Solar Outreach Activities Handbook

QESST

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Quantum Energy and sustainable solar technologies (QESST), is an NSF/DOE Engineering Research Center that focuses on advancing photovoltaic science, technology and education. This publication collects lesson plans from QESST researchers, teachers, and students, as well as lessons from guest educators.

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QESST Administrative Offices
ASU Tempe Campus
Engineering Research Center building
551 E. Tyler Mall, Tempe, AZ 85287
qesst.asu.edu

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EDITORS

Silvana Ayala Peláez

Michelle Jordan

FACULTY ADVISOR

Michelle Jordan

COVER AND LAYOUT DESIGN

Silvana Ayala Peláez

COVER PHOTO

Outreach by QESST Scholar

Swirl created by Freepik

COPY EDITORS

Rebecca Glaudel, Yongjie Zou, Jennifer Lumbres, Liliana Ruiz Diaz, Emily Finan, Luca Febbraro, Melisa Jane Bohlman, Nereyda Carlos, Poorva Milind Rajguru, Xuesen Tan, Isela D. Howlett, Benjamin Chrysler

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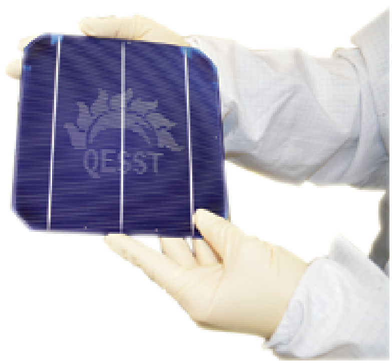
Adam Doolitle, Raymond K. Kostuk, Melissa Jurist, Ganesh Balakrishnan, Fernando Ponce, Christiana Honsberg

QESST is an Engineering Research Center sponsored by the National Science Foundation and Department of Energy. We are an interdisciplinary team of scientists from universities partnering with solar industry leaders. Our mission is focused on advancing photovoltaic science, technology, and education to address one of society's greatest challenges: helping meet the growing energy needs of the 21st century. QESST is developing new technologies that will make solar energy sustainable, cost-effective, and available to everyone.

Want to learn more about photovoltaics and solar energy? Check out these websites for information and fun activities!

- Learn more about what we do at QESST
https://qesst.asu.edu/
- QESST wrote the book on photovoltaics!
http://pveducation.org/pvcdrom
- Learn more about photovoltaics and find ideas for solar science fair projects http://bit.ly/2nHt5Vo
- See a video about why we do solar engineering research at QESST http://pv.asu.edu/
- Understand how a solar cell works
http://www.explainthatstuff.com/solarcells.html
- See a video explaining how a solar panel works
https://www.youtube.com/watch?v=xKxrkht7CpY



Education is.. "a constellation of encounters, both planned and unplanned, that promote growth through the acquisition of knowledge, skills, understanding and appreciation."

–Nel Noddings, 2002

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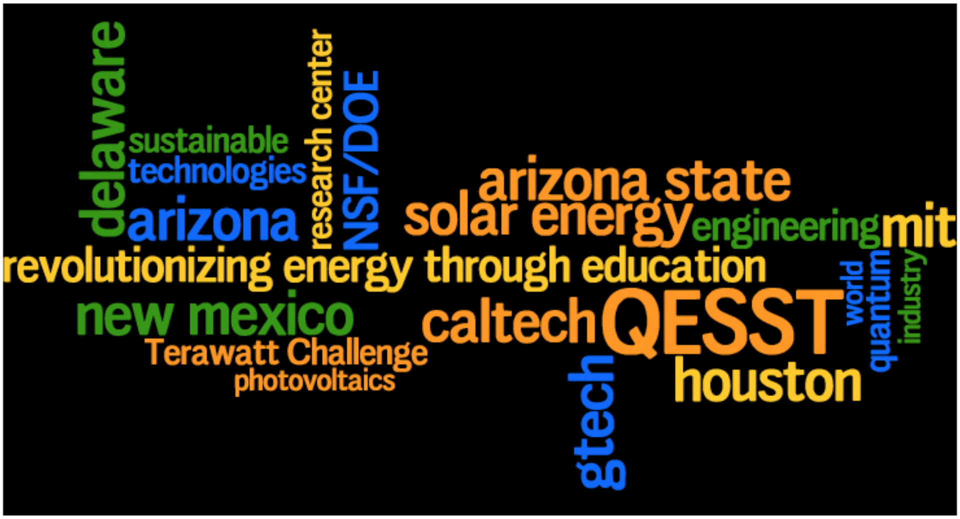
Introduction to QESST

Quantum Energy and Sustainable Solar Technologies (QESST) is an Engineering Research Center sponsored by the National Science Foundation and Department of Energy that is focused on advancing photovoltaic science (PV), technology, and education in order to address one of society's greatest challenges: transforming electricity generation to meet the needs of growing generations. QESST is developing new technologies that will transform the existing electricity generation system, making it sustainable, cost-effective, and available to everyone. Based at Arizona State University, the QESST center brings together an interdisciplinary team from multiple universities, world-renowned energy companies, leaders in photovoltaics (PV) and entrepreneurs to generate innovative solutions to sustainable electricity generation.

