Designing with the Sun: Solar Curriculum Project

January 2022

A Report from the National Center for Sustainable Transportation

Beth Ferguson, University of California, Davis

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The solar curriculum materials are free for educators and self-learners to download and explore at their own pace on the Adapting City Lab Website (https://adaptingcitylab.ucdavis.edu/designing-w-the-sun.html).

16. Abstract

This report presents creative engagement activities based on the *Designing with the Sun: Solar Curriculum Project* that teaches high school and undergraduate students the principles of solar design and the steps needed to design and build a solar charging station. This in-depth curriculum covers renewable energy, electricity basics, solar design principles, and solar-supported mobility. Each chapter has a PowerPoint presentation, an active learning activity, video clips, and links to learn more. The solar curriculum materials are free for educators and self-learners to download and explore at their own pace. Small scale solar charging stations provide a living lab for research and a place to recharge e-bikes and e-scooters. Shared micromobility (e-bike and e-scooter fleets) have exploded in popularity on college campuses and can help reduce car ownership and carbon emissions when recharged with the sun. As universities plan for the challenges of the 21st century, incorporating multifaceted forms of renewable energy with electric vehicle charging is a step toward climate action and decarbonization. Creative rethinking on a massive scale is required to meet the goals set by the Intergovernmental Panel on Climate Change and the COP 21 Paris Agreement to limit global warming to 1.5°C. The UN's Sustainable Development Goals such as numbers 7, Affordable and Clean Energy; 9, Industry, Innovation and Infrastructure; and 11, Sustainable Cities and Communities are all important guides for modeling solar education.

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Glossary

Acronym	Definition
AC	alternating current
CAD	computer-aided design
DC	direct current
LED	light-emitting diode
PV	photovoltaic

Designing with the Sun: Solar Curriculum Project

EXECUTIVE SUMMARY

High schools and universities worldwide have the opportunity to play a key role in sustainable design education and the global shift to renewable energy. As educators plan for the challenges of the 21st century, using multifaceted forms of curricula on renewable energy, including material on electric vehicle charging, is a step toward climate action and decarbonization. Shared micromobility (e-bike and e-scooter fleets) have exploded in popularity on college campuses and city centers and can help reduce car ownership and carbon emissions when recharged with the sun. Creative rethinking on a massive scale is required to meet the goals set by the Intergovernmental Panel on Climate Change and the COP 21 Paris Agreement [15] to limit global warming to 1.5°C. The UN's Sustainable Development Goals [16]—such as numbers 7. Affordable and Clean Energy, 9. Industry, Innovation, and Infrastructure, and 11. Sustainable Cities and Communities—are all important guides for modeling solar education.

This report presents creative engagement activities based on the curriculum series *Designing with the Sun: Solar Curriculum Project* to teach high school and undergraduate students the principles of solar design and the steps needed to design and build a solar charging station. This in-depth curriculum covers renewable energy, electricity basics, solar design principles, and solar-supported mobility. Each chapter incorporates a PowerPoint presentation, a learning exercise, video clips, and links to learn more. The solar curriculum materials are free for educators and self-learners to download and explore at their own pace on the Adapting City Lab website (https://adaptingcitylab.ucdavis.edu/designing-w-the-sun.html). Small scale solar charging stations provide both a living lab for solar learning and a place to recharge mobile electronics, e-bikes, and e-scooters with the sun.

The methodology covered in this report includes the creation of an introductory solar design curriculum for high school, undergraduate design, and engineering students. The curriculum includes the recommended steps for a solar charging station design assignment that has been used by undergraduate design and engineering students at UC Davis. Student solar project outcomes from UC Davis are shown in Figure ES-1 and in Figure 8the Appendix. This assignment covers the creative engineering design process and solar equipment. The report clarifies the term *solar charging station* as a structure or object with solar panels, a charging system, and battery bank not connected to the local electrical grid. The report also clarifies the term *e-bike* as referring to a two-wheeled bicycle with either an electric motor assist when pedaling or a motor assist with or without pedaling.

The goal of this interdisciplinary solar curriculum is to engage students in designing green infrastructure for their campus or community that will inspire renewable energy adoption and hands-on learning. The curriculum walks students through seven steps: concept development, problem statement, concept sketch, computer-aided design (CAD) model, solar design, prototype, and final concept board. The student projects can be designed as a concept idea or with the goal of collaboratively building a functioning prototype on campus to extend the team learning.

