Design Document

Team: GAPS

Project: Mobile Science Lab

Date: 05/11/2018

Table of Contents

2 Revision History

Date	Author	Revisions Made
26 Sep 2017	All Fall 2017 Members	Document Created
01 Dec 2017	All Fall 2017 Members	Document Updated to reflect progress made between 09/26/17 and 12/01/17
14 Feb 2018	All Spring 2018 Members	Document updated to reflect progress made between 01/12/17 and 02/14/18

3 Design Status

Phase 1: Project Identification	**Status:** *Completed* **Semester:** *Fall 2017*
Phase 2: Specification Development	**Status:** *Completed* **Semester:** *Spring 2018*
Phase 3: Conceptual Design	**Status:** *Completed* **Semester:** *Spring 2018*
Phase 4: Detailed Design	**Status:** *In Progress* **Semester:** *Spring 2018*
Phase 5: Delivery	**Status:** *To be completed** **Semester:** *Spring 2018*
Phase 6: Service / Maintenance	**Status:** *To be completed** **Semester:** *Summer 2018*

Project Identification

4.1 Description of Project Partner

The EPICS GAPS Mobile Science Lab team will be working with Tom Braak, who runs a non-government, non-profit organization in Haiti. His goal in working with EPICS is to improve the science education available to the youth in his local area. The overall goal of our project is to create a mobile science lab that can be moved from school to school, and which will be used in Haiti's rural areas where there are fewer available resources like microscope, projectors, and basic power. Depending on the success of this project, our hope is that this mobile lab can be implemented in other areas, such as rural India or Colombia, to further promote and encourage science education. All of these locations, along with our Haiti location, have a high demand for science equipment and interactive science learning.

4.2 Stakeholders

Tom Braak:
Tom Braak is the Executive Director at Faith In Action International through which he lives and works in Haiti. He will be the one directing the use of the mobile lab units in Haiti, and interacting with the local community. Mr. Braak will initially be using the mobile science lab himself but also will be teaching other locals how to use the lab once the project is solidified. This will allow the science labs to be used and moved around from school to school without him, which maximizes the amount of children we can impact and allows for sustainable practices regarding the project. He is our primary point of contact as well as the source of more specific requirements.

Purdue University - Professor Oakes
Professor Oakes is the advisor for this project at Purdue University. His goal with the project is to introduce the mobile lab concept in Haiti, but he is also interested in expanding this to other countries and working with other universities. If the unit in Haiti is successful, he wants to partner with other organizations and universities across the world so as many underdeveloped areas as possible can have their own mobile science

labs. This first wave of mobile science labs will determine the life and success of this overall project for him.

Purdue University - Professor Gray

Professor Gray, an Electrical Engineering professor, is also an advisor on the project, so he largely oversees the technical section of solar power of the project. One student on the mobile science lab is doing Electrical Engineering senior design, and Professor Gray oversees this student's work and acts as this student's the senior design advisor.

Children of Haiti:

Children in Haiti will be the ones being taught and benefiting from the mobile science labs. The labs will be used so the children can complete hands-on or otherwise engaging experiments that supplement the learning they already do in school. It is essential that the labs work as well as possible so that the students can focus on the content, as this will likely be the first time they're learning about or hearing this information.

Context Considerations

In rural schools in Haiti, teachers normally teach lessons with just a textbook and chalkboard. The teacher writes notes on the board and the students copy this down and simply memorize it. There are no hands-on activities that go along with the learning; the students are not given the chance to perform experiments to reinforce what they've learned in class and develop further interest in the subject. These lessons are also not very exciting for students, so their learning experience is less engaging than desired. This leads to a general lack of critical thinking among the students. Tom Braak has told the team that if a student is asked a question whose answer they have not explicitly learned, they cannot generate this answer on their own.

Because Haiti is a very agrarian nation, agriculture is critical to the livelihood of the citizens. However, the children are not taught to see the cause and effect of environmental processes, so they do not understand important agricultural practices. For example, erosion has very far-reaching effects in Haiti, but people cannot see the link between removing trees near a waterway and an increase in erosion because they were not taught about this link in school. This can lead to communities doing things that makes the problem worse, and although they may realize this, they may not know how to change anything. Tom Braak also told us that currently, local farming practices come from religious beliefs. For example, the people in Haiti do not link nutrient rich soil with fertile land, but instead think spirits in the ground cause an area to be fertile. Our goal is to provide examples to the people of Haiti of the science that is involved in agriculture.

Additionally, the country has a very poor power distribution. Only a quarter of the country has access to power, and about half of these connections are illegal. The lab will also be used in remote areas where connections are not possible, which means that it will need its own sustainable power source to run electronics. This also poses a threat because if power is very rare and in high demand, we have to consider that the power system could be targeted for theft. Therefore, security of the labs will have to be considered throughout the design.

User Needs

The user's overall need is to educate children in schools in the remote villages of Haiti. However, with this solution, the science lab has more challenges than the compiling of experiments. Most of these needs serve the purpose of accommodating Haiti's terrain and culture.

- The first requirement is that the mobile lab must be able to be transported in the back of a small pickup truck, so the base must be smaller than 4'x4'.
- The lab must also be able to be carried from the truck to the schools by two men, which translates to a weight less than 80 lbs (estimated by Tom Braak).
- In order for it to get inside of the school, it must also be able to fit through a standard size door.
- The mobile labs must be durable to survive the terrain and weather of the region.
- Haiti is in the Caribbean, so there is risk of hurricanes, heavy rains, and destructive winds.
- Tom also told us that flooding rivers is very common, so the lab will need to be waterproof when it is not in use.
- The terrain is very mountainous, so the lab should also be able to withstand the shaking and rattling it may undergo during transport as well as the possibility of being dropped.
- The unit needs to be able to have power in any weather condition as well as when a generator is not available. Tom Braak has a generator, but there are going to be multiple labs, so the generator will not be able to power all of them simultaneously. In order to have several labs powered at once, we will provide a solar power supply. However, because the labs also need power when the

weather does not permit solar power to be used for extended periods of time, they also need to be able to be powered by the generator.

4.3 Project Objectives

The first objective of the mobile science lab team will be to deliver a module featuring environmental science and agronomy to our partner in Haiti. This will involve two main components: (1) the lab itself (the container for the educational materials), and (2) the experiments, lesson plans, and other contents. The team's objective in regards to the physical lab will be to deliver a solution that allows the lab to be stored and transported in Haiti. The objective regarding the contents is to find or make experiments that are at an appropriate level for the students at the schools. Once we have found appropriate experiments, we will determine which ones are suitable to our budget and other specifications.

The second objective of the team is to build a power system for the lab. To do this, the first goal is to meet the demands of the loads from the mobile lab. Once the loads have been estimated, a solar power system will be designed that can supply enough power for the demand. The last objective of the power system is to have a power distribution unit that will automatically switch between solar power or generator power, such that no connections have to be moved by the user.

4.4 Outcomes/Deliverables

Deliverables for the project include:

- Containment units for storage and transportation of lab
- Lab equipment needed for experiments
- Lesson plan on different experiments that can be completed with lab
- Instructions on how to use and transport lab
- Solar power system
    - Layout instructions
    - batteries
- Switching AC/DC power distribution unit
- Solar Power Manual

4.5 Expected Semester Timeline

The semester milestone includes the delivery of an agricultural and environmental science module by the last couple weeks of this semester. Specifically, our module will contain experiments that that teach children about water erosion, wind erosion, the formation and composition of soil, and microorganisms. To power the experiments, we will also need to have a source of electricity, so we are also working to develop a solar power system. This system will have the capability to be powered by solar panels or a generator, depending on the user's needs. Because this module is our end goal for the semester, smaller steps along the way would take the form of construction benchmarks. The two most important benchmarks will be the physical construction of the module and the incorporation of the educational materials.

5. Semester Documentation

5.1 Team Members

Logan Quaas (Design Lead)

- lquaas@purdue.edu
- Electrical Engineering, Senior
- Responsible for delegation of tasks to team members
- Responsible for completion of semester milestone
- Responsible for assisting team members with their work

Arpan Adhikari

- adhikar1@purdue.edu
- FYE, Freshman
- Solar Team

Carolina Aguilar

- aguila11@purdue.edu
- Electrical Engineering, Junior
- Solar Team

Caesar Guillen

- cguillen@purdue.edu
- FYE, Freshman
- Solar Team

Andy Dong

- adong@purdue.edu
- Electrical Engineering, Junior
- Modeling and building the circuit for solar power

Andrew Peritore (Financial Officer)

- aperitore@purdue.edu
- FYE, Freshman
- Responsible for developing experiments
- Responsible for GAPS budget, grants, and purchase requests

Jenna Harrison (Project Archivist)

- harri670@purdue.edu
- FYE, Freshman
- Responsible for developing and testing experiments

Nick Hellgoth (Team Member)

- nhellgot@purdue.edu
- FYE, Freshman
- Responsible for developing experiments

Yousuf Abbas (Team Member)

- yabbas@purdue.edu
- Electrical Engineering, Junior
- Responsible for developing solar panel testing procedure

5.2 Current Status and Location on Timeline

Project identification specification development, and conceptual design has been completed. The team is currently finishing detailed design.

