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Photovoltaic Design Projects as an Innovation in Our Fundamentals of Electric Circuits Course

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Photovoltaic Design Projects as an Innovation in Fundamentals of Electric Circuits Course

Abstract

As engineering instructors, we continue to review and test novel pedagogical ideas that can better engage engineers in learning the challenging fundamentals of our very often rigorous engineering curricula. This paper explores one significant change to the laboratories of our fundamental circuits course (ECEG 210) at Bucknell University. After students completed many core laboratories during the first half of the semester, we challenged student teams to consider new applications of solar photovoltaic (PV) technology to provide reliable electricity to various electrical end-uses at the residential level (off-grid). The students derived with many creative applications and developed and tested minimum viable product (MVP) demonstrations of their ideas during the last 6 weeks of the semester. The results were very encouraging from this project-based learning innovation to our course labs. Our intent was to reinforce the fundamentals of circuits they had learned through the course with a real-world challenge to see how many more things PV may be able to economically power in the future. This paper shares some of the exciting project results as well as the student assessment of this novel lab addition.

Why Photovoltaic Applications as Project-Based Learning and Extended Labs?

Incorporating extended laboratories into core engineering courses can have numerous benefits, such as promoting deeper learning and enhancing the application and retention of fundamental concepts. However, despite these advantages, extended, open-ended design experiences are not frequently utilized in ECE and other core engineering disciplines. Possible reasons for this could be the added demands on instructors to maintain course focus when teams are working on various projects or the need for greater resources to support investigations into unconstrained ideas, which could result in numerous project variations being undertaken by motivated students.

Many engineering instructors have reported benefits from engaging students with novel technologies through service learning or extracurricular university activities [1,2], with project-based learning experiences focused on renewable energy being particularly effective [3-7]. Certain experiences that we would like to give all our engineering students are best delivered by these extra-curricular or co-curricular opportunities. Unfortunately, not all students have the time available, resources, or access to those types of educational engagements. It remains a challenging task to bring those types of real-world experiences into the classroom. Laboratories, however, are often a key part of many engineering core courses and can be modified into extended laboratories (running many weeks) to similarly engage all students in challenging design experiences with real-world appeal.

Our decision to pilot a pedagogical implementation of PV in one of our core ECE courses was motivated not only by our own goals, but also by an external request to see what innovative ideas our undergraduate students could generate for PV applications. This paper describes our endeavor to evaluate the innovative capacity of sophomore ECE students when presented with an open-ended challenge.

We also describe the details of this innovative implementation in Reference 8, a companion paper that outlines (in much greater depth) the organization of the pilot project and the specific details of the scaffolding provided for each project-lab milestone. Reference 8 also addresses the benefits of the project experience to ABET student outcomes. While both papers highlight some of the final projects produced by the ECE teams, this paper focuses specifically on surprising innovations that exceeded our expectations. Finally, the course evaluation and student feedback are described in each of our papers, but in this paper the focus is on what new learning may have been provided from the projects.

To support this project, we received a generous gift from a university alumnus who is passionate about seeing students engaged in developing the PV innovative applications of tomorrow. The William Corrington Renewable Energy Fund has been created at Bucknell to promote innovation in PV. Each year the Bucknell Center for Sustainability & the Environment issues a call for applications to the William Corrington Renewable Energy Fellowship Fund, which solicit projects from a wide variety of disciplines across the campus, provided they are related to renewable energy. The fund is encouraging research efforts that focus on PV (renewable energy) and how it can be used to create economically preferable products and services that are better for the environment. The projects that students generate in these labs could also enable them to get summer research fellowships. Fellows at the BCSE under this initiative receive a stipend of $4,500 for up to 10 weeks of full-time scholarly work, as well as up to $500 for equipment, supplies, conference travel, and on-campus housing. Instructors also desired to provide potentially interested ECE students with opportunities for summer research internships.

What Was the Lab Innovation?