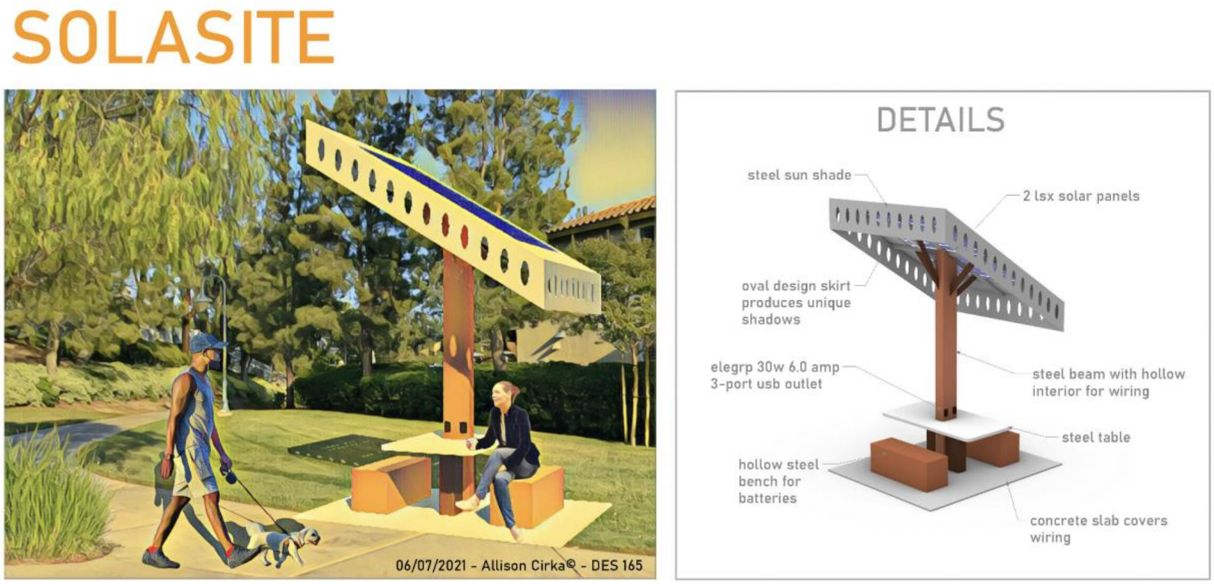

Figure ES-1. SOLASITE, Allison Cirka, Studio Practice in Industrial Design course project, 2021

Introduction

Universities worldwide have the opportunity to play a key role in sustainable design education and the global shift to renewable energy. Stanford Engineering professor Mark Jacobson states:

> Three of the most significant world problems associated with energy today are air pollution, global warming, and energy insecurity… A solution that does address all three problems at the same time is to transition the world's all-purpose energy to electricity and heat that are provided by clean, renewable energy and storage. [7]

Innovative solar design education with solar charging stations is a creative way to help with the renewable energy transition at high school, universities, and beyond. Student-focused competitions, such as the US Department of Energy Solar Decathlon [14], running biennially since 2002, have engaged multidisciplinary teams of students to design and build their own solar-powered homes that travel together to one U.S. location for a multi-week solar home performance competition against the other international university projects. Judged on innovation, cost, quality, efficiency, and local connection, this exciting program inspires students to pursue careers in renewable energy and invites the public to learn about cutting-edge solar technologies, energy efficiency, and design excellence.

The *Designing with the Sun* solar curriculum project modules created by Professor Ferguson at the University of California Davis (UC Davis) are based on her experience teaching solar workshops connected to physical campus charging stations at The University of California Davis, The University of Texas at Austin, Stanford University, and Hampshire College [3,4,5,6,8,9,10,11]. The goal of this interdisciplinary work is to engage students in designing green infrastructure for their campus community that will inspire renewable energy adoption and hands-on learning. The curriculum walks students through seven steps: concept development, problem statement, concept sketch, CAD model, solar design, prototype, and final concept board. The student projects can be designed as a concept only or with the goal of collaboratively building a functioning prototype on campus.

Off-grid solar charging stations can be used outdoors to charge mobile electronics or e-bikes depending on the size of the solar array and battery bank. The photovoltaic (PV) system converts solar energy from the sun into electricity that can be stored in a stationary battery bank. An inverter converts the direct current (DC) electricity stored in the batteries into alternating current (AC) connected to a standard outlet that can be used to charge electronics. A charge controller can be used to prevent the batteries from being overcharged by the sun. Even small solar arrays can have remote monitoring software used to manage the system, along with recording useful data on air quality, weather, and daily user charging behavior (Figure 1).

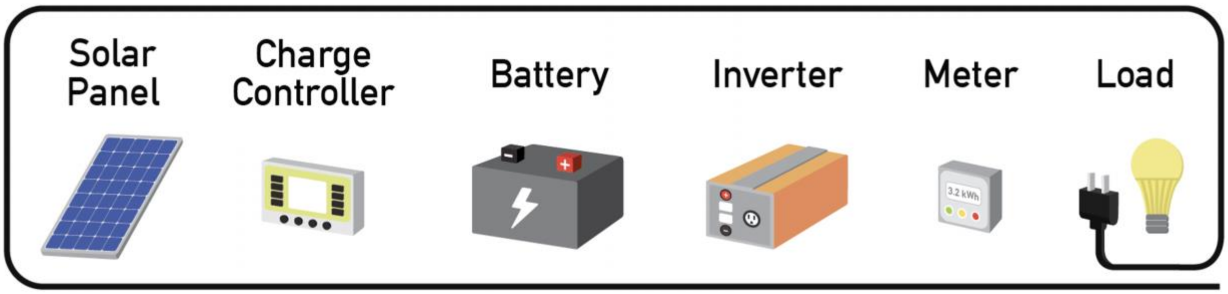

Figure 1. Solar charging station equipment (image: © B. Ferguson, J. Wattimena, 2021) What are off-grid solar charging stations?

The term off-grid solar charging station refers to a structure or object with solar panels, a charging system, and battery bank not connected to the local electrical grid. It can range in size depending on how it is used. The main characteristics of a solar charging station include: solar panels, charge controller, batteries, inverter, USB ports and/or AC outlets, supporting structure and electrical enclosure box (Figure 1). A solar charging station can also include lighting, monitoring software, sensors, Wi-Fi, seating, tables, digital display, plants, art, educational signage, and bike racks. Small mobile solar charging stations (10–250 watts single solar panel) can be used for phone charging, sensors, lighting, tablets, or speakers. Medium size solar charging stations (250–2000 watts solar array) can be used for outdoor lighting, mobile electronics, sensors, and e-bike charging. Large solar charging stations (parking roof cover or ground mounted, 2–6 kW) can be used for charging electric cars or powering a house. This paper will focus on medium size solar charging stations for university campus settings, equipped to support students' outdoor activities.

What is an e-bike?

The term e-bike refers to a two-wheeled bicycle with either an electric motor assist when pedaling (electric assist), or a motor assist with or without pedaling. Some cities regulate them differently, or mandate speed limiters. E-bikes can range in style, top speed, and battery capacity but typically use motors (150 Watts–750 Watts) and batteries (0.3–0.6 kWh), with a speed <25 km/h and travel distance per change ranging from 50-150 km [1]. According to the National Association of City Transportation Officials, 136 million trips on shared micromobility (bike share, e-bike share, and e-scooter share) were made in 2019, up 60% from 2018 [13].

