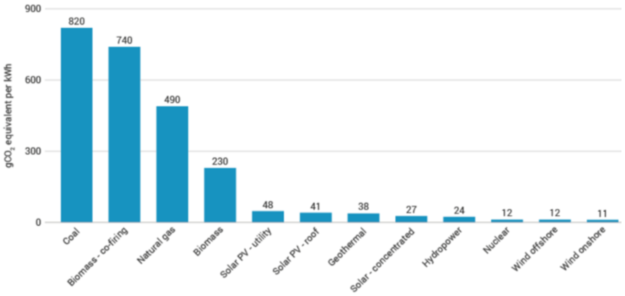


Figure 2. Average life-cycle carbon dioxide-equivalent emissions for different electricity generators [13]

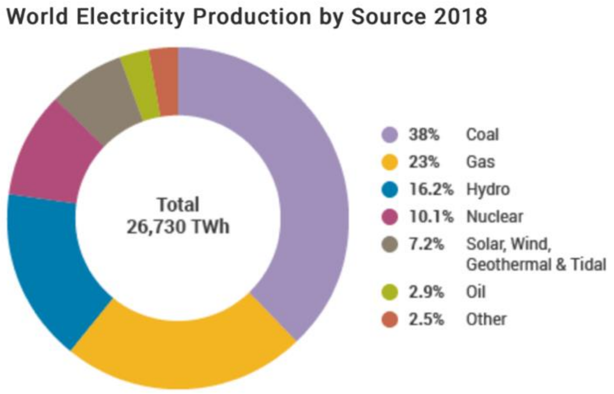


Figure 3. World Electricity Production by Source [14]

As we can see in 2018, nuclear power plants produced around 10% of global electricity, however this does not take into account the hazards involved. France obtains almost three-quarters of its power from nuclear, Slovakia and Ukraine get more than half, while Hungary, Belgium, Finland, and the Czech Republic get on-third or more. South Korea typically gets more than 30 percent of its power from nuclear, whereas the United States, United Kingdom, Spain, Romania, and Russia get approximately one-fifth of their electricity from nuclear [14].

After that, we must understand that nuclear energy has a variety of negative impacts on the environment that are unique from those conventional energy sources. Following a catastrophic earthquake, nuclear power plants discharge radioactive material, which can have serious environmental implications. High-level radioactive spent fuel and low to intermediate-level radioactive waste are released. A contemporary nuclear reactor generates around 1,050 cubic feet of compacted waste each year, but a 1000-megawatt coal plant emits approximately 24,250 tons of nitrous oxides and 48,500 tons of sulfur oxides into the environment each year [15].

Renewable energy is one of the finest kinds of energy to utilize since it has the least amount of impact on the environment. This is due to the fact that renewable energy sources such as solar and wind do not generate carbon dioxide or other greenhouse gases that contribute to global warming. The expanding industry provides jobs, strengthens the electric infrastructure, increases energy access in emerging nations, and lowers energy prices. All of these elements have contributed to a recent renewable energy revolution, with wind and solar establishing we power output records.

Renewable energy sources, such as wind, hydropower, and solar do nevertheless have environmental consequences, some of which are considerable. The precise nature and severity of environmental consequences vary depending on the technology employed, the geographic region, and a variety of other factors. By understanding the present and prospective environmental concerns connected with each renewable energy source, we can take efforts to avoid or mitigate these consequences as they become a bigger component of our power supply.

One of the renewable powers if wind. Wind energy is one of the cleanest and most sustainable ways to generate electricity since it creates no harmful pollutants or contributes to global warming. Wind is also abundant, limitless, and inexpensive, making it a viable and large-scale alternative to fossil fuels. The way wind energy works is that wind turbines utilize blades to gather the kinetic energy of the wind. Wind blows over the blades, producing life and causing the blades to revolve. The blades are linked to a driving shaft, which drives an electric generator, which generates energy.

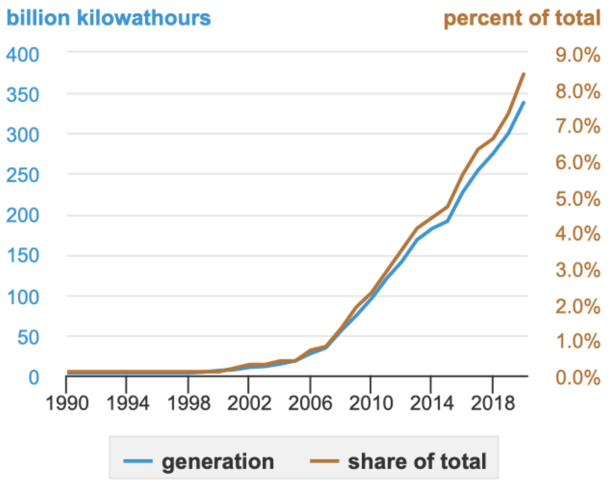


Figure 4. Wind Production by Share of Total Production for the United States [16]

Wind energy generation has increased considerably during the last 30 years. Wind energy technological advancements have reduced the cost of producing power from wind. Total annual wind energy output in the United States rose from around 6 billion Kilowatt-hours in 2000 to approximately 338 billion kWh in 2020 [16].

Despite its great potential, wind power generation has a number of environmental effects that should be acknowledged and managed. They include concerns with land use as well as threats to wildlife and habitat. Wind turbines generate electricity but also alter the atmospheric flow," says Lee Miller. "Those effects redistribute heat and moisture in the atmosphere, which impacts climate.” [17].

The blades of a wind turbine are quite big and revolve at tremendous speeds. Unfortunately, their blades may injure or kill animals who fly into them, such as birds. These fatalities may lead to species population reductions.
A few wind turbines have caught fire, and several have spilled lubricating fluids, although these are uncommon incidents. However, technical improvements and properly located wind farms can help to alleviate some of these issues [18].

The most important and extensively utilized renewable energy source is hydropower. Hydropower accounts for around 17% of overall electricity output. Other renewable energy sources used by industries include wood, municipal waste, landfill gas, biomass, and geothermal energy. China is now the biggest hydroelectricity generator, followed by Canada, Brazil, and The United States [5]. Approximately two-thirds of the hydropower economic potential has yet to be realized. Latin American, Central Africa, India, and China still have an abundance of untapped hydro resources. Although hydropower may create energy without producing greenhouse gases, it can also pose environmental and societal risks, such as destroyed wildlife habitat and impaired water quality.

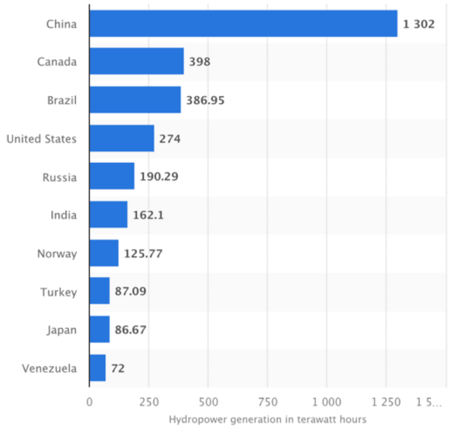


Figure 5. Hydropower Generation by Country [19]

Hydroelectric power is not perfect, as there are some existing significant disadvantages [5]. While hydropower is non-polluting, it does have environmental consequences. Hydropower facilities can have an impact on land usage, housing, and natural ecosystems around dams. Reservoirs can engulf people’s houses, natural regions, agricultural land, and archaeological sites. Reservoir construction in the United State is “drying up.” Surface reservoir development has slowed significantly in recent years. Building a dam and reservoir to provide hydroelectric power requires a significant investment in terms of money, time, and construction, and the majority of ideal locations for locating hydro facilities have already been taken. Hydroelectricity is hydrologic in nature. The system is dependent on precipitation amounts, which might vary from year to year, producing instabilities. Hydroelectricity can harm wildlife habitat in some situations. Hydroelectric power facilities can affect the loss or alteration of fish habitat, resulting in fish entrapment and passage restrictions. In rare situations, hydroelectricity can alter the quality of reservoir and steam water. The operation of a hydroelectric power plant may cause changes in the temperature and flow of the river. These alterations have the potential to damage native plants and animals in the river and on land.

2) *Issues with Power Delivery*

Before the prevalence of self-generated power supplies transmission grids were designed to handle peak load times, with customers taking their power almost entirely from centralized power stations. This allowed a passive system with little to no need for real-time delivery management. With the goal of transferring to a system less dependent on non-renewable and carbon-based fuels, it is important to consider the evolving demands of the market [20]. Countries such as Spain and states in the U.S in locations with climates favorable to renewable energy are adapting to new grid technologies to handle increased appliance load and the prevalence of two-way energy flow from consumers selling excess power back to the grid [12]. However, concerns have been raised over the unintended consequences they can introduce. For example, California and New York have employed regulatory policies to encourage growth in solar power, such as net-zero metering. This policy allows consumers to sell the surplus power they generate back to the grid and provides additional subsidies for the installation of solar panels. According to Henderson et al., these policies force customers who do not have solar power to subsidize those who do, due to the necessitated expansion and increased maintenance costs of the distribution system, which is included in the base cost to consumers. Conversely, states such as Nevada and Florida have introduced policies reducing incentives and requiring consumers to pay additional fees to install new solar panels, in an effort to offset this cost [2]. Another major concern when adapting to new sources and technologies is in maintaining grid reliability. Distributed Energy Resources (DERs) including solar, wind, and battery storage offer the capability of a more efficient and controllable power grid; however, some sources question the ability of currently employed technologies to handle these changes, as well as economic and commercial challenges [20]. Distributed energy resource management systems (DERMS) are one proposed solution to this issue, placing a heavy focus on interconnected sources and consumers, managed by a central processing facility. Some of the features integrated into these systems include high voltage controls and voltage fluctuation management [21].

3) *Availability of Sources*

The sun provides the majority of our energy. It's referred to as solar energy. It travels in rays from the sun to the Earth. Some of these are visible light rays. Some rays, such as x-rays, are invisible. Solar energy is used in a variety of ways. We use sunshine to see what we're doing and where we're going throughout the day. When sunlight strikes something, it converts to heat. We couldn't survive on Earth without the sun because it would be too chilly. We heat water and dry clothing with the sun's energy. Plants grow by absorbing the sun's light. Light energy is captured by plants and stored in their roots and leaves. Every living thing on the planet is nourished by this energy. Plants can also be burned to generate heat [22]. The sun's energy causes rain to fall and wind to blow. Dams and wind turbines can be used to harness that energy. Prehistoric plants and animals were used to create coal, oil, and natural gas. They got their energy from the sun. We use that energy to heat our homes, drive our automobiles, and generate power. Solar energy is both free and environmentally friendly. We will never run out of it since there is plenty for everyone. Solar power is a renewable resource. For a very long time, the sun will continue to generate energy. Many people have solar collectors installed on their roofs. Solar collectors take the sun's energy and convert it to heat. People can use the sun's energy to heat their homes and water. Solar cells are devices that convert sunlight into electricity. Solar cells are used instead of batteries in several toys and calculators. Solar panels are made up of a large number of solar cells. Some homeowners have solar panels installed on their roofs. These solar panels are capable of generating enough electricity to power a home. Solar panels are ideal for homes, buildings, and equipment that do not have access to electricity. Solar energy currently produces less than 1% of the electricity we use, but that percentage is expanding every year. It has the potential to become a major source of energy in the future. New techniques to capture and utilize solar energy are being researched by scientists. With the cost of power increasing by 3% to 5% per year, you may be investigating alternative energy sources like solar [23]. However, before you go ahead and put a solar system on your home, there are a few big drawbacks to consider. Solar power has the greatest beginning expenses of any renewable energy source, so you'd think it'd be a good investment. Solar panels, on the other hand, have a low efficiency. With the best and most expensive equipment available, you'll be lucky to get more than a 22% conversion rate if you're in a prime location. Then there's the possibility that storms will damage the solar panels. Aside from the cost of replacing the solar panels, the damaged ones must be appropriately handled and disposed of due to the poisonous substances employed inside. One of the most important elements in influencing the effectiveness of solar electricity is your latitude. The efficacy of solar electricity drops substantially as you move away from the equator, and not all sites receive the same amount of annual sunlight. As a result, citizens in regions like Canada and Russia are at a disadvantage when it comes to solar energy. However, in regions like Hawaii, where rain and clouds fall on average 277 days per year, proximity to the equator is meaningless since there is just not enough unclouded sunshine reaching the ground. Solar panels, like everything else left in the sun, will deteriorate due to ultraviolet rays. Solar panels are also vulnerable to elements such as wind, hail, snow, dirt, and temperature variations. The fact that solar energy is dependent on the sun means that electricity cannot be created at night, forcing you to either store surplus energy generated during the day or connect to a backup power source such as the local utility system. This implies you'll have to spend more on top of the solar panels' expensive price. Clouds and storms also limit the amount of energy you can generate since they block light rays that would otherwise be absorbed by the solar panel. Land and water consumption and pollution, habitat loss, and the use of highly hazardous compounds in the production process are all environmental consequences linked with solar power. In terms of the installation space, solar fields can consume a lot of land, and unlike wind power, sharing the land for agricultural purposes is not a possibility. When it comes to mining and producing the materials needed to make photovoltaics, solar power has an impact on land use. For average-sized systems that produce between 4kW and 8kW of power, it costs between $15,000 and $29,000. Solar panels, inverters, mounting hardware and wiring, installation, permits, repairs, monitoring, and maintenance fees, as well as additional operation and administrative expenditures are all included in these costs. You'll notice that there's no mention of a battery storage system, which is an extra cost. If you want to supplement your energy needs by connecting to the local electricity grid, battery storage solutions are not required. When you include in the expense of a battery storage system, you're looking at a total cost of between $33,300 and $47,300 to consistently supply adequate energy for the average four-bedroom household at all hours of the day and night. Even so, depending on the environment and your region, you may need to minimize your energy use and be more frugal with your energy use [3].

Wind power or wind energy is the process of using the wind to generate mechanical or electrical energy [24]. Wind turbines convert the kinetic energy of the wind into mechanical energy. This mechanical energy can be used for specific tasks (like grain grinding or water pumping) or converted into electricity by a generator. Wind turbines work on a simple principle: rather than using electricity to create wind (like a fan does), they utilize wind to create electricity. The propeller-like blades of a turbine are turned by the wind around a rotor, which spins a generator, which generates power. Wind is a type of solar energy that is produced by a series of three events: The sun heats the atmosphere unevenly, irregularities on the surface of the world, and the earth's axis of rotation. Wind patterns and speeds range dramatically across the United States, and are influenced by bodies of water, vegetation, and topography changes. Sailing, flying a kite, and even generating electricity are all examples of how humans employ wind flow, or motion energy. Both "wind energy" and "wind power" refer to the process of using the wind to generate mechanical or electrical power. This mechanical energy can be employed for specialized purposes (such as grinding grain or pumping water), or it can be converted to electricity using a generator [25]. Wind isn't always reliable;. If the weather does not cooperate, you may lose electricity (or, at least, you will have to rely on the electric provider to take care of you during those times). It is difficult to predict the given output generation from wind energy at a given time. Furthermore, wind turbines can be damaged by severe storms or high winds, especially if they are struck by lightning. Wind turbines' edges can be hazardous to wildlife, particularly birds and other flying critters that may be present. Although there is no way to prevent it, you should be aware of the potential implications. Wind power's cost-competitiveness is a hotly debated topic. Financial incentives are generally used substantially in both utility-scale wind farms and tiny residential wind turbines. Financial incentives are critical to giving wind power a fair opportunity in the intense struggle against well-established energy sources such as fossil fuels and coal [4].

Hydropower, often known as hydroelectric power, is a type of renewable energy that generates electricity by harnessing the natural flow of flowing water [26]. Hydropower presently accounts for 37% of total renewable electricity output and 7% of overall electricity generation in the United States. The elevation difference formed by a dam or diversion construction allows water to flow in on one side and out, far below, on the other, generating electricity. The environmental impact of hydroelectric energy is perhaps its most significant negative. Dams have the potential to harm or otherwise disrupt the ecosystem both upstream and downstream during the construction process. To construct a dam, additional roads and electrical lines must be built, causing environmental disruption. Dams frequently create reservoirs, which flood enormous areas and dispense with natural habitats. When dams flood areas, they generate areas of still or stagnant water, which kills flora and causes it to decompose, emitting greenhouse gases. This is especially true in tropical and humid climates. Another downside of hydroelectric energy is the initial investment necessary to construct a dam. Despite their low operating costs, the time it takes for a dam to pay for itself varies greatly. Some dams take two to five years to build, while others take much longer, such as the Itaipu Dam in Brazil and Paraguay, resulting in higher expenses. It's vital to consider the fact that water can and does go through cycles of abundance and drought when considering the benefits and drawbacks of hydroelectric energy. Lower-than-normal water levels can have a significant impact on energy production, which is a drawback of hydroelectric power. Hydro energy production, in addition to being affected by drought, can also produce drought conditions downstream if it does not allow enough water to pass through. This is particularly problematic if the dam is built along a river or reservoir that permits water to flow into another country. Intentionally or unintentionally, the country upstream could trigger a drought in their adjacent country [27].