QESST is more than the sum of its parts; its impact extends beyond individual labs, schools, and communities of its members because it is comprised of researchers with diverse backgrounds united around the Terawatt Challenge. QESST is developing the knowledge, technology, and engineered systems to provide continued improvement in the efficiency, economic viability, and sustainability of photovoltaic (PV) systems. To this end, QESST is committed to research that spans the three leading commercial PV technologies: silicon, thin films, and tandem devices. More importantly, QESST is blurring the traditional lines between technologies by recognizing and exploiting their commonalities. This research is organized into three complementary thrusts—Terawatt-Scale Silicon Photovoltaics, Tandem Integration with Silicon Technologies, and Fundamentals

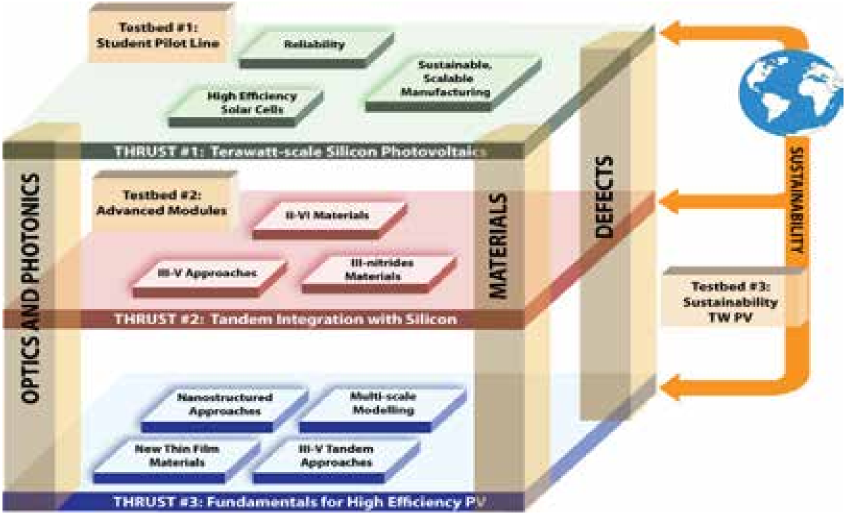


for High Efficiency Photovoltaics—and three demonstrative testbeds—Student-Led Pilot Line, Advanced Modules and Integration and Sustainability of Terawatt Photovoltaics. In addition, two themes—Sustainability and Education Research—permeate all areas of QESST research.

QESST Education and Outreach

The mission of the K-12 element of the Education arm of QESST is driven by the confluence of four current engineering and social problems that also represent opportunities to advance engineering in the United States, particularly in the area of photovoltaics.

- Foremost, there is the overall need for more engineers in all of the engineering sub-disciplines, and particularly for broader participation from historically underrepresented groups.



- The Next Generation Science Standards (NGSS) include engineering education at the K-12 level, but schools and curriculum developers are not yet ready to provide this content in the breadth and depth that they would, say, in biology or physics.
- There has been an up-swell in the public's interest in "greener" technology and environmental and economic sustainability, all concerns that photovoltaics can address.
- There is growing interest in solar. The public has only a superficial understanding of photovoltaics, and this could be a problem in coming years. We need to continue to deploy the current generation of solar technology while preparing for a transition to the next generation of solar; furthermore, we believe that maintaining a combination of current and next generation solar will bring the greatest benefits, but understanding why this is so and what each provides requires deeper public knowledge than currently exists.

Given the need for greater student interest in engineering and more engineering content for the K-12 classroom, the opportunity to meet public concerns about renewable energy and the need to have a more informed public to address those concerns effectively, QESST education strives to create a pool of students interested in photovoltaic engineering to help students become part of a diverse STEM workforce and an informed public that can shape policy at national, state, and community levels and further raise the call for renewable energy.

Through a wide range of programs—university education, public engagement and outreach, pre-college curriculum development, teacher training, participation with policymakers and external stakeholders—QESST aims to use sustainable energy as a vehicle to revitalize the popular perception of science and engineering. QESST broadens participation in science and engineering through its support of community-based projects that are well connected to our students' social contexts. QESST leverages education at all levels to engage students and develop a trained workforce capable of advancing the fast-paced solar industry. QESST conducts educational research to determine the best practices for training this workforce, and develops programs and curriculum which utilize those best practices. QESST scholars, in-service teachers, and youth have the opportunity to make meaningful connections with national and international experts in PV. This outreach book is one small part of our ongoing efforts to meet the mission of the QESST education program:

- to recruit young people to solar energy and photovoltaics,
- to increase the photovoltaics workforce, and
- to provide learning experiences to ensure QESST students at all levels are building the necessary skill sets to participate in a sustainable energy future.