5.3 Goals for the Semester

The mobile science will be composed of different boxes that each have a different scientific subject focus. This semester's goal includes the completion of the agricultural lab box. The prototype will include the contents of the agricultural box that will be used for the soil experiments as well as training instructions for the topics involved in the experiments.

5.4 Semester Budget

Project 2: Mobile Lab		
	Items required for project	**Estimated Cost**
2.1	Microscope	150
2.2	Snap Circuits 203 x 2	76
2.3	Metering	20
2.4	Solar Panels x2	200
2.5	Storage Solution	450
2.6	Beakers x6	36
2.7	Computing Solution	300
2.8	Projector	100
2.9	Batteries x2	280
2.10	Charge Controller	100
2.11	Inverter	30
2.12	Wires	60
2.13	Contactor	40
2.14	Relays	40
2.15	Monitoring Relay	40
2.16	Delay Relay	25
2.17	Plexiglass	$30.00
	TOTAL	$1,977.00

The following budget tentatively describes the expected expenses for the 2018 spring semester. The budget will be updated as the design needs change.

EPICS funding will cover $600.00 of expected expenses, while a Purdue Service Learning Grant will cover the remaining amount, $1,377.00.

6. Current Design

6.1 Conceptual Design

After specification development the team split into two sub-teams. One team is working on the experiments and box for the mobile lab, and another is working on the power system. We will first discuss the conceptual design of the experiments and containment for the lab. Second, we will discuss the conceptual design of the power system. This system is being designed to meet requirements of the experiments in this lab. However, similar power systems could be used for other mobile labs based that will likely be completed in the future.

Design Requirements/Specifications

After completing specification development, we moved into conceptual design. By talking with our project partner and advisors, we came up with a list of requirements for the mobile lab and the power system.

Some of the design requirements for the lab are that:

- The mobile lab box fits through a door.
- The weight of each unit box does not exceed 80 lbs.
  - This requirement was validated by confirming that 80 lbs can be handled by two adults without much difficulty.
- The volume of the box easily fits in the back of the transport truck used in Haiti.
  - This requirement was mentioned by our Project Partner, as he owns trucks in Haiti with which would be transport our final product.
- The mobile lab is shock-resistant to impacts during transport.
  - The mobile science lab will contain equipment that could be easily damaged due to uneven road conditions. Hence, proper precautions must be taken to prevent any damage.

- The mobile lab contains a power source to power the lab and its components.

    - The lab will contain several pieces of equipment that need to be powered and thus requires a power source.
- The mobile lab is secure and theft-proof.
- The mobile lab is transportable via airplane (does not contain any hazardous materials and can clear customs).
    - The mobile science lab will needed to be delivered in Haiti after being built in the United States, so this requirement is very important.

Equipment malfunctions would detract from the effectiveness of the experiments, so these must be anticipated and prevented before they occur.

Power System Specifications

Along with these overall design requirement, we also came up with the design requirements for our power system. There were two types of design requirements. The first requirements are ones that we will have take into account when coming up with different options, such as weight and hours of operation. The second type of requirements are ones that we will have to design solutions to, such as being waterproof and safe from theft.

They include:

- 4 hours of use per day
    - Validated after confirmation with our advisors on how long they expect the mobile lab to be used on average every day.
- Powered by solar power or a generator
    - Validated after confirmation with our project partner that he owns a generator that we could use. However, we also considered that the generator may run low on fuel or might not be available all the time, so we needed to consider another power source option.
- Transported with lab
    - Validated after confirmation with our advisors that the power system would need to be transported with the mobile science lab. However, it would not necessarily be the entire power system, and could include only the batteries.
- Safe

- Easy to Operate
- Transportable parts weight less than 80 pounds
    - Validated after confirming that 80 lbs was the threshold weight that could be easily carried by two adults.
- Water-proof
    - Validated after researching that the weather in Haiti includes a lot of rain.
- Operate in ambient temperatures up to 110°F
    - Validated after researching the average and maximum daytime temperatures experienced in Haiti over the last 30 years. This requirement is important to confirm that none of our power equipment could malfunction due to unexpectedly high ambient temperatures. The internal temperature of the power system will almost always be higher than the ambient temperature.
- Access to replacement parts

Experiment specifications

The specifications that we have developed and received from our project partner for the development of the experiments are as follows:

- The experiments for the mobile lab system need to be fun and engaging for the children.
- Experiments need to educate children such that they see how scientific principles apply to the world they live in.
- Materials and ingredients for the experiments need to be available within Haiti.
- The experiments need to foster critical thinking in the children.
- Our project partner requested specific concepts be taught and certain questions be answered within subject umbrellas.
    - Environmental Science
        - Soil - what it is, what it does, what worms do in soil, the function of organic matter in soil, why it is important to feed soil
        - Erosion - addressing wind and water erosion and what effects they have on the environment
        - Importance of trees
    - Biology

        - Microorganisms - What are they? How do we know they are really there? What do they do? How do they make you sick?
            - Relate all the microorganisms information back to the need for clean water.
    - Chemistry, biology, and physics
        - Not the main focus for the first module, but these specifications will developed later in the project's development.

Possible Solutions

Solar Power System

The team came up with multiple designs for the power system. Along with these designs, we created detailed scenarios of how the project partner could use these solutions. This allowed us to determine if the solutions would be feasible, based on how we intend to use them. With each solution, we still had to allow for a generator to be used instead of our system. A generator could be favorable to solar power in situations like poor weather or the solar-charged batteries not having time to recharge. To make this transfer possible, we will design an automatic switching power box. This would default to use the power from the batteries or solar cells, but if a generator is plugged in, the unit will switch to the power from the generator. We have researched such a switching box, but will begin designing one next semester after the solar power system is developed.

There were three main solutions we came up with for the power system, which are discussed below.

Our first solution is a large and central solar power system. This system would be set up in one location selected by the project partner, and would not be able to be moved after its installation. It would act as a “home base”, and would be used to charge batteries going out with the lab itself. These batteries would be used for a day of operating the lab and then brought back to the central system to be charged. As stated in the requirements section above, we expect a day of use to consist of 4 hours of operating the power system at full load. The batteries could also be charged from a wall outlet if available. Additionally, we could use multiple sets of battery banks so that one set could be charging while the other is being used with the lab.

The second solution is a small solar powered system that is transported with the lab and set up wherever the lab is used. This would be large enough to power smaller items in the lab, but not the larger ones. In order to use the more powerful items in the lab, the user would have to connect a generator. As with a standard home solar power system, a battery would be included to capture any excess energy. With this energy, the battery could be used for short amounts of time that the sun is not out, like a passing rain shower. However, if the sun is not available for an extended amount of time, the generator would have to be used.

Our third solution is to transport a large solar power system with the mobile science lab. This system would be large enough to power everything in the lab. Like the second system, it would have a battery with it, and would need a generator if the sun is not out for an extended period of time. This system would require the most intensive design, as we would have to find a way to transport a large solar panel while using space efficiently and keeping the panel free from damage.

After laying out these designs we believe the first option would have the most success given our needs. Our advisors agreed with this conclusion, so we began to create a more detailed design. Once we added these details, we created a presentation to send to our project partner for approval. If he likes the design, we will incorporate his feedback and then move on to the next phase of development. The following information are the expanded details on the first solution.

Large stationary solar panels will be used to charge batteries. A base amount of 3x100 Watt solar panels will be used. For some of the loads that require a higher capacity (to get a full 4 hours of use), an additional panel will be needed to keep charge times as 1 day. The batteries will be transported with the mobile science lab and will match the energy needs for 4 hours of use. The mobile lab will be able to be powered by the battery or a generator. After 4 hours of use, the batteries will be returned to the solar panels to be charged. The tables below show the math required to determine the cost of the system and how many panels it would require.