4) Energy Storage

To accommodate the inherent issues with many non-fossil fuel-based energy sources governments around the world are looking to develop energy storage. This is because many renewable sources suffer from intermittency and at the same time energy demand is not constant and fluctuates throughout the day. Energy storage is judged by its dynamism in response to the changing conditions of the amount of energy needing storage, rate of charge and discharge, overall storage capacity, cost to build, response to changes in demand, and increasing power quality (power peaking, voltage & frequency stability).

a) Flywheel: Flywheels are most effective for load-leveling and load-shifting and are known for low maintenance costs, high energy density, and fast response. Flywheels are designed to operate in a vacuum to minimize air friction. A flywheel was implemented in Stephentown, New York and has an energy capacity of 20 MW and was the first commercial use of this technology in the US [28]. Flywheels spin a mass at their center by driving a motor and deliver uninterrupted power of high quality (as the motor speed can be adjusted), they can employ a vacuum for the mass to reduce drag and even magnetic levitation in place of bearings to increase rotation speed. They have a long lifespan and large efficiency of between 85-87% [29] and are used in high power/low energy applications [30].

b) Compressed Air Energy Storage (CAES): Works by pumping air underground during hours when electricity is cheap and released back into an expansion turbine where it is heated. This causes an expansion that turns a generator, although the heating process uses natural gas it extends the energy output significantly (up to 3 times) compared to natural gas alone. CAES has up to 70% energy efficiency if the heat from air pressure is maintained and 42-55% otherwise. There are two operating facilities currently one in McIntosh, Alabama and another in Huntorf, Germany [29].

c) Thermal: Material (often rocks, molten salt, water, etc.) is heated via concentrated sunlight and stored in an insulated environment to be used later to drive a turbine (for example by pouring water on heated rocks). Depending on the facility and implementation the energy efficiency can range from 50-90% [28].

d) Batteries: Batteries store chemical energy using an anode, cathode, and electrolyte material in the middle to create a flow of ions between the electrodes and out to wires for current. Different chemistries for batteries include lead-acid, nickel-based, sodium-based, lithium-ion, and flow batteries.

Lithium-ion is the most common and accounts for more than 90% of the global battery grid storage market. Because of their frequent use in smaller scale electronics and electric vehicles due to lightweight and high energy density, the lithium-ion battery has experienced a rapid decrease in price and since the commercial release by Sony in 1991, the cost of lithium batteries has decreased by 97% [31]. Lithium-ion batteries are around $150-120/kWh and costs are expected to decline to $100/kWh by 2024. At this price, they are competitive with combustion engines [31]. Li-ion batteries do not have a “memory effect” which is a process of charging & discharging the battery causes it to “remember” a lower charge capacity, along with a low self-discharge rate (1.5-2% per month) give Li-ion a large advantage over other battery chemistries [32]. Despite this, Li-ion can suffer from overheating which can lead to thermal runaway and fires. They also need circuitry to manage charging and discharging within an optimal range to avoid damage and this increases their cost. Lead-acid batteries were some of the original chemistries used for storage although they suffer from lower energy density, short life cycle, and toxicity during recycling. They have been commonly used in transportation although they are being replaced for Li-ion as time goes on.

Another problem with batteries across different chemistries is their recycling potential and waste. Many are very toxic and difficult to recycle but the most developed techniques are for the most common battery the Li-ion. Currently, it is not economical to recycle Li-ion batteries and this is partly due to the lack of international manufacturing standards that has produced too many variations and color-coding [33]. The recycling process cannot recover the necessary amount of metals to recreate batteries which means they end up in landfills and contaminate the environment; despite battery collection requirements in the US and EU, only about 3-5% of Li-ion are recycled. However, electric vehicle batteries once they have lost sufficient capacity can be repurposed for residential & commercial “second life” storage systems [34].

e) Pumped Hydro Energy Storage (PHES): PHES is a promising option for specific geographies and particularly isolated islands and can assist the high electricity production cost of those isolated regions. Studies show that pumped storage is a necessity to absorb the excess power generated by variable sources and a hybrid system composed of multiple sources such as wind and solar operating together to pump water was more realistic. This is partly due to the economic viability of the combination over wind power alone. The energy is stored by pumping water from a lower reservoir to a higher reservoir during hours when there is excess energy; during times of high demand, the water is released into hydro turbines. The energy efficiency varies from 70-80% with some studies claiming up to 87%. [35]

f) Superconducting energy storage system (SMES): SMES uses a superconducted coil and material that stores electrical energy in the form of a magnetic field. Because the resistance in a superconductor is close to 0 this storage has little power loss. SEMS is advantageous in long-term storage without loss, high efficiency, and quick discharging. This technology can be used to adjust grid power, reactive power, frequency, and voltage but it has a high cost to build. SMES has been implemented successfully as a 100KJ system in Huazhong University of Science and Technology in China [36].

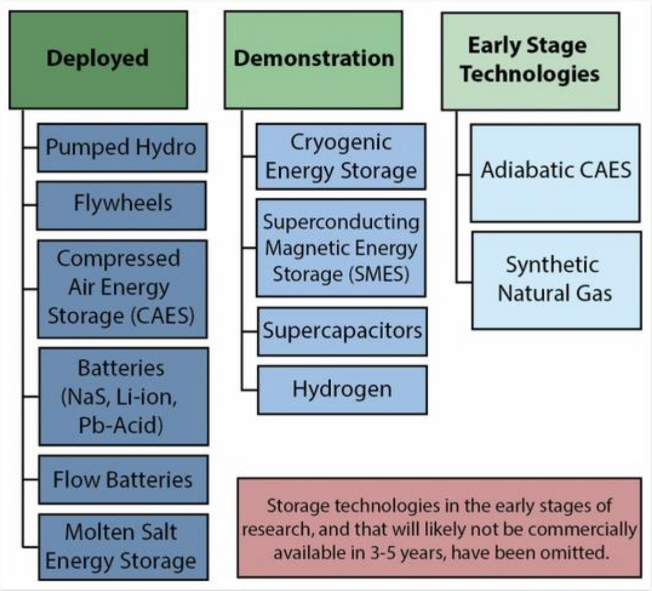


Figure 6. U.S Grid Energy Storage Fact Sheet [29]

g) Methods to evaluate and compare storage: Renewable energy is different from conventional power generation in several ways: generator output varies due to resource variance, it is unpredictable, renewable generators are small and modular, they are constrained by location, renewable generators are non-synchronous, and they have low short-run costs. This creates unique challenges such as missing transmission grid capacity or poor generation adequacy (ability of a generation portfolio to match power demand) and failure to solve these will delay decarbonization goals. There are numerous technological solutions but the deployment of them is complicated by three factors: 1) the choice of which tech is based on cost, maturity, range of applications, and preferences by companies and governments. 2) decisions about what to use are not overseen by a central authority but instead many actors such as system operators, utilities, and regulators. 3) needs vary based on the region from renewable energy share in the power portfolio or power system configuration such as an island system vs an interconnected system.

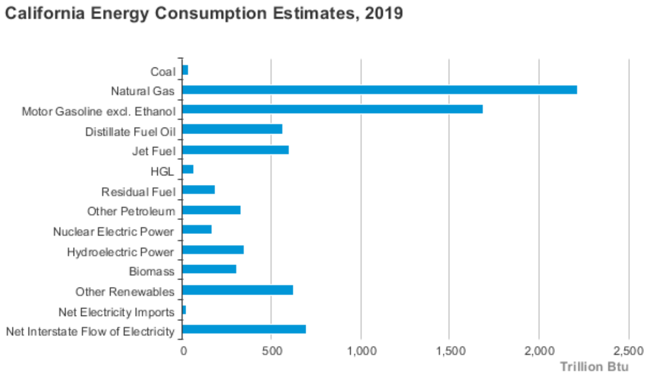
The challenges of renewable integration can be broken down into several categories involving quality, flow, stability, and balance. Consumers need sufficient power quality, and this is composed of an uninterrupted power supply, stable voltage & current, and safety. Flow is about the efficient transmission and distribution of power and the challenges include safety hazards, shorter lifespan, and damage to equipment for consumers. Stability is focused on the frequency and voltage in the system as well as cold-starts after power blackouts. Balance is the challenge of balancing long-term and short-term supply and demand mismatches caused by renewable energy variability and unpredictability.

Technological solutions can be broken into multiple categories; flexible (generated or consumed power) or grid (transmission or distribution) and distributed or centralized. Distributed storage is usually battery units in residential locations and centralized storage can be large pumped-hydro or large-scale batteries that can be for short-term supply to grid during peak hours and are owned by utilities. By organizing the common solutions to renewable integration one can draw several important insights to decarbonizing the power sector:

One, more than one solution can be applied for any specific challenge but firms and governments often do not recognize what solutions can be a good substitution, and sometimes by not using multiple technologies together the market viability of singular technology can be reduced. Two, there is no generic solution as the needs for renewable integration vary by region. By using the method of analysis described, governments can begin to address challenges such as if a region has power quality issues from large amounts of wind power then they should look to distributed flexibility and grid technologies. This is shown in a study [37] where smart grid projects are a high priority for southern Germany and the southern UK. Flow challenges for transmission (in Germany) need centralized grid solutions like grid reinforcement or HVDC transmission systems. Stability challenges (like in Spain and Ireland) are solved by having system operators make renewable energy generators support grid stability. And balance problems (maintaining balance during sunset) are solved in California by creating incentives for investment in storage and more flexible conventional generators [38]. The third and final insight is that the solutions should be prioritized by ease and cost of implementation and many researchers recommend creating a local power market.

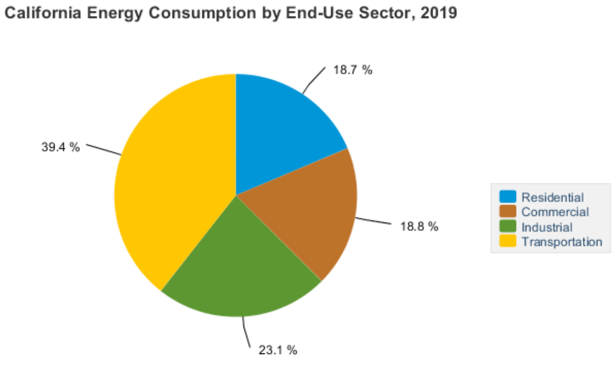
5) Residential Power Sources and Distribution in California

According to the U.S Energy Information Administration (EIA), California was the top producer of solar, geothermal, and biomass energy in the United States as of 2019. At the same time, it is the largest consumer of jet fuel and motor oil, reporting 17% and 11%, respectively, of the entire country's consumption [6]. [6], Fig.7] denotes the energy consumption estimates for the state as of 2019 in trillion British Thermal Units (Btu). Combined, this gives a consumption of 1.66×10^{12} kWh per year from non-renewable sources and 4.24×10^{11} kWh from renewable sources. In other words, even though California is the leading producer of renewable sources in the United States, nonrenewable energy still accounts for 79.7% of the power consumption from sources produced in-state. 18.7% of the total energy consumption went to residential uses [6, Fig. 8].



Source: Energy Information Administration, State Energy Data System

Figure 7. California Energy Consumption Estimates [6]



Source: Energy Information Administration, State Energy Data System

Figure 8. California Energy Consumption by End-Use Sector [6]

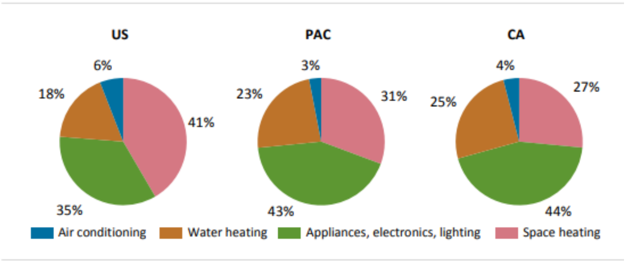
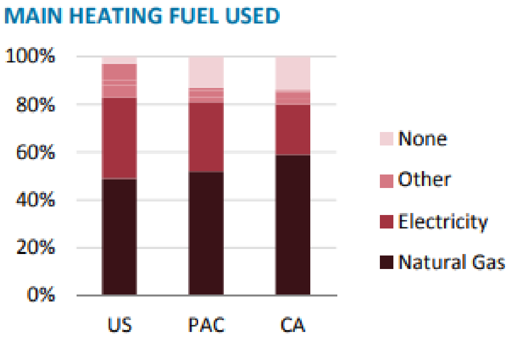


Figure 9. Distribution of Energy Usage in Residences [39]

Furthermore, a large percentage of residential energy use went to appliance and electronics at 44%, rather than air conditioning and space heating (31%) compared to the rest of the United States [39, Fig. 9]. With a high percentage of residential power usage being dedicated towards powering electronics and appliances, increasing energy storage efficiency is an essential component in addressing the effects of climate change.

Fuel type used in heating can be broken into four categories, namely natural gas, electricity, other, and none. According to the EIA, 59% of residents use natural gas for heating, higher than the national average, as seen in [39, Fig. 10].



Compared to the U.S. average, a greater share of California residents use natural gas for heating (59%). Due to the mild climate, 14% of California homes are not heated.

Figure 10. Primary Heating Fuel in Residences [39]

The largest percentage of energy consumption in California is dedicated to transportation, at 39.4% [39, Fig. 3]. In September of 2020 California Governor Newsom signed an executive order mandating, "[…] that, by 2035, all new cars and passenger trucks sold in California be zero-emission vehicles." The goal of this initiative is to achieve a 35% reduction in greenhouse gas emissions. Furthermore, regulations are being developed by the Air Resources Board to achieve a similar mandate for medium and heavy-duty vehicles, targeting the year 2045 [40].

As of 2019 the United States Department of Energy reported that of the 18.9 billion gasoline gallon equivalents (GGEs) consumed by the transportation sector in California, only 21.8 million came from electric fuel consumption, or 0.115% [41]. It is important to note that the transportation sector encompasses all vehicles used in transporting people or goods, including but not limited to cars, trucks, buses, trains, aircraft, and ships [42]. In 2016, of the 35.3 million vehicles registered by the DMV cars outpaced trucks and trailers by a 3:1 ratio [43]. As the state transitions to relying more heavily on zero-emission vehicles the average residential electricity consumption will increase as people recharge their cars at home.

6) Design Idea Outline

Every battery storage system needs to be managed to maintain voltage, temperature, current, and other factors within a specific range for long-term health and safety. Our smart battery management system will be designed for electric vehicles and will account for second life use in residential and commercial storage. To make this easier, it must be wireless for communication between the master microcontroller and the slave battery cell sensors. In addition, a single board computer will be collecting data from the battery manager and the thermal management system and communicate with a remote server for diagnostics and repairs; this feature further reduces costs of battery systems which will accelerate decarbonization.

B. Second Semester Interpretation of the Societal Problem

1) Discussion of Societal Problem

Given how large of a problem climate change is, it was difficult to decide on how best to approach the problem and we originally were thinking of battery management systems and electric vehicles. However, from our greater understanding of the issue we decided to pivot to energy management systems overall. This is because it covers a large scope that includes battery management and technology like Vehicle-to-grid power management, and also allows more potential customers to use our product which will be more effective in reducing carbon emissions [44].

In our original research for the societal problem, we focused primarily on comparing different renewable energy sources, including some that are out of reach for the majority of consumers such as geothermal energy. We also focused on energy storage solutions that are rarely used commercially, let alone residentially. Many of the solutions for the societal problem, such as more advanced battery design, were too theoretical and out of the scope of an undergraduate project and instead were projects needing state or federal level support to prototype. The area of study around residential power usage and management is an area in which a product can be designed by our team to address the problem. Commercial building energy management is also important in reducing carbon emissions and may have a larger impact due to having more potential for energy savings, however a scaled residential prototype is more cost effective for our project's budget.

Due to the growing amount of work from home employees due to Covid, there is a growing need for residential energy management systems as the accuracy of traditional energy forecasting from utilities has declined and this places stress on the grid [45]. This confirms the necessity of our design idea as the system can reduce need for load shedding on the grid by having users power their home with batteries during peak hours. While in recent years utilities have been moving to generate power from renewable sources, non-renewable sources such as coal still make up a large percentage of total power production. Furthermore, during peak energy use hours utility companies such as SMUD rely on non-renewable sources to meet the demand [46]. By affording residences the opportunity to produce their own power to meet this demand the carbon footprint of homeowners who do not have solar power will also decrease.

2) Features of Rapid Prototype that Address Climate Change

Our choice of the wireless transmission protocol MQTT was effective in reliable data transmission for low power consumption and only requires the microcontroller handle standard 2.4GHz Wi-Fi connection as opposed to protocols like ZigBee which need additional hardware and therefore create more waste [47].

Our selection of LiFEPO4 batteries was another good design choice as they are safer in comparison to other lithium batteries. They also have a larger charging capacity in comparison to lead acid and are not as toxic to recycle. An energy management system needs to have a large battery storage system for helping reduce the peak load on the grid but also for reducing the waste of solar power on sunny days. This avoids the expense of having to change the grid to allow power to be sent to the utility when the home cannot use all of the solar power.

The charge controller can also measure the carbon dioxide that amount of power the home is using would have generated; the longer the system runs the more metric tons of CO2 the user can see being saved.

3) Possible Design Changes that Could Better Address Climate Change

A Canadian study found that with smart home devices such as temperature management systems can at times cause the user to spend more time messing with the device settings than if they had never purchased the smart system [8] and set the temperature manually. Our design, in order to reach as many homes as possible, (to better reduce CO2 output and address societal problem) should be made for users who are not tech savvy and want a simple system that will reduce their electric bill and carbon footprint. By converting the current system to be more readily accessible to less tech-savvy users, we could increase the effectiveness of our design for a wider range of consumers.

Including a relay switch inside the smart outlet would have been a wise design choice as that allows the user to turn off for example a wasteful HVAC system they left on and creates potential for more smart home features like a scheduler to better plan power use.

Currently our design is made for the market of residential areas who have SMUD as their utility company, but for this product to be effective elsewhere the energy cost calculations would need to be configured differently as some areas have a floating cost to electricity. Additionally, the system should be designed to have software updates that could share data and communicate with national and local smart grid operators and networks to coordinate power distribution [48]. After review of several academic studies on the design of energy management systems, there were a few other features commonly discussed such as higher quality security/encryption [49], artificial intelligence or analytics on big data from these systems, and interactive mobile applications [50].