For more about QESST

- To learn more about how QESST is leading the solar energy future of the United States, visit http://quest.asu.edu
- To find out more about solar energy and photovoltaics http://pveducation.org
- To view a video about why we do solar engineering research at QESST http://pv.asu.edu/

Sustainable value creation with photovoltaics

Parikhit Sinha, First Solar

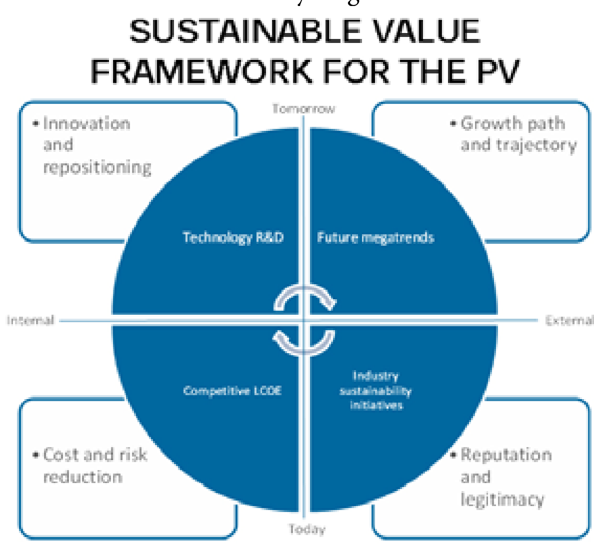
Solar energy has the greatest technical potential for electricity generation among renewable energy technologies [1], and with the levelized cost of energy (LCOE) of solar photovoltaic (PV) systems reaching below $50 USD/MWh [2], solar energy is also cost-competitive. Scalable and cost-effective renewable energy technologies are key to accelerating the global transition to a low carbon economy. Over 228 GW of solar PV has been installed worldwide through 2015 [3], and although still small in comparison to the global demand for energy, solar energy accounts for a significant fraction of newly installed generation (e.g., 39% in the U.S. in 2016 [4]). During operation, PV systems generate electricity with minimal emissions and resource use, and over the product life cycle, replacing existing grid electricity with solar PV can help reduce emissions of greenhouse gases, criteria air pollutants, heavy metals and radioactive species by up to 98 percent [5].

Emerging PV industry sustainability initiatives

With the emergence of PV as a competitive, mainstream energy source, stakeholders are looking for confirmation that the environmental performance of PV is keeping pace with the technology. Over the past decade, the PV industry has seen several sustainability-related milestones (Fig. 1) such as the establishment of commercial recycling programs [6][7], methodology guidelines for life cycle assessment of PV [8], and corporate sustainability scorecards [9]10]. However, the past year has seen an effort to take these individual efforts and standardize them

across the industry to promote transparency and credibility when measuring environmental performance. These include a sustainability leadership standard for PV modules (NSF 457) developed by NSF International [11], product environmental footprint category rules (PEFCR) developed by the European Commission [12], and a national PV recycling program developed by the U.S. Solar Energy Industries Association (SEIA) [13].

The NSF 457 standard development was launched to formalize the PV manufacturer sustainability scorecard process first initiated by SVTC. The PEFCR for PV is a pilot program within the European Commission's Single Market for Green Products Initiative to provide a standard method for quantifying the life cycle environmental footprint of PV modules. The SEIA national PV recycling program was initiated by U.S. PV industry members to proactively develop waste management solutions in anticipation of future product end-of-life waste volumes. It should be noted that takeback and recycling of end-of-life PV modules is already mandated in Europe under the EU WEEE Directive [14] and PV-specific end-of-life treatment requirements are being developed by CENELEC [15]. High-value recycling policies, standards, and technologies will help increase the sustainability of the PV industry by maximizing resource recovery and minimizing life cycle impacts while creating socioeconomic benefits, with an estimated cumulative recoverable value exceeding $15 billion by 2050 [16].



More generally, principles of sustainability when applied to industry involve an approach of creating sustainable value by balancing between internal and external priorities and meeting today's and tomorrow's challenges [17]. Industry must perform well simultaneously in all four quadrants of this framework in order to maximize value over time (Fig. 2). Despite the considerable progress of the photovoltaic industry, it remains a volatile industry with primary focus on today's internal challenges. The emerging PV industry sustainability initiatives aim to rebalance the industry's trajectory toward also addressing external concerns and future trends to help promote the industry's long-term viability.