In the ECEG 210 course, instructors have historically used various approaches to laboratory sessions. They have debated whether the labs should primarily reinforce the material covered in lectures, expose ECE students to cutting-edge technology, or aim for a balance between the two. With only a two-hour session each week, instructors must carefully consider the goals of their labs and how they fit into the broader ECE curriculum. During the COVID-19 pandemic, the course was taught in hybrid mode (both online and in person) and used five labs, including Introduction to Multisim, an Electronic Thermometer, Automatic Streetlights, an Integrator, and Modeling the Charging Behavior of a Capacitor in an RC Circuit. In the past, the labs have been less comprehensive, only requiring students to build or model a circuit.

In the most recent iteration of the course (Autumn 2022), we incorporated nine labs to reinforce core learning outcomes in addition to the six project-based labs during the latter half of the semester. These labs used a different approach to better engage students with the material. We required students to conduct calculations to predict circuit behavior, simulate the circuit in

Multisim, analyze and compare simulated results to calculated results, build the circuit, and finally measure its behavior using lab equipment. This hands-on approach enabled students to practice lecture material and connect theoretical concepts to real-world situations.

Specifically, Lab 1 provided a foundation in using the benchtop multimeter and power supply, while Lab 2 delved into the principles of Ohm's law, Kirchhoff's current and voltage laws, and nodal analysis. Lab 3 focused on diode fundamentals and the design of a simple digital-to-analog converter. Lab 4 further explored diode behavior and introduced the desktop oscilloscope and function generator. In Lab 5, students used Thevenin and Norton equivalent techniques to analyze and simplify complex circuits. Lab 6 introduced the use of operational amplifiers in the formation of basic linear equations. Labs 7 and 8 covered inductors in RL circuits and capacitors in RC circuits. The final Lab 9 dealt with complex power analysis and the distinction between leading and lagging phases in electricity.

We initiated the PV end-use project following the completion of these nine laboratory sessions intended to reinforce students' understanding of essential electrical and computer engineering concepts. ECE instructors introduced the Residential End-Use Applications of PV project to students in a six-part laboratory sequence, which is outlined in Table 1 along with the associated assignments and outcomes.

Table 1 – Scaffolded Assignments for Photovoltaic Project

Lab Title	***Description***	***Outcomes***
Part A	What are Photovoltaic Modules and Cells?	Study PV, residential electric users; identify four applications
Part B	Probe Deeper into Four End-Uses for PV	Research charge controllers, modules, Level 0 diagram
Part C	Assess Four for Cost, Value, and Feasibility	Learn how to compare, contrast, and assess options
Part D	Analyze Market for Selected Project	Complete Level 1 & 2 Block Diagrams, order parts list
Part E	Draft Presentation Slides & Specifications	For MVP; value proposition, metrics, tests, scalability
Part F	Build, Test, Document MVP	Showcase results: two videos (performance & marketing)

Examples of the details for three of these assignments are available from the appendices to this paper as those details outline how the project was delivered to and scoped for the student teams. Reference 8 also includes detailed descriptions. Each Appendix is labelled as A through C to correspond with the Table 1 assignments described above. All are available from the author should they be desired, but the 12-page limit has restricted their inclusion to three.

How Can Others Adopt This Approach or Modify it Easily?

At a high level, this paper describes the steps involved and required to make this innovation possible. Detailed lab assignments, which enabled the student teams to make such significant progress on their projects in such a short time, are attached in the appendix.

Results: Student-Generated Projects

Of the nine unique projects (Residential End-Use Applications of PV), a majority did not provide significant innovations that would be considered early versions of "economically preferable products and/or services that are better for the environment”. While the teams researched competing products on the market, not all projects resulted in an improvement over the competitors. These projects include: solar porch light, solar laptop charger, solar phone charging station, or a solar universal tool battery charger. However, some students contributed surprising and existing innovations. See Table 2.

Table 2 – Potentially Innovative Photovoltaic Applications

Project Title	***Description***	***Benefits***
PV Air Conditioner	Room A/C Unit powered directly from PV & battery	*Reduce 7 Megatons CO_2
PV Washer/Dryer	Hi-eff. laundry done directly from PV & battery	Smart & “green” laundry
PV Lawn Mower	Smart lawn mower powered directly from PV/battery	Lawncare automation
PV Toolbox Charger	Toolbox powered directly from PV & battery	Power tool availability
PV Well Pump	Home water supply (well) powered from PV/battery	Water during grid outages

*- assuming 5% market penetration

Figures 1 and 2 show block diagrams and CAD renderings for two of the innovative PV applications to a specific residential end-use. It was encouraging to see how far a team of three ECE sophomores could go in a 6-week extended lab setting to take a bold new idea from initial concept to MVP.