4) Prototype Description

The current design utilizes a monocrystalline solar panel, theoretically capable of producing 100W of power during peak sun hour, connected to a 500Wh LiFePO4 battery pack. Utilizing an ESP32 microcontroller, the system reads the statistics from the solar charge controller RS485 connector using the Modbus protocol, sending the data via MQTT over Wi-Fi to a Raspberry Pi. Similar software is used on the other ESP32 devices inside the smart outlets except they are using the onboard 12-bit analog-to-digital converter to read the outlet voltage and current for the user's devices.

The ESP32 uses timers to schedule the sending of data to the Raspberry Pi. The Pi is a 4-core 64-bit Arm Linux computer with 8 GB of RAM that is running multiple processes: Mosquitto to manage the multiple wireless connections, our Python script to convert the data received, and another main Python program that interprets the data and compares it to the forecasts to make decisions.

The Pi logs and interprets the charge controller statistics such as battery state of charge and PV power and based on this chooses the appropriate solid-state relay to power, switching between utility and renewable power based on a number of factors such as time of day, available battery power, and the cost of the utility power. The system as designed prioritizes maintaining enough battery power throughout the day to provide the estimated power consumption of the user during peak hours (5 PM – 8PM).

III. DESIGN IDEA

A. *Design Philosophy*

1) *Addressing Climate Change and Energy Efficiency*

In order to address the concerns of energy efficiency, limitations of solar power due to non-peak hour operation, and variable power costs based on Time-of-Day usage rates, we plan to create an Energy Management System (EMS). According to the Office of Energy Efficiency & Renewable Energy, an EMS is a system which controls and monitors energy consuming devices, such as heating equipment, fans, lighting, etc [51]. The system we propose will be based on the average power consumption of a home in the Sacramento area, scaled down for feasibility within the scope of the project. This addresses the problem described in section II by both automatically and manually allowing the user to regulate their power sources in real-time, making the most efficient use of solar power, battery systems, and from the local utility. Sacramento Municipal Utility District (SMUD) is currently working towards a zero-carbon energy plan, with the goal of generating 100% of power from non-carbon sources by the year 2030. Part of this plan includes the adoption of customer-owned solar systems to provide widely distributed and renewable two-way power generation.

In order to create a sufficient and accurate design, SMUD has provided average power estimates for a Sacramento home as of January 2021. This estimate came to 750 kWh per month for the average household, or roughly 25 kWh per day. SMUD electricity rates are based on a Time-of-Day rating system, meaning that cost per kWh increases during the peak hours of use. To meet the demand at these peak hours, SMUD and other utilities buy energy from external sources, often produced using non-renewable and less environmentally friendly methods [7]. [7, Fig. 11] denotes the cost per kWh based of this system year-round.

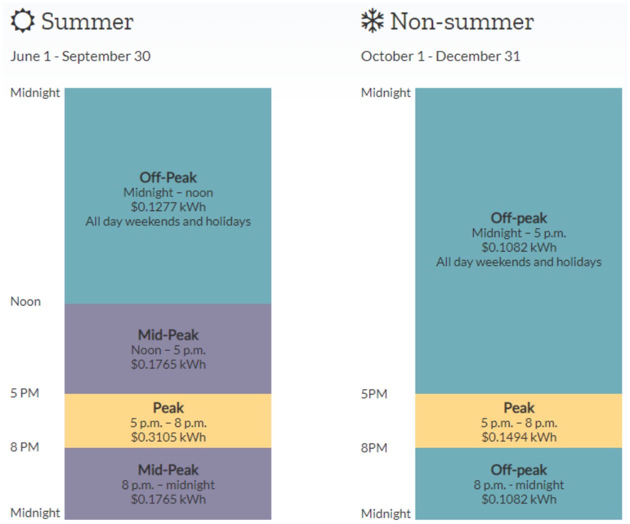


Figure 11: Time-of-Day Rates [7]

As shown in the above figure, it is cost-effective to avoid utility power consumption from 5 p.m. to 8 p.m. year-round, and Noon to midnight during the Summer in order to get the best price per kWh possible. An EMS based on this system would primarily rely on stored energy and solar power during peak and mid-peak hours.

Solar power systems normally generate electricity from 8 a.m. to 5 p.m., with the best output between 10 a.m. and 3 p.m., though this varies depending on the season. As a result, the optimal period to use solar panels for power is between the hours of 10 a.m. and 3 p.m. Households, on the other hand, often do not consume large amounts of electricity during the day when solar panels are producing energy; instead, energy consumption is highest between 7 and 9 a.m. and 4 and 7 p.m. Peak periods are also when the cost of electricity is highest if you have a Time of Day (TOD) electricity plan.

2) *What makes our approach unique?*

As we all know, solar energy is one of the most affordable energy sources accessible, and because it is harvested through technology rather than fuel, its costs will naturally fall as technology develops. Unlike some forms of traditional energy generating technologies, solar energy produces no air pollution. Solar panels emit no carbon emissions that contribute to acid rain or greenhouse gas emissions. The United States contains some of the world's most abundant solar resources, notably in the Southwest area. Solar is a renewable energy source that utilizes the sun's energy, which is naturally abundant, inexhaustible, and free, as opposed to fossil fuels, which are finite and expensive.

The power switching between battery, solar, and electricity is one of the major aspects that distinguishes our design. The customer will be able to choose from battery, solar, and utility power source they want to utilize to operate their household equipment. Power will also be shifted according to what is best for the weather and specific conditions. The solar panels will be charged during the hours of 10 a.m. to 3 p.m., as previously stated; users will have the option of running on solar energy or switching to utility power.

3) Other approaches to problem

Section II outlined various problems with adapting to renewable sources, including the limitations of these sources including solar, wind, and hydroelectric. Our major concern was that a lot of fossil fuels are beginning to be used resulting in a lot of gas emissions, with climate change beginning to become a large component of it. The transition to greener energy can help clear the air, lowering asthma rates and other health risks. With the broadness of our societal problem, multiple design approaches were available. At first, we planned on creating a battery management system, but decided that it did not fully address the concerns we discussed with climate change and the adaption and integration of renewable sources. In the process of creating our design idea we encountered numerous approaches. Due to safety concerns, the skillsets of our team members, cost limitations, and time constraints we have developed the approach in subsection B.

4) Required Resources

We will require a few resources to complete this project. Most of these resources will be testing equipment and laboratory work areas. We'll need RVR 3016A, a multimeter, PQube for power measurement, and oscilloscope. In order to develop our prototype system, we'll also need access to Santa Clara 1119D. Any access to associated grant funding will be included in non-facilities related resources.

TABLE I.
PUNCH LIST [52]

Feature	Measurable Metric
Monitor load and panel voltage and current	Measure voltage (+3/-3 V) and current (+0.1/-0.1 A) every 5 seconds at the load Measure voltage (+0.1/-0.1) and current (+0.3/-0.3) every 5 seconds at the solar panel
Power source switching	Relays switch power source in 10 ms
MCU controlled algorithm to implement most carbon-efficient energy source that meets load demand	Compare solar production to expected value every 60 seconds. Switch to utility power if production is below 1 standard deviations from expected production, throw error message
Algorithm incorporates estimated Wh production per day to balance power sources and avoid utility power usage during peak hours	Charge battery during peak sun hours if forecasted production for the day does not meet average power draw of 500 Wh for the day.
Website for user interaction and monitoring	MCU will receive data measured every 10 seconds via wireless transmission. Sensor data will be sent to server
Access weather data to allow informed calculations on effectiveness of solar panel	Weather API provided information on solar radiation compared to actual production within acceptable range of 1 standard deviation

B. *Specific Design Components*

1) Hardware to implement features

We will need a charge controller for the battery system as the panel will output current into a fully charged battery which will cause permanent damage. A MPPT (Maximum Power Point Tracking) solar charge controller will connect the solar panel to a battery supply and electrical relays, where it will be combined with utility power. The solar panel will be put outside to capture and convert the sun's rays into power. Solar panels generate Direct Current (DC) power, and household power is alternating current (AC). So, our inverter converts the solar panel’s DC power output into AC power maintaining the AC voltage.

The major connection of our software component of our project will be the Raspberry Pi, though which the user will be able to provide input and the pi will control the output and switch on whichever source the user desires. Along with that, the Pi will analyze data to identify the optimum power source to use at the time. Relay switches will be utilized in conjunction with a Raspberry Pi. When the user/algorithm decides whether to utilize utility power, battery power, or solar power. The pi will then send a signal to the relay, which will flip on one switch, allowing current to flow through to a DC power switch, providing electricity to the user’s home. LCD will be needed for the user / client so they can monitor the programming and know what they are numbers on the power usage.

A voltage sensor is a device that measures and calculates the amount of voltage in an object. Voltage sensors can tell whether the voltage is AC or DC. The voltage is the sensor's input, while the switches, analog voltage signal, current signal, or audible signal are the sensor's output. A voltage sensor can be used to determine, monitor, and measure the voltage supply. It can measure both AC and DC voltage levels. The voltage sensor's input is the voltage itself, with analog voltage signals, switches, audio signals, analog current levels, frequency, or even frequency-modulated outputs as outputs.

A current sensor is a device that detects current and transforms it to a voltage that can be easily measured and is proportionate to the current flowing through the measured route. Voltage drop happens when current travels across a wire or in a circuit. A magnetic field is also created around the current-carrying wire. In the design of current sensors, both of these phenomena are considered. Direct and indirect current sensing are the two types of current sensing.

A transformer is a device that uses magnetic coupling to transmit energy from one electrical circuit to another without utilizing any moving elements. It's frequently used to convert between high and low voltages and to change impedance. In the development of high-voltage electric power transmission and central producing plants, the transformer played a crucial role.

The battery system will consist of a custom-built battery pack made of lithium iron phosphate (LiFePO4) batteries connected in series and parallel. We plan to design the system to output 12.8V DC, and store around 40 Amp-Hours of charge. We currently estimate that this system will require around 28 individual LiFePO4 battery cells.

ESP32 is a system on a chip with useful and quality characteristics such as Wi-Fi (2.4 GHz band), Bluetooth, and Dual excellent centers. The addition of an Ultra-Low Power co-processor and multiple peripherals makes the overall package substantially more appealing. ESP32 provides a powerful, excellently included stage that aids meet the continual needs for effective force use, lowered plan, security, elite, and dependability, thanks to 40 nm innovation.

Other required components include an electrical outlet, a large sheet of plywood to house and secure our design features, appliances to simulate the power draw of an average house such as fans and lightbulbs, and a DC/AC converter.

2) Software to implement features

Each microcontroller (ESP32) will need a Real Time Operating System to measure current and voltage and use IEEE 802.11 Wi-Fi to send the data to Raspberry Pi. The Raspberry Pi will be running a version of Linux that will run MQTT to collect ESP32 data and send to a remote server. The server will run a LAMP (Linux, Apache, MySQL, and PHP/Python) configuration to collect and display data for the home user to observe.

A weather API can be used to pull data from local weather stations to get information on conditions such as wind speed, temperature, humidity, and cloudiness. We will use this information to allow our system to decide when to rely on solar power generation to power appliances, versus the battery system and utility power.

3) Individual Responsibilities

Each team member will take on large responsibilities for this project:

Matt will be configuring and programming the operating systems, writing drivers, & configuring and programming the website. Inder will be designing, creating, and testing the Smart Outlet electronics. Cameron will be responsible for configuring the solar panel, charge controller, and battery supply, as well as setting up the relay to operate through the GPIO pins on the raspberry pi. Simron will set up the overall design on a support structure, and wire the AC/DC transformers and DC/AC converters to operate through the DC power link.

4) Estimate total hours to complete

Our major aim is to complete the project before the deadline; therefore, we're considering splitting into two teams or delegating tasks to each person so they may complete their portion of the project before a team meeting, which will give us everyone an indication of what phase of work we should be focusing on. We plan to work approximately 20 hours or more per week until the 15th of November, when the first prototype is due. As a team, we'll be working for about (20 hours * 4 week = 80) (80 hours * 6 weeks = 480 hours over the course of 6 weeks).

5) Measurable Metrics

The average rooftop solar panel is 250 Watts, producing about 1.25 kWh of power per day. With an average power consumption of 25 kWh per day in Sacramento, a home would need around 20 solar panels. The solar panel we intend to buy is 100 Watts, and can produce about 500 Wh per day, giving us a scale of 1/50.

Sun hours in California produce about 5 hours of peak generation, for a 100W solar panel this is 500Wh per day. With a panel at 12V this produces 41.66Ah. Energy is most expensive during peak demand from 5PM-8PM so it is ideal to use the battery power during this time. Our electrical loads will be under 100W and we simulate a residential system with an HVAC unit of about ~13W (given average residential system has close to 13% energy from air conditioning [53]), an LED system of ~10W, PC/electronics of about ~8W. So, this means our system is designed for a person who comes home from work there and uses most of their daily electricity from 5-8PM. The battery bank capacity should be equal to the daily consumption of about 42Ah. The 32650-battery cell has an average capacity of about 6000mAh, so this means we need about 7 parallel connections. To meet the 12V output we will need about 4 batteries per row for a total of 28 batteries.

For confirming the functionality of the smart outlet, we will test the load with a multimeter and record the voltage and current. The smart outlet will be complete when we can see the same data stored by the Raspberry Pi and sent by the ESP32.

6) Connect design to team member skills

This project needs an array of skills from design of electronics to high-level programming. Matt is assigned the firmware, OS development, and website as that is in line with his previous experience (programming microcontrollers and the Linux kernel) and personal interests. Cameron’s responsibilities were chosen due to experience with configuring sensors to operate from GPIO ports on a MCU, as well as knowledge on the operation of the solar charge controller. Due to prior experiences in courses and other projects completed during previous semesters, Inder’s task is to develop and test the smart outlet electronics. Simron’s task is to design a support structure and wire the AC/DC transformers due to his experience with power, and previous projects involving transformers.

IV. FUNDING

Our suggested budget for this project as a team of four members was set at $800, which has been divided evenly among the four of us for a total contribution of $200 each in order to study and produce the design contract that we agreed to. After completion of the rapid prototype and deployable prototype build processes, the actual cost was much larger than our initial expectation, coming to a total cost of $1085. This was due to the team underestimating the cost of certain components, as well as not including components that would prove necessary to build the design. Furthermore, on three occasions parts were purchased the needed to be replaced due to them not being correct for the scope of the project. This includes the solid 12-gauge wire which was replaced with stranded, the power adapter which did not have the necessary voltage regulation to ensure the system remained on while switching, and the current sensor, which was initially improperly sized at 30 A rating and had to be replaced by a 1A rated sensor.

TABLE II.
BUDGET BREAKDOWN [52]

Funding Source	Cost
Cameron	$272
Matthew	$375
Lovesimron	$214
Inder	$224
TOTAL	$1085

V. WORK BREAKDOWN STRUCTURE

The feature set of Energy System necessitates extensive preparation in order to finish the development and guarantee that it functions properly. To manage the process and maintain track of the project's progress, the next important milestone was the separation of each key feature into a group of tasks and subtasks, and the development of a plan to schedule work over the duration of class time. Each sub task has been assigned a duration in weeks, as well as a group member (or group members) who will primarily be responsible for its completion in appendix D.

A. Power Supplied from carbon-efficient source

In order to achieve a system powered primarily by low-carbon sources we have purchased a 100 W solar panel which will be connected to a custom lithium iron phosphate (LiFePO4) battery pack. The battery will consist of twenty-eight 32650 cells, arranged as four series-connected packs with 7 parallel cells in each. To accomplish this, we must spot weld nickel strips in the appropriate configuration and attach a battery management system (BMS) to monitor the cells and allow higher charge capacity through active cell balancing. We have allotted one week of time for completion of this task. After this is complete, we will wire the solar panel and battery with appropriately gauged wire to the solar charge controller, as well as attach the solar panel to mounting hardware which will allow it to be positioned at the most effective angle for capturing solar radiation. This task has been assigned to the week of November 02, from 11/02 – 11/09.

B. Monitor panel and load voltage and current

For this portion of the assignment, it can be broken down into two main sections: configuring the smart outlets and data transmission from the solar panel to the microcontroller then to the Raspberry Pi. The configuring of smart outlets has several subtasks which are writing C based drivers so the microcontroller can interface with the current and voltage sensors. This task is set to be within the date range of October 26th to November 2nd. Software also needs to be written for the microcontroller to send to the Raspberry Pi over wireless communication and this will occur from November 2nd to November 9th. For the second part of data transmission from the solar panel this is one main task which is creating a circuit translating the charge controllers RS485 serial signal, stepping down its voltage, and reading it with another microcontroller. This is sent wirelessly similar to the other microcontrollers to the Raspberry Pi and this task will be worked on from November 2nd to November 9th.

C. "Green" Power Algorithm

The Raspberry Pi is the main connection in this section of our project's. This is due to the fact that user will be able to supply input, and the pi will control the output and turn on whichever source the user wishes. Pi will also evaluate data in order to decide the optimal power source to utilize at the time (It will compare all three sources battery, utility, and solar to determine which is the best during that time of day). A weather API will also be utilized; it will allow us to get data from weather station in order to obtain information on weather conditions so that we can ensure that pi is presenting the correct information to the user (It will display weather conditions it is windy, rainy, or sunny to guarantee that if the user chooses to utilize solar or battery power, both of the power sources must be charged, and knowing the weather state is critical for that). Because there will be CO2 emissions if the user chooses to utilize the utility, power loss after the breaker from the charger controller and the AC-DC connection for the utility source will be measured. This task is assigned as follow working on Weather API week of October 26th – November 2nd, Data server will be worked on from November 2nd to November 15th.