Energy-water nexus

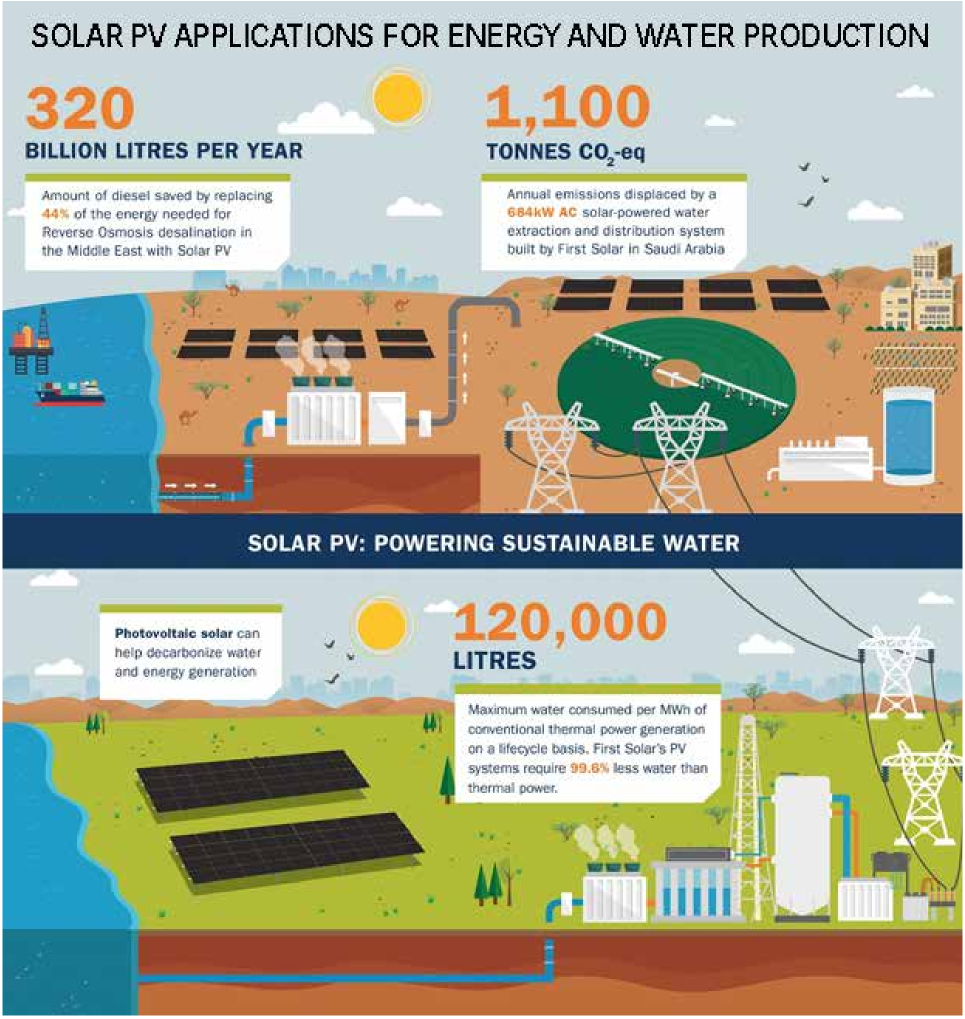
Addressing external concerns and future trends can provide potential opportunities for the PV industry. An example of a future trend with relevance for the PV industry is the energy-water nexus. Water and energy are inextricably connected, as water is required to generate energy, and energy is needed to pump, treat, and transport water. Population growth and industrialization combined with a rising demand for energy are placing an increasing strain on limited water resources, with a global freshwater deficit of 40% projected by 2030, based on current usage rates [18]. This trend combined with the forecast for a 30% rise in global energy demand by 2040 [19] indicates that a transition to a sustainable energy-water nexus is needed.

Specifically, in 2014, approximately 4% of global electricity consumption was used to extract, distribute and treat water and wastewater, with a further 50 million metric tons of oil equivalent of thermal energy used for irrigation pumps and desalination plants, and by 2040, the amount of energy used in the water sector is projected to more than double [19]. As drought and climate change further exacerbate the world's declining freshwater resources, desalinating seawater is becoming increasingly essential to meeting freshwater needs.

Conventional desalination, however, is an energy-intensive process. Saudi Arabia, for example, uses more than 1.5 million barrels of oil per day to power its desalination plants and produce an estimated 3.3 million m3 of desalinated water per day [20]. With desalination capacity set to rise sharply in the Middle East and North Africa, 16% of electricity consumption in the Middle East is projected to be related to water supply by 2040 [19].

Solar PV can further a transition to a sustainable energy-water nexus by helping to power water processing, extraction, and distribution (Fig. 3). Using PV to power 44% of the reverse osmosis desalination process has the potential to displace 19 billion liters of diesel fuel per year in Saudi Arabia and approximately 320 billion liters per year across the entire Middle East, which would result in carbon emission reductions of 51.5 million metric tons and 832 million metric tons per year, respectively [20]. Since reverse osmosis is used to recycle water, solar PV could feasibly also decarbonize the recycling process.

Similarly, solar PV can help address the dependence of water extraction and irrigation on fossil fuel-based energy. The amount of energy used globally for irrigation purposes is directly linked to the quantity of water required to produce that energy. Powering water pumps and irrigation systems with solar electricity helps displace carbon emissions and mitigate trade-offs between energy and agriculture related to water supply. A 684kW solar-powered water extraction and distribution system, installed at the Al Watania Organic



farm in Saudi Arabia, is helping displace over 1,000 metric tons of greenhouse gas emissions on an annual basis while saving 628,000 liters of diesel per year [21].