In the chart for energy use, notice that an extra 20% is included. This is to account for uncertainties, like adding additional items other than the projector. In the charts for price we compare the price at 20%, our base, 50%, and 100% additional power. This is to see how price increase as the system grows.

We want our system to be able to fully charge in one day of good weather, where one day is considered from sunrise to sunset. Charge times are based on a guideline from Solar Technology International. The guideline says that to calculate the necessary amount of energy for the batteries each day, multiply the power the panels by 6.

Therefore, 6*(watts of panel) = watt-hour of energy that the batteries can store per day. This means that we could generate 1800 watt-hours of energy for three panels and 2400 watt-hours for four panels. This also accounts for losses in the system.

This guideline is based on the sun insolation on an average summer day in the United Kingdom. To be safe in our calculations, we are assuming this comes from the strongest regions of insolation in the country in the peak sun of summer. That means this figure comes from an insolation of 5.3 kW/m^2 at maximum. In Haiti, the year-round average for insolation in almost every region is at this level or higher; in the weakest regions it is 4.98 kW/m^2. These number are close enough to use as approximation, but in the detailed design we will get more accurate measurements.

Power Consumption					
Item	**Quantity**	**Min Power**	**Max Power**	**Min Total**	**Max Total**
Projector	1	150 W	300 W	150 W	300 W
Raspberry Pi/Computer	1	12.5 W	65 W	12.5 W	65 W
Digital Microscope	1	-	2 W	2 W	2 W
Lights	2	-	6 W	12 W	12 W
Battery Charger	1	-	9.5 W	9.5 W	9.5 W
Total				186 W	389 W

Energy Use

	Power Consumption (With 20% Extra)	Hours of Operation	Energy Use
Min	223 W	4	892 Wh
Max	467 W	4	1868 Wh

Cost of system			
Non-Varying Components			
Item	**Quantity**	**Cost**	**Total Cost**
Solar Panels	3	$100	$300
DC Breaker	1	$8.84	$8.84
Metering	2	$8.00	$16.00
Wire	1	$20.00	$20.00
Total			$345.00

Cost of system
Battery

	Energy Need Min	Energy Need Max	Battery for Min	Battery for Max	Total Min	Total Max
20% Extra	892 Wh	*1860 Wh	1200 Wh	1200 Wh + 660 Wh	$140	$230
50% Extra	1116 Wh	*2334 Wh	1200 Wh	2 x 1200 Wh	$140	$280
100% Extra	1488 Wh	*3112 Wh	1200 Wh + 660 Wh	3 x 1200 Wh	$230	$370

***These capacities will require an additional solar panel to keep charge time to 1 day**

Cost of system				
Inverter				
	Power Min	**Power Max**	**Inverter for Min**	**Inverter for Max**
20% Extra	223 W	467 W	$29.99	$45.00
50% Extra	279 W	584 W	$29.99	$49.99
100% Extra	372 W	778 W	$39.99	$90.00

Automatic Transfer Switch

The power system for the lab will use an automatic transfer switch (ATS) to transfer between the solar powered batteries and the generator. When just the batteries are connected the system will be powered from them. However, if a generator is connected the ATS will transfer to the generator to save the charge on the batteries. If the generator is disconnected the ATS will switch back to the batteries.

There are two main options for building an automatic transfer switch. The first would be to use semiconductors based power electronics. These circuits also use integrated circuits, IC, as controller. These types of transfer circuits are easy to find as DC input, DC output circuits. Two circuits with DC inputs and DC outputs where found. The first uses a 555 timer IC to control the circuit. The circuit would have to be modified to use a transistor based switching circuit that would be controlled based on if there was power in the AC leg instead of a manual switch. The circuit diagram is shown below in Figure 1. Another type of circuit was found that uses a LTC4412 IC to control the circuit. In this circuit a rectifying circuit would have to be added between the wall power and the input. It is shown below in Figure 2.