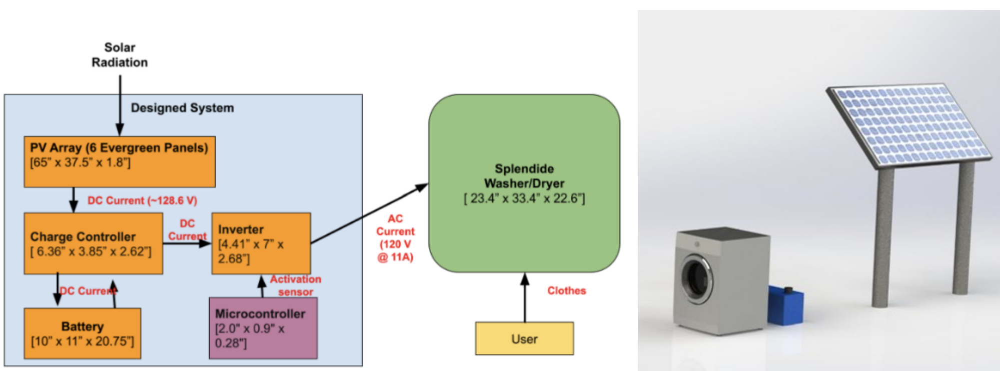


Figure 1 – Solar Washer/Dryer: Block Diagram & CAD Rendering

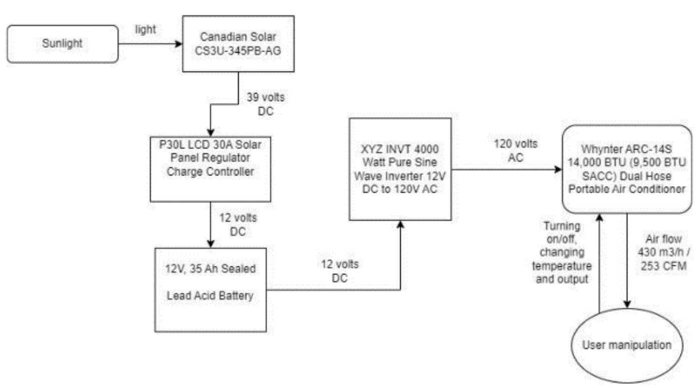


Figure 2a – PV Powered AC Unit: Block Diagram

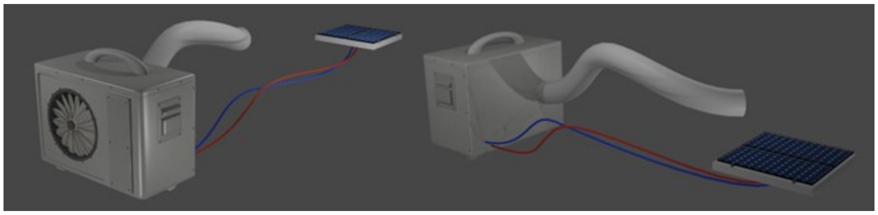


Figure 2b – PV Powered AC Unit: CAD Rendering

Assessment and Student Response

In this section, we summarize the feedback we received from 20 out of the 28 enrolled students regarding what they learned during the course and from the project. Although the feedback presented in the tables suggests some contradictions, as some students do not consider the project a significant contributor to their education, they still rated some aspects of it highly. For instance, Table 3 indicates that creating their MVP received an 8.5 rating on a scale of 1 to 10, and four other elements of the PV application project received ratings at or above 70% when the project was first offered in the course. The student feedback survey also included questions on the various components of the course pedagogy, from lecture sessions to course outcomes, highlighted in Table 4. While initial ratings suggest perceived pedagogical benefits, the overall feedback indicates room for improvement.