Solar Curriculum

The *Designing with the Sun* solar curriculum project is an in-depth educational tool covering renewable energy, electricity basics, solar energy design principles, solar job training, and solar mobility innovation. The curriculum is designed for high school and undergraduate students. Each chapter has a PowerPoint presentation, an active learning exercise, video clips, and links to learn more. The solar curriculum materials are free for educators and self-learners to download and explore at their own pace on the Adapting City Lab website and users are encouraged to provide feedback [4]. Below we describe the solar charging station design assignment considerations given to students (Table 1) along with key solar design steps Table 2). The steps are aimed at helping students to design their own solar charging station concept or prototype over four weeks. This curriculum is key to engaging students in campus solar projects after they learn basic solar design principles and gain creative confidence in their first solar design-build project activity.

Table 1. Solar Charging Station Design Considerations

Design Feature	**Considerations**
Site Placement	South facing (Northern Hemisphere), free of shade obstacles (tree, building).
Structure	Roof should be angled to the south approximately equal to the location's latitude. Example: Austin, TX: 30° angle to maximize solar gain.
Solar Electronics	PV panels, battery, inverter, outlets, lighting, electrical enclosure. Battery capacity depends on system load (what you want to charge and for how long). Off-grid solar design calculators can be used.
Software	Software that connects to the electronics to remotely monitor solar energy production, temperature, battery storage, and system use. (Rhino, Fusion360).
Use	AC outlets, USB ports, signage, ergonomic considerations (human factors) of furniture and structure. Example: roof should be more than 7 feet high at the lowest point, wheelchair accessibility, e-bike racks.
Placemaking	Attractive design, outdoor rated paint, seating (17" high), lighting, info.

Table 2. Designing with the Sun Solar Charging Station Steps

Step	Instructions
1. Concept Development	Use your imagination! Design and sketch your own solar charging station.
2. Problem Statement	How will your project be used? Where will it be located? Who will use it? What size will it be? Will it have special features? What materials will be used? What will it charge? Will it have furniture or bike racks?
3. Concept Sketch	Hand sketch multiple ideas (pencil, markers). Develop best iterations with detailed use notes (Photoshop, Procreate.art).
4. CAD Model	Design project structure to scale with CAD software (Rhino, Fusion 360).
5. Solar Design	Create a parts list (photovoltaic panels, battery, inverter, outlets, display and lighting, electrical enclosure). Size the equipment to meet the needs of the items you want the station to charge. (Use an off-grid solar calculator for help.) Example: https://www.altestore.com/store/calculators/off_grid_calculator/
6. Prototype	Build a to-scale prototype (3D print, laser cut, or hand cut matt board).
7. Poster	Include: title, description, digital renderings, material, fabrication plan, prototype photo, CAD model with dimensions: side, front, top, isometric.

Student Solar Design Assignment

Students can design their own solar charging station by following multiple steps in the design process, including: concept development, sketching, CAD modeling, solar engineering, prototyping, and final concept poster with project renderings (Table 2). Students can work in teams or alone on this assignment. Students should be encouraged to iterate their design concept after receiving feedback from their peers, instructor, and guest reviewers. Figures 2–6 show examples from the solar curriculum PowerPoint presentations that illustrate how passive solar energy and solar panels work and how photovoltaic orientation, angle, and avoidance of shade are important to maximize solar gain [2,11]. One goal of this curriculum is to be accessible and inviting to students of all genders and disciplines without engineering backgrounds and to encourage future research in renewable energy and sustainable design fields. Low-tech tools such as hand sketching and cardboard prototype models are helpful for hands-on learning related to this assignment. High-tech tools and resources are valuable in building prototypes, and these include CAD software, laser cutters, 3D printers, wood shops, electric labs, and metal shops.

Solar Electrical Engineering Basics

It is important that a solar charging station's structure is designed for maximum solar gain and to protect the equipment from extreme weather conditions and theft. Concrete footings, steel poles, wind load structural analysis, and security hardware are a few examples for the design team to consider. Figure 2 shows the basic off-grid equipment found in a solar charging station with a simple circuit diagram. A design team can partner with a local solar installation company to make sure they have correctly sourced the right size equipment and meet campus safety and permitting guidelines. Figure 3 shows a diagram of how a solar panel creates electricity. Figure 4 shows a grid-tied photovoltaic system circuit diagram that is common for solar panels installed on the roof of a home and connected to the public utility grid without battery storage.