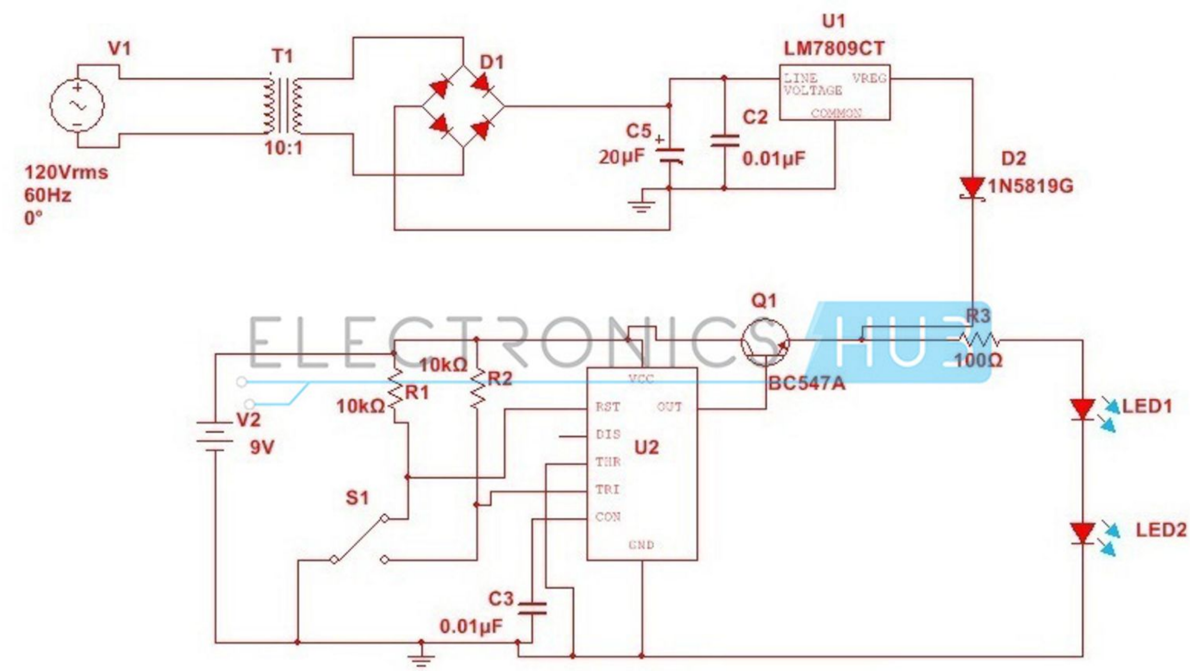


Figure 1 IC Controlled Switching Circuit

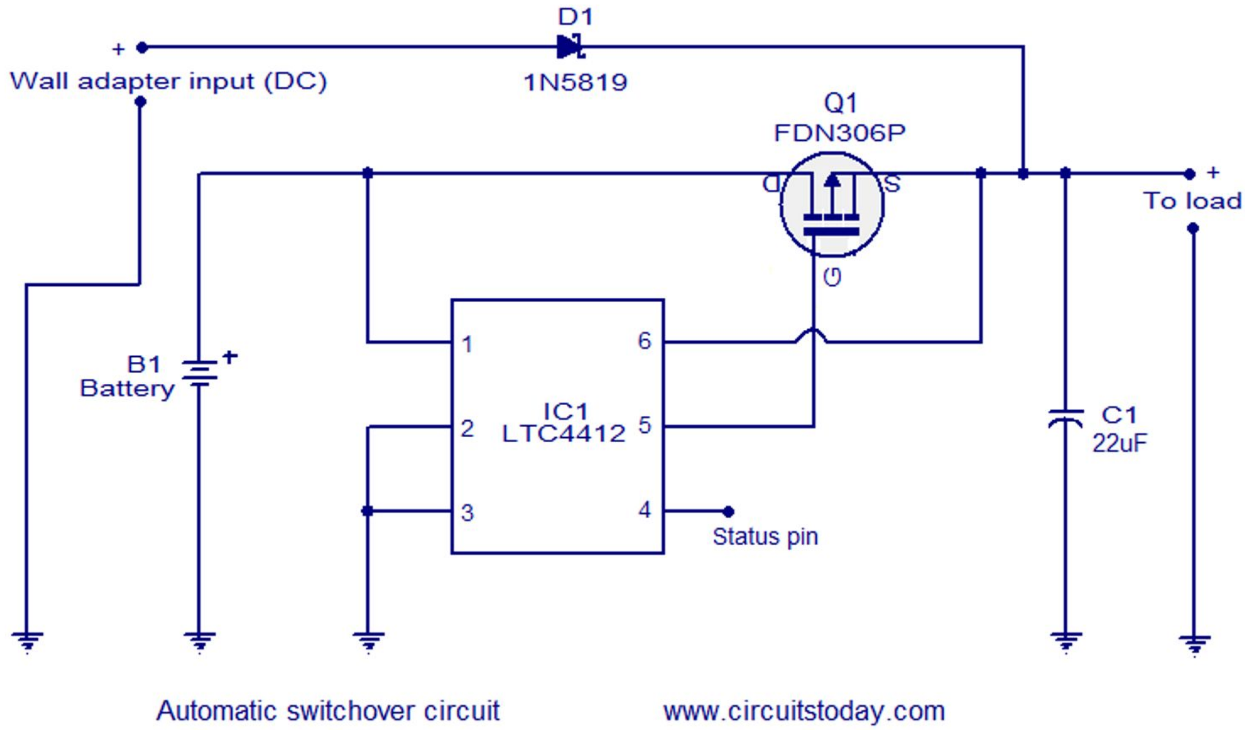


Figure 2 IC Controlled Switching Circuit

The other option is to use an electromechanical automatic transfer switch. These switches use contractors and relays to control which source is used to power the system. A contractor is an electromechanical switch that can be opened or closed based on if power is applied to a coil. Contractors also often have auxiliary normally opened and normally closed contacts. By using two of these the auxiliary contacts of one contactor can be used to turn the other off if wired correctly. Contactors have a mechanical lock-out that is used to ensure that both contactors are not on at the same time. They can be wired to also have an electrical lock-out so that one can only turn on if there other is off. A timer relay is used to delay the switch so that you do not get a voltage spike when transferring from one source to the other. An example of a contactor pair with mechanical interlocking is shown below in figure 3. This contractor supports 3 phase power so there are additional connections points.

Figure 3 Mechanical Contactor

For our project we are choosing to use to use the electromechanical automatic transfer switch (ATS). There are multiple reason that is preferable. First, it has AC input and output which will be prefered in our system. Second, electromechanical parts are more durable than semiconductor devices. They would also be easier to find in countries such as Haiti. The last reason is that we determined these types of switches are already being used in similar counties. For example, Covenant University, a college in Nigeria, worked on a project to build an ATS with contactors and relays. It was used to switch between grid power and a generator.

Wiring

All the connections which carry high voltage current inside the ATS use 10-gauge wires. These wires were chosen to make the ATS safe and to decrease the amount of resistance in the system. Additionally, use of 10-gauge wires enables the ATS to handle higher voltages and power than it is currently being used for making it easy to add more batteries and loads to the system without the need to make a new ATS. The wires used for the switching logic of the ATS are 16-gauge wires since these wires need to carry small amounts of current. All of the stripped ends and junctions of the wires were covered with plastic or insulating tape making it safe to use.

Packaging:

The ATS box will comprise of the automatic switching system along with the included inverter and an outlet. This system is packaged in a waterproof box with two AC outlets and two inputs. One of the inputs plugs into the battery whereas the other one plugs into an AC source such as a generator or a wall power source. The battery outlet is suited to handle a 12V DC source. The included inverter is rated at 800 watts.

Experiments

We created a list of experiments last semester to put into the environmental science mobile lab unit which can be seen in the past semester archive.

Containment

We have began brainstorming about the type of containment that the lab will go into for transportation. We have considered several options such as plastic storage containers, metal truck case, and a pelican storage case. We decided that using a pelican case for our containment or some case similar to this would be our best option due to the resiliency and security that these types of cases would provide for the lab.

6.2 Detailed Design

Experiments

Experiment Testing

This semester our experiment subteam is taking our experiments to the Imagination Station, a local interactive STEM center, in order to test them with children. The goal of this trial run is to test how engaging and interesting our current experiments are for children within our target age range. We will take the feedback that we get from this trial run and reevaluate our experiment list and change any components of an experiment that don’t quite work.

Imagination Station

We demoed the film canister rockets and the water erosion lab at the Imagination Station this semester. The children their reacted very positively to both experiments. The rockets drew children over to our station and captivated them so we believe that this experiment will work great for getting the children I Haiti interested in science. We discovered a few ways that we need to alter the soil erosion experiment to fit our needs better during the demo as well.

Film Canister Rockets

To create an exciting experiment to grab the kids attention and get them interested in science and learning, we decided on doing film canister rockets. These rockets take an empty film canister, alka seltzer tablets, and water. You fill the canister with water, drop in the tablet, put the cap on tight, and turn it over. After the pressure inside the canister builds up it pops up into the air. Even though this experiment is mainly to gain their interest, it will also be explained why the film canister acts this way.

Wind Erosion Lab

Using a combination of research found online, along with our own designs, we created an experiment to demonstrate the effects of wind erosion using real dirt. Students will blow on the dirt with varying degrees of strength to demonstrate how wind displaces soil. They will then blow on soil containing vegetation to see the difference. We bought a clear tray with an open top that will allow the students to blow on and see how the soil moves differently with varying wind strengths.

Water Erosion Lab

For this lab we used an experiment created by the University of Wisconsin given to the team by Dr. John Graveel, a retired Purdue agronomy professor. In this experiment, students get to visualize the effect that water can have on loose soil due to rainfall. The experiment is performed in an apparatus made of empty two liter soda bottles or a prefabricated 3D printed model we will be sending down with the lab. Additionally, the students can see how rainfall will affect soil with plants in it, because they can also run the experiment with soil that has plants in it. This will demonstrate the importance of having organic material in soil.

Soil Autopsy Lab

This lab allows students to analyze the composition of soil, and through this lab students, should be able to learn about what soil is composed of and identify the organic and inorganic substances in it.

Rock Makes Soil Lab

This lab allows students to see how soil is formed and where it comes from by having students break down rocks to make particles that look like dirt. This lab teaches the children how weathering creates the inorganic matter in soil.

Microorganism Lab

This lab allows students to swab certain surfaces and grow microorganisms from these swabs. This lab is designed to show the kids the bacteria that lives on surfaces and we can provide print outs of different microorganisms so that the students can identify what grew.

Experiment Packaging Decision Process

One of our major goals for this semester was to choose a container and method for how to package up all the experiments for delivery. We decided to go with a Pelican brand case because they are water resistant, the box came padded and with a lock for security. All of those expectations were major deciding factors in choosing a box because they were explicitly stated by our project partner. The size of the box was chosen by gathering up all our materials from inside the box and then putting them together and measuring out the dimensions needed to fix them all. As for the packaging in the box, we decided to group the smaller materials for each experiment together by the experiment they go with and the larger items - such as the microscope and projector are just being left a place in the box because our project partner already has them.

Solar Power System

After talking to our client, Tom Braak and doing detailed research on power consumption there has been some changes on the items used in our power system. In order to make the system efficient and to fit with our design specifications we changed the number of solar panels used from three to four since we needed a stronger energy source. We are no longer using Raspberry Pi since the digital microscope needs to be connected to a computer, so we are replacing it for a laptop. Also, lights are no longer useful for our system so we are going to take them out in order to save power.

Discharging the Battery

To discharge the battery, we need to use a resistive load to slowly draw out the current which decreases the charge of the battery. Based on calculations of loads that we would use, we would need a resistor that is less than 1Ω. This is not reasonable to use such a small resistor so a better solution is to use an inverter connected to the battery and plug in a device that needs to be charged like a laptop to discharge the battery. Then using a multimeter to read the voltage across the battery at different times, we can get a % of battery that is available versus the voltage. Using a linear fit, we get the model for Voltage across the terminals = 10.95 + 0.0126(State of charge in %). So if we wanted a full charge, the voltage across the battery should be around 12.2V.

Instructional Solar Power Manual

A manual has been made specifically with the materials, procedure and troubleshooting situations of the Solar Power System. All the materials needed are included, also there are two different procedures, one for the switching system and the other one with the solar panel set up. The procedure is concise yet detailed and it also have pictures in order for to make it easier for a third party to follow the instructions. At the end, we decided to add a troubleshooting section with two of the most common problems you could have with a system like this. This will be helpful because since we are not there to help our project partner this section will make them more independent.