D. Power Source Switching

One of the two basic forms of power supply design used in electronics goods is the switching power supply. Precision switching distinguishes these power supplies, allowing for designs that enable DC to DC, DC to AC, AC to DC, and frequency conversions. For power source switching to work we will be connecting an electrical relay input and write a code to switch either on or off. Once that is complete, we will connect power from DC adapter and charge controller. To get power to the load we will connect the power switch output to the pure sine wave inverter. We then configure the inverter outputs to voltage, and current sensor circuits. This task is assigned to the week of November 2nd to November 16th .

E. Course Assignments

The course assignments follow a pre-announced schedule, ranging over the course of the two semesters assigned to this project. The work breakdown structure has been completed during the week of October 18th and is followed by the project timeline. This assignment continues the work completed in the WBS, laying out a visual representation of the features, tasks, and subtasks that make up the overall project. After it's completion on November 2nd we will create a formal risk assessment, considering possible unforeseen delays and other issues that may arise in the completion of the first prototype. This assignment leads up the to first in-person demonstration of our prototype, taking place on November 16th. Currently we are planning to have implemented the majority of our features by this deadline, leaving the rest of the semester to improve the design and completing other course assignments. The last course assignment for the Fall 2021 semester is the progress technical evaluation. By this point all features should be fully implemented, leading up to the in-person demonstration which will consist of a technical discussion and demonstration of the first semester prototype. This assignment also requires a statical list of the content completed during the first semester. Beginning in the Spring semester of 2022, the first assignment is to revisit the team problem statement which forms the basis for the creation of our design. Using knowledge gained over the course of the Fall semester we will rewrite this assignment documenting our new understanding of the problem, during the week of January 25th – February 1st. Following this, we will create a device test plan, which will outline the methodology that will be implemented in testing the accuracy and reliability of the features listed in our measurable metrics, due February 8th. Next, we will prepare for the first in-person demonstration of our revised project on February 15th. In the following week there will be another writing assignment, focused on studying the market demand and competition for products similar to our energy management system. In the weeks leading up to the end of the semester we will complete a feature report, documenting the finalized features of our complete prototype, and begin preparing for the final end of project documentation and deployable prototype technical review on May 03rd.

VI. PROJECT MILESTONES AND TIMELINE

The project timeline was similar to our work breakdown structure, but it also required us to provide a visual representation of our task for the year. We created task list but this time we were able to separate it into three sections: hardware, software, and class assignments. The major objective for doing so was to figure out how many days it would take us to finish our assignment and have a completely functional project by the end of the class.

A. Fall Semester Milestones Hardware

The first large task for hardware is spot welding the battery together with nickel strips and harnesses and this will be done by Cameron and Inder and will take place between 26th October through 5th November. Once the battery is together, they can attach the BMS and this will take place during the same dates with the same team members. These tasks are critical to the project's survival as we will not have energy storage without it and cannot collect data about power use during hours with no sunlight. Next, Cameron, Inder, and Simron can attach the solar panel to a mount and wire together the charge controller, solar panel, and battery to complete that section of the system and this will take place from 5th November to 8th November. After that, the DC adapter can be connected to the charge controller to provide power in case of a lack of sunlight/battery power and this will be done by Simron from 5th November to 10th November. The prototype smart outlet must be built including the sensor drivers that will be written by Matt from 26th October to 2nd November and then these can be connected to the inverter outputs by Simron form 5th November to 10th November. Finally, the relay outputs to the automatic power switch and the power switch output to the sine wave inverter can be connected by Simron from 5th November to 10th November.

B. Software

The majority of the software will be running on the raspberry pi. The first task is to pull solar data from the weather API for the algorithm comparisons and this will be done by Cameron and Matt from 26th October to 2nd November. Next, we will need to collect the data from the smart outlets over wireless protocols and this script will be written by Matt from 7th November to 15th November. This will also require modifying the microcontrollers to utilize their wireless components and this program will be written by Matt from November 2nd to November 9th. The relays will be switched by the Pi and this interface will be written by Cameron from November 2nd to November 9th. Finally, the collected data will be pushed to a remote server for storage, and this will be done by Matt from November 2nd to November 9th.

C. Fall Semester Assignment Milestones

This project has a lot of milestones that we want to complete in an orderly manner. The very first three assignments were to create a team problem statement, make a design contract, and complete a work breakdown structure. Before we fully started, we had to form a team of four and after we were done with that. After the forming the team we each had an assignment to do which was the individual problem statement. With that finished and presented by each team member, we chose one of the team members' individual problem statements and made it into our team problem statement. There were a lot of other tasks completed we managed to write a design idea contract that was approved by the professor after we made couple of changed in out feature list. We spent a lot of time researching each thing we needed to buy, and after that was done, we created a work breakdown structure. This led to the creation of a project timeline with a list of events for both the fall and spring semesters, as well as the presentation of out project in the spring. The risk assessment, technical evaluation, and lab prototype are the next three milestones we expect to complete from the class assignments, which will be presented this fall in November and December. We will determine the important approaches and hazards that our project will provide during the risk assessment. We'll need to plan ahead for these dangers and come up with a list of potential solutions to mitigate them (since we are working with high voltage, we will need to do a lot of research and have the right equipment). For the technical evaluation we will be meeting in person on the 15th of November, where will be presenting our progress that has been done on the project so far. On the 15th of November, we will meet in person for the technical review, during which we will show our work on the project thus far. Lastly, we will need to prepare an oral presentation and present our working prototype in person on December 10th. As this will complete our fall semester class events. Our main focus on the class assignments during the fall semester was to get them done as soon as we can in the week, so we can have longer time period of working on our project.

D. Spring Semester Milestones

Our PERT diagram for the spring semester has a list of tasks and milestones that we will need to achieve in order to complete our project. In the spring semester, the milestones are mainly focused on the necessary assignments. Our punch list of tasks will be essentially complete in the fall semester, as seen in the GANTT chart and PERT diagram. As a result, the assignments in the spring semester will assist us in polishing our project. We'll update the code and make any necessary hardware adjustments. The testing and modification of certain elements to attain improved precision will e the main job. Furthermore, we will integrate our project together and fully assemble it. Both diagrams also indicate the spring semester assignments as milestones, because the assignments include tasks such as testing and market review. Which will be the emphasis of our work. Some milestones and tasks are still up in the air since, as we work on our punch list, we'll surely discover new aspects of our project that will become milestones in the spring semester. Out ultimate objective is to create a useful product and equipment. We have a concept of how this will be done, however our milestones and tasks will be changed and modified to ensure that the result is as planned.

VII. RISK ASSESSMENT

In this part, we will detect and evaluate any incidents that may have a negative influence on our workload, team members, assistants, or the environment. This will all be founded on the premise that when developing and creating our project, we would consider all conceivable eventualities. Implementing the various components to our will introduce numerous risk considerations when creating. Mechanical, hardware, and software problems such as inadequate network capacity, poor signal transmission, and component breakdowns are examples of these. These elements have an impact on the project and its overall success.

A. Hardware: The hardware makes up a significant percentage of the project and appears at various places along the critical path. This implies that any catastrophic failure might jeopardize our ability to achieve our deadlines.

1) Inaccurate Power Measurements

a) Associated Risks: Measuring power in our project is a risk if we get inaccurate values, we will not be sure what is working as expected.

b) Mitigation: Our mitigation for measuring power will be to use high quality lab equipment like an oscilloscope and ammeter to confirm our sensors and USB scope are accurate.

2) Hazards working with 110V AV

a) Associated Risks: Working with 120V AC power from the main outlet which has a change of death if in contact for too long.

b) Mitigation: When handling power sources at 120V AC we have several mitigations starting with team members only touching or working on the system when all power is off and sufficient time has passed for any capacitors to discharge. The main danger from the power outlet is mitigated by purchasing an adapter that will convert the 120V AC down to 12V DC so the portion we are building will have far lower and less harmful voltage; for the sine wave inverter output that is also 120V AC we will mitigate this with the inverter's wired on/off switch that will allow is to safely power down the inverter and load from a sufficient distance along with having the smart outlet inside a junction box that will have any internal and external wires wrapped in insulation. We will use circuit breakers that will detect a current larger than 10A in critical sections so that we have an automated shutdown if unsafe current is detected.

3) Improper Relay Setup / Heat dissipation

a) Associated Risks: Control of the relays is a risk in that the relays can melt from overheating

b) Mitigation: The relay risk is mitigated by using heatsinks with thermal paste to prevent overheating of the electrical components.

4) LiFePO4 Battery Cells Exploding

a) Associated Risks: the battery system uses lithium iron phosphate cells, which while known for their relativity safety compared to other lithium compositions, still carry a risk of over-heating and catching fire. With a configuration of seven 6 Amp cells in parallel, our battery pack can provide an instantaneous discharge current of over 40 Amps. When combined with a high enough voltage, this is easily enough to be fatal, or cause serious damage to vital and expensive components of our project such as the solar charge controller.

b) Mitigation: Fire risk from the battery system is mitigated by using a BMS to evenly charge all cells protect against overcharging along with the charge controller protecting against over voltage and over discharge. There is also a fireproof casing for the battery system as a final precaution along with a fire extinguisher.

5) Breaking Solar Panel

a) Associated Risks: Finally, the solar panel is an integral and expensive component of the project, which must be handled carefully to avoid damage to the photovoltaic cells and connection ports.

b) Mitigation: We must ensure that we can store the solar panel in one location on campus or at the home of one of our team members. Another thing we must do when driving with the solar panel in our automobile is to drive safely.

B. Software: The software will be the intelligent component of our system, aggregating and managing data to make it a smart EMS. The risks in this section are mostly connected to the software side of our project and how we may mitigate them so that we can finish on time.

1) Losing Files

a) Associated Risks: losing files can have a high impact on our project as files are necessary to understand schematics and run the programs.

b) Mitigation: Protecting against the loss of files in modern software projects is easier than ever with the use of Git so long as every team member is competent in using this tool. It will track changes and store all our documentation, code, and backup reports.

2) School Login Information

a) Associated Risks: If a team member is working on a certain code and they upload their code to a repository with their SSID and password written in the code.

b) Mitigation: WIFI credential exposure can be prevented by informing team members of the risk and enforcing a rule to not include one's networking credentials in code that is to be uploaded to the GitHub repository and when downloading file, they can insert their information in the noted locations.

3) Data Transmission issues

a) Associated Risks: loss of packets when transmitting the sensor data over WIFI is predicted to occur along with the ESP microcontrollers switching between reading an ADC and transmitting over the network while maintaining the network connection and meeting our feature list timing constraints.

b) Mitigation: Programming bugs have a high chance of affecting the project. However, the devices we chose to use have a long use history and large amounts of documentation. This documentation along with use of debugging tools and careful design of our programs will decrease the frequency and intensity of software bugs. Data transmission problems from the ESP devices to the Raspberry Pi are mitigated by designing the software such that it will check for internet connection before sending data to not lose information and if the connection is dropped it will cache the data to send once reconnected. The ESP32 is a dual core processor so multitasking can be used to collect data and maintain the connection

4) WIFI Data Link through School Servers

a) Associated Risks: The CSUS WIFI network, Eduroam, is different than a home WIFI network and is likely to present challenges getting a unique device to connect to it as previously is has been challenging to get unique devices such as Linux single board computers to be allowed network access by IRT.

b) Mitigation: The risk of enterprise WIFI Sacramento State uses can be mitigated by contacting IT at the school and checking for methods to add unsupported devices like getting up to date certificates and registering the device's MAC address.

C. External/Interpersonal Risks: Examining both internal and external factors that might affect the execution of a project by the stated deadline is an essential element of risk management. A lot has transpired in the COVID pandemic during the last few years. If the team agrees to meet in person, we will be faced with several constraints and requirements to comply with.

1) COVID-19

a) Associated Risks: As of November 2021, CSUS has established requirements for all on-campus students and staff to be fully vaccinated, wear face coverings when entering any buildings, and maintain social distancing in accordance with California guidelines. If one or more members of our team were to become infected with COVID-19, it would severely inhibit our progress towards completion as we would be forced to split the remaining workload between the remaining team members. While the impact of COVID varies greatly from person to person, it is a real possibility that an infection could lead to a level of sickness requiring a student or staff member to step down from their studies / work for the remainder of the semester.

b) Mitigation: Steps that can be taken to mitigate the effects of the COVID-19 pandemic include always practicing social distancing, maintaining awareness of large gatherings, and storing essential project hardware off-campus in the event of a shutdown.

2) School Shut down / lockout

a) Associated Risks: If the spread of a variant which is not protected against by currently available vaccinations were to reach levels requiring stay-at-home orders as in the year 2020, it is possible that the team would no longer have access to necessary facilities with which we need to complete the project.

b) Mitigation: To avoid having our components locked up in the CSUS locker. We can keep track of our needs by visiting the CSUS COVID guideline website on a regular basis. We may also begin keeping some of the pieces at the homes of team members who will be working on that component.

3) Shipping Delays

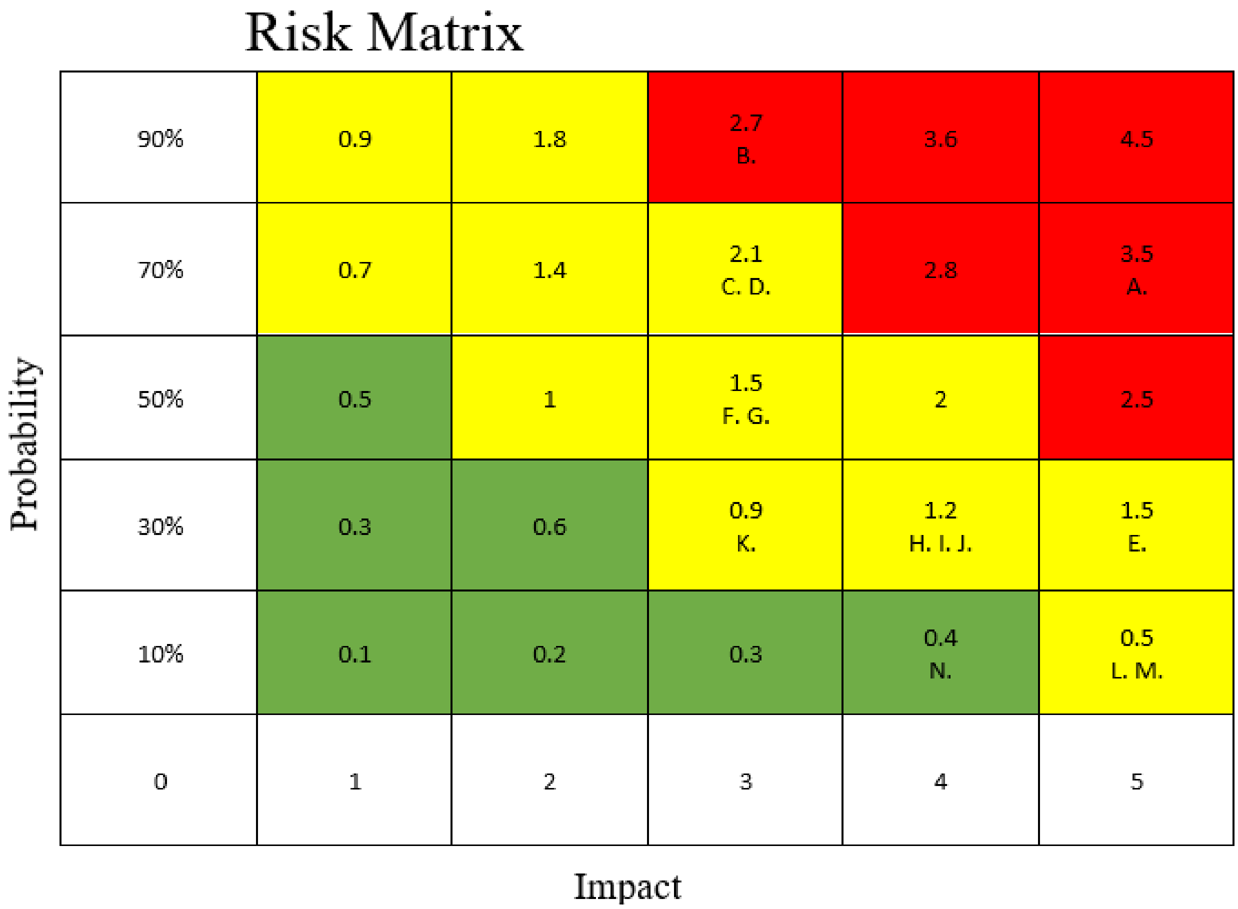
a) Associated Risks: Shipping delays are another issue that has both been faced and will continue to be an issue moving forward. Shipping companies such as FedEx have recently been experiencing issues with meeting deadlines and handling the large volume of online orders. This has already impacted our team, as we were forced to re-order 12 of the LiFePO4 cells included in our custom battery pack, as well as delays with delivery of our charge controller and relays. Relating back to earlier sections, it is also possible that we will need to rush order new or replacement parts in the event of a malfunction or unforeseen necessity. Increased cost and shipping delays are the main impacts of this risk, which can lead to both a higher budget than anticipated as well as falling behind our planned project timeline

b) Mitigation: Shipping delays and increased costs can be avoided through careful planning of necessary hardware and other components, as well as attention to detail when wiring and soldering to avoid burning out or destroying delicate components

4) Interpersonal Communication

a) Associated Risks: Beyond external factors, there also exists internal and interpersonal issues that can impact the progression of our prototype to completion by the December deadline. Communication is perhaps the most significant, as each team member has responsibilities and independent schedules that must be coordinated to meet the assignment deadlines.

b) Mitigation: Interpersonal risks such as communication relies heavily on each group member taking responsibility for their role in the project. This is achieved through active participation on team discussion forums, taking initiative on completing assignments and tasks, and communicating weekly schedules and workloads so that everyone is aware of the number of hours each member will be able to dedicate on a given week.