While solar PV's contribution to decarbonizing the global power generation portfolio is well documented, it must also be recognized that solar PV helps reduce the amount of water needed to generate energy. Just as energy is needed for irrigation and desalination, thermal electric power plants require water for steam production and cooling, to generate electricity. Today, the energy sector accounts for 10% of global water withdrawals [19] and by 2035, electricity generation could account for more than one-third of global water withdrawals [18]. The energy-water nexus is placing increasing constraints on the expansion of the energy sector as the same regions that have growing needs for energy are often water-scarce or drought-prone. However, by directly converting sunlight to electricity without water, solar PV has one of the lowest water footprints in the energy sector, using up to 300-times less water than conventional energy technologies on a life cycle basis [22][23].

In summary, in addition to the PV industry's increasingly attractive economics and technology innovation, emerging sustainability initiatives that promote environmental performance and opportunities related to future megatrends (e.g., energy-water nexus) will encourage sustainable value creation for the industry.

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Outreach Activities

Outreach Activities Introduction

Michelle Jordan

Educational outreach refers to activities that support formal or classroom-based education, as well as informal education that occurs outside the classroom. Educational outreach provides educational experiences for young people in classrooms, after-school programs, community-based organizations, museums, summer camps, and a host of other formal and informal contexts as well as supporting the professional development of teachers who work with students.

Working with education students and community youth-serving organizations, QESST seeks to implement outreach events that create pathways for learning the lead participants toward photovoltaic engineering futures. Our efforts should help participants

- Construct knowledge,
- Identify with the domain, and
- Navigate pathways toward photovoltaic and engineering goals

QESST outreach volunteers participate in this work in a myriad of ways, including

- Designing and sharing photovoltaic engineering learning materials and curriculum (the outreach activities and classroom lessons in this book are a few of the many examples!)
- Creating learning environments for learners to encounter online, during outreach events, and in the everyday world

- Teaching the community about core disciplinary ideas and cross-cutting concepts, and mentoring learners into engineering practices

Here are some Tips and Good Practices shared by QESST Education leaders and outreach leaders.

Tips on Preparing for Outreach Events

Tiffany Rowland, QESST Outreach Coordinator

- **Email the host prior to coming**: Do you have a table? Ask about space, and number of participants.
- **Know your audience**: What are the demographics and age levels of students? What is their prior knowledge and experience related to the activities you plan to present?
- **Have a plan**: What lesson/activity are you teaching? Do you understand the anticipated learning outcomes?
- **Be prepared**: Do you have the necessary materials to complete your lesson? Have you personally "walked through" all the steps necessary to teach and participate in the activity?
- **Expect the unexpected!** Just go with the flow, and remember you are making a difference!
- **HAVE FUN!**

Tips for Motivating and Engaging Outreach Participants

Stefi Weisburd, University of New Mexico Outreach Coordinator

- If you do a presentation, pick big vivid, captivating, unusual or funny images and use few words on slides. Ask as many questions throughout the presentation as you can. Act silly sometimes.
- Talk about the social consequences of engineering. Students listen very attentively, for instance, when I describe how solar-powered LED lamps given to the women in a town in Mali resulted in a night school and health clinic for the town.
- To engage girls in engineering, emphasize that engineering needs people who are interested in a lot of different things; you don't have to be coding every free moment of your life to belong in engineering. I like to show videos from Engineer Your Life that amplify that message.
- Bring it home – there are 18,000 people in New Mexico who do not have access to an electric grid. Some live just a few miles from Albuquerque. A company in Albuquerque makes most of the solar cells for satellites. Also, if it's possible, have college or high school students who grew up in the area conduct the outreach.

3-minute Strategies for Active Learning

- Research suggests that learning is more likely when participants are **interactive**, explaining ideas and elaborating on their thinking with peers (Chi & Wiley, 2014).
- **Think-Pair-Share**: Pose a question to which individuals think of own answer; two individuals then pair up to discuss their individual answers; pairs then share with a group.
- **Peer Instruction**: Pose a multiple-choice question to all participants who think a minute by themselves and then respond with an answer shown by 1-5 fingers; if answers split give 2-minute small-group discussion.
- **One Explain-One question**: Give participant-pairs a problem; one partner be the explainer and the other be the questioner who asks for elaboration and further explanation; then reverse.
- **White boarding**: Small groups are given a few different short problems; they use white boards to solve problems; they then report out their solution to the whole group.

What other smart teaching moves do you use in outreach?

Collected Wisdom of QESST Scholars

Outreach leaders at QESST ASU are implementing "event debriefings" to inform the continual improvement of their outreach efforts. At the immediate close of an event, the outreach team gathers for 10 to 15 minutes to discuss: What went well and what can we improve?

Here are some insights shared at event debriefings.

- The entire outreach team should meet at least 30 minutes before an outreach activity to "talk through and walk through" the entire sequence of their planned activities.

- Avoid overloading participants with too much information at once. Instead, engage participants in iterative cycles of learning: (a) get a little information, (b) do something, (c) explain what you did and get feedback, (d) do something again in a different way, coupled with expert explanation.
- As a general rule, young learners can only actively listen for 10 to 20 minutes. Use "just in time" learning: tell a little, do a little, tell a little, do a little…
- Model good engagement and attention – no texting while others are teaching!
- Explicitly communicate the VALUE of an activity (why is it important) and the EXPECTATION that participants can be successful.

