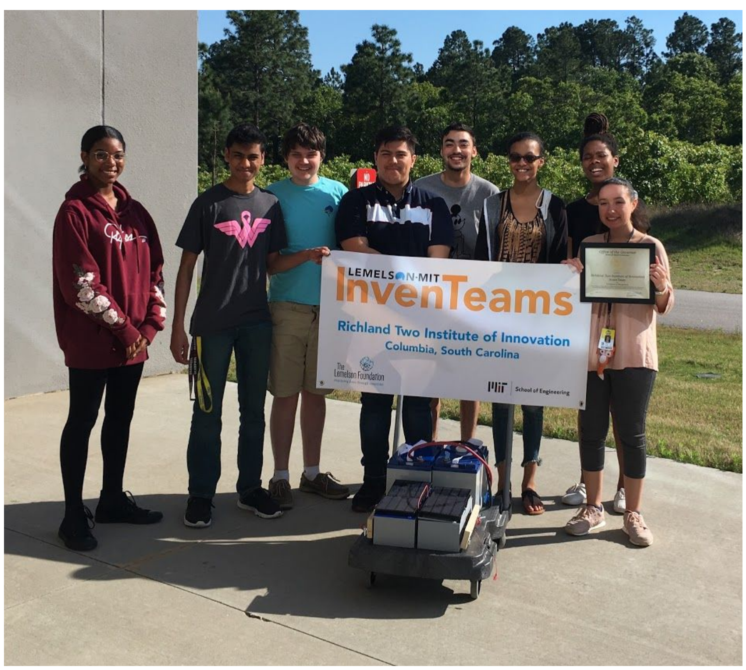
Modular Solar Power Supply (MSPS): A Sustainable and Adaptable Energy Solution

Kay Brown, Andrea Cerda, Ronnie Fowler, Omar Herrera, Murray McDaniel, Nithin Saravanapandian, Anaiah Thompson, Laila Thompson
Richland Two Institute of Innovation InvenTeam
2018-2019



Abstract:

The Richland Two Institute of Innovation InvenTeam invented a system of interlocking solar modules to power a photocopier for a secondary school in Sare Bilaly, Senegal. This invention is needed because the school has no electricity and limited educational resources beyond notebooks and blackboards. The modules snap together and trickle charge two deep cycling pure gel 12-volt batteries. The photocopier can then be run using the batteries with a 2000 watt inverter. The module was designed using sustainable materials and locally accessible materials so it can be assembled, replicated, and repaired by the students of Sare Bilaly themselves. Each module consists of a 3 watt solar cell (12 V, 0.25 A) with a step-down transformer and two switches to route the current to an internal rechargeable battery pack, allowing the module to be used independently as a small study light or 5 volt USB charger that can last for one hour. When combined, the solar modules reach the power requirements to charge two 12-volt batteries in series to get the required 24V of DC power, which in turn are routed through the inverter to run the photocopier on the needed 220V AC. Each power module is made of Balsa wood but can be easily reproduced with available materials. The modular nature of the device ensures that the device has the ability to be stored indoors at night and can be modified if the power needs of the school change over time. Design validation was confirmed through successful charging of the batteries with the solar modules, then running a Samsung multifunction printer off the batteries. Our next steps include incorporating beta testing feedback from the students at Sare Bilaly, testing more bioenergy iterations as a secondary energy source during the rainy season, and pursuing an open patent to ensure equity of access to the concept to similar communities.

Introduction

R2i2 Lemelson-InvenTeam created a modular sustainable power supply to operate a photocopier in Sare Bilaly, Senegal. Madame Fanta Fofana Boiro, the principal of a secondary school in Sare Bilaly, reached out to our school in 2018 with a specific energy problem. Her school was given a photocopier, but there is no access to electricity in that village. Next Energy Engineering students at R2i2 had worked with her students two years ago on a solar study light project, and she asked for ideas to power the tabletop photocopier. At first, this may not seem like an urgent problem, but the school does not have any print resources at all. Students learn by lecture and by copying notes from the chalkboard into their notebooks. As a result, the 343 students, who come from 43 surrounding villages, only have a 24% pass rate on the national exams. These students range in age from 12-20, and only have two attempts to repeat the same grade when they fail the national exam. Because education is not compulsory at this level, many students drop out of secondary school after failing exams, especially female students, who face social pressures for early marriage. Collaborating with Sare Bilaly to create a feasible solution is important to the R2i2 InvenTeam because we are aware we are fortunate to have resources and modern technology to aid us in our educational journey. Providing access to more educational materials could help more students in Sare Bilaly pass the national exams, and give them a greater chance to improve their futures.