90%	0.9	1.8	2.7 B.	3.6	4.5
70%	0.7	1.4	2.1 C. D.	2.8	3.5 A.
50%	0.5	1	1.5 F. G.	2	2.5
30%	0.3	0.6	0.9 K.	1.2 H. I. J.	1.5 E.
10%	0.1	0.2	0.3	0.4 N.	0.5 L. M.
0	1	2	3	4	5

Figure 12. Risk Matrix [52]

TABLE III.
RISK MATRIX TABULATED [52]

Risk Matrix Table			
Risks	Probability	Impact	Rating (PxI)
A. Interpersonal Communication	70%	5	3.5
B. Shipping Delays	90%	3	2.7
C. Wifi Data Link through School Servers	70%	3	2.1
D. Data transmission issues	70%	3	2.1
E. School Shut-down / Lockout	30%	5	1.5
F. Inaccurate Power Measurements	50%	3	1.5
G. School login information	50%	3	1.5
H. Burning out MCU through improper wiring	30%	4	1.2
I. Breaking Solar Panel	30%	4	1.2
J. COVID-19	30%	4	1.2
K. Improper Relay Setup / Heat dissipation	30%	3	0.9
L. LiFePO4 Battery Cells Exploding	10%	5	0.5
M. Loss of files	10%	5	0.5
N. Hazards working with 110V AC	10%	4	0.4

VIII. DEPLOYABLE PROTOTYPE STATUS

In this portion of the report, we will go through our test plans for our laboratory prototype. Because our design incorporates both hardware and software components, our objective in testing is to have a variety of individual tests that will quantitatively assess the accuracy of our design to the measurable metrics stated in section III. The table in appendix G provides a more specific breakdown of which team members will be working on each test as well as an estimated timeline for when they will be completed.

1) Hardware Testing Plan:

A major component of our design, as well as the measurable metrics, is the accurate reporting of the voltage and current at the solar panel and load at a given time. To test this, we have comprised a series of four tests addressing these factors. First, we will use a multimeter to compare the voltage found at the smart outlet to that calculated through our ZMPT-101B voltage sensor. In order to accurately meet the metric, this reading must be within 3 volts (plus or minus) when connected to a 120 V AC source. For the current, we will use multiple known current sources, such as a desktop fan and heating element, to check the accuracy of the hall effect current sensor and ensure it is within 0.1 A over a range of 0.1 – 1.3 A AC. As documented in appendix G**,** these tests will be performed by Cameron and Inder, and Matt and Simron respectively. Following this, we will perform similar tests with a multimeter on the charge controller, comparing the voltage and current readouts from the solar panel to confirm it is accurate within 0.1V and 0.3A. These tests have been assigned to Matt, Inder, and Cameron.

The next metric that will be tested under this section involves the time delay of the two solid state relays. In order to ensure the switching times fall within the <10ms specification, we will use an oscilloscope to calculate the rise and fall times of both relays. Finally, we will compare how accurately the API forecast for solar radiation matches with our calculated solar panel production. This step will be time consuming, as multiple measurements will need to be taken over a series of weeks and changing weather conditions. To meet the metric, our system's production should be within one standard deviation of the expected values, throwing an error code if it is exceeded.

2) Software Testing Plan:

The other tests we need to do are related to the programming and other software we are using for the project. Starting with the microcontrollers, each of which contain internal timers to schedule a task such as sending data wirelessly. To confirm our measurable metrics we can user serial print outs from the microcontrollers to evaluate if they are sending data precisely every 5 seconds for voltage and current and every 30 minutes for the charge controller. These tests will be performed by Matt, Inder, and Cameron to be completed by 20th Feb 2022.

Another element of this metric is confirming the data transmission successfully finished and that the Raspberry Pi will always have complete data. We can test this by running a program to capture data from the wireless transmission and record it and compare to the microcontroller logs to ensure there is no loss. We also have to confirm that the microcontrollers perform their measurements to collect new data before transmitting it so we must repeatedly test the ADC and the reading of the charge controller. These tests will be performed by Matt, to be completed by 12th Mar 2022.

3) Results:

The finalization procedures for device testing for each of the project's features have been completed. The general purpose of testing the device is to guarantee that it fulfills the engineering standards and specifications laid out by the team at the start of this project. We are making certain that each component can be tested independently. We will be able to merge the elements into our functional gadget while remaining safe and honoring the social distancing guidance using tested and operating individual parts. A brief summary of the testing technique for each feature is provided here, as well as a discussion of the results and how they influenced the project. Appendix I contains all of the hardware tests that were performed and their findings, whereas Appendix II contains all of the software tests that were performed.

a) Hardware Testing Results:

We have tested the smart outlets' current and voltage sensors to confirm they are within the accuracy range specified by our measurable metric. These tests were completed as a team, with Matt and Cameron being responsible for operating the sensors, ensuring they are properly calibrated, and Simron and Inder using a multimeter to find reference voltage and current values to compare the sensors against. These tests were completed throughout the month of March, beginning on March 4th and ending on March 25th. These tests took much longer than originally anticipated due to issues encountered with the calibration of the sensors. We found that after updating other components of the project the sensors would report values outside of the accuracy range dictated by the metric, which then required additional calibration after full integration had been achieved. The final test results found that the voltage sensor was accurate within the metric of 3V (+/-) given an input voltage of 121 V, reporting values around 122 V. We also found that the current sensor did not scale linearly across a wide current range, so we chose to calibrate it towards the middle of our expected values, around 350 mA. With the four input currents we tested, ranging from 200 mA – 500 mA, the largest variance we found was at 500 mA, where the sensor was off by just under 0.1 A. This reading fell within the range of our measurable metric.

In order to test the switching times of our relays we used an oscilloscope provided by CSUS along with a power supply. A DC voltage of 5V was connected to the load side of the relays, with a probe being placed on both the control and load pins. The delay between the two signals when set to switch at a constant rate was found to be within the metric of 10 ms, averaging around 6.5 ms delay between toggling the relay and the load disconnecting. This test was performed primarily by Simron and Cameron.

b) Software Testing Results:

At the beginning of the second semester we were confident that most of the metrics could be easily met individually but were worried about some bottleneck causing a system slowdown that will miss a timing window. These turned out to be software bugs in mostly the Python program on Raspberry Pi but several issues within the smart outlet as well. Matt preformed the software testing starting in February and completed by April 1st, 2022; this was because software optimization in Linux and FreeRTOS is more suited to computer engineering. The limitations of our testing are from a lack of professional testing equipment that we can take back and forth to campus and leave outside on the system while running, so we used the college's lab resources alongside the open-source testing frameworks like Cprofiler (output list of function calls with the number of times called and statistics on time per call, total time inside function, average time in functions, etc). With this we could find the expensive poorly optimized parts and refactor to meet all metrics at once and consistently.

Several of the tests were for testing the values from the charge controller for accuracy and speed such as checking PV voltage, current, and power. To accomplish this on the ESP32 I simply reduced the timers reading the RS485 port and increased the clock speed. Then on both devices I can print out the time sent and received and confirm it is under 5 seconds every time. For the smart outlet there was a very similar procedure of speeding up the ESP32 and reducing any unnecessary processing tasks that were included for debugging and this was enough to easily meet the metric of checking current and voltage at the outlet in under 5 seconds. For the wireless transmission, print statements on both devices confirm the data is sent uncorrupted successfully and sent in under 10 seconds.

For the comparisons on the forecast data, this process is run immediately after the Pi has collected the wireless data and is compared to the JSON file containing forecast values and this is done in under 2 seconds and meets the metric for comparing every 30 minutes. We have notifications for when the solar is out of range statistically and when the system is running outside, we never receive them which means it is within 1.5 standard deviations of the mean of the day when there is sunlight. We also compared the solar panels power output to the forecast and can see it is accurate up to a limit since the forecast returns data for a whole week we decided to refresh the file every day to make sure we have the most up to date predictions.

The Raspberry Pi needed more work on making sure it was always listening for a connection and data so I used multiprocessing and threading modules to confirm the system can obtain the data over the network

IX. MARKETABILITY FORECAST

Smart electric grid technology has the potential to minimize CO2 emissions. The electric grid is divided into three primary components: generation, transmission/distribution, and consumption. The usage of renewable energy sources is part of smart generating (wind, solar, or hydropower). Our prototype employs a renewable energy source (solar), which will assist our user in minimizing emissions generated by the combustion of fissile fuels [54]. According to a study conducted by the Pew Research Center, around 43 percent of customers are willing to put solar panels on rooftops in order to assist in the United States [55].

A. Population, Demographics, and End Users

California has the highest capability for generating electricity from small-scale solar power in the country. According to the EIA, California accounted for 43 percent of all electricity-generating capacity from small-scale solar in the United States as of September 2019 [6]. As of 2020 California is requiring solar panels to be installed on most new homes. Alaska and Hawaii are also leaders in residential solar power compared to the rest of the United States [55]. Homeowners consider solar panels for a number of reasons. 96% of consumers have stated cost saving on utilities as a primary reason for installing solar, while 87% list environmental factors as an additional reason for their decision to switch to solar [55]. Homeowners that install solar power systems benefit from a variety of advantages, including cheaper utility bills, smaller carbon footprints, and potentially greater property values. According to a study Renewable Energy World, statistically those who adopt solar have tended towards higher income homes. However, over time, likely due to technological advancements improving costs, this has trended down to become more accessible to lower income houses [56]. [56, Fig. 13] shows the median income trend of household compared to solar adopters as of 2019. The report additionally found that while higher income houses did have a higher percentage of solar adoption, panels were still somewhat prevalent amongst low to medium income households.

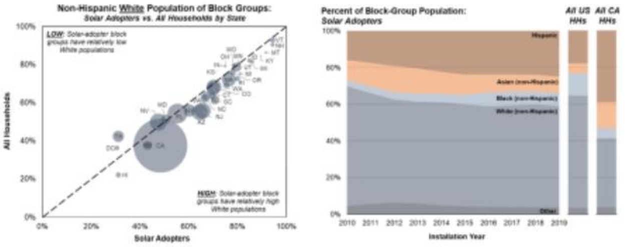


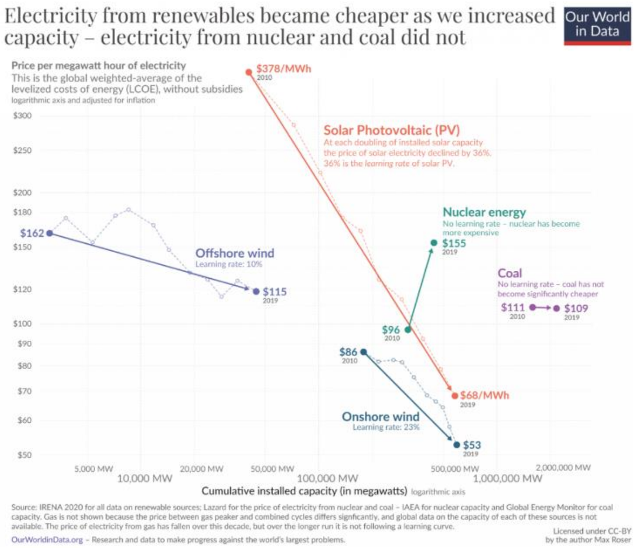
Figure 13. Solar Adoption Demographics [56]

Furthermore, when analyzing the most prevalent location of solar adoption, it was found that roughly 14% went to homeowners in rural areas, which make up 19% of the overall population studied. In other words, while this trend is also decreasing, homeowners in non-rural areas are more likely to have solar panels than those in rural areas. Finally, the study used census data to compare racial and ethnic trends amongst solar adopters, finding that they tended towards neighborhoods with high White and Asian populations. With that being said, like other trends discussed in this section this is trending downwards, and solar is becoming more accessible and common amongst all demographics throughout the United States [56].

If a solar system is constructed in a community that previously had no solar, neighbors who see it are more inclined to adopt it themselves. Moving into new markets may have a higher impact on low-income adoption rates than reaching out to lower-income families in current areas. Increasing sales to low and moderate-income households can also provide access to a bigger pool of potential consumers. According to research conducted by the United States National Renewable Energy Lab (NREL), 42 percent of roofs where solar electricity may be used are on low- and moderate-income dwellings [57].

B. Competitive Environment

Before considering the facts, our team felt rather confident in the market's growth for our product. Looking at the worldwide scene and the current surge in goods with comparable aspects of reducing CO2 emissions, we are certain that market research confirms our conclusions. There are only a couple of similar projects that are out there and are doing well for their business. But compared to our project they do not have all the features that we are providing and some of them are based out of state. Which can give our project the upper hand on there. Below is the chart [58, Fig. 14] that was presented by *Our world in data*, that shows how the prices in solar and renewable energy have decreased significantly. Which can help us get more customers on board.


Electricity from renewables became cheaper as we increased capacity – electricity from nuclear and coal did not

Source: IRENA 2020 for all data on renewable sources; Lazard for the price of electricity from nuclear and coal – IAEA for nuclear capacity and Global Energy Monitor for coal capacity. Gas is not shown because the price between gas peaker and combined cycles differs signficantly, and global data on the capacity of each of these sources is not available. The price of electricity from gas has fallen over this decade, but over the longer run it is not following a learning curve.

OurWorldinData.org – Research and data to make progress against the world's largest problems.

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Figure 14. Cost of Renewable Energy over Time [58]

When the cost of energy from new power plants is examined between 2009 and 2019, one graph shows how the cost of solar photovoltaic electricity (from solar panels) reduces from $359 per megawatt hour to $40, the cheapest of any power alternative on the chart and an 89 percent decrease. Because of the growing number of houses having solar panels, the price of solar panels may continue to decline as more individuals seek to install solar on their rooftops to save money on their power bills [58]. This prototype was tested in the Sacramento, California region. With SMUD in charge of power, the non-peak rate was cheap at 11c kwh, while the peak hour cost was 15 cents per kwh [7]. So, as part of our market plan, we will take this prototype and offer it in places with high electricity rates, such as the Bay Area, which as of March 2022 cost 31 cents per kWh. On average, the Bay Area pays at least 51.4% more than the US average per month [9]. As a result, marketing this project will be extremely beneficial in areas where power is costly, as customers will be more interested in the project and desire to purchase it in order to save money on their electricity bills.

Despite the hours of work already put into the device, the design is still in its early stages of development. We will need to take the product out into the market and run a lot of marketing drills where we can host samples and try to acquire additional investors since the deployable prototype will need to be improved for particular places depending on our market research. Because our prototype is currently a tiny sized RV or another small portion of a home. As a result, our investors can assist us in raising funds to develop a system capable of powering a whole house for our consumers. As a result, we are exploring a couple range for our project, with the deployable prototype serving as the product for RVs and tiny residences. Which may vary from $5000 to $10,000, and for a fully developed system that can work across the entire home, which can cost from $10,000 to $25,000. We can vary this product since it depends on which portion of the roof the customer wants to place the panels and how the wiring will be installed. This is the pricing we are aiming for, but it is subject to change if new rivals enter the market or if inflation rises.

C. Comparison of other Products by Features

Energy Management System products currently on the market serve a wide variety of consumers, with an array of feature sets for different uses. Perhaps most common are EMS's targeted at businesses, with features such as energy usage monitoring and optimization. One of the primary companies that offers such a product in California is Siemens, who create a variety of different software solutions from energy management to financing and industrial automation. The EMS offered by Siemens is software based, providing energy monitoring, analysis, and load management [10]. This is different from the system we created in that it lacks hardware and photovoltaic components, while also being focused on the business market rather than residential.

Other companies, such as Bluesky Energy, offer similar products to what we have created, focused on residential usage and providing UI-focused photovoltaic production and storage data allowing consumers to better monitor and control where they get their power. Their system, named GREENROCK Home, is marketed as an add-on to already existing solar infrastructure, providing increased efficiency and expandability. The Bluesky EMS uses Sodium Ion batteries, which are relatively safer and have a longer life span, at the expense of decreased energy density compared to lithium ion. This product focuses on the ability to automatically toggle devices such as washers, dryers, and heating to improve energy efficiency as opposed to our system which switches between solar and utility power at intervals designed to reduce carbon-dependent energy usage and save money during expensive peak-hours. Furthermore, our product has increased relevance to the local demographic of California residents due to the use of time-of-day electricity rates in the green energy algorithm. Bluesky is a company based out of Austria, with offices in Idaho, which may not provide a system as relevant to consumers within our target demographic [11].

Another common product type that consumers have been adopting to reduce carbon emissions and save money is the smart home. Similar to the aforementioned GREENROCK home EMS, these products focus on providing consumers with the ability to remotely control their power usage through smart outlets, lights, and other sensors. These providers, such as Google Nest, focus on providing consumers with the mans to automate their lifestyles, which can be useful for those willing to learn. The advantage our system has over products similar to this is that it both provides handsfree automation for cost savings and carbon reduction, but also includes personal power generation through photovoltaic cells.

By marketing our product towards people who are not interested in the learning curve of setting up their own smart home we believe we can compete with other well established residential carbon reduction solutions.

D. SWOT Analysis

Our team has a mix of the following strengths and weaknesses:

Strengths:

- Experienced use of embedded frameworks/build systems which makes adapting to supply chain constraints easier. We can pick any of the major manufacturers that compete for embedded microcontrollers and adapt to their product to save money and continue production.
- Development Operations: ability to automate technical tasks with cross platform scripting can save time and engineering cost. This crosses over into automated testing and backups of our system and work. Our board and embedded testing can be automated using similar skills to prove we are meeting our metrics. Automated backups of all operating systems and repositories is set to occur daily at a minimum using the 3-2-1 rule (3 backups 2 onsite and 1 offsite), this prevents data corruption and loss of months of work.
- Experience in the solar industry: Simron has experience in the California Energy Commission and Matt has experience in solar engineering and construction along with customer outreach & marketing. This could be a competitive advantage among startups of engineers with less diverse skill sets.