<u>How much time do you have?</u>

Learning takes place over time and there is little we can do to rush the process of coming to awareness, gaining knowledge, applying knowledge, and identifying with and committing one's self to a discipline. So, we must be careful not to overload learners with information. Limit new vocabulary – people have difficulty making sense of information with too many unfamiliar words.

7 Reasons Why You Should do Outreach

Silvana Ayala, University of Arizona

Outreach is awesome for bringing engineering activities to students that would otherwise not have access to it. The goal is to engage students in the coolness of science, to break down their fear of math, to increase representation of women and minorities in all of STEM fields, and in general to form better, more prepared students. Moreover, teaching others has long been shown through educational research to be one of the best ways to learn. Thus, when QESST Scholars participate in outreach, they are supporting not only the larger community, but also their own learning trajectories. However, some college and graduate students are discouraged from doing any activities other than lab research, and they miss out on (or don't see) the value of outreach for themselves. So, here are 7 reasons why you should participate in Outreach, for your own benefit:

1) **Publicizes your research.** Maybe 4th graders will not understand the intricacies of the research that you've devoted years into, but planting seeds of ideas or showing people that things are happening in your area is very important to create momentum. Reaching a wider audience gives your area more credibility and impact.
2) **Makes funding agencies happy.** A lot of grant proposals include sections asking

how your research will impact society, and doing outreach is a direct way of giving back and expanding knowledge.

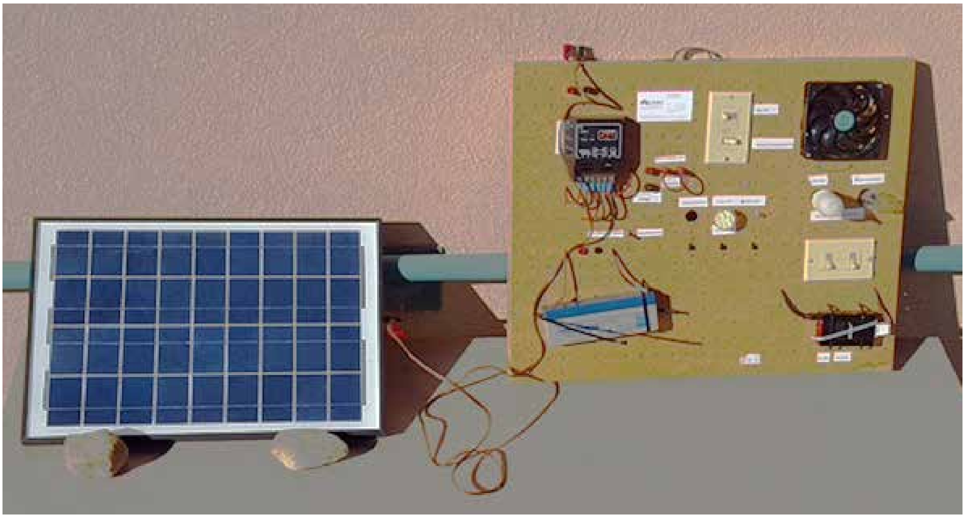
3) **Brings you back to basics.** As you advance on your career, you learn the basics of your area, then you learn the sometimes asphyxiating math, theories, and state-of-the-art research, and the knowledge tower grows taller, and taller, and taller. It is easy to forget your foundations if you don't dust them off now and then. Even if it's scary to find out you have "expert blind spots", what better scenario than to find out during outreach where you can turn it into a "curiosity" opportunity for you and the students, and get to feel that astonishment at the wonders of the world again?
4) **Teaches you how to teach.** Being able to explain your research with different levels of depth to different audiences ensures that you know your topic from the foundations, the big picture, to the little details.
5) **Builds relationships others won't build.** Participating in outreach connects you with peers, teachers, parents, adults and kids with unique stories and points of view on the world. You might find mentors, collaboration opportunities, or just many more reasons to remember why what you do is important.
6) **It's not only "out-reach" but "in-reach".** Doing outreach generates dialogue with other areas, and in a multi-disciplinary world this only leads to progress. If you are not establishing dialogue with people of other fields, you are missing critical opportunities for breaking new ground!
7) **And last but not least: it is an investment in the future of STEM.** Some of those kids, teenagers or adults who you are educating will hold a vote and hold a say in the future of funding for education, and will become leaders of schools, universities, companies and even government. Showing them that STEM opportunities are all around us, and that learning matters, is putting coins into a piggy bank that will eventually support or fund future generations of graduate students. Okay, this one is not totally for your benefit but, you see what we mean? Outreach is an important part in the life-cycle of STEM, so make sure to save some space in your agenda to join one of the many activities going on in QESST, and in your University, for outreach.

Creating Resources for Solar Outreach

Outreach involves more than standing in front of a group of students, talking and demonstrating processes and concepts. Outreach can also involve designing and building resources to support learning. Three QESST projects demonstrate this kind of outreach activity.