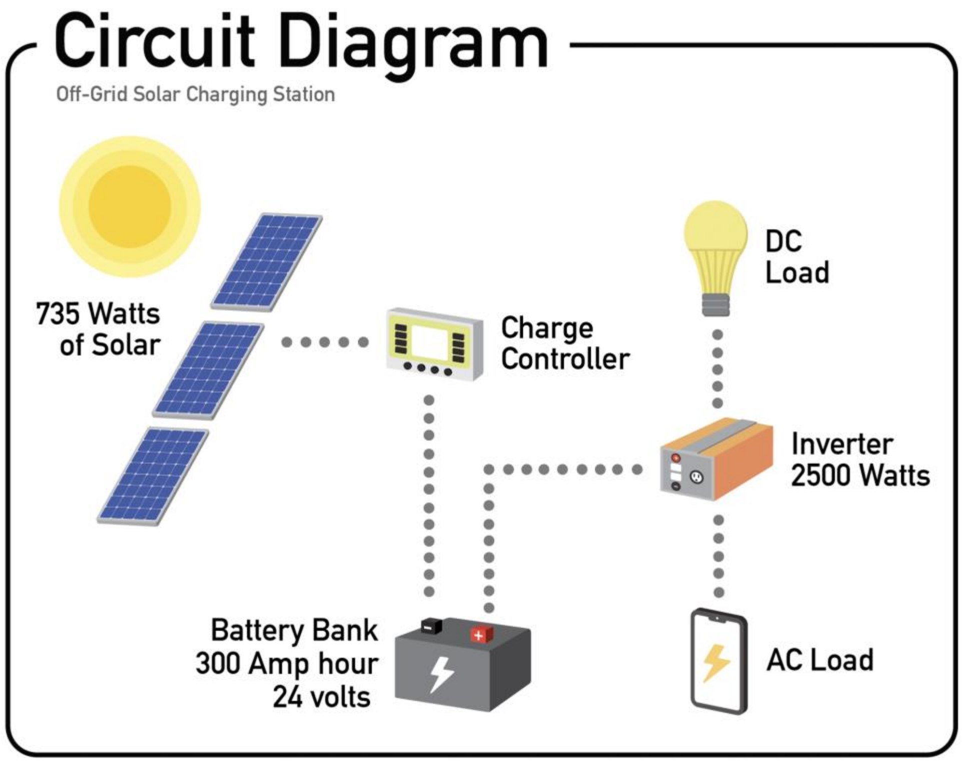

Figure 2. Solar charging station circuit diagram (image: © B. Ferguson, J. Wattimena, 2021)

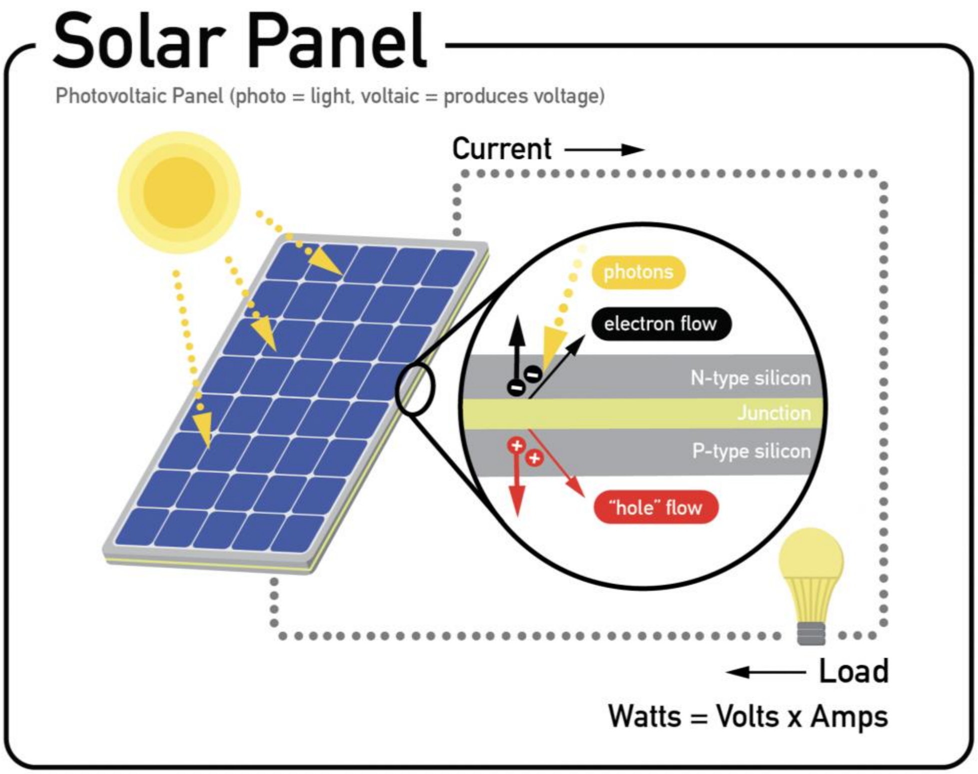

Figure 3. Solar panel (image: © B. Ferguson, J. Wattimena, 2021)

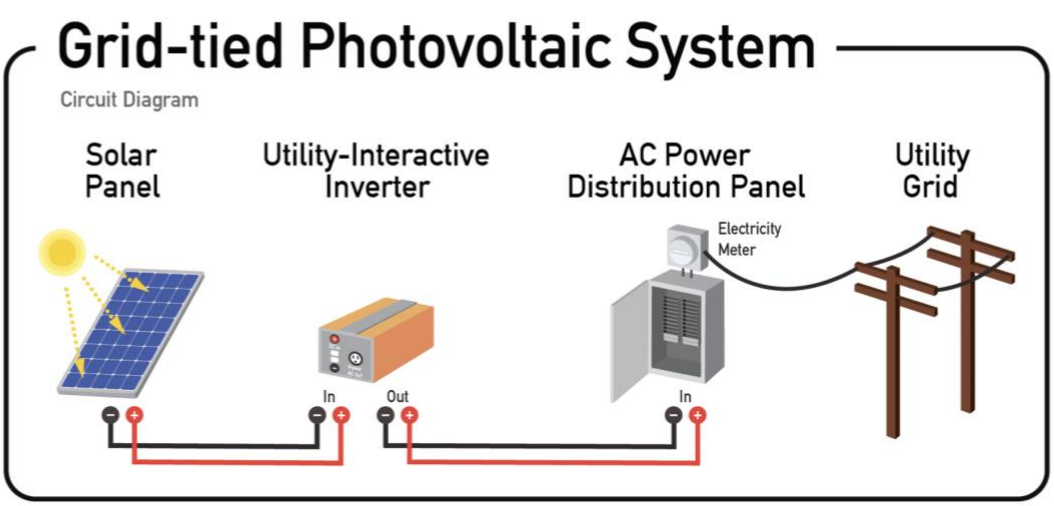

Figure 4. Grid-tied photovoltaic (PV) system (image: © B. Ferguson, J. Wattimena, 2021)