Table 3 – Feedback on Final PV Project Components

On a Scale from 1 to 10, How Effective Did you Find the Following Project Areas at Enhancing Your Overall Engineering Education (20 students)	Average
Creating the Minimum Viable Product of the design we developed	8.5
Creating representations including block and data-flow diagrams	7.5
Testing and evaluating the MVP we created	7.4
Evaluating PV cell/module capabilities	7.1
Estimating economic benefits of my product and design using PV to take a particular end-use off-grid	7.0
Creating a technical video for my project	6.7
Evaluating carbon emission savings of my design	6.6

The second student survey – focused particularly on course outcomes and learning pedagogical elements (laboratories, homework, lecture sessions, online textbook, and the project) shows different results. When asked if students agreed that the PV project was ***"very helpful to my learning & experience,"*** the average reply was 3.4 out of 5 (with 5 being strongly agree and 1 being strongly disagree). This places it on par with the online textbook (rated at 3.5) and the learning meetings (lecture sessions) rated at 3.8. One interpretation is that work (going to class, reading textbooks, and completing projects) are not the most enjoyable aspects of an engineer's education. But another perspective and possible interpretation of this data is to think that the project may have provided knowledge and engagement levels similar to attending class or working with the excellent online text that was provided for students and used quite extensively in the course. Reviewing Table 4 shows that the majority of course outcomes were perceived as achieved by the greater number of students who filled out the survey.

To better illustrate the students' thoughts about the project, we solicited open-ended reflections on what they learned and accomplished during the project. The resulting feedback indicates that the project was generally well-received and valuable. Of the students who participated in the evaluation, 70% believed that the project allowed them to apply essential ECE concepts taught in the labs and coursework, with specific topics such as Ohm' law, power and energy calculations, circuit analysis, and the use of measurement equipment like multimeters and oscilloscopes frequently cited.

Many students found the project to be a useful opportunity for hands-on problem-solving, as well as for gaining knowledge of engineering design and product marketing. 70% of surveyed students also reported learning new ideas beyond the material presented in the course, including improved time management, novel calculation techniques, CAD software, market analysis, carbon emissions and energy savings estimates, and sustainability strategies.

Additionally, the project provided students with opportunities to develop their soft skills such as communication, problem-solving, and team coordination. Despite the overall positive response, some students did not feel that the project augmented their education. Some students felt that the project was disjointed from the ECEG 210 course material, or that the relationship between the two was minimal. This feedback implies that the project requires better integration with the course material. One student suggested that the core concepts of PV should be introduced in lectures and homework examples to provide students with a better understanding of the technology and make them more comfortable with it before working with physical modules during the project.

Students also suggested that more time should have been provided to complete the final two parts of the project. These deliverables were assigned before Thanksgiving break, with no additional class time provided between the posting and due dates. Some students felt that they were unable to efficiently work on the final deliverables during the break because they were separated from their lab partners. Beginning the final project earlier or reducing the number of deliverables would have helped alleviate stress. For Part A of the project, where students were asked to identify three potential appliances they could power using solar energy, assigning the final appliance earlier would have given students more time to focus on their deliverables. Instructors might have checked more regularly with each group to ensure they stayed on schedule. Many students desired more guidance throughout the project. Providing clearer guidelines for faculty expectations earlier in the process might have clarified the deliverables sought by instructors. Incorporating some lecture time to work on the project or integrating examples related to PV and carbon emissions calculations would have improved student and professor interaction and provided a stronger background for their project work. Instructors will use the feedback received to enhance the project and course in the future, aiming to provide a more meaningful and enriching experience for students.