The Solar Energy Board

Working with a team of QESST students, University of New Mexico Outreach Coordinator Stefi Weisburd designed and built a board that demonstrates how a home solar system works (solar cell, inverter, battery, charge controller) with loads including an incandescent, LED and compact fluorescence light and a fan. The board essentially consists of basic electrical elements such as a fan and a few lighting components that are driven by a solar panel through a charge controller. It also has a 12V battery which can be charged by the solar panel. When they use it for outreach demonstrations, the New Mexico team usually packages it as a "virtual" home that could be run entirely on solar power and the battery could be used to store charge during the day to be used later. With regards to the lighting components, there are a couple more concepts that can be demonstrated using this setup. It consists of DC lamps (incandescent, LED, halogen) and AC lamps (incandescent and CFL) and an inverter between the two lamps. The team uses this to explain the differences between the energy produced by the solar panel versus the conventional city electricity supply. Also, even amongst the DC or the AC lamps, we could use the different types as in hal-



ogen vs incandescent vs LED to demonstrate which one of these is the most efficient by measuring the voltage and current (the board has hookups for this too). Learn more about this project on the QESST Education website.

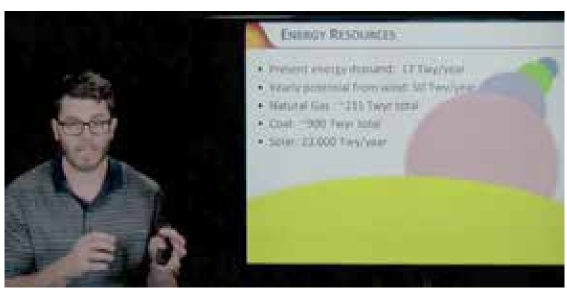
Tonto Creek Solar Install Project

QESST graduate and undergraduate students at Arizona State University, the University of Arizona, University of Delaware, and Caltech banded together to design and build a stand-alone photovoltaic energy system. The student-led project aims to design, build, and install a PV battery demo system for use at Tonto Creek Camp, a new QESST Education partner. The energy generated from this student-initiated and student-led project could be used to provide power for lighting or electrical outlets to power a myriad of energy needs for campers. Educational materials and activities are being developed around the installation so that it can serve as an educational resource for campers. QEEST Scholars Pablo Guimera Coll and Sebastian Husein are leading the project, with support from University Student Liaison Officer Michael

Goryll, Education Director Michelle Jordan, and QESST faculty Stuart Bowden. QESST students from four partner universities participated in the first planning meeting. Several of our solar industry partners contributed mentoring and materials. QESST scholars see this student-initiated project as a way to learn hands-on skills in PV installation, thereby gaining broad knowledge to situate their research in the larger applied picture. Find solar installation documentation for this project on the QESST Education website.

Audio-Video Lecture Series on Photovoltaics

Edward Lebeau, ASU undergraduate in Electrical Engineering and Barrett Honors student, completed his honors thesis project with QESST in spring 2017. Edward created an animated lecture series, All about Photovoltaics, aimed at a high-school/early college level audience. Having worked in the ASU Solar Power Lab during his sophomore year, Edward knows the complete cell process. The lecture series includes 10-minute videos recorded in a colloquial style appealing to a broad audience. Edward's intention was to completely document the process of making silicon-based solar cells to help train students. The five-part lecture series is available on YouTube; the links are also posted to the QESST Education website. This kind of "outreach" has the potential to impact thousands of people who may click on these links for years to come. This project was supported by Michael Goryll, Edward's thesis director, as well as Stuart Bowden, Chris Honsberg, and Som Dahal who provided materials and assistance.



<u>Lecture 1: Introduction to the lecture series (Terawatt Challenge, Motivation)</u>

https://youtu.be/ETrlygFyZWo

Lecture 2 Part 1: Operation of Silicon Solar Cells

Topics: operation, generation of band gaps, losses, lifetime, and IV curves of solar cells

https://youtu.be/TZG6J4sYJ_k

Lecture 2 Part 2: Operation of Silicon Solar Cells

Topics: open circuit voltage, contacts, resistance, and reflectance.

https://youtu.be/2zFTgFi8RAs

Lecture 3 Part 1: Manufacturing

Topics: touches on physical aspects of a solar cell: wafer, emitter, ARC (anti-reflective coating), BSF (back surface field), front contacts, losses/balance

https://youtu.be/cj7isZa-q7E

Lecture 3 Part 2: Manufacturing

Topics: the manufacturing process from sand to cell: Making wafers, cleaning, texturing, diffusion, screen printing, firing

https://youtu.be/khivg12I1g0

Partner Universities Participate in Virtual Outreach

QESST Scholars enacted a virtual activity entitled "Visiting College Campuses" for a STEM Saturday outreach event in Spring 2017. This activity was created as one way to involve all QESST university partners in a single outreach event. A Google document was organized by the education coordinator and shared with all QESST volunteers across partner universities. This document was intended to collect ideas about how the scholars wanted to share information about their research, university and themselves. A script was created for them to use to talk to the STEM participants. QESST scholars from the University of Delaware (UD), Caltech, MIT, and the University of Arizona (UA) introduced the STEM students to their perspective labs and talked about engineering and college life in general. Audio-video recordings were made of these interactions and plans are being made to share them in order to inspire and inform future virtual outreach activities.