The beneficiaries of our invention are the students in Sare Bilaly because a consistent power supply will enable their educators to supplement their teaching with visual aids and other resources. To address the lack of print resources, teachers have traveled to Kolda to make copies, which has proven to be too expensive to do on a regular basis. This is why the R2i2 Lemelson-InvenTeam has made our design cost-efficient by using locally sourced materials that can be easily repaired by the students themselves.

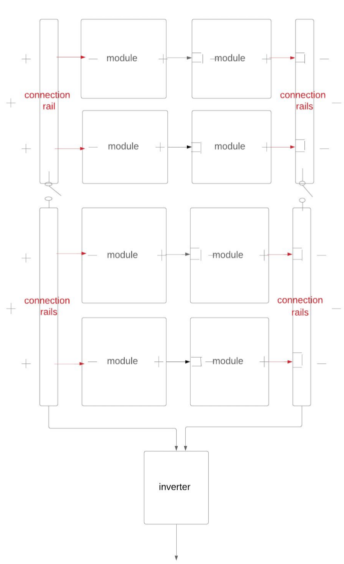
Many developments have been made in recent years advancing solar panel technologies, and many patents already exist in solar and solar hybrid chargers. In fact, a US patent exists for our original idea of a single solar hybrid charger that we missed in our first searches before the first application (US Patent 8212142 B2). When we met over the summer to discuss a different approach, we thought of how solar cells are connected in series to increase voltage, and wondered if we could simplify the design to an interconnecting system of smaller chargers. A more detailed search yielded a similar idea of interconnecting modules, but one that is used exclusively by solar energy, and not a hybrid with bioenergy (USPA 20090140689) . The existing connector also does not have the additional benefit of using each module as a stand-alone USB charger. After reading the claims of the similar devices, we believe our invention is unique in the way it will be used, and its focus on simple wiring with terminal blocks so that students can easily make repairs. Even without the addition of bioenergy, we believe that our design is distinct and unique from existing technology.

There are many patents on solar technologies and mobile power supplies, but the following are the patents that are most applicable to the proposed solution:

- Deployable Power Supply System, USPA 8212142 B2
- Charger for Electronic Devices having a Rechargeable Battery, USPA 20120043937
- Solar Charger (interconnecting independent modules), USPA 20090140689

The Invention

Our current design for each solar module is a simple six inch cubic wooden box that can be joined through box joints or finishing nails. Four millimeter banana jacks and sockets on



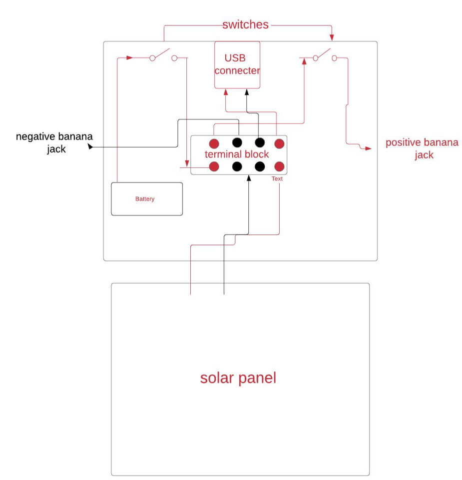


Figure 1 (left): Electric schematic for Modular Solar Power System; Figure 2 (right): Individual module electric diagram opposite sides connect the boxes in series to increase voltage. The lid has a hole near the center top with angled handles so that the 3-watt (12 volt, 0.25 A) solar panels can be angled for optimal solar insolation at different times of the day. Wooden parallel rails connect the module series in parallel circuits to increase current and reduce the time needed to charge the pure gel batteries.

Within each module is an 8-port terminal block to route power from the solar panel to the banana jacks for charging the pure gel batteries. Two switches can divert the solar power to an internal battery back (6 AA batteries), which in turn power a 5 volt USB charger with step-down transformer, so that each module can function independently as a phone or study light charger. One switch connects to the positive lead of the batteries to avoid draining electricity when using the external connections. The second switch connects to the positive lead in the external connection banana jack.