Weaknesses:

- Inability to design custom PCBs makes the mass production of cheap units less likely and limits us to OEM/proprietary products which increases cost. We would need to hire someone with PCB design and thermal management. This would also require someone have product owner experience and be responsible for picking smaller items like capacitors, filters, and lab equipment.

- Lack of access to capital: the team does not have enough industry connections and investor contacts to meet the capital requirements to create a hardware & energy startup. Significant networking among Angel investors is one potential way to address this weakness. Another potential issue from less industry connections is during unique crises that can affect solar business. Investors see gas costs increasing and solar and lithium costs decreasing, however the renewable production mostly comes from China and political crisis with the US can damage access to these materials.

The lifecycles of the technologies we chose has shown a fair resilience to repeated testing and the batteries in particular were chosen due to reduced fire hazard and longer lifespans. The microcontrollers have been left running for over 24 hours at a time with no crashing and are not known to break from temperature spikes. One weak link so far is the volatility of micro-SD cards that are used as the main boot and storage drive of our Raspberry Pi; this is mitigated so far with software by not writing to memory frequently and with backups but the modern solution is to use the Raspberry Pi Computer Module 4 which has a PCIe slot to allow normal SSD and M.2 drive usage. Our solar panel and inverter have not shown any signs of insufficient performance and are not known by customers to be low quality.

E. Estimated Potential Follow-on Opportunities

We anticipate creating upgradable options including inserting relays into the outlets to allow remote toggling of power sources, a subscription service to use our software that could use machine learning and location data to anticipate when the customer will be home and in need of power. Locking customers into a subscription mitigates loss of revenue needed for development for future products. Solar panels and batteries along with Linux ARM devices do have a lifespan and repeat customers after a few years is another income stream.

X. CONCLUSION

A. *Societal Problem*

Fossil fuels in general have provided us with the energy which is needed to propel our cars and even our homes and businesses. Even though fossil fuels have many disadvantages, it has provided us with the majority of our energy needs. Consuming fossil fuels releases greenhouse gasses that heat the biosphere as well as causing other ecological problems and because of climate change governments around the world must switch to carbon neutral energy sources. Renewable energy sources such as wind, hydro, and solar do not release greenhouse gasses and are part of the solution to this global issue.

There are many challenges in adapting existing grid infrastructure to accommodate renewable sources. Demand for electricity varies throughout the day and many renewable sources are inconsistent and need assistance improving the quality of power. Previous generations of grids did not allow for real-time management of energy production and delivery. However, today in the US it is possible for consumers to sell excess power back to utilities. There are many other changes in policy that are aiding the transition such as net-zero metering.

Renewable energy also has problems with efficiency such as solar which can only convert a small portion to electricity. Due to weather variability, it is difficult to predict the capacity wind turbines will operate under at a given time. Hydropower can also have negative environmental impacts from damming and is affected by floods and drought.

Energy also needs to be stored for later use when the renewable source has faded and there are a variety of methods for storage. Which method to use depends on many factors but an increasingly common method is battery storage systems. Lithium-ion batteries have seen a dramatic decrease in price and technology has made possible their usage in small electronics, electric cars, and residential & commercial systems. California is a leader in renewable energy however still 79.7% of electricity comes from non-renewable sources so there are many adaptations that need to occur [6].

B. *Design Idea*

We propose to build an energy management system to address the concerns of climate change and the necessity of adapting to renewable energy. This project is unique in that it incorporates power control from three energy sources, namely solar power, battery storage, and utility power. Furthermore, it will be controlled by a MCU that takes data from voltage and current sensors and decides the most cost-efficient and effective power source at a given time based on Time-of-Day electricity rates specifically for the Sacramento area and the power generated by the solar panel. SMUD has provided us with information regarding the average power consumption of home in Sacramento, which came to 750 kWh per month or roughly 25 kWh per day [7].

The hardware needed to realize this design includes a 100W solar panel, custom-built lithium-ion battery pack, solar charge controller, AC/DC Inverter, DC/AC converter, relay, Raspberry Pi, wall outlet, several ESP32 MCU to take voltage/current measurements at the load, multiple voltage/current sensors, and a server to store data and host the website. The ESP32 uses MQTT framework to send data via Wi-Fi. The Raspberry Pi sends that data to the server and controls the relays to switch power by computing what is most efficient. A weather API will be used by the Pi to help calculate if the solar is going to be efficient. The solar panel will be connected to a pulse width modulator which will control the charging of the battery.

The project will be self-funded, and the prototype will take about 480 hours to complete. The project modules are assigned based on who has prior expertise dealing with certain technology, since this can assist us in completing the assignment more quickly and efficiently. This will aid us during the project, and if one person completes their work ahead of schedule, they will be able to assist with another activity that has to be completed.

C. *Work Breakdown Structure*

The Work Breakdown Structure is a narrative device based upon the table found within appendix D, which provides an overview for the work packages and timeline necessary to complete the project by the assigned deadlines. We have separated the feature set into five primary sections, including power supplied, power switching, green energy algorithm, voltage and current monitoring, and course assignments. These features are then further broken into tasks and subtasks, which are then individually assigned estimated start and completion dates as well as the person who will be working on it. By creating this table we provide a two-semester overview of the overall project through both semesters, which is to be further supplemented by section IV, project timeline.

D. *Project Timeline*

Our timeline is a helpful summarization and breakdown of the general family the various tasks belong in such as Class Assignment or Hardware. In appendix E the PERT diagram and Gantt chart visualize the complex relationships between tasks, semester, milestones, priority, team member responsibility, and estimated dates with durations. The Gantt chart, with color-coded priority and worksheet structure, are a quick way for readers of this report and team members to reference the detail associated with each family of tasks. The PERT diagram show the flow of the tasks and milestones until the project is complete along with dates, team members assigned, and duration of the task. This is a visualization of potential bottlenecks in the implementation such as the “Green algorithm” that will interpret data and switch power sources and if dysfunctional will have large consequences for the following tasks such as connecting and using the relays.

E. *Risk Assessment*

The risk assessment assignment was needed find risks at every part of the system. With various expensive components it was crucial to create a plan to mitigate that risk. Also, due to Covid-19, the ways we work on the device will alter, since one of the big risks we had was shipping delays and supplies for certain parts we need. We also needed to analyze the risk posed by pandemic and create a strategy to overcome those challenges. Overall, we categorized and graded each section by severity. We graphically displayed the rank of the risk variables which are being considered, which did allow our team to clearly see the risks we will be dealing with working on our project.

F. Problem Statement Revision

Due to the complexity of the climate change issue, we decided to focus on energy management systems instead of just battery management systems. In our first study, we evaluated various renewable energy sources, such as wind and solar. We also looked into energy storage systems that are rarely used but are important for the home. Our findings revealed that the MQTT wireless transmission protocol was well-suited for low-power consumption and was less prone to errors. Another solid design decision was the use of LiFePO4 batteries, which are safer than traditional lead acid batteries. Our design should be simple to use and address the needs of non-computer-smart users. We should also consider incorporating a relay switch to allow users to turn off and save energy.

G. Device Test Plan

In order to confirm our device prototype meets the standards outlined in section B, Design Idea, and specifically the measurable metrics found in table I, we have outlined a device test plan. To test the hardware components of our design we will be using two primary testing devices, a multimeter and oscilloscope. The multimeter will be used to check the voltage and current readings of our panel and sensors to confirm they are accurate to the specification listed in the punch list. The oscilloscope will be used to obtain graphs of the switching of our solid-state relays to confirm the rise and fall times are within 10 ms. To meet the measurable metrics for software, we will be using timestamps to test the frequency in which we are receiving data on the Raspberry Pi from the solar charge controller and smart outlet. The team members responsible for each of these tests have also been listed in this section, as well as in appendix G., Device Test Plan along with an estimated timeline for their completion.

H. Market Review

In order to determine the viability of our prototype as a product, we performed a market review that examined possible target demographics, competitors with a feature-by-feature comparison to our design, and performed a SWOT analysis. As stated in our design idea contract, our target consumers are single family homes in Sacramento, CA. We have determined that in order to reach a broader customer base, with whom a reduced electricity bill would be more appealing, it would be beneficial to expand the current scope of our ‘Green’ algorithm to apply to areas with different electricity rates and plans than those in Sacramento. Competitive products that appeal to a similar demographic include other EMS’s available such as those produced by BlueSky, which focuses more heavily on automated scheduling of high-power devices such as washers. In the SWOT analysis we examine the strengths and weaknesses of both our prototype and the team as a whole, as well as determine what some of the key weaknesses in the design are that could be improved if the product was to be pushed onto the market.

I. Testing Results

After finishing our test plan, we have confirmed we meet the measurable metrics found in table I. We tested our hardware components using two main devices, a multimeter and oscilloscope. We were able to determine the voltage and current readings of our panel and did in fact confirm we met the metrics. Primary use of the oscilloscope was used to test the solid state relays fall times are within 10ms using the graphs we were able to obtain. Using a Raspberry PI for our software testing to test the frequency in which we receive our data which is from the smart outlet and solar charge.

J. End of Project Documentation

Throughout the course of this project the team has gained valuable insight into some of the processes involved in completing a project involving multiple critical tasks and assignments. Some of the assignments proved essential to ensure the team progressed on time throughout the build process to meet assigned deadlines. As a team, we became increasingly more efficient at finishing assignments over the course of the two semesters as we better understood the strengths and weaknesses of individuals, and where it would be necessary for everyone to work together. The system we have created is something we are proud of, and meets are initial goal of allowing the user to reduce their carbon footprint by generating a good portion of their energy needs from renewable sources. Aside from the technical aspects and research, assignments such as risk assessment, work breakdown structure, and marketability forecast provided us with the opportunity to learn skills we can take with us as we transition to industry with the conclusion of the semester.

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GLOSSARY

Energy Management System: A system to control electric utility grids to monitor and optimize power generation and distribution

Solar Charge Controller: A solar powered voltage and current regulator

Superconducting energy storage system (SMES): Energy storage system that uses a superconducted coil to store electrical energy in the form of a magnetic field.

Compressed Air Energy Storage (CAES): Energy storage method that pumps air underground and expands with natural gas.

Pumped Hydro Energy Storage (PHES): Energy storage method that uses two reservoirs to pump water to higher ground when energy is cheap.

Li-ion: Lithium-ion batteries are the most common battery that are also some of the cheapest to produce with high power density.

Solar panel: are used to convert light from the sun, which is composed of particles of energy called “photons”.

Raspberry pi: Pi is a small, low-cost computer the size of a credit card that connects to a computer monitor or television and uses a standard keyboard and mouse. It's a capable little device that allows people of all ages to learn about computers and programming languages like Scratch and Python.

AC: Alternative current is another name for it. The typical electricity that comes out of power outlets is known as power, which is described as a charge flow with a periodic change in direction.

DC: Direct Current is another name for it. A linear electrical current flow in a Straight line and can originate from a variety of sources such as batterie and solar cells
Voltage Sensor: This sensor is used to monitor, compute, and determine the voltage supply. The sensor is capable of determine if the voltage is AC or DC.

Current Sensor: A device that detects current and transforms it to a voltage that may be measured.

ESP32: Is a system on a chip with useful and high-quality properties.

MPPT: Maximum Power Point Tracking is a type of charge controller that maximizes energy usage

Appendix A. Hardware

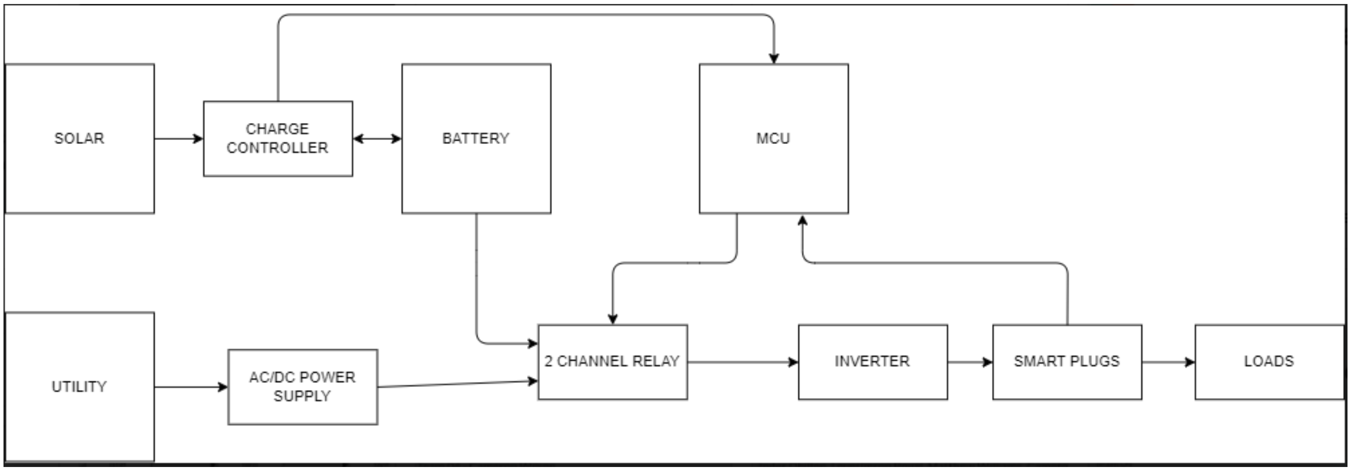

Figure A1. First Semester Block Diagram [52]

Figure A2. LiFePO4 Battery [52]

Shown in [52, Fig. A2] is the side profile of the LiFePO4 battery that was designed and built by the team early in the spring semester. It is comprised of 28 cells in a 4 series 7 parallel configuration, with a capacity of ~42Ah at 12.8-13.4 V

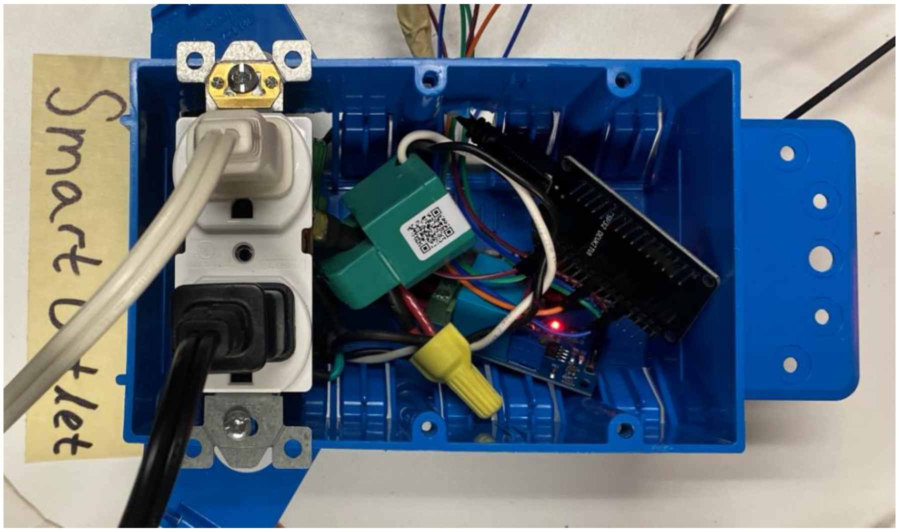

Figure A3. Smart Outlet [52]

Figure A4. 100W Solar Panel

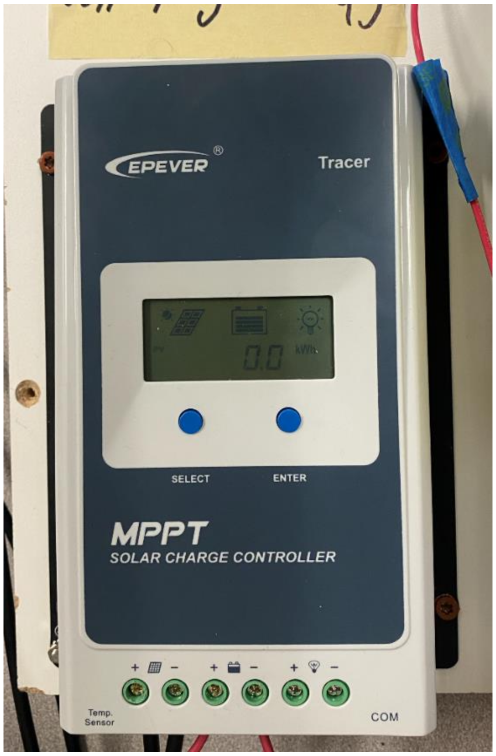

Figure A5. EPEVER 30A MPPT Solar Charge Controller

Figure A5. DC Power Converter

Figure A6. 25A Solid State Relay

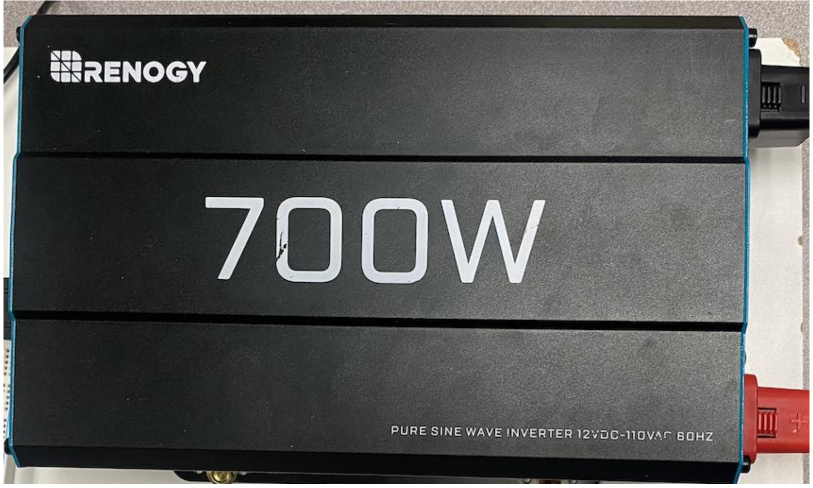

Figure A7. Renogy 700W Pure Sine Wave Inverter

TABLE A-I.
HARDWARE TEST PLAN [52]