Power Consumption		
Item	**Quantity**	**Max Power Total**
3-D Projector	1	283W
Computer	1	65 W
Digital Microscope	1	2 W
Battery Charger	1	9.5 W

Total		359.5 W

Energy Use			
	Power Consumption (With 20% Extra)1.2	**Hours of Operation**	**Energy Use**
Max Power	431.4 W	4	1725.6Wh

Cost of system			
Non-Varying Components			
Item	**Quantity**	**Cost**	**Total Cost**
Solar Panels	4	$100	$400
DC Breaker	1	$8.84	$8.84
Metering	2	$8.00	$16.00
Wire	1	$20.00	$20.00

Connectors	1	$30.00	$30.00
Ring Terminals	1	$7.00	$7.00
Fuse			
Batteries	2	$140.00	$280.00
Inverter	1	$50.00	$50.00
Total			$812.00

Items Purchased

ITEM	QUANTITY	COST	FINAL COST
Solar Panels	3	$100	$300
Batteries	1	$90	$90
Connectors	1	$30	$30

Procedure:

Wiring:

The solar panels are connected in parallel by using 4 to 1 MC-4 branch connectors that connect the panels to the charge controller. Coming out of the charge controller are two 10-gauge wires which are stripped at both ends, for easier connection, to the battery. At the battery terminals, we add ring connectors to the stripped wire for a more secure connection between the battery and the wires. An inverter is connected to the battery using the included clamps, which spark when connected. The Automatic Transfer Switch (ATS) will have one of the inputs connected to the inverter and the other to a generator.

Testing:

In developing a solar panel testing procedure, we met with the ECET head of the Sustainable Energy Lab, Professor Hutzel, to devise an equation in order to accurately predict the solar panel power output for Haiti. Given the various constraints we must consider with our solar panel testing, Professor Hutzel showed us how we can factor them in to a compact equation when we manually calculate the solar panel power output relative to Haiti. A single sun hour is defined as 1000 W/m^2 and the safety factor for solar panels is the sum of power loss through the wiring, charge controller, battery and inverter (each individual efficiency summed for SF). Then, given our solar panel max power rating, the formula to calculate kWh is the product of sun hours for the desired location (see solar insolation map) by the calculated safety factor (~ 0.7 - 0.9) by the solar panel power specification.

When we test our solar panel here in West Lafayette, we can use data directly from Purdue's Solar Lab in the polytechnic school to manually calculate the kWh. Our findings can then be translated to determine the power output for Haiti by setting up a simple ratio using the respective sun hours for the two locations.

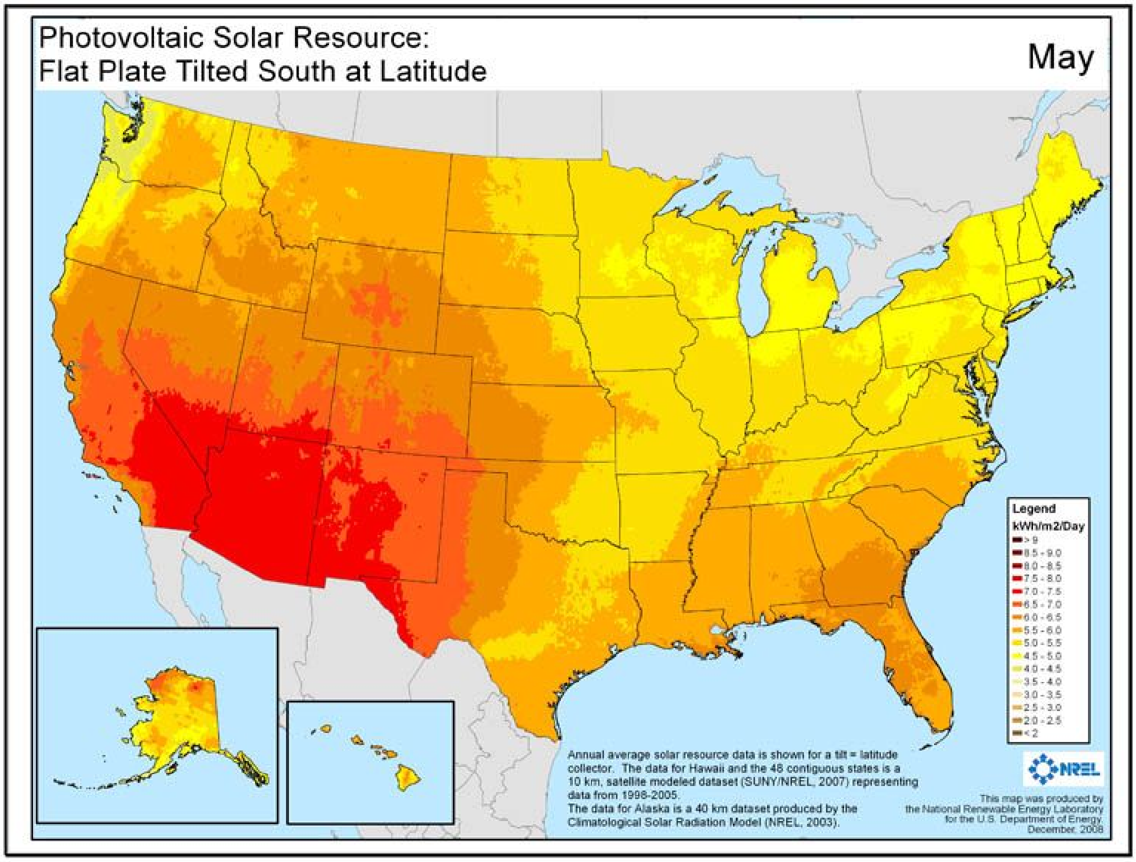
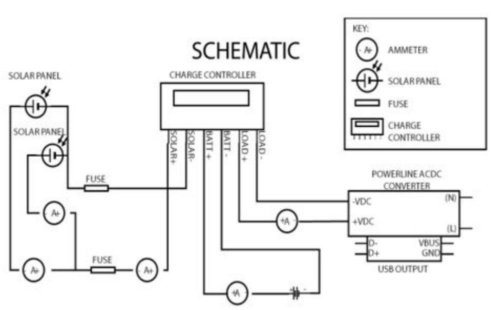


Figure 4. This figure shows the solar insolation map of the United States. The higher the solar insolation the more power output we will get out of the panels.

Upon testing our completed circuit it took just over 3 hours to charge our 12V - 50Ah battery to its energy capacity at 600Wh. Solving for sun hours using the below equation, we successfully charged the battery within the range of the predicted charge time.

Energy = n(Pmax) * SF * SH

- **Energy:** the kWh of energy generated
- **n:** the number of solar panels
- **Pmax:** the max power specification for the solar panel (*100 W)
- **SF:** Safety factor is the sum of percentage power loss through each current carrying component (~0.7-0.9)
- **SH:** 1 sun hour = 1000 W/m^2



Solving this equation, for SH (sun hours)

600Wh = 3(100W) * 0.7 * SH -----> 2.857 Sun hours

UPDATE: Since we tested our circuit in poor conditions and we charged only a 600Wh battery, the calculated sun hours were close approximately 3.857 sun hours which is roughly half of the anticipated sun hours for West Lafayette in the month of April.

Automatic Transfer Switch

A contactor used for this design needs to have auxiliary switches on it. Auxiliary switches are just switches that open or close when the contactor opens or closes. They can be used to control other contactors. If a contactor can not been found with auxiliary switches then a single pole relay can be used in place and wired into the circuit in a similar fashion. Contactors normally have two auxiliary switches. A normally closed, NC, and a normally open, NO, switch. The only important one for this design will be the normally closed switch.

For this project our first choice of contactor was sold out so we picked our second choice. We are using a 30 Amp 3 pole 120V contactor from Electrodepot. This contactor has an extra pole that will not be used. The current it is rated for is much higher than what is needed. This will ensure that it is not damaged even in a fault. It has both a NC and NO auxiliary switch on it.

The automatic switching unit will be wired such that there is a primary and secondary source. The secondary source will only come on if the primary is disconnected. However, the primary will turn on and switch off the secondary even if the secondary is plugged in. For our use the primary will be a generator. So if a generator is connected, the power from the inverter will be cut off and the generator will will start providing power. When it is disconnected the power will start coming from the inverter again.

The first step in building the Automatic Transfer Switch, ATS, was to wire the contactors such the switching worked properly. First, the contactors were wired individually to make sure that a single unit would engage when power was applied. After it was confirmed that both contactors worked properly they were wired to follow the switching logic described in the previous paragraph. In the first iteration the outputs of both contactors were wired to individual lamps. This allowed for the lamps to indicated which source was active. After it was confirmed that the logic was correct the two outputs were connector in parallel to an outlet. It was then tested to see if a single lamp would stay on when changing which cord was plugged in. One cord being the primary source and the other the secondary. The switch was then confirmed to operate as intended.