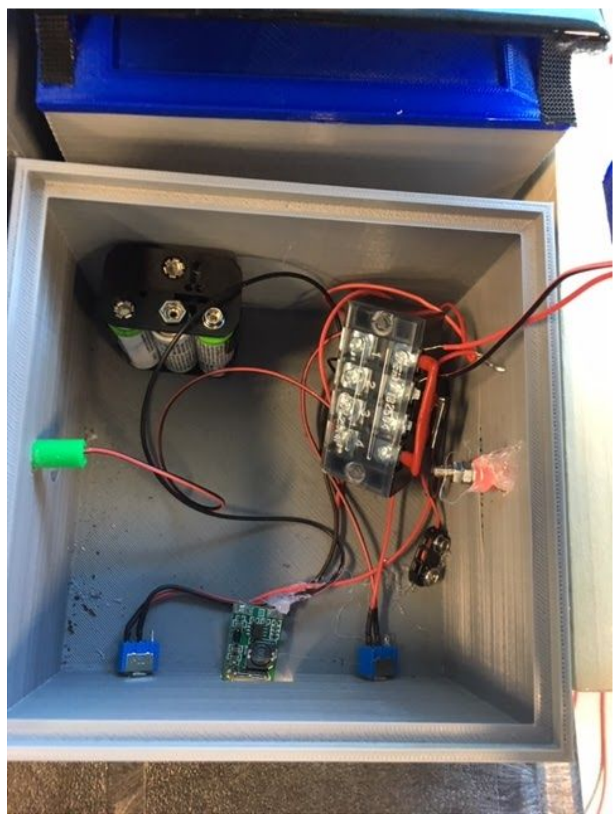
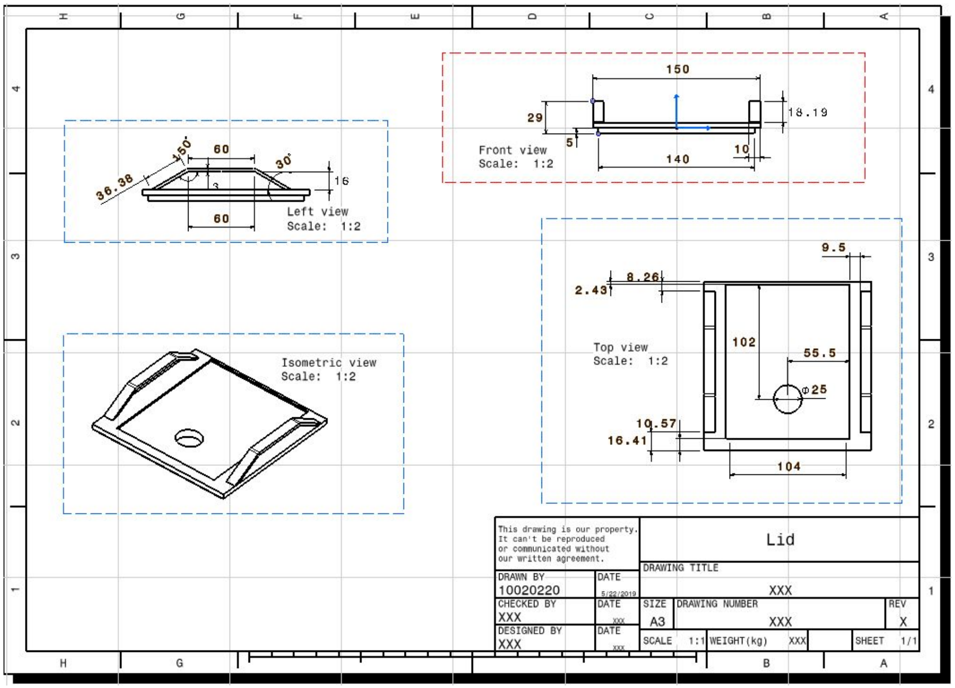
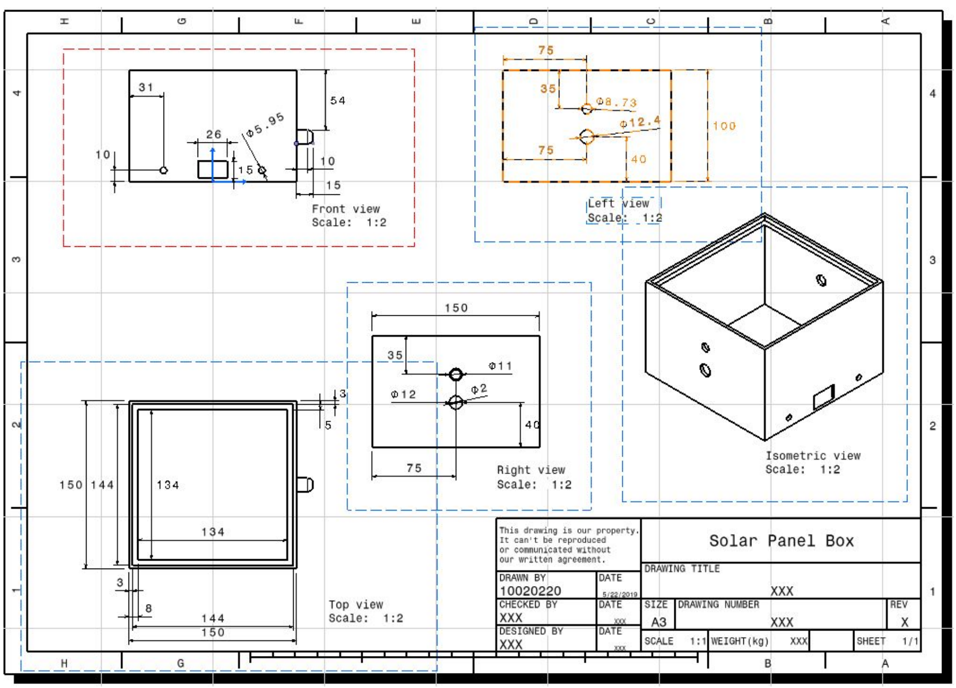