Table 4 – Feedback on Laboratory and Coursework Instruction

How Strongly Do You Agree with the Following Statements on a Scale From 1 to 5 (20 students)	Average
I believe I have learned many ECE / circuit fundamentals in this course	4.7
I can ***effectively apply nodal analysis to electric circuits***	4.7
I can ***effectively analyze electric circuits using Ohm's law KVL and KCL***	4.7
I can ***effectively use ECE tools (multimeter, signal gen, scope, AD2, MultiSim)***	4.6
I am able to ***work effectively in teams to solve problems and deliver reports***	4.5
Laboratories were supportive of course learning outcomes	4.4
I can ***effectively test and measure parameters in electric circuits***	4.4
I can ***calculate the voltage, current and power across capacitors and inductors***	4.2
The homework assignments were very helpful to my learning	4.0
I am ***able to solve first-order RC and RL circuits***	4.0
Learning meetings (lecture period) was very helpful to my learning	3.8
I am ***able to use complex algebra to perform phasor domain analysis***	3.7
The textbook (online available) was very helpful to my learning	3.5
I am ***able to solve simple second-order RLC circuits***	3.5
The project experience was very helpful to my learning & experience	3.4

Conclusions

While it was challenging to integrate a 6-week long PV design project into our ECEG 210 circuits courses, we were encouraged by the positive response it received for its initial run. While it is unclear if future instructors will continue with this specific application as an extended project, design-based laboratory, these instructors are encouraged by the teams' efforts, learning, and project results. We know now that encouraging students to think about renewable energy (especially early in their academic career) can play an important role in molding positive perceptions regarding renewables and building sustainability values and attitudes. Social psychology theories such as the Theory of Planned Behavior [9] and the Value-Belief-Norm theory [10] suggest that attitudes strongly predict behaviors and increase their salience. Our hope is that early student engagement with an innovative engineering project design challenge may lead to the formation of positive attitudes towards renewables, technology adoption, and possibly interest in future careers in the important area of PV systems.

References

1. M.G. Newberry, S.M. Myers and P.M. Jansson, ***“Sustainability Experiential Learning Laboratory – A Method for SELLing Photovoltaic Technology and Education to College Students,”*** American Solar Energy Society - SOLAR 2021: Empowering a Sustainable Future (50th Annual National Solar Conference), University of Boulder, Boulder, Colorado, 3-6 August 2021

2. P.M. Jansson, J. Murphy, J. Stewart, R. Molner, P. Tomkiewicz and W. Heston, ***“Undergraduate Service Learning: Photovoltaic System Design and Construction,”*** ASEE 2005 Annual Conference, Seattle, WA, June 12-15, 2005

3. P.M. Jansson, K. Whitten, C. Delia, M. Angelow, B. Ferraro, M. Giordano, M. Colosa, ***“EE Students Complete Photovoltaic R&D for Industry in Electrical Engineering Curriculum,”*** Proceedings of the 118th ASEE Annual Conference, Vancouver, BC, Canada, 26-29 June 2011

4. W.T. Riddell, E. Constans, J. Courtney, K. Dahm, R. Harvey, P.M. Jansson, M. Simone, P. von Lockette, B. Wolff, ***“Lessons Learned from Teaching Project Based Learning Communication and Design Courses,”*** 2007 ASEE Middle Atlantic Section Fall 2007 Conference, Philadelphia, PA, November 3, 2007

5. P.M. Jansson and R. Elwell, ***“Design of Photovoltaic Systems for Municipal and School Buildings in Ocean City, New Jersey,”*** ASEE 2007 Annual Conference Proceedings, Honolulu, HI, June 24-27, 2007

6. S. Hazel and P.M. Jansson, ***“Photovoltaic System Feasibility Assessments: Engineering Clinics Transforming Renewable Markets,”*** ASEE 2006 Annual Conference Proceedings, Chicago, IL, June 18-21, 2006

7. P.M. Jansson, S. A. Mandayam and J.L Schmalzel, ***"Green Power Engineering: Pedagogy for the Next Generation of Electrical Engineers,"*** ***Proceedings of the 2004 IEEE Annual Power Engineering Society Conference***, Denver, CO, June 6-10, 2004, ***IEEE Xplore Digital Object Identifier: 10.1109/ PES.2004.1372755, Vol. 1, pp. 65-70***

8. D. Whalen and P.M. Jansson, ***“Renewable Energy Projects Enhance Pedagogy in Foundational ECE Course,”*** final manuscript submitted to the 2023 ASEE Annual Conference and Exhibition, Baltimore, Maryland, 25-28 June 2023

9. A.H. Seyal and M.N. Abd Rahman MN, eds. **“*Theory of Planned Behavior: New Research*”**. New York: Nova Science; 2017. http://search.ebscohost.com/login.aspx?direct=true&scope=site&db=nlebk&db=nlabk&AN=1530922. Accessed February 13, 2023.