Solar Design Principles

It is important for solar designers to consider basic solar design principles when choosing a location for a temporary or permanent solar charging station or house. The left side of Figure 5 demonstrates the importance of a solar panel to face south and be at an angle equal to the latitude of the location for maximum solar efficiency. The right side of Figure 5 illustrates the importance of avoiding shade barriers (trees, utility poles, other buildings, etc.) that would limit the amount of sunlight reaching a solar array. Solar panels should be free from shade between 9am to 3pm for maximum energy production. Solar Pathfinder™ tools and solar design software calculators can be used to accurately orient a solar charging station given the constants of the site. Figure 6 extends solar design principles beyond solar panels to include passive solar design in architecture. A passive solar building can use south facing windows to increase natural light and warm the space with heat absorbing tiles or stone flooring (thermal mass). A south facing roof overhang and deciduous tree can shade the interior space in the summer when the sun is higher in the sky and leaves are on the tree. This design technique will naturally cool the space and reduce the need for air conditioning. In the winter the sun is lower on the horizon and deciduous trees lose their leaves. This makes it easier for south facing windows to help reduce the need for winter heating because the sun can radiate in below the roof overhang and directly warm the space like a greenhouse. Passive solar design principles help reduce the number of solar panels on a house because they reduce the buildings energy load for lighting, cooling, and heating, depending on the location.

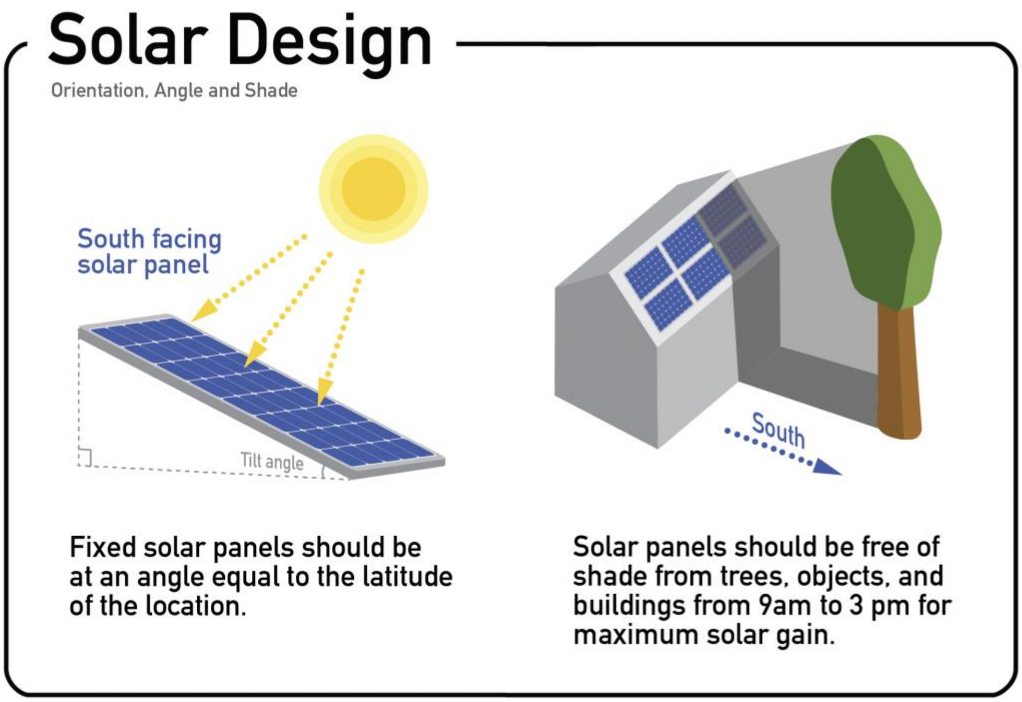

Figure 5. Solar design (angle, shade, south facing) (image: © B. Wattimena, 2021)

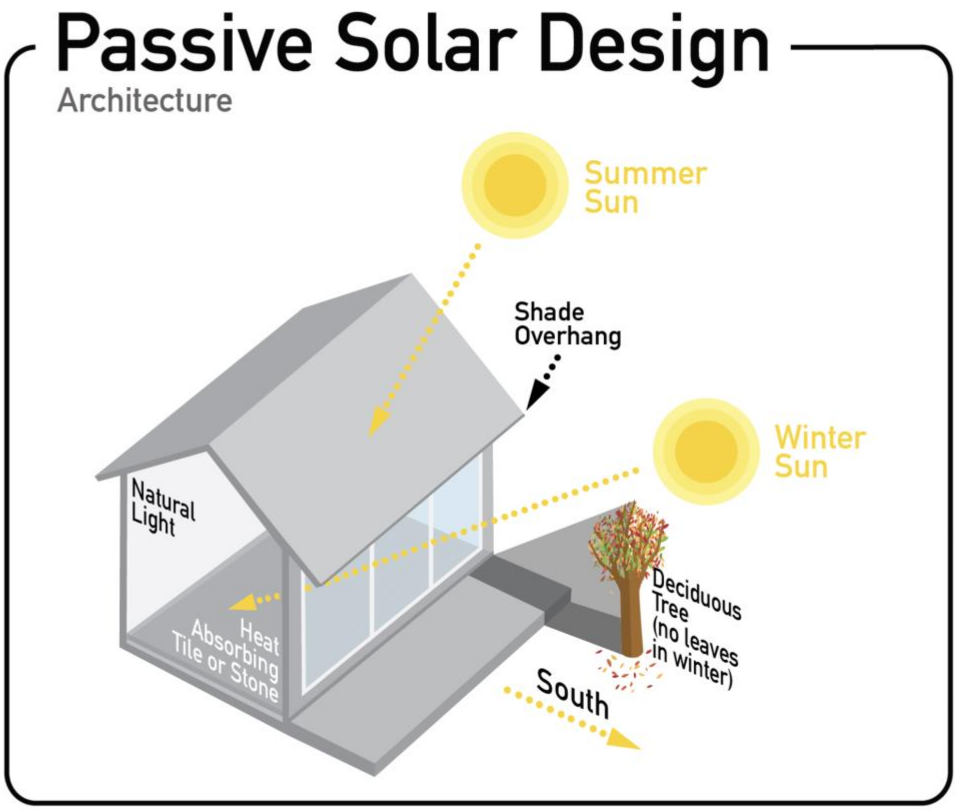

Figure 6. Passive solar design (image: © B. Ferguson, J. Wattimena, 2021)