Image 1 (left): Modular Solar Power System charging deep cycle battery; Image 2 (right): Internal view of individual module.





Drawing 1 (top)and Drawing 2 (bottom): Technical drawings of the lid and module box, respectively, generated in CATIA.

Sustainability

Sustainability of the modular power system was a significant concern for both the students in Sare Bilaly and the R2i2 InvenTeam. The modules were originally designed in CATIA and printed in ABS plastic to rapidly prototype and test the concept. 3D printing our solution allowed for modifications, such as adjusting the lid handles to allow the solar panel to be angled for optimal insolation. However, we knew that 3D printing was not available in southern Senegal, and needed to use locally available materials.

Madame Boiro and the local forestry manager of the Kolda Region were able to confirm that sustainable harvesting of local trees is permitted within the national forests. Forest regions are divided into different sections, and then one or two of those sections each year are allowed to be harvested for charcoal or for wood. Small businesses are encouraged to generate business from the permitted sections. At the end of that year, that land is off limits for harvesting for eight years. There are also many regulations for how the tree must be cut in order to let the seedlings grow, and size restrictions on what trees may be harvested. Given this forestry management, wood seemed like an optimal sustainable solution for the module boxes, as it is locally available and promotes regional entrepreneurship.

In order to quantify the module's sustainability, we imported our CATIA files into Solidworks, and ran the Sustainability application to analyze the impact of an ABS module on four indicators: energy, water, air, and carbon. We then changed the material to pine (the closest choice to the wood available in the Kolda region), and determined the percent change in environmental impact at each stage of the product life cycle.

Table 1: Sustainability Comparison of Module Box; Pine wood vs. PLA

Carbon (kg CO_2)			
Stage of Product Life Cycle	Wood (Pine)	PLA (3D Printing Filament)	Percent Change
Material	0.026	0.961	-97.29448491
Manufacturing	0	0.3272	-100
Use	n/a	n/a	n/a
End of Life	0.052	0.152	-65.78947368
Transportation	0.0015	0.0079	-81.01265823
Energy Consumption (MJ)			
Stage of Product Life Cycle	Wood (Pine)	PLA (3D Printing Filament)	Percent Change