Test ID	**Test Description**	**Start Date**	**End Date**	**Person Responsible**	**Expected Results**	**Actual Results**	**Pass/Fail (To Measurable Metrics)**
1.0	Use a multimeter to check voltage sensor is accurate to +3/-3V at 120 V	02/07/22	02/08/22	Cameron, Inder	117 – 123 V	122 V	Pass
1.1	Use a multimeter to check current sensor is accurate within +0.1/-0.1 A from 0.1 to 1.3A	02/07/22	2/08/22	Matt, Lovesimron	Within 0.1 of actual current	Varied between +/- 0.09 of actual current	Pass
1.4	Use multimeter to check voltage readout at panel is accurate within +0.1/-0.1V	2/19/22	2/20/22	Cameron, Inder	Within 0.1 V of measurement provided by solar charge controller	Matched expected results	Pass
1.5	Use multimeter to check current readout at panel is accurate within +0.3/-0.3 A	2/19/22	2/20/22	Lovesimorn, Inder	Within 0.3 A of measurement provided by solar charge controller	Matched expected results	Pass
1.9	Use oscilloscope to test delay time of solid state relays, <10ms	3/24/22	4/1/22	Matt, Inder, Cameron	<10 ms	6.4 ms	Pass

Appendix B. Software

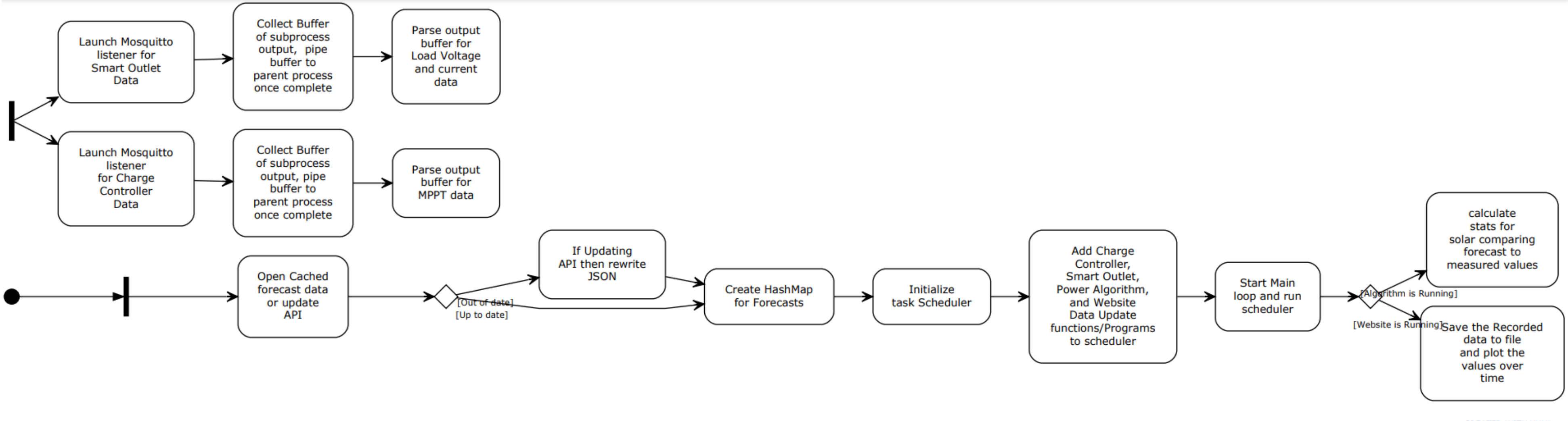

Figure B1. Raspberry Pi Main Program Flowchart [52]

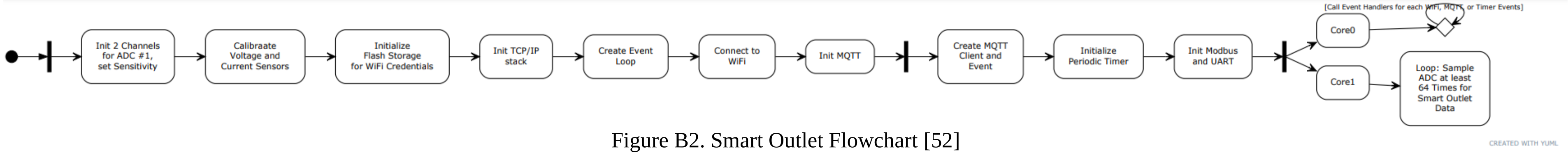

Figure B2. Smart Outlet Flowchart [52]

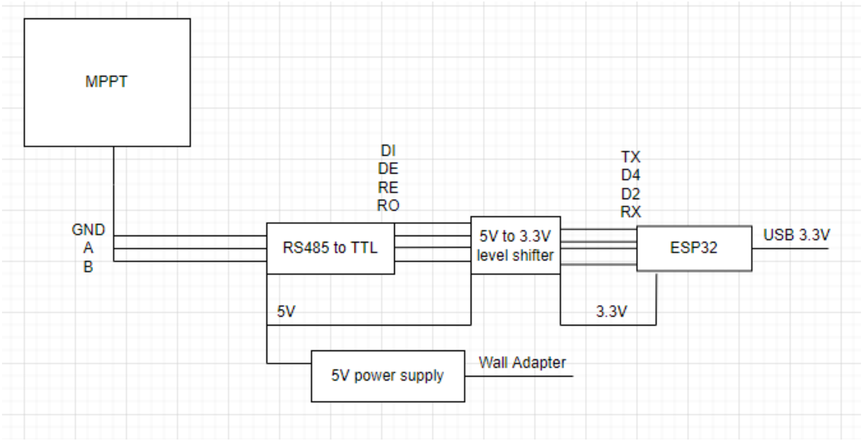

Figure B3. Modbus Circuit Block Diagram [52]

TABLE B-I.
SOFTWARE TEST PLAN [52]

Test ID	Test Description	Start Date	End Date	Person Responsible	Expected Results	Actual Results	Pass/Fail (To Measurable Metrics)
1.2	Run software with timestamps to confirm voltage is checked at the load is 5 seconds or less	2/08/22	2/08/22	Matt, Cameron	Voltage can be read in 2 – 5 seconds	Consistent reading in under 5 seconds	Pass
1.3	Run software with timestamps to confirm current is checked at the load is 5 seconds or less	2/08/22	2/08/22	Cameron, Inder, lovesimron, Matt	Current can be read in 2 - 5 seconds	Consistent reading in under 5 seconds	Pass
1.6	Run software with timestamps to confirm frequency of voltage at panel is 5 seconds or less	2/20/22	2/20/22	Matt, Inder	Frequency of voltage can be read in 2 - 5 seconds	Consistent reading in under 5 seconds	Pass
1.7	Run software with timestamps to confirm frequency of current at the panel is 5 seconds or less	2/20/22	2/20/22	Matt, Inder, Cameron	Frequency of current can be read in 2 - 5 seconds	Consistent reading in under 5 seconds	Pass
2.0	Use timestamps to confirm solar production is compared to expected values every 30 minutes	3/04/22	3/04/22	Matt, Cameron	Solar production is compared immediately after collecting sensor data, comparisons under 2 seconds	Consistent comparisons to expected values every 30 minutes	Pass
2.1	Use timestamps to confirm data is sent wirelessly to server every 10 seconds	3/04/22	3/04/22	Matt, Cameron, Inder, Lovesimron	Wireless data sent immediately after collection in under 5 seconds	Consistent data transfer in under 10 seconds	Pass

Test ID	**Test Description**	**Start Date**	**End Date**	**Person Responsible**	**Expected Results**	**Actual Results**	**Pass/Fail (To Measurable Metrics)**
2.3	Confirm each wireless data transmission completes successfully	3/12/22	3/13/22	Matt	Wireless data reaches destination successfully	Consistent successful transfer of data	Pass

Appendix C. Mechanical Aspects

The primary mechanical aspects of this design relate to the wiring and securing of components to the wooden board. We used screws to secure the power adapter, inverter, solar charge controller, relays, and smart outlet to the board so that it can be moved without completely disassembling all of the components. We also used spade bits with a drill to places holes in the board at strategic locations so that wires could be routed underneath the board, saving space and making the overall design easier to follow and understand.

Figure C1. 14 AWG Stranded Wire

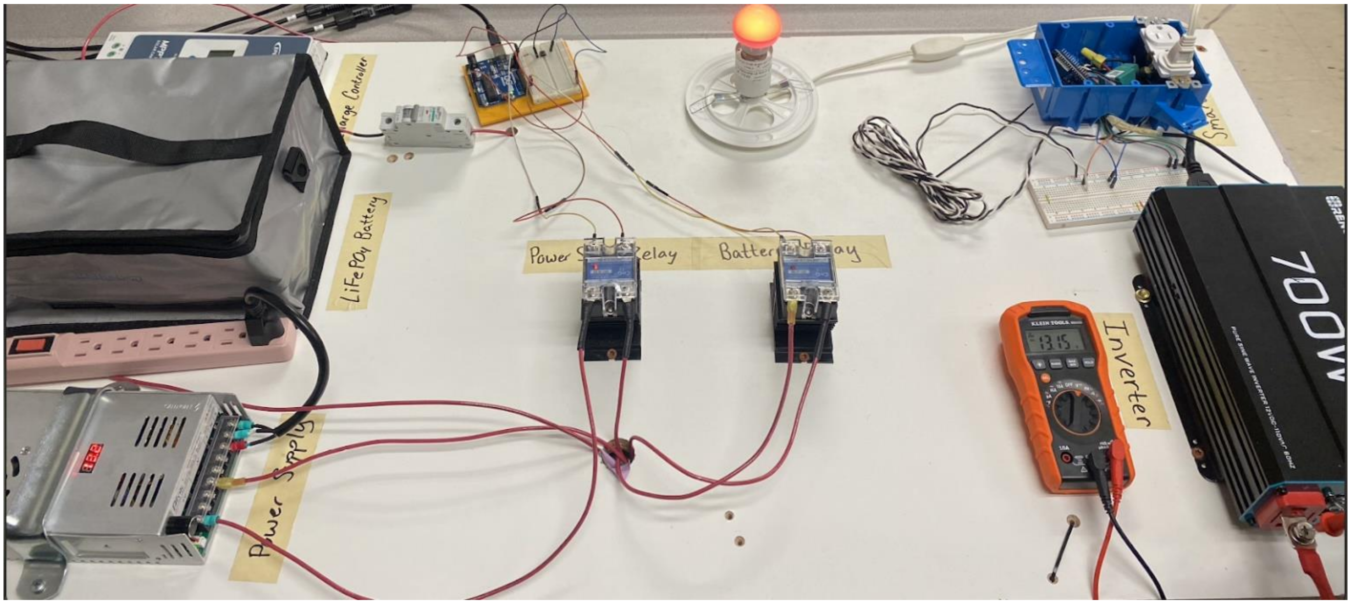

Figure C2. Rapid Prototype Wiring and Layout

Appendix D. Work Breakdown Structure

TABLE D-I.
WORK BREAKDOWN STRUCTURE [52]

Feature	Task	Subtask	Person	Time
1. Power Supplied from carbon-efficient source	1.1 Setting up solar panel, battery, Charge controller	1.1.1 Spot weld battery cells, connect BMS and test to ensure functionality	Cameron, Inder	10/26-11/02
		1.1.2 Attach solar panel to mounting hardware, wire to charge controller and battery	Cameron, Inder, Simron	11/02-11/09
2. Monitor panel and load voltage and current	2.1 Configuring smart outlets	2.1.1 Current sensor driver	Matt	10/26-11/02
		2.1.2 Voltage sensor driver	Matt	10/26-11/02
		2.1.3 Wireless data transmission	Matt	11/02-11/09
	2.2 Data transmission from panel to MCU	2.2.1 Connect MCU to rs485 port to send production data to main MCU	Matt/Cameron	11/02-11/09
3 "Green" Power Algorithm	3.1 Configuring Raspberry Pi	3.1.1 Implement weather API	Matt/Cameron	10/26-11/02
		3.1.2 Send data to server	Matt	11/02-11/09
		3.1.3 Receive data from outlets	Matt	11/06-11/16
4. Power Source Switching	4.1 Electrical Relays	4.1.1 Connect relay input to MCU and write code to switch on/off	Cameron	11/02-11/09
		4.1.2 Connect power from DC adapter and charge controller	Simron	11/02-11/09
		4.1.3 Connect relay outputs to automatic power switch	Simron	11/02-11/09
	4.2 Power to load	4.2.1 Connect power switch output to pure sine wave inverter	Simron	11/02-11/09
		4.2.2 Connecting inverter outputs to voltage/current sensor circuits	Simron	11/09-11/16
5. Course Assignments	5.1 Work Breakdown Structure	5.1.1 Creating WBS table	Cameron, Inder	10/19-10/26

Feature	**Task**	**Subtask**	**Person**	**Time**
		5.1.2 Writing main section, introduction, abstract, E.S, conclusion	Cam, Matt, Inder, Simron	10/19-10/26
	5.2 Project Timeline	5.2.1 Creating charts and diagrams	Simron	10/26-11/02
		5.2.2 Writing sections for assignment	Cam, Matt, Inder, Simron	10/26-11/02
	5.3 Risk Assessment	5.3.1 Writing sections for assignment	Cam, Matt, Inder, Simron	11/02-11/09
	5.4 Progress Review	5.4.1 In-Person demonstration of prototype progress	Cam, Matt, Inder, Simron	11/16
	5.5 Progress Technical Evaluation	5.5.1 Technical discussion of design idea	Cam, Matt, Inder, Simron	11/30-12/07
		5.5.2 Remaining tasks for Fall semester	Cam, Matt, Inder, Simron	11/30-12/07
		5.5.3 First semester statistics	Cam, Matt, Inder, Simron	11/30-12/07
	5.6 Revised problem statement	5.6.1 Writing sections for revised statement	Cam, Matt, Inder, Simron	1/25-2/01
	5.7 Device Test Plan Report	5.7.1 Creating a device test plan	Cam, Matt, Inder, Simron	2/01-2/08
		5.7.2 Writing sections for assignment	Cam, Matt, Inder, Simron	2/01-2/08
	5.8 Progress Demonstration	5.8.1 In-Person demonstration of revised project	Cam, Matt, Inder, Simron	2/15
	5.9 Market Review	5.9.1 Research into market for EMS systems	Cam, Matt, Inder, Simron	2/22-3/01
		5.9.2 Writing sections for assignment	Cam, Matt, Inder, Simron	2/22-3/01
	5.10 Feature Report	5.10.1 Writing Feature report	Cam, Matt, Inder, Simron	3/01-3/08
	5.11 Mid-Term Progress Review	5.11.1 Test Results Report	Cam, Matt, Inder, Simron	3/29-4/05
		5.11.2 Demonstration of project progress	Cam, Matt, Inder, Simron	04/05
	5.12 Deployable Prototype Technical Review	5.12.1 Demonstration and final review of finished prototype	Cam, Matt, Inder, Simron	4/26
	5.13 Final Documentation Report	5.13.1 Two-Minute video summarizing project	Cam, Matt, Inder, Simron	4/26-5/03
		5.13.2 Finalizing E.O.P Documentation	Cam, Matt, Inder, Simron	4/26-5/03

Appendix E. Timeline Charts and PERT Diagrams

TABLE E-I.
GANTT CHART [52]