10. L. Zhang et al., “***Predicting Climate Change Mitigation and Adaptation Behaviors in Agricultural Production: A Comparison of the Theory of Planned Behavior and the Value-Belief-Norm Theory,”*** 68 Journal of Environmental Psychology (2020)

Appendix A:

Lab Project – Photovoltaics Off-Grid Applications – PART A

Objectives: The objective of this lab is to become familiar with the end-use applications of electricity in a typical home in the U.S. (or world). In this lab, you will identify a number of potential applications of off-grid solar (photovoltaic) electricity that could serve those loads in place of the electric power grid.

Part A – What are Photovoltaic Modules and Cells?

1) Research photovoltaic (PV) materials, cells, and modules. Learn how they work. How much power are they typically capable of producing per area of the device? Calculate the power & energy you could likely harvest from the sun in the northeastern portions of the U.S. over some specific period of time like a 24-hour day, a week or month during the year. Did you find models or tools out there that can help you calculate or estimate that?
2) Pick at least four (4) different electrical or electronic functions in your home that you think could be offloaded from the utility grid to a PV subsystem that you might design. For each of these end-use categories:
   a. Do some research into the potential end-use applications.
   b. How much power does it require, how much energy over a day, week, or month?
   c. Is this something that someone has already done? What kinds of products already exist in the marketplace? How efficient/effective are they?
   d. What are the other requirements for this end-use? Is a PV module or set of PV cells capable of powering this end-use device?
3) List at least two (2) things you learned so far in ECEG 201 that you believe your team could apply to building a circuit that achieves the desired behavior of these end-users of electricity.
4) Based on your power and energy calculations, would you require a battery to serve its load for a typical day or week using a PV module? What other components would you need?
5) Keep track of all of the sources of information you have researched as you build your project references and bibliography
6) Submit your list of the four (4) potential end-uses your team is considering to take "off-grid with solar PV" and all of the answers to PART A of this project on Moodle.

Appendix B:

Lab Project – Photovoltaic Off-Grid Applications – PART B

Objectives: Dig deeper into the design of each of the 4+ applications you chose in last week's Part A lab. Create basic block diagrams for each potential design to characterize the required physical components and behavior of each part of the hypothetical systems. Research power storage methods (batteries, capacitors, etc.) as well as DC charge controllers. Familiarize yourself with PV Watts and confirm that your device can be powered reliably.

Part A – Dive Deeper into Each of Your Hypothetical PV Applications

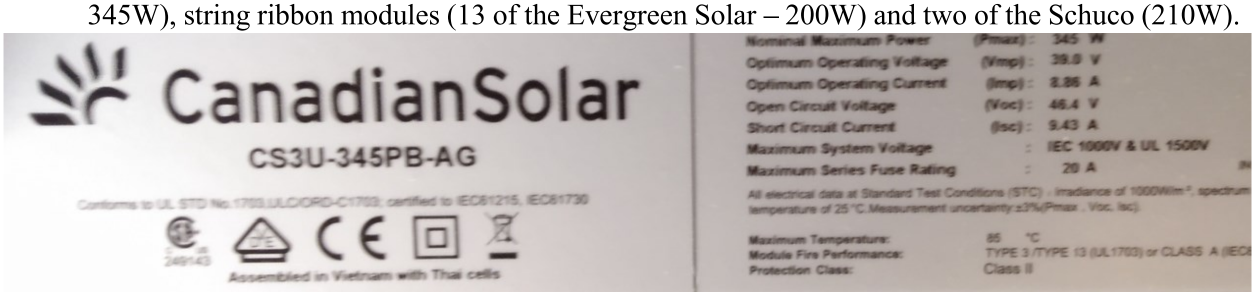
1) For each application create a Level 0 system diagram. The diagram should include the major physical components of your application connected with arrows that label all inputs and outputs.
   a. Think about how each application can be broken into individual subsystems that could be built and tested independent of the complete system.
2) Describe the intended behavior of each block in your diagram. What kind of interface would it need to integrate with the rest of the system? (AC to DC conversion, DC to AC, USB, Bluetooth, other