The next step was to wire it into a receptacle box to ensure no wires were exposed. For safety in the initial testing the outlet was left on a concrete floor and everyone stepped away before it was ever plugged in. This was done in a garage to make sure no one accidently entered the area while the outlet was hot. Once it was properly wired in a receptacle box the outlet is insulated and can be safety handled. A GFCI, Ground Fault Circuit Interrupter, outlet was used. These outlets turn off in the event of a short. An outlet tester was used to ensure the outlet was wired properly and the GFCI turns off when a short occured.

Figure 5. ATS Outlet Being Tested

The ATS operates properly when using two wall outlets as sources. It could switch without the projector turning off. However, some issues arise when trying to use an inverter. The inverter did not produce a high enough quality output for the contactors to switch completely properly. The one connected to the inverter worked but made a humming noise which is not normal operation. This comes from the inverter being too cheap of an inverter. The solution is to use a higher quality inverter when the ATS is shipped. The second problem is mechanical interlocking. Mechanical interlocking is a safety measure that mechanically ensures that both contactors are not open at the same time. Our first choice contactor came with this interlock. However, our model did not. While the switching logic of the circuit should also ensure this, we will not ship the ATS until it is mechanically interlocked. If out contactors don't have parts available to mechanical interlock them we will either have to find a different brand of contactors or add delay relays. Delay relays would make it so the ATS is no longer non-interruptive switching. However, it would ensure that even if there was an overlap of both contactors being open they would never both be open and have power passing through them.

Correspondents:

Ag-Bus: info@agsciencecenter.org
Bio-Bus: learning@biobus.org
NSSTI: info@nssti.org
Purdue Physics outreach: Dr. David Sederberg, Dr. Lynn Bryan, Dr. Andy Hirsch
Erosion Professor: Dr. John Graveel
Imagination Station director: Philip Cardella philip@imagination-station.org

Appendix A: Past Semester Archive

A.1 Fall 2017

Specification Development

The first step the team took to develop the specifications of the lab was to look at how other groups around the world have previously built mobile labs. We found that the requirements of our team are unique. Most mobile labs are much larger than ours is going to be; many of them are repurposed buses or semi-truck trailers. The smaller ones are built in the back of vans, but still require a dedicated automobile. We will not be able to mimic any one solution, but there is still value in researching the components of the existing labs to see what we can learn and determine if any of their designs are applicable to our lab.

The first place that we looked was Purdue University, which has a program called Science Express. Science Express supplies equipment and training to schools in the state of Indiana. A member of our team met with Sarah Nern, the director of the program, to gain insight into how their organization achieves their goals. Ultimately, we were able to see some of the specialized methods they developed for packaging and transporting equipment. A lot of their packaging methods were intended to be carefully transported in a van, which unfortunately makes them unsuitable for our application. However one of their containers was much more durable and could apply to our project. A picture of it is shown below in Figure 1.

Figure 1: Science Express Durable Container

Sarah Nern also directed us to some experiments that we could potentially include in our lab. Purdue uploads all of the labs used with science express to https://www.science.purdue.edu/science-express/participant/labs/index.html. These include labs from the fields of chemistry, biology, physics, and earth, atmospheric, and planetary sciences. These labs are intended for high school students, however, whereas our experiments need to target elementary-aged students. Sarah did believe that some activities could be adapted for use with kindergarten through middle school aged students, and she gave us permission to use and modify any of the materials on the website. Her only request was that we send a copy of the modified lab to Science Express.

We also researched organizations outside of Purdue University that had concepts similar to what we are trying to develop. A Pace University team, for example, designed a wood and bamboo mobile cart to take by bicycle to developing country villages to show them applications. The cart folds out to provide a space similar to that in a Verizon or Apple store. The team put tablets and mobile devices, loaded with locally developed applications, in the carts, along with charging ports and wifi. This will teach the locals about the applications while allowing them to learn more through the access to the internet. The reason we chose not to focus on applications like this is that we believe they are not pertinent to developing countries. The locals have very little need for them and don't understand the concepts behind them, so they will be less effective at achieving our goals.

Another group we found is the Mobile Lab Coalition. The Mobile Lab Coalition is a group of independently travelling labs that teach children about science. Most of these labs are big trailers, RVs, or buses, but there is one particular group in California called the "Ag Bus", with whom we have been in contact. Their design consists of a 53 foot trailer that has lab benches with microscopes along the outside of the trailer, which is obviously not practical for our design. Instead of this, though, we could use the general principles behind their microscope center curriculum. They created an educational program centered around the foods that children eat, which mainly focuses on applications of soil science, bio-engineering, agricultural technology, and sustainability. The lessons they teach include Photosynthesis, Bug Morphology, Strawberry DNA Extraction, Seed Dispersal, Soil Chemistry pH, Soil Chemistry, Chemistry of Nutrition-Dairy, and Density, some of which we could develop for use in our own mobile lab.

Additionally, we analyzed the practicality of using a Raspberry Pi in our lab box. There have been many universities and groups around the world that have used the Raspberry Pi for instrumentation and lab data analysis. There is a group in England, for example, that used the Raspberry Pi to analyze weather data and air quality. After the user uploads data, the Raspberry Pi then completes a graphical analysis of the data. Another group turned the Raspberry Pi into a digital microscope by attaching a camera module to an analog microscope. They were then able to take photos of the samples and store them in a digital library. A third group made temperature sensors from the Raspberry Pi and put the plans for it online. We believe this would be our best option for the computers in our lab boxes because they are inexpensive and extremely modifiable. If in the future, if our project partner wanted to add something to the Raspberry Pi, we could easily send a program and the required hardware down to Haiti. The Raspberry Pi is also extremely powerful for such a small computer, as it packs 1.2 GHz into its small motherboard. It can also run off either a Linux or Windows variant.

Our original belief was that typical wall power would not be an option, but we did research to make sure a simple solution was not missed. This was confirmed by what we found the electricity sector in Haiti to be like. Only 12.5% of the country's population has a legal access to electricity, and even with illegal connections, only 25% of population has access to power. This power is also not reliable, as it goes out periodically throughout the day. In most areas, people only average 5-15 hours of power a day. This confirmed that we will have to use an alternative power supply.

Gas prices are around the same in the US and Haiti. Haiti has a much lower average income, which means that gas would be harder to purchase. To solve this problem, a renewable energy solution would be the most effective. It is common for remote weather stations and weather buoys to use solar panels, so that was our first thought for a renewable energy source.

Solar panels are not viable everywhere, as there needs to be enough solar radiation in an area for the panels to be effective. When looking at a solar map of Haiti, it is apparent that most areas get around the same amount of solar radiation as parts of the American southwest (Texas, Arizona, New Mexico, and Nevada). This shows that there is plenty of solar radiation to power solar cells. Figure 2 shows solar radiation in Haiti and Figure 3 shows solar radiation in the United States for comparison.