Task Family	Semester	Milestone	Task	Status	Priority	Assignee	Team Leader	Start Date	End Date	Duration	Hours	Finished TASK	September	October	November	December	January	February	March	April	May
Class Assignment	Fall 2021		Assisgnment 1a - Individual Problem Statement	100%	Normal	Team	Cameron	9/1/21	9/12/21	12 Days	107.5 hours	Completed	🟦								
			Assignment 1b - Team Societal Problem	100%	Normal	Team	Cameron	9/12/21	9/27/21	16 days	93 hours	Completed	🟦								
			Assisgnment 2 - Design Idea Contract	100%	Normal	Team	Cameron	9/27/21	10/4/21	9 days	80 hours	Completed		🟦							
			Assignment 3 - Work Breakdown Structure	100%	Normal	Team	Cameron	10/19/21	10/25/21	7 days	22 hours	Completed		🟦							
			Assisgnment 4 - Project Timeline	100%	Normal	Team	Inder	26-Oct	11/1/21	7 days	18.9 hours	Completed			🟦						
			Assisgnment 5 - Risk Assessment	100%	Normal	Team	Inder	11/2/21	11/8/21	7 days	14.4 hours	Completed			🟦	🟦					
		Moving Prototype	Assisgnment 6 - Project Technical Evaluation	100%	Normal	Team	Inder	11/30/21	12/6/21	7 days		Completed				🟦					
			Assisgnment 7 - Laboratory Prototype Presentation	100%	Normal	Team	Inder	11/30/21	12/10/21	11 days	33 hours	Completed				🟦					
	Spring 2022		Assisgnemnt 1 - Revised Problem Statement	100%	Normal	Team	Matt	1/25/22	2/1/22	8 days							🟦	🟦			
			Assignment 2 - Device Test Plan Report		Normal	Team	Matt	2/1/22	2/8/22	8 days									🟦		
		Progess Demonstartion	Assisgnment 3 - Market Review		Normal	Team	Matt	2/22/22	3/1/22	8 days									🟦		
			Assisgnment 4 - Freature Report		Normal	Team	Lovesimron	3/1/22	3/8/22	8 days									🟦	🟦	
			Assisgnment 6 - Progess Review		Normal	Team	Lovesimron	3/29/22	5-Apr	8 days										🟦	
			Assisgnment 7 - Deployable Prototype		Normal	Team	Lovesimron	4/19/22	4/26/22	8 days										🟦	
			Assisgnment 8 - Final Documentation Report		Normal	Team	Lovesimron	4/26/22	5/3/22	8 days											🟦
Task Family	**Semester**	**Milestone**	**Task**	**Status**	**Priority**	**Assignee**	**Team Leader**	**Start Date**	**End Date**	**Duration**			**September**	**October**	**November**	**December**	**January**	**February**	**March**	**April**	**May**
Hardware	Fall 2021		Spot Weld Battery	100%	High	Cameron / Inder	Cameron	10/26/21	11/5/21	11 Days		Completed		🟥	🟥						
		Test to ensure functionalit	Connect BMS	100%	High	Cameron / Inder	Cameron / Inder	10/26/21	11/5/21	11 Days		Completed		🟥	🟥						
			Attach solar panel to mounting	100%	High	Cameron/. Inder/Simron	Cameron / Inder	11/5/21	11/8/21	4 Days+J:K		completed			🟥						
			Wire Charge Controller, Solar Panel, and Battery	100%	High	Cameron/ Inder/Simron	Cameron / Inder	11/5/21	11/8/21	4 Days		completed			🟥						
			Current Sensor Driver	88%	High	Matt	Cameron / Inder	10/26/21	11/2/21	8 Days				🟥	🟥						
			Voltage Sensor Driver	88%	High	Matt	Cameron	10/26/21	11/2/21	8 Days				🟥	🟥						
			Connect relay input to MCU	95%	Normal	Cameron	Inder	11/5/21	11/10/21	5 days					🟦						
			Connect power from DC adapter and Charge Controller	100%	High	Simron	Inder	11/5/21	11/10/21	5 days		copmleted			🟥						
			Connect relay outpus to automatic power switch	100%	High	Simron	Inder	11/5/21	11/10/21	5 days		Completed			🟥						
		Test to ensure functionalit	Connect power switch output to pure sine wave inverter	100%	Normal	Simron	Inder	11/5/21	11/10/21	5 days		completed			🟦						
		Checking Power to load is working	Connecting inverter outputs to voltage / sensor circuits	100%	Normal	Simron	Inder	11/5/21	11/10/21	5 days		completed			🟦						
Hardware	Spring 2022	Problems	Fixing Errors as they come up	55%	🟦	Team	Everyone	10/20/21	5/30/21	Full semseter			🟥	🟥	🟦	🟥	🟥	🟥	🟥	🟥	🟥
		Rewiring Poject	Rewiring the inverter to relay	100%	Normal	Everyone	Matt	1/29/22	1/29/22	1 day	2 hours	Completed					🟦				
			rewiring the Battery to MPPT Charge Controller	100%	High	Everyone	Matt	1/29/22	1/29/22	1 day	1 hour	Completed					🟥				
			Tesing the MPPT charge Controller	90%	Normal	Cameron/ Inder/Simron	Matt	1/29/22	1/29/22	1 day	1 hour						🟦				
			Test the whole project for functionality	20%	High	Everyone	Matt	1/29/22	2/5/22	2 day	5 hours						🟥	🟥			
					🟦																
					🟦																
					🟦																
					🟦																
Task Family	**Semester**	**Milestone**	**Task**	**Status**	**Priority**	**Assignee**	**Team Leader**	**Start Date**	**End Date**	**Duration**			**September**	**October**	**November**	**December**	**January**	**February**	**March**	**April**	**May**
Software	Fall 2021 / Spring 2022	Configuring Raspberry PI	Implement Weather API	50%	High	Matt/Cameron	Inder	10/26/21	3/26/22	6 months				🟥	🟥	🟥	🟥	🟥	🟥		
			Send Data to server	60%	High	Matt	Inder	11/2/21	3/2/22	5 months					🟥	🟥	🟥	🟥	🟥		
			Receive data from outlets	70%	High	Matt	Inder	11/7/21 & 1/10/22	11/15/21 & 2/10/22	9 days					🟥		🟥	🟥			
			Wireless Data Transmission	50%	High	Matt	Inder	11/2/21	11/9/21	8 days					🟥						
			Write Code to switch the relay on / off	65%	High	Cameron	Inder	11/2/21	11/9/21	8 days					🟥						
		Problems	Fixing errors in the code	50%	High	Team	Everyone	9/1/21	5/30/21	Full semseter			🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
		building a Website	Build a User Friendly Website	10%	Normal	Matt	Matt/Lovesimron	1/31/22	4/1/22	90day							🟦	🟦	🟦	🟦	
			recalibrating Current Sensor	60%	Normal	Cameron	Matt	1/29/22	2/4/22	1 day	4 hours						🟦	🟦			

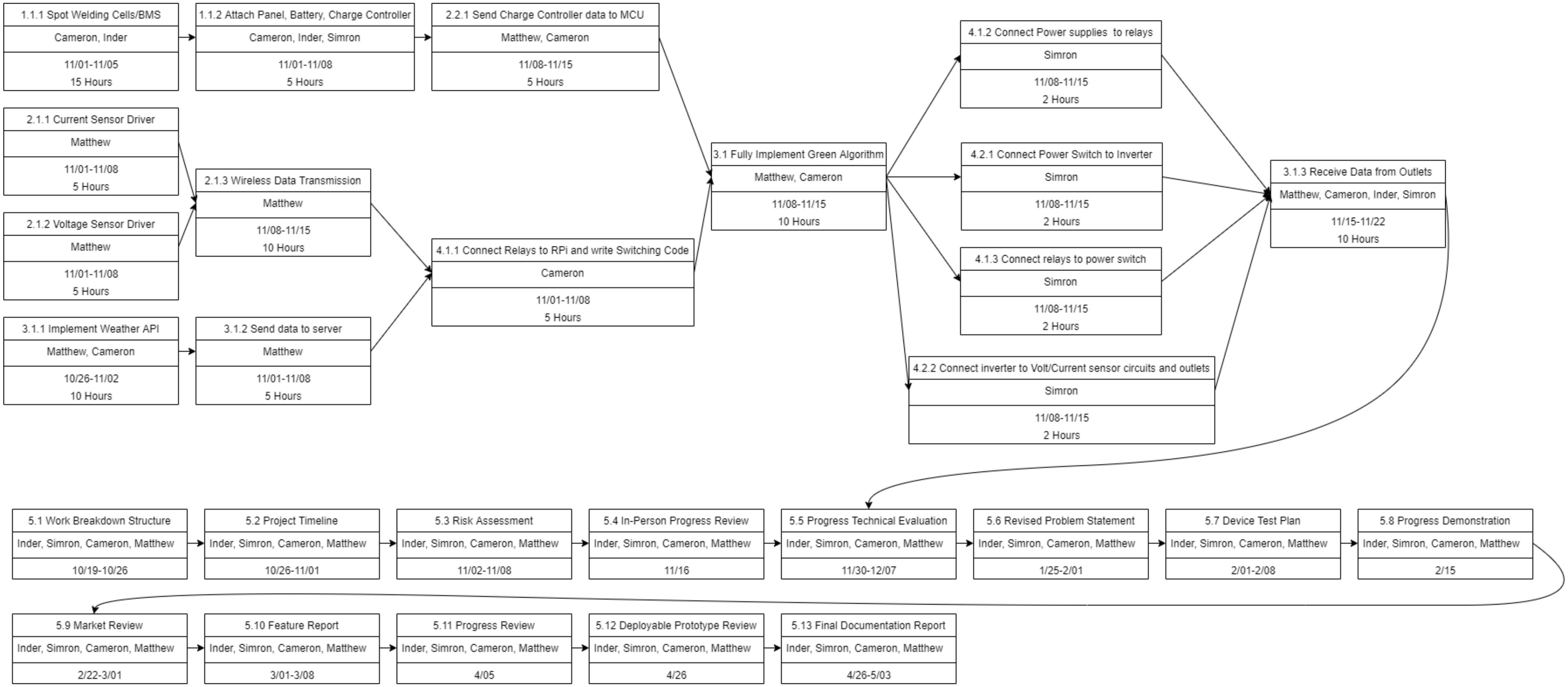

Figure E1. PERT Diagram [52]

Inder Dhillon

Education

B.S.E IN ELECTRICAL & ELECTRONIC ENGINEERING | IN PROGRESS | CALIFORNIA STATE UNIVERSITY SACRAMENTO

- Expected Graduation date: June 2022, CSUS GPA: 3.45

Experience

OPERATIONS MANAGER | RDI EXPRESS INC | JUNE 2017 – CURRENT

- Excellent Team member
- Conclude all person job allocated in a timely and productive way, controlling both logistics and transportation demands within an organization.
    - Budgets
    - Schedules
    - Route planning

CASHIER | WALMART | FEBRUARY 2017 – SEPTEMBER 2018

- Manteca, CA
- Given exemplary customer support
- Performed some jobs, including self-checkout, and front desk management

Additional Projects, Experience, and Skills

PROJECTS

- State Machine Application (Team Member): Designed traffic stop lights on the breadboard by FPGA and set the timer and clock in Verilog
- Low Pass Filter: Low pass filter using a simulation on PSpice.
- Raspberry pi: GPIO traffic light project on breadboard. Created a python code that was similar to how Traffic lights function
- Raspberry pi: Some security camera. Which was made with camera and active sensor which was used to record any movement and take a picture of intruder and pi will send it to user's phone.
- Energy Management System Designed an EMS prototype that draws power from 100W solar panel, 42Ah custom LiFePO4 battery, and utility . Determines the lowest carbon emission power source of the time of day using ESP32 to read data from the MPPT solar charge controller via RS485 and Modbus Protocols.

Additional Experience

- As a Community Manager for the university, I oversaw a Discord server. My main responsibilities included keeping everyone organized and assisting with the distribution of news to the community.
- Working for a shoe reselling company as a marketing manager. My main responsibility was to publicize the company so that I could make as many relationships as possible with the major resale firms. Along with that we worked as Lemon Proxies and Redditt Proxies.

Extracurricular

- Sac State IEEE Club – Club member who works with seniors on projects and in the organization of engineering programs
- Jakara Movement – We as a team go out to places where help is needed, working alongside a members of the local Sikh Community to strengthen my role as a leader in (MISL 209 – Stockton, Modesto, Tracy, Lodi)

LANGUAGES AND TECHNOLOGIES

- Main Programming Language: C
- Familiar with C++, Verilog, MATLAB, Multisim Tool, ADS (Advanced Design System), Oscilloscope, MS office, Excel

Cameron Wilson

Education

B.S.E IN ELECTRICAL & ELECTRONIC ENGINEERING | IN PROGRESS | CALIFORNIA STATE UNIVERSITY SACRAMENTO

- Expected Graduation date: June 2022

A.S IN COMPUTER SCIENCE | COMPLETED | AMERICAN RIVER COLLEGE

Experience

ASSISTANT MANAGER | MR PICKLES SANDWICH SHOP | DECEMBER 2016 – AUGUST 2020

- Communicated expectations between management and team members
- Handled catering scheduling and delivery
- Assisted with scheduling and product ordering
- Maintained professionalism and standards of store

Additional Projects, Experience, and Skills

PROJECTS

- 2-Step Authentication Security System: Implemented a RFID security system including RFID tags, pin pad, and UART communication for automated email confirmation
- Patch Antenna Project: Utilized HFSS and MATLAB to design patch antenna to meet frequency specifications
- Raspberry pi: Some security camera. Which was made with camera and active sensor which was used to record any movement and take a picture of intruder and pi will send it to user's phone.
- Energy Management System Designed an EMS prototype that draws power from 100W solar panel, 42Ah custom LiFePO4 battery, and utility . Determines the lowest carbon emission power source of the time of day using ESP32 to read data from the MPPT solar charge controller via RS485 and Modbus Protocols.

Additional Experience

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LANGUAGES AND TECHNOLOGIES

- C++, Familiar with Python, Verilog, VHDL
- Electronic Soldering, Troubleshooting, Oscilloscope, DMM

Matt Williams

Education

B.S.E IN COMPUTER ENGINEERING | IN PROGRESS | CALIFORNIA STATE UNIVERSITY SACRAMENTO

- Expected Graduation date: June 2022, CSUS GPA: 3.87

Experience

EMBEDDED SOFTWARE ENGINEER | BARCO INC | JAN 2022 - PRESENT

- Working on the image processing team writing C++ on Xilinx SoCs for software updates including embedding/disembedding and then routing audio I/O through 12G-SDI, DisplayPort 1.2, HDMI 2.0, and Dante AV-over-IP
- Prototyping fture products through emulation using Vulkan API to process audio and 4K 60Hz video
- Writing Python scripts to automate the building of software/firmware installers, managing repositories & servers, and enhancing debugging and testing

SOLAR DESIGN INTERN | GRID ALTERNATIVES | JUNE 2017 – OCTOBER 2017

- Experience in solar PV installation, completed engineering designs of residential solar systems & increased efficiency of energy production, assembled and delivered solar permits for Sacramento City/County, assisted with inventory management, and participated in client outreach

Additional Projects, Experience, and Skills

PROJECTS

- **Energy Management System**:
- Designed an EMS prototype that draws power from a 100W solar panel, 42Ah custom LiFePO4 battery, and utility Determines the lowest carbon emission power source for the time of day using an ESP32 to read data from the MPPT solar charge controller via RS485 and Modbus protocols
- Energy sources are switched through solid-state relays and flow into a pure sine inverter; smart AC power meters were built to determine the load and to send data to a server via MQTT.
- Raspberry Pi 4 hosts a server for ESP32 clients to send data to. The Pi calculates Std. deviation of solar power to solar forecasts read via web API returned in JSON. Communicates power warnings to user via SMPT emails. The Pi hosts a Flask site for user to interact with their battery & solar data, energy use, and costs
- **16-bit MIPS Pipelined CPU**:
- Group project implementing MIPS architecture including features such as register forwarding, exception handling, and hazard detection. Includes instructions such as signed division, branch less than, halt, etc. 5 stages separated by register buffers for pipelining
- **Embedded Piano**:
- Using Texas Instruments TM4C123 to implement a basic piano using the board's 4-bit DAC to generate high-quality sound. Uses breadboard buttons to select which note to play such as C, D, E, or G by calling interrupts at the frequency of the note to generate a sine wave
- **Unix XV6 kernel programming:**
- Built features for the Unix kernel Version 6 ported to RISC-V and run in QEMU, features include system calls, userspace programs, improving virtual memory. Implemented various OS algorithms for CPU scheduling (Round Robin, FCFS, Shortest-Remaining time first); process synchronization (counting semaphores, mutex locks, POSIX multithreading); page replacement algorithms (Least-recently used, Optimal replacement, Second-chance replacement)
- **STM32F303K8 Microcontroller Weather Station:**
- Implemented temperature and humidity sensor with both DHT11 and thermistor using an ADC, transmitted data via UART to Raspberry Pi, and displayed graphed data using matplotlib in python and Flask as a web server

LANGUAGES AND TECHNOLOGIES

- Main Programming Languages: C++, C, Python, Assembly, Java, Verilog, MATLAB, SQL, HTML/CSS, JavaScript
- Technologies: PSPICE, GDB, DMM/Oscilloscope, Git/SVN, CMake, Valgrind, Linux kernel programming, Vivado, Cadence

Coursework

- Embedded Systems, Computer Architecture, Signals and Systems, OOP in C++, Operating Systems Design, Circuit Networks, Computer Networking Fundamentals, Probability and Random Signals, Software Engineering

Extracurricular

- CSUS IEEE Officer Spring/Fall 2018- Took leadership role in IEEE and assisted with recruitment, organizing events, fundraising/grant writing, building website, and building relationships with local companies

Lovesimron Boyal

Education

B.S.E IN ELECTRICAL ENGINEERING | IN PROGRESS | CALIFORNIA STATE UNIVERSITY SACRAMENTO

- Expected Graduation date: May 2022

Experience

ENGINEERING STUDENT ASSISTANT | CALIFORNIA ENERGY COMMISION | AUGUST 2021 – CURRENT

- Will provide technical assistance to staff, research and prepare responses to correspondences, and become familiar with the state energy efficiency codes, manuals, forms, and computer software used to assist the building industry

STUDENT ASSISTANT | OFFICE OF APPEALS | AUGUST 2020 – FEBURARY 2021

- Working as an engineering assistant to provide support and resolve technical issues.
- Researching and responding to public and stakeholder inquiries as they arise.

Additional Projects, Experience, and Skills

PROJECTS

- Senior Project 2021: Starting Fall 2021
- State Machine Application (Team Member): Designed traffic stop lights on the breadboard by FPGA and set the timer and clock in Verilog.
- Low Pass Filter (Team Member): Low pass filter using a simulation on PSpice.
- Patch Antenna Design Project (Team Member): Designed, Simulated, Fabricated and Measured a patch antenna using HFSS software and generating a layout.
- Microstrip Circuits Design: ADS simulation with microstrip transmission lines.
- Common Emitter Biasing: DC bias of a common-emitter amplifier

Extracurricular

- Sac State IEEE Club: Member of the club working with seniors in projects and in organizing engineering events.

LANGUAGES AND TECHNOLOGIES

- C, Python, Verilog basics, 3D printing, Microcontrollers, FPGA, Bode Plot and Smith Chart.

Appendix G. Vendor Contracts

No vendors were used in the design and build process of this project.