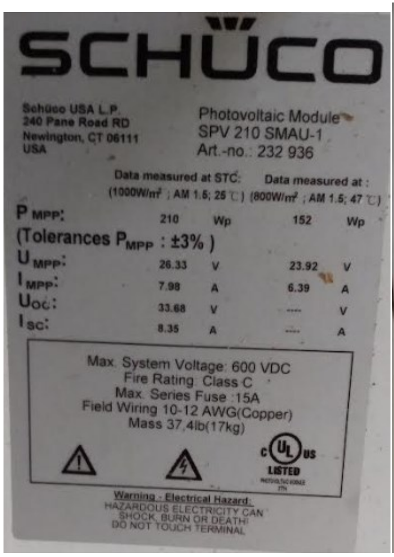
communication protocols or application interfaces?) Do some research and include what you learned about each and the components you would require to implement each of these four design ideas – ultimately, we are researching what it will take to build and prove your concept could represent a viable future commercial product.

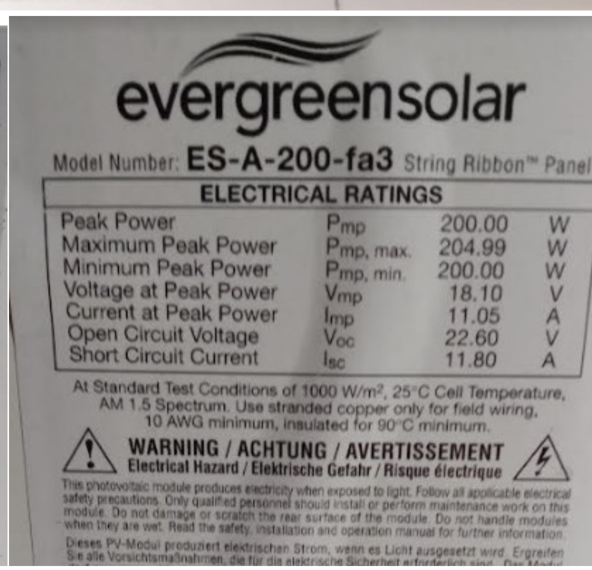
3) Some of your applications will likely require a battery to operate during hours when the sun is down. Do some research on charge controllers.
    a. What is a DC-DC charge controller?
    b. Why is it necessary for most of the designs you may be considering?
    c. Make some estimations about the power draw of your application. What kind of battery would be most appropriate (think voltage, milliwatts or watts, Joules, etc.)
    d. What kind of charge controller would be appropriate to manage this battery (shunt, series, PWM, MPPT)?
    e. What technology options exist for you if you want to power an AC load from your DC system of PV module(s), charge controller and battery?
    f. What are the costs for the technologies you need from your block diagrams?

<u>Part B: Constraint 1: Your PV Modules Available</u>

1) For each of your end-use design applications you will need to research how much energy your system requires on an instantaneous, daily, weekly, monthly and annual basis – create a table that provides your best (referenced and documented) engineering estimate of how much power and energy your end-use is likely to need.
2) Consult the module specification sheets that you can find on the internet for each of the three types of PV modules shown in the photos below. We have bi-facial modules (four of the Canadian Solar 345W), string ribbon modules (13 of the Evergreen Solar – 200W) and two of the Schuco (210W).







3) Typically, each kilowatt of PV installed in Pennsylvania produces approximately 1100 kWh per year once you convert it to AC.

Think about how each application end-use in your design group and create a table that would estimate (initially – using a “back of the envelope” design estimate) how many modules your end-use would require of each module type available for your projects. What type and size seems the best fit?