Student Solar Charging Station Concept Project Examples

The *Designing with the Sun* curriculum was designed and tested by Professor Beth Ferguson in her course DES 165 Studio Practices in Industrial Design in the Department of Design at UC Davis between 2018-2021. The curriculum was influenced by the solar design workshops she taught at Stanford University, the University of Texas at Austin, and Hampshire College with Dallas Swindle between 2013-2016. Students were introduced to five modules: Intro to Energy, Sunshine into Electricity, Solar Design, Solar Futures, and Solar Mobility, before designing their own solar changing station project. Students were encouraged to propose creative and experimental solar design concepts that fit their research interests and proposed site location. Students made weekly improvements after receiving feedback from their peers, faculty, and guest reviewers. Some students made working prototypes with 5-watt solar panels that could charge cell phones, flashlights, and small speakers. Other students created designs, without physical prototypes, for site-specific solar charging stations with 1–4 solar panels (200–1000 watts) and a variety of creative features such as seating, shade, and e-bike charging. Additional goals of this curriculum include teaching creative problem-solving, cultivating interest in renewable energy innovation, and encouraging female students to pursue studies and careers in STEAM (science, technology, engineering, arts, mathematics). Twelve student projects selected from those of 60 students in 4 different classes are shown in Figure 7. Four more student projects are shown in detail in the Appendix.

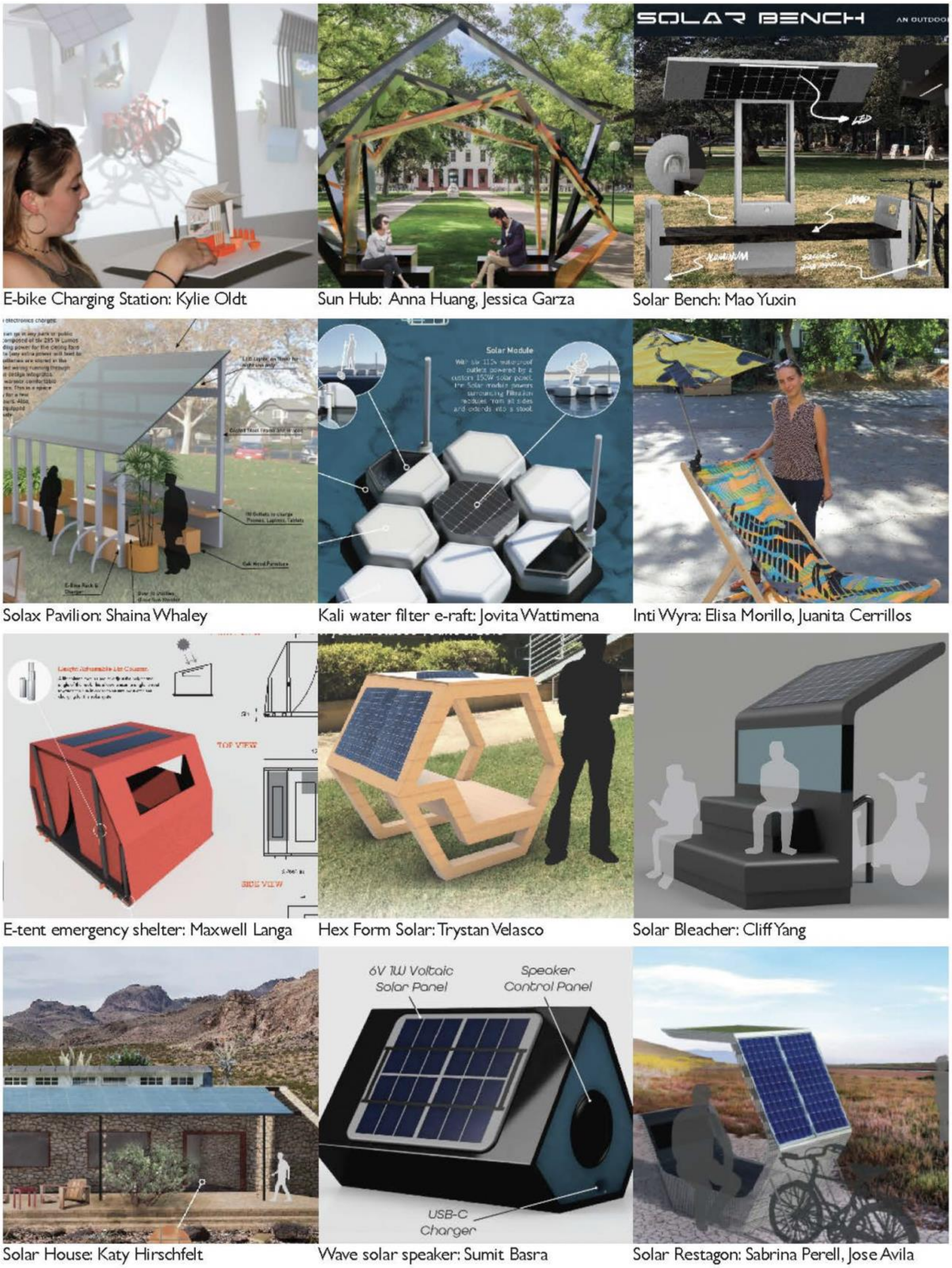

Figure 7. Designing with the Sun, student project examples from the Department of Design at UC Davis, December, 2018-2020

Discussion

The *Designing with the Sun* solar curriculum project teaches students key solar design principles and can be used with or without advanced prototyping equipment or the intention of building a physical solar charging station. Student solar charging station concept projects foster students to be creative and experiment with solar energy in new forms. Students learn key steps in the design process such as research, concept and problem statement development, solar design engineering, furniture design, structural analysis, solar site analysis, CAD modeling, prototyping, fabrication techniques, and final concept presentation. Students also gain valuable experience by participating in interdisciplinary work across the fields of design and engineering as they relate to renewable energy, sustainable transportation, and climate resilience planning.