Material	0.137	22	-99.37727273
Manufacturing	0	5.4	-100
Use	n/a	n/a	n/a
End of Life	0.036	0.109	-66.97247706
Transportation	0.018	0.096	-81.25
Air Acidification (kg SO_2)			
Stage of Product Life Cycle	Wood (Pine)	PLA (3D Printing Filament)	Percent Change
Material	0.000053	0.0032	-98.34375
Manufacturing	0	0.000025	-100
Use	n/a	n/a	n/a
End of Life	0.000019	0.00006	-68.33333333
Transportation	0.000048	0.00025	-80.8
Water Eutrophication (kg PO4)			
Stage of Product Life Cycle	Wood (Pine)	PLA (3D Printing Filament)	Percent Change
Material	0.000011	0.00039	-97.17948718
Manufacturing	0	0.000092	-100
Use	n/a	n/a	n/a
End of Life	0.000085	0.00025	-66
Transportation	0.0000045	0.000024	-81.25

It is important to note that there were some assumptions that had to be made in order to use Solidworks Sustainability. Sub-Saharan Africa is not available as a manufacturing or use region in Solidworks, which is likely due to insufficient available data. We therefore used Asia as the selected region, and adjusted the default transportation distances to reflect the actual distance between Columbia and Sare Bilaly (about 7000 km). Even with these limitations, it is clear that wood is the better choice from the environmental aspect of sustainability, based on the significant improvements to carbon, air, water and energy.

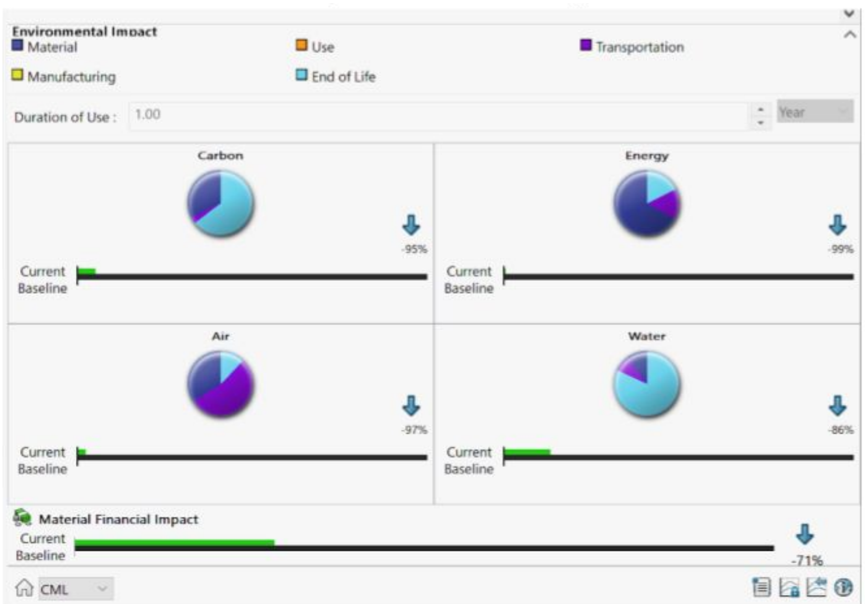


Image 3: Screenshot of Solidworks Sustainability (2018 Version) Analysis of PLA vs. Balsa Wood

Materials and Methods

The design of our module was heavily influenced by the criteria and constraints we generated from our email conversations with Madame Boiro and her students. Our criteria for our modular solar chargers included that the invention is a new and unique concept, the reason being that currently available technologies are either not available or feasible in Sare Bilaly. Another criteria we had was for the chargers to be portable. We wanted the modules to be able to be brought home by the students, taken out during the day, and bought in at night to keep it safe from theft, cattle herds, and sand and wind during the dry season. We also needed the solution to be easy to assemble and use because the students are the ones responsible for maintaining the charger. Another criterion we created was ensuring that our invention has sufficient power to operate a copier or charge a battery that can operate the copier. Lastly, we wanted the solution to be adaptable for changing output or other equipment. While we are confident that we created something that will last a long time, we cannot assure that a part will never malfunction or need to be replaced. This is the reason why we wanted it to be adaptable and to use materials that can be found in the Kolda region as much as possible.

One of our biggest constraints was time: as the team is divided across five high schools, we had to maximize the time together to ensure progress would continue, and find ways to communicate remotely. Another constraint was the transportation of materials; both R2i2 and Sare Bilaly wanted the components of the modules to be as local as possible, but we needed to supply hard-to-find parts like the solar panels and electronic configuration parts. We had to find a balance of how to make a working solution with one that will be sustainable for years to come. We had a limited budget for shipping , and discovered specific restrictions to shipping batteries. Another constraint was the available energy sources; most people in the Kolda region use charcoal or kerosene for their energy needs. Delivery of kerosene can be unreliable due to politics and weather, and we wanted to avoid charcoal if possible due to pollution. Initially, solar energy and bioenergy were our best options in terms of available energy for our invention (because of the large number of cattle in the area so cow manure is available). However, in the final design, we decided to utilize only solar power because the microbial fuel cells (bioenergy) were not producing enough current and were hard to maintain.