Part C: Constraint 2: Available Solar Energy in Central PA – Using PV Watts

1) Navigate to the PV Watts website and enter Lewisburg PA (zip 17837) as the location
2) Enter parameters based on what you know about your systems and the PV module types you are considering using in your application
3) How much power and energy are you capable of producing
    a. every year
    b. every month?
        i. Why does it vary so much from month to month?
    c. download the hourly spreadsheet and calculate the average power you could produce in a day during the darkest month.
4) Based on your calculations, will the solar array keep your application powered indefinitely or intermittently? Use the daily/hourly data available to determine how much energy storage you may need. How might you find that amount of energy storage? What technologies are capable of providing your system with that amount of energy?
5) Revisit your block diagram now, armed with the data on energy that can be provided by your PV harvesting system on an hourly, daily, and monthly basis (based on PV Watts estimates). Draw the power and energy information on the diagram to show your system can meet the energy you have estimated it requires from Part B.

Appendix C:

Semester Photovoltaic (PV) Project – PART C

1) Now let us redirect our focus to the PV project you have been working on. In this lab you will be asked to objectively assess and then rank each of your application ideas based on some objective and subjective criteria. You will then (as a team) assign a rank to each of your options (Best being 1 and Worst being 4, etc.) based on the following explicit parameters. One method we suggest is to have each team member submit their own ranking for any parameters that are subjective and then review them as a team and discuss your best compromise.
    a. Cost parameter:
        i. Put together a list of all components that you would need to build your application. Search online and find specific (real) parts you would need.
        ii. Record the cost of all components for each project and determine your best preliminary estimate of your system’s overall cost (assign the best rank to the least expensive).
    b. Feasibility/Complexity parameter:
        i. You have about 3 weeks left to complete your projects. Do some critical thinking about the amount of time would take to design/construct each project.

ii. Reference your block diagrams when thinking about this. How many subsystems would each application have? What needs to be designed and what can you buy off the shelf?
iii. For each component you listed previously, check the delivery lead times and take these into consideration as well.
iv. How feasible is your design completion and construction in the next fortnight?
v. Develop a subjective weighting scheme that captures all the parts of this parameter as your team sees it – to make sure you can effectively rank each of the potential designs from Best (1) to Toughest (4) to get done based on complexity.

c. Value Proposition parameter:
i. Start by figuring out how much energy (kWh) the application you're trying to replace consumes in a year (This is also how much power would be saved by taking that device off the grid and powering it by solar PV.)
ii. Now compare this to the number of people in America that actually own such a device that could be replaced by your application. After you have determined a reasonable U.S. market figure, multiply this number of people / households / consumers by the amount of energy your application saves to calculate the realistic maximum energy reduction.
iii. Convert this energy savings number to lbs. of CO_2 offset by your system – to find the alternative carbon reduction that your application provides use the EPA's online greenhouse gas calculator – found HERE: https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator
iv. Rank each application based on its beneficial carbon reduction impact.

d. Originality/Interest parameter: Is your product something that already exists in some capacity? If so, how does your solution provide value beyond what is already available?
i. Which of your potential PV applications interests your team members the most? Which would you be most passionate about designing, building, and testing?
ii. Rank each application according to its originality and your personal interest in it.

2) Create a summary chart that shows each project and your rankings for each of the calculated/estimated parameters above. If all of these parameters are weighed equally, which has the lowest (best) score overall? What if you assigned weightings to the design parameters where carbon savings (Value parameter) was 50% of the weight and the cost 30% and the other 2 parameters were only 10% each – does that change the final ranking of what comes out best (lowest) in your scoring/ranking? How would you (as a team) weigh the relative importance of each of these four parameters? Would you add a 5th or 6th? Finally, create a table that shows your weighted rankings for; A) equal weights; B) assigned weights above 50-30-10-10; C) Your team's parameter weightings (based on averaging all of your personal weightings; and D) if you added any additional parameters your team thought important. As you review these 3–4 rankings do you see any patterns in your result? Do the same options continue to dominate (rise to the top) or do the various weightings play a big part in creating variance in the results? What is your team's overall consolidated ranking of the options you have been working on? Share that in your write up, and we will review your work and recommendation and then assign your team one of your top ranked options to do a deep dive in PART D.

3) For each application, determine which of the provided solar cells or modules (and the possible number) would be most appropriate for your system to meet the end-use need you have designed for.