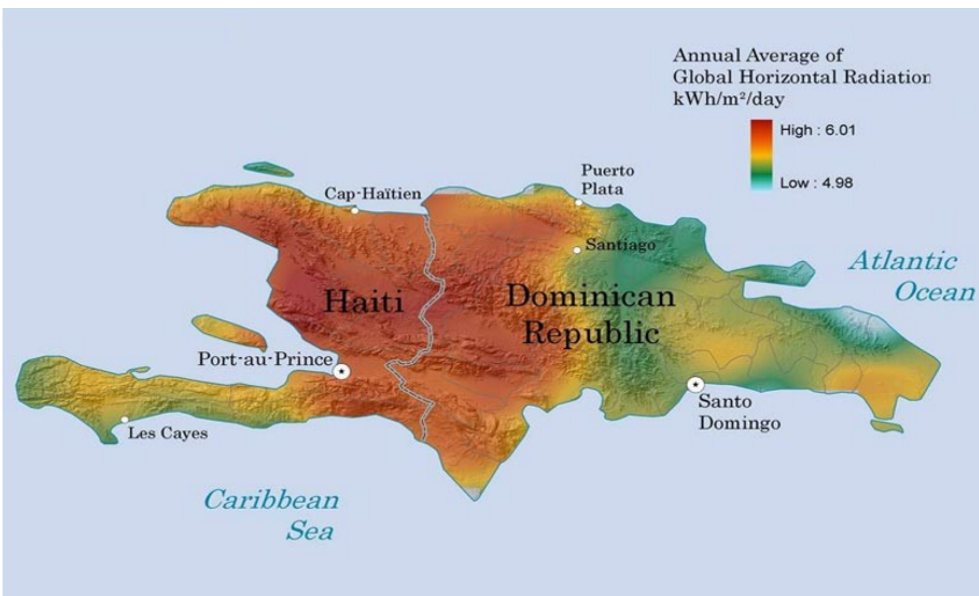


Figure 2: Solar Map of Haiti

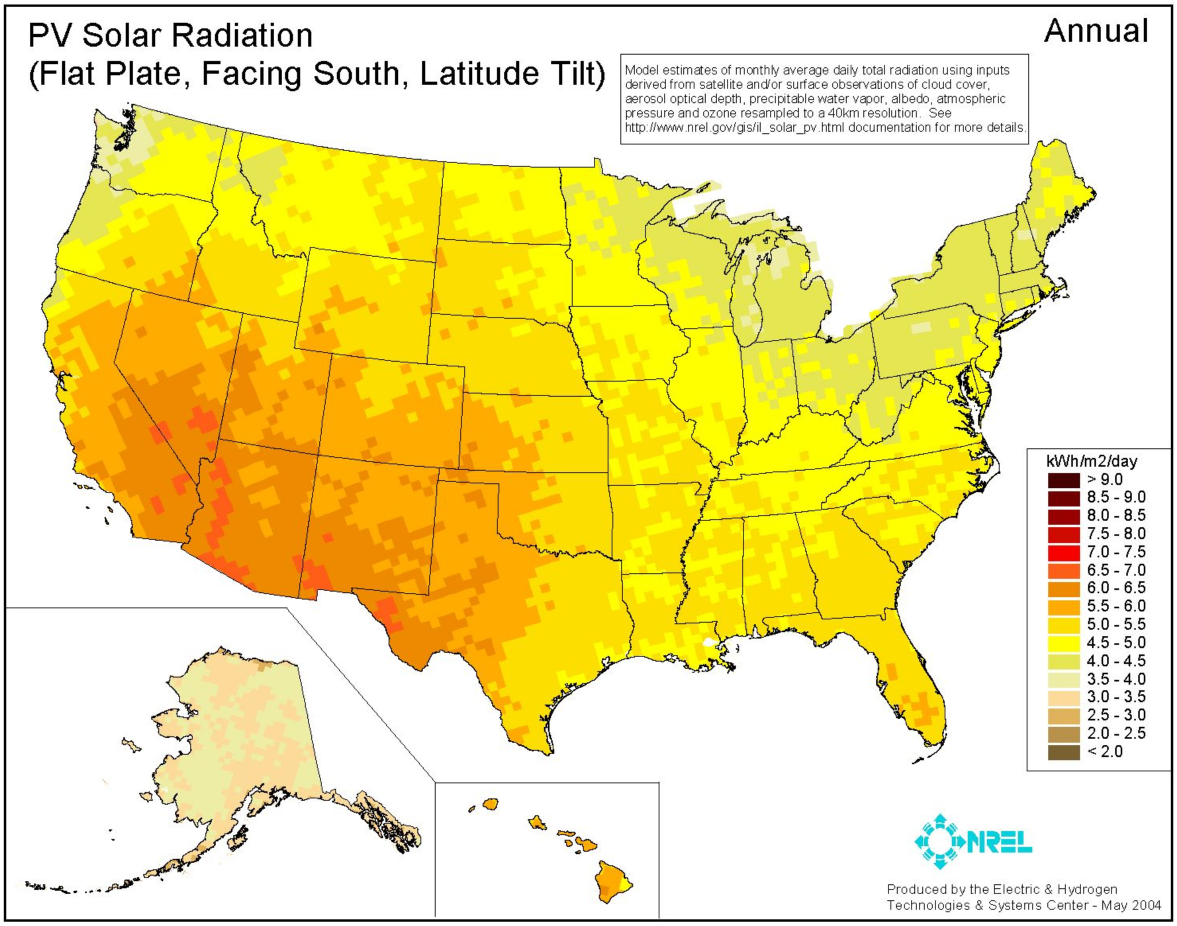


Figure 3: Solar Map of United States 1

As our team worked to create specifications for our unique mobile lab, we conducted further research into conditions in Haiti. This research was inclusive of both the terrain and the climate of the area. As can be seen in Figure 4, a majority of the terrain in Haiti consists of a rugged and mountainous landscape interspersed with small coastal plains and river valleys. Altitudes in the northern mountains range from 2000 to 4000 feet and 4000 to 8900 feet in the southern mountains. Terrain in the mountains is steep and eroded, with deep gullies and a mixture of dense forest and open slope. The country also contains more than 100 rivers, with higher concentrations in the mountainous regions. Figure 5 shows the general area where Tom Braak is located, which will be the beginning area of land where our first products will be transported and used. In order to continue to be functional while being transported in a pickup truck in this terrain, our containment for storage must be secure and robust.

Figure 4: Physical Map of Haiti

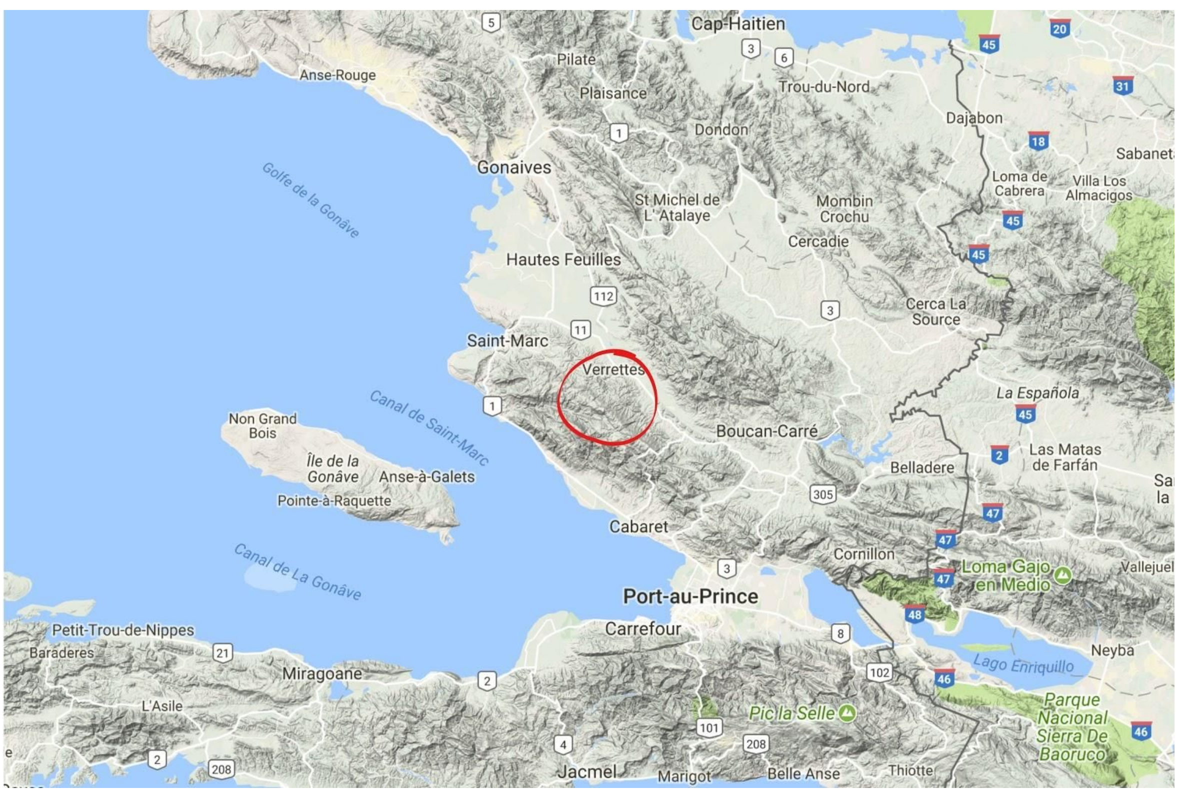


Figure 5: Location of Verrettes

The weather in Haiti can be extreme, of which we have become aware through our research on the climate and global news. The island is vulnerable to a multitude of different natural disasters, including hurricanes, flooding, earthquakes and periodic droughts. Haiti experiences two rainy seasons; April–June and October–November; where rainfall can average as much as 45 inches. Figure 6 shows the average rainfall in millimeters per year for the country. Due to the immense amount of rainfall during these seasons and the mountainous terrain, lower altitude areas are subject to flash flooding. Along with the large about of rainfall and threats of hurricanes and other natural disasters, the temperature in Haiti remains fairly high, usually averaging between 73 and 95 degrees Fahrenheit. These factors influenced our team as we set the goal of creating a potentially hurricane proof container.