Our final design meets the specifications requested by Sare Bilaly in that the modules are portable, adaptable for future needs, and can be easily replicated with locally available materials, with the exception of the electronic components. However, it is possible to find most of the electric parts in Dakar, and we anticipate that the few items not currently available in the Kolda region, such as solar cells, will become more available in the future. While we considered reducing the size of the module itself once we eliminated the bioenergy component, we opted to keep the box sufficiently large to make it easier to repair loose connections and replace internal batteries. With each design decision, we first considered what materials and skills might be available, and secondly chose items based on weight to reduce shipping costs. The adjustable lid takes into consideration that the modules will have to spend most of the day outside to fully charge, so the solar cells will therefore need to have an adjustable angle to optimize capture of energy from the sun as it changes position throughout the day.

Discussion

We ensured that the device meets the needs of the beneficiary by first testing the available voltage and current from each module with a multimeter, then confirming power by charging and operating a USB light, cell phone, and photocopier with the system. We then calculated the charging and operating times for individual modules and for the larger battery system. Actual charge rates were verified with a USB multimeter. Based on our observed charging rates, individual modules take between eight and nine hours to fully charge the internal battery pack. Given that Sare Bilaly experiences more direct sunlight than South Carolina, their charging times are likely to be less than what we observed. On the other hand, power output decreases with temperatures over 25℃, so actual charging times in Sare Bilaly will need to be tested and reported back in order to make any needed adjustments for efficiency. When the internal battery is fully charged, the USB charger can operate at one hour to charge a cell phone (5 V, 1A), and for ten hours with a LED light (5 V, 100 mA).

While latitude and temperature will also affect the charging rates for the pure gel deep cycling batteries for the photocopier, the main consideration in charging times is how many modules are linked in parallel, which in turn determines the current. The desktop printer/photocopier that will be used in Sare Bilaly had a reported power requirement of 50 watts; however, when we researched this, we discovered that the reported requirement was for standby mode; operating power is closer to 400 watts, with starting surges closer to 900 watts. In order to accommodate this, we had to switch from a 750 watt inverter to a 2000 watt inverter. The change in power need does not affect the batteries needed, but it does impact the amount of time the batteries can run the photocopier. Our current estimate, verified with a Samsung multifunction printer that has the same power requirements, is that the fully charged pure gel batteries can run the photocopier for two hours.

The next step for the R2I2 Lemelson-MIT InvenTeam is pursuing a patent for our invention. A provisional patent has been filed, and a full patent search will be conducted to ensure uniqueness of our system. Our plan is to file for an open patent, to ensure the system is accessible by all. We are also going to continue to explore bioenergy or a sustainable alternative for the rainy season, although it is important to note that the Senegalese school year is mainly in the dry season. As the students begin to use the modules this fall, we have been promised written feedback so that we can work together to ensure optimal operability of the modular solar power system. Once we have finalized the specifications, we will seek additional international partners that may find our invention to be of use in addressing their energy needs.

Acknowledgments

The R2i2 Lemelson-MIT InvenTeam would like to thank Richland School District Two, Richland Two Institute of Innovation (R2i2), McDaniels Paint and Body, and Summit Engineering for their donations to fund our EurekaFest trip. We would also like to thank Martha Jones, Director of Strategic Partnerships for Richland Two for helping us secure these donations. We are also grateful to Ruben Navarre from Trane for his technical feedback, and the entire CATE advisory board of R2i2 for their support. We would also like to thank the Lemelson-MIT Program for selecting us to receive the $10,000 grant to impact real-world change and for their considerable support throughout the process.

This project would not have possible without the collaborative efforts of Madame Fanta Fofana Boiro and her students in Sare Bilaly, as well as Madame Rokhaya Diop for her willingness to assist in transport logistics within Senegal. We are grateful to our Senegalese partners for the insights they provide and for enriching our experience.