Installing a physical solar charging station project on campus extends this curriculum into the community and provides an outdoor classroom environment for continued data collection, research, and analysis. Building a permanent campus solar charging station can take many years and involves time-consuming steps such as fundraising, following campus design and engineering guidelines, permitting, fabrication, and installation (Table 2). Building a smaller scale mobile solar charging station can reduce the project budget and timeline and involve students in more of the hands-on fabrication, wiring, and testing steps. Solar equipment has become less expensive over the years and has become more common in communities worldwide.

Conclusion

The *Designing with the Sun* curriculum taught in courses with design and engineering students has been shown to encourage green infrastructure innovation, creative confidence, and students' enthusiastic participation in the concept design and prototyping of their own solar projects. The curriculum serves as an introductory springboard for students to gain a basic understanding of solar design principles, as well as public engagement and educational placemaking. Campus solar charging stations are places for students to gather, directly use solar energy for the first time, and consider ways of benefiting the campus environment while reducing fossil fuel energy now and transportation-related carbon emissions in the future.

A major lesson observed from testing this curriculum was consistent enthusiasm and creativity from students when asked to participate and create their own vision for a solar charging station or solar product. Figure 7 and the Appendix show images of student projects that range from solar benches, solar emergency shelters, solar pavilions, solar microplastic cleaning rafts, solar public art, and e-bike solar charging stations. Students have used this assignment to learn CAD modeling, LED wiring, 3D printing, and laser cut mat board model making. The unique student projects show that both engineering and design students are curious and motivated to learn how to implement solar design principles into their own work and that they have an interest in learning practical skills for the urgent renewable energy transition taking place worldwide. Future prospects for this work include translating the curriculum to multiple languages, creating do-it-yourself (DIY) solar kits, and testing the curriculum in high schools and beyond. UC Davis is currently in the process of permitting a new campus solar charging station for the Department of Design courtyard with support from the UC Davis Green Initiative Fund and the 3 Revolutions Future Mobility Program. This new station will include shaded outdoor seating, air quality sensors, e-bike and wheelchair charging, and data logging software. Follow the project here: https://adaptingcitylab.ucdavis.edu/campus-charging-station.html.

The COVID-19 pandemic has increased the need for campuses and cities to provide outdoor seating along with safe, socially distanced work and gathering spaces. Solar charging can have a notable influence on the popularity of these new shared spaces. Solar infrastructure could have a powerful impact on recharging options for personal e-bikes or shared micromobility services available on college campuses to offer affordable last mile rides from public transit hubs. If we embrace the opportunity to reshape the land currently dedicated to the automobile, we can strengthen the resiliency infrastructure needed during this urgent renewable energy transition period. Implementing renewable energy and sustainable mobility systems creates green job training opportunities, so important to meeting the challenges of the 21st century head on.

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Appendix

Designing with the Sun, student projects from UC Davis course DES 165 Studio Practices in Industrial Design 5-week assignment taught by Prof. Beth Ferguson, Spring, 2021

Figure 8. Student project from Allison Cirka, 2021

Poster text: SOLASITE by Allison Cirka

- Description: Solasite is a solar powered sitting device that promotes users to enjoy the outdoors while using and charging their devices.
- Fabrication: Welding and screws, nuts, and bolts
- Materials: Steel, paint, 2 LSX solar panels (290 Watts each or 580 Watt PV array), 1500 watt Inverter and 150 Amp/hour battery bank, and outlets.

Figure 9. Student project from Yusuf Azam, 2021

Poster text: SOL EV Charge Port by Yusuf Azam

- Design: Sol is designed for installation at a residence to simplify at home EV charging. Taking weather into account Sol is designed to withstand and protect your EV from the elements.
- Specifications: Sol uses 20 Lumos 290 watt solar panels to charge 20 Sun Xtender 12V deep cycle AGM batteries. Additionally, Sol includes the best ChargePoint+ home charger for ease of use.