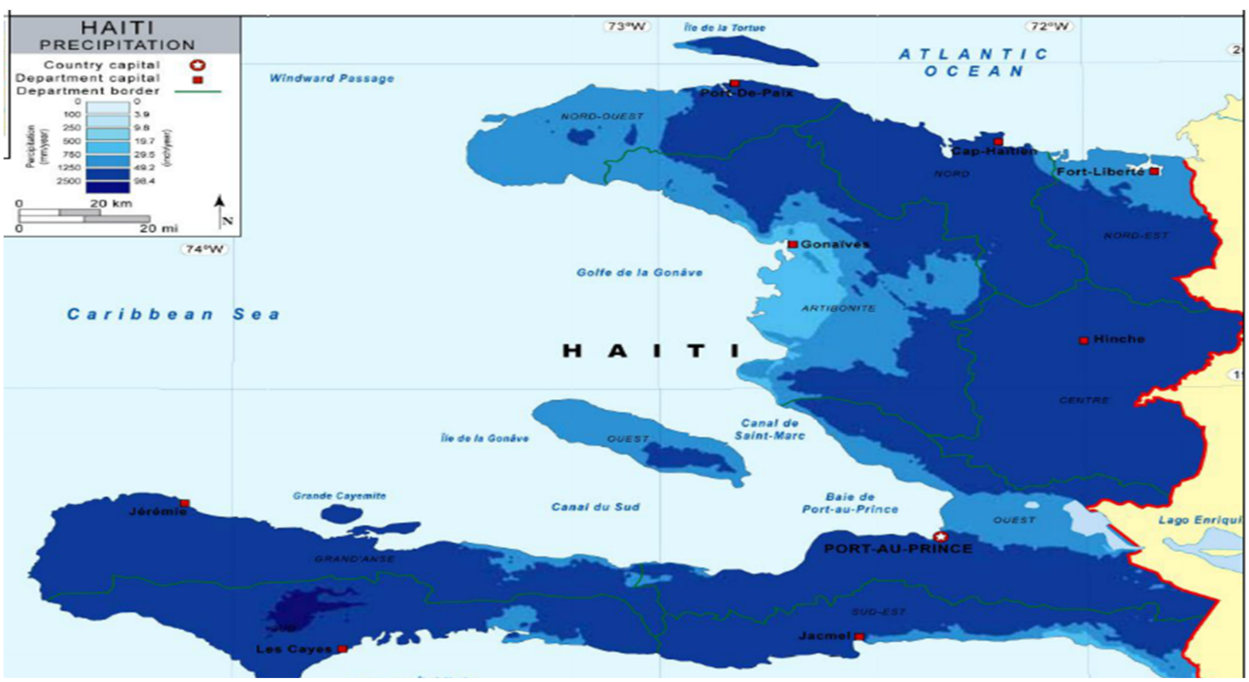


Figure 6: Average Precipitation Map of Haiti

One additional aspect of Haiti that the team needs to consider is the language barrier. English is not one of the official languages of the country, and very few people within the country know how to speak it. Instead, the local languages are Creole and French, where Creole is spoken predominantly by the villagers and normal citizens and French is spoken by the aristocrats in the cities. Our project partner informed us of this distribution, and further added that very few people outside of the cities can understand either English or French. Because of this, all of our materials will need to be in Creole in order to be used by the audience. In order to alleviate this issue (as none of the team members know Creole), our project partner has offered to translate all of our materials from English to Creole for us. Another similarly overlooked detail is that Haiti has a relatively low literacy rate. The national rate is about 60%, though Tom Braak assured us that anyone who would use the mobile labs (students and teachers) will be able to read and write.

Conceptual Design

Experiments

This semester, the team has worked on developing prototypes of several experiments for the Environmental Science Portion of the Mobile Lab. Specifically, we have been working on wind and water erosion experiments, as well as several soil science experiments.

Wind Erosion Lab
Using a combination of research found online, along with our own designs, we created an experiment to demonstrate the effects of wind erosion using real dirt. Students will blow on dirt with varying degrees of strength to demonstrate how wind can displace soil.

Water Erosion Lab
For this lab we used an experiment created by the University of Wisconsin given to the team by Dr. John Graveel. In this experiment, students get to visualize the effect that water can have on loose soil due to rainfall. The experiment is performed in an apparatus made of empty two liter soda bottles. Additionally, the students can see how rainfall will affect soil with plants in it, because they can also run the experiment with soil that has plants in it. This will demonstrate the importance of having organic material in soil.

Soil Autopsy Lab

This lab allows students to analyze the composition of soil, and through this lab students, should be able to learn about what soil is composed of.

Rock Makes Soil Lab
This lab allows students to see how soil is formed and where it comes from by having students break down rocks to make particles that look like dirt.

Appendix B: Overall Project Design

B.1 Project Identification

Phase 1: Project Identification	**Status:**	**Evidence can be found:**
Goal is to identify a specific, compelling need to be addressed		
· Conduct needs assessment (if need not already defined)	Completed	See Section 4 of this document
· Identify stakeholders (customer, users, person maintaining project, etc.)	Completed	See Section 4 of this document
· Understand the Social Context	Completed	See Section 4 of this document
· Define basic stakeholder requirements (objectives or goals of projects and constraints)	Completed	See Section 4 of this document
· Determine time constraints of the project	Completed	See Section 5 of this document

Project Identification phase is completed

B.2 Specification Development

Phase 2: Specification Development	Status:	Evidence can be found:
Goal is to understand "what" is needed by understanding the context, stakeholders, requirements of the project, and why current solutions don't meet need, and to develop measurable criteria in which design concepts can be evaluated.		
· Understand and describe context (current situation and environment)	Completed	See Section 5 of this document
· Create stakeholder profiles	Completed	See Section 4 of this document
· Create mock-ups and simple prototypes: quick, low-cost, multiple cycles incorporating feedback	In Progress	Mobile Lab Team OneNote
· Develop a task analysis and define how users will interact with project (user scenarios)	In Progress	Mobile Lab Team OneNote
· Identify other solutions to similar needs and identify benchmark products (prior art)	Completed	Mobile Lab Team OneNote
· Define customer requirements in more detail; get project partner approval	Completed	Mobile Lab Team OneNote
· Develop specifications document	Completed	Mobile Lab Team Shared Folder
· Establish evaluation criteria	Completed	Mobile Lab Team OneNote

Specification Development phase will be completed early Spring 2018.

B.3 Conceptual Design

Phase 3: Conceptual Design	Status:	Evidence can be found:
Goal is to expand the design space to include as many solutions as possible. Evaluate different approaches and selecting "best" one to move forward. Exploring "how".		
· Complete functional decomposition	In Progress	Mobile Lab Team OneNote
· Brainstorm several possible solutions	Completed	Mobile Lab Team OneNote
· Prior Artifacts Research	Completed	Mobile Lab Team OneNote
· Create prototypes of multiple concepts, get feedback from users, refine specifications	In Progress	Mobile Lab Team Google Drive
· Evaluate feasibility of potential solutions (proof-of-concept prototypes)	Completed	Mobile Lab Team Google Drive
· Choose "best" solution	Completed	Mobile Lab Team OneNote

Conceptual Design phase will be completed Spring 2018.

B.4 Detailed design

Phase 4: Detailed Design	Status:	Evidence can be found:
Goal is to design working prototype which meets functional specifications.		
· Bottom-Up Development of component designs	In Progress	See Section 6 of this document
· Develop Design Specification for components	In Progress	See Section 6 of this document

· Design/analysis/evaluation of project, sub-modules and/or components (freeze interfaces)	To be completed	
· Design for Failure Mode Analysis (DFMEA)	To be completed	
· Prototyping of project, sub-modules and/or components	In Progress	Mobile Lab Team OneNote
· Field test prototype/usability testing	To be completed	

Detailed design phase will be completed Spring 2018.

B.5 Delivery

Phase 5: Delivery	Status:	Evidence can be found:
Goal is to refine detailed design so as to produce a product that is ready to be delivered! In addition, the goal is to develop user manuals and training materials.		
· Complete deliverable version of project including Bill of Materials	To be completed	
· Complete usability and reliability testing	To be completed	
· Complete user manuals/training material	To be completed	
· Complete delivery review	To be completed	
· Project Partner, Advisor, and EPICS Admin Approval	To be completed	

Delivery phase will be completed in Spring 2018.

B.6 Service / Maintenance

Phase 6: Service / Maintenance	Status:	Evidence can be found:
· Evaluate performance of fielded project	To be completed	
· Determine what resources are necessary to support and maintain the project	To be completed	

Service / Maintenance will be completed in the future.