Finally, a project like this cannot be completed without a supportive community. The Richland Two Institute of Innovation InvenTeam would like to thank their mentors, Kirstin Bullington and Robin Jones, the faculty and staff at R2i2, the Richland Two School Board of Trustees, Mayor Steve Benjamin and the Columbia City Council, Governor Henry McMaster, and our families for all of the ways they provided encouragement and support throughout the year.

Appendices

1) References

Clarifying Questions for Module Charger in Sare Bilaly, Senegal [E-mail interview]. (2018, August 24). Interview was conducted with Madame Fanta Fofana Boiro through messaging to confirm technical details and answer R2i2 student questions about the region and problem.

Energy - United Nations Sustainable Development. (n.d.). Retrieved August 31, 2018, from https://www.un.org/sustainabledevelopment/energy/

Hargreaves, J. D., & Clark, A. (2018, August 17). Senegal. Retrieved August 31, 2018, from https://www.britannica.com/place/Senegal/Economy

Herrera, O. (n.d.). Lucidchart [Computer software]. Retrieved May 02, 2019, from https://www.lucidchart.com/pages/Electronic schematics

(n.d.). Retrieved August 31, 2018, from https://app.discoveryeducation.com/learn/player/955acd60-ca0b-49be-b60b-2d145beca08b

Power Africa in Senegal | Power Africa. (n.d.). Retrieved August 31, 2018, from https://www.usaid.gov/powerafrica/senegal

Purdue Online Writing Lab. *General Writing FAQs.* Retrieved from https://owl.purdue.edu/owl/general_writing/general_writing_faqs.html

SolidWorks (Version 2018) [Computer software]. (n.d.). Retrieved February 13, 2019. Sustainability Application

Thompson, A. (n.d.). CATIA® V5 [Computer software]. Retrieved May 22, 2019.

Technical Drawings for Solar Modules and Lids

The World Factbook: SENEGAL. (2018, August 20). Retrieved on August 31,2018, from https://www.cia.gov/library/publications/the-world-factbook/geos/sg.html

Ulsan National Institute of Science and Technology(UNIST). (2017, April 24). New breakthrough in battery charging technology. *ScienceDaily*. Retrieved September 1, 2018 from www.sciencedaily.com/releases/2017/04/170424101222.htm

2) Financial Summary

R2i2 Lemelson-MIT InvenTeam's budgeting process started with projected needs for our invention and travel to Eurekafest. Our initial projected budget was approximately \$6,200 (including a 5% contingency) for the invention and \$5,100 for travel. We started with \$7,000 from the Lemelson MIT Grant. Through donations and fundraising, we received an additional \$6,040. As of May 22, 2019, we've used 88% of our total funds. There were a few variances. We projected \$1,518 for ideating/setup. The actual spent was \$2,940, almost double our projection. This was largely in part to testing various inverters and batteries to achieve our desired results. We projected \$3,728 for prototyping. The actual spent was \$2,384, 37% less than projected. We will purchase and ship additional materials to be used in Senegal. This will consume the final 12% of our budget. Overall, we managed to stay on target with our total invention budget. (See Figure 3)

Our estimated travel expenses to Eurekafest were \$5,100. Our projections included additional dorm rooms at MIT and hotel stay for two nights. The hotel rooms were not needed, but instead, the purchase of transportation to the airport was necessary. Also, the plane tickets were more expensive than projected. The actual expenses were \$6,040, 18% more than projected. We received monetary donations from Summit Engineering, McDaniel Paint and Body, and Richland Two Institute of Innovation, totaling \$5,540. The team participated in a fundraiser April 5-6, 2019 to secure an additional \$500. Because of these generous donations and efforts of the team, our travel is fully funded. (See Figure 4)