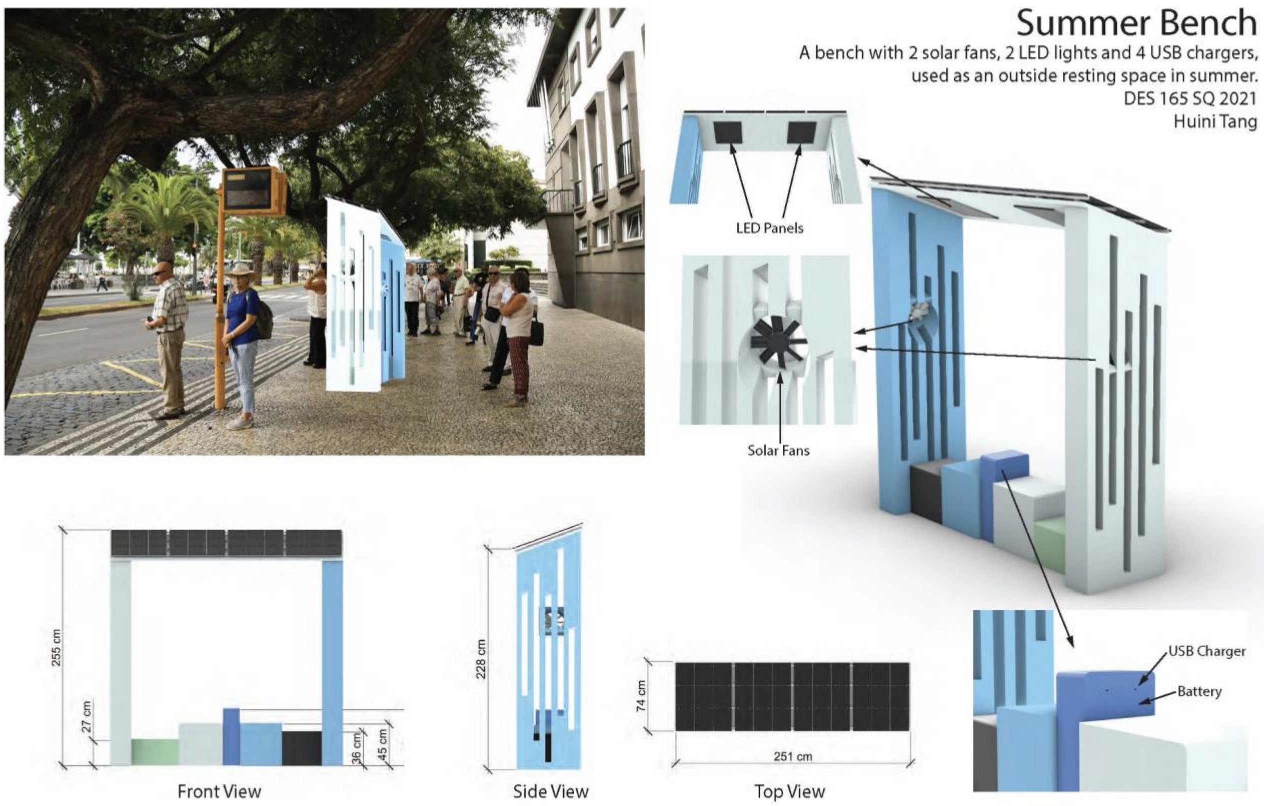

Figure 10. Student project from Huini Tang, 2021

Poster text: Summer Bench by Huini Tang

- A bench with 2 solar fans, 2 LED lights and 4 USB chargers, used as an outside resting space in summer.

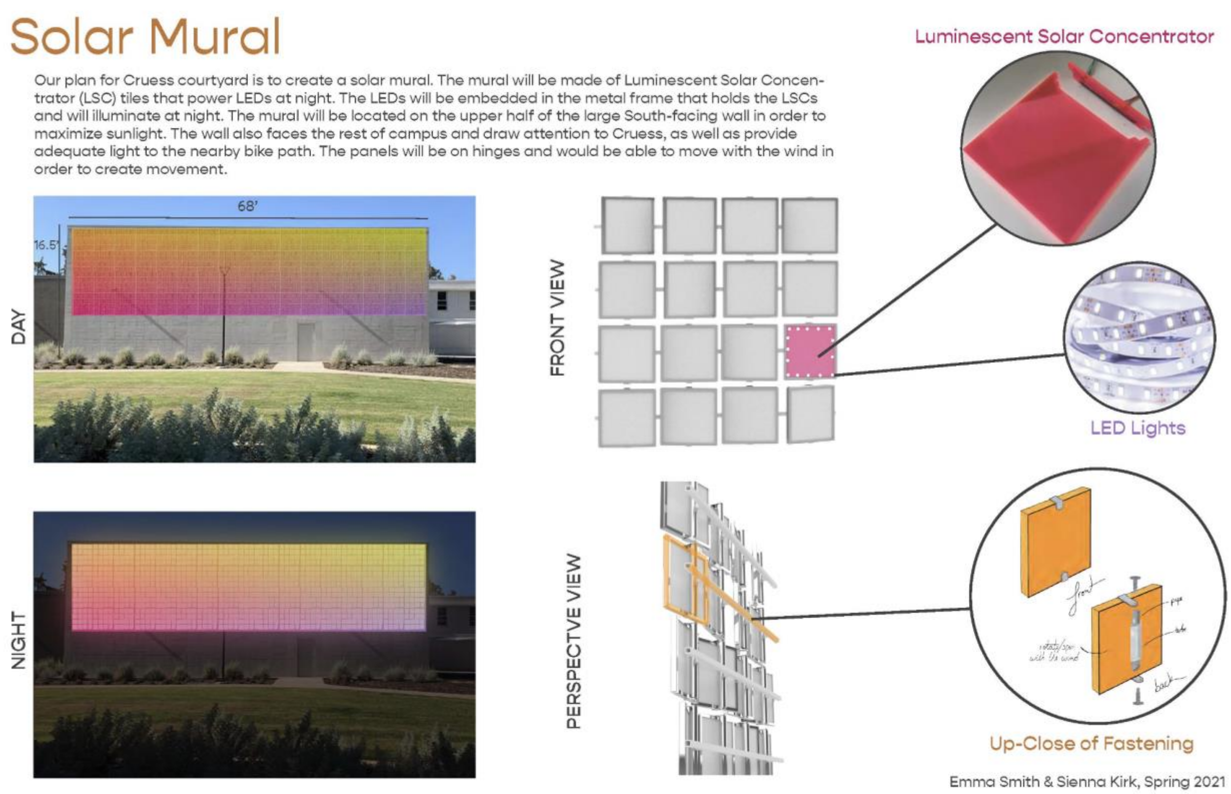

Figure 11. Student project by Emma Smith and Sienna Kirk, 2021

Poster text: Solar Mural by Emma Smith and Sienna Kirk

- Our plan for Cruess courtyard is to create a solar mural. The mural will be made of Luminescent Solar Concentrator (LSC) tiles that power LEDs at night. The LEDs will be embedded in the metal frame that holds the LSCs and will illuminate at night. The mural will be located on the upper half of the large South-facing wall in order to maximize sunlight. The wall also faces the rest of campus and draws attention to Cruess, as well as provides adequate light to the nearby bike path. The panels will be on hinges and able to move with the wind, in order to create movement.