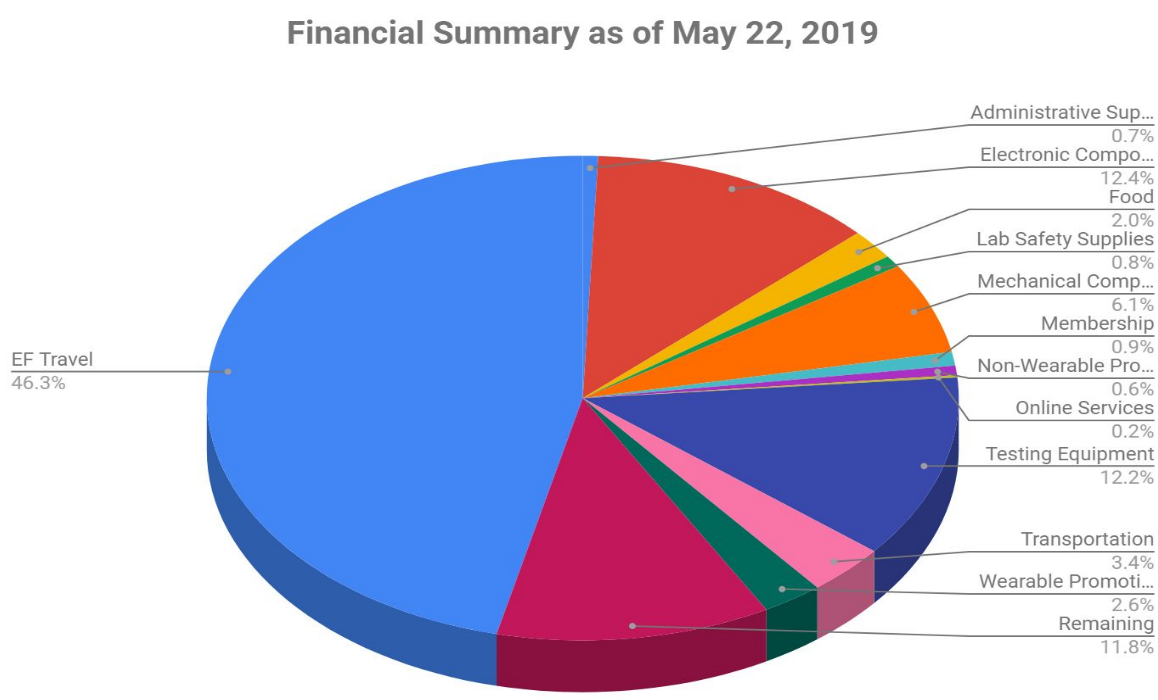


Figure 3: Summary of Expenses

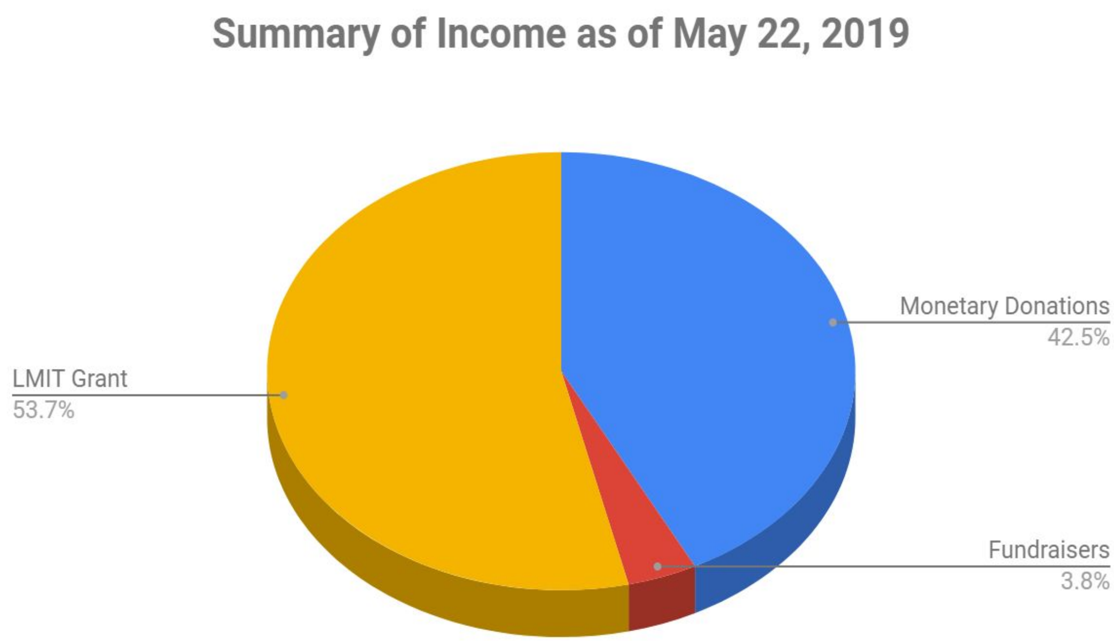


Figure 4: Income as of May 22, 2019