Flame Challenge

QESST faculty Mariana Bertoni's DEfECT Lab participated in the "Flame Challenge", an international competition in which scientists communicate their answer to a technical question in a clear and entertaining way to an audience of 11-year-olds. Each year, young students from around the world submit their questions as a challenge to scientists who wish to enter The Flame Challenge. Based on popularity, a team from the Alda Center selects an appropriate question and challenges scientists to submit written or visual entries that an 11-year-old would find interesting, understandable, and maybe even entertaining. After screening for scientific accuracy, the entries are judged by thousands of 11-year-olds in schools around the world. The winning scientists are brought to New York to be honored in June at the World Science Festival.

Bertoni and her students submitted a video and written entry answering the 2016 competition question, "What is sound?" Their 5-minute video entitled, "Hello, What's that Sound?" features lab members singing to the tune of Adele's "Hello." It also features multiple shots of the DQESST lab! Their video was close-captioned for people with hearing impairments.

In 2016, about 26,000 students from 440 different schools participated as judges for The Flame Challenge. The United States was well-represented, with 38 schools registered, including a few from Puerto Rico and the US Virgin Islands. Additionally, the contest attracted participation from across the globe, with participating schools including: Australia, China, India, New Zealand, and Thailand among others. Because the contest entries are judged by thousands of 5th and 6th grade students around the world, members of the DEfECT Lab possibly influenced a significant number of young people. You can see their video link here: https://www.youtube.com/watch?v=U-67VDG244Y

We challenge QESST scholars to submit to the Flame Challenge next year!

Education Outreach Awards

The "QESST Excellence in Outreach" award is based on number of hours of outreach participated in over the year. QESST seeks to honor scholars' dedication to educating K-12 students and the greater public about solar energy. Two QESST Scholars received the "Outstanding Outreach" award for 2016: Mark Bailly and Joe Carpenter. The award includes $500.00 for conference travel.

Mark quotes George Eastman, "The progress of the world depends almost entirely upon education." Mark writes of outreach, "I would love to have a world full of individuals with a better understanding of the scientific process and how to apply critical thinking to problem solving. So, I figured if I wanted that to happen I should try and make it happen. Education outreach seems like a good way to progress the world, even if it's just a nudge."

Joe writes, "As a former tutor, I love to help children learn. With outreach, it is even more fun because they are building something like a solar car. One of my favorite moments was when I was explaining gear ratios to a child, teaching division and fractions, and his father thanked me for giving a real-life application of them."

Electron Chairs

Subject: Modeling trade-offs between light capture and electron transport on a solar cell using an interactive game

Grade Levels: Elementary school and higher

Lesson Length: 15 minutes

Authors: Brian Tracy, Tiffany Rowlands, Maxwell Cotton

Solar cells have a limited amount of space on their surfaces. The silicon wafer must be exposed to sunlight for electron/hole pair generation to occur. This is commonly the blue portion observed on the solar cell. The metal busbars/fingers (silver lines) are present to enable the transportation of current to a device. In other words the busbar/fingers are providing the "highways" to travel on and the silicon wafer represents the "electron's home". Maximizing the amount of current in a circuit requires tradeoffs in design between electron generation and transport. This is achieved by deciding how many and what size the busbars/fingers are as well as how much of the surface area of the silicon wafer is exposed. In this activity, participants model some of the trade-offs between the amount of busbars/fingers and the area of exposed silicon using a musical chairs-like game. This activity needs a minimum of 10 students and no maximum number is required.

Learning Goals

Participants will learn how the silicon wafer and the metal contacts differ in their effect on the solar cell's overall efficiency and how optimization must reach a happy medium between the materials' surface areas to maximize efficiency.

Materials

- 1 chair per student
- Masking tape

Setup

Using the tape, mark a square on the ground. Declare this the "solar cell". The square should be small enough that students can have tradeoffs, but large enough that you can see the effect of varying the finger/ busbar spacing. Aim to just barely fit one chair for every student present.

Leave two gaps at opposite ends of the square. These are the connections to the device. The goal is to maximize how many students can pass through these points. (For more information about polarity and current flow in a solar cell, see http://pveducation.org/pvcdrom/light-generated-current)

Instructions

Participants will play a game with chairs to physically demonstrate electron/hole generation and transport and how the two interact with one another.

To begin, select a student to be a leader. Have all the students with their chairs stand around the square and explain the rules of the game. These rules are as follow:

- All chairs used must be completely in the square (none hanging over the lines).
- All students participating in a round must start in a chair. (Not all the chairs will fit in the optimum design, so not all students will be able to participate in each round).

- No climbing over chairs (safety first).
- Students will be given a set amount of time to move through the solar cell to make it to the device. Each student that makes it through the solar cell to the device will earn a point.

Have the student leader direct the students in placing the chairs in the square. Once the students are sitting in their chairs the teacher will indicate how much time the students have to pass through the cell, and set a timer.

Start timer, and tell the students to "GO!" and count how many students make it through to the device before time runs out.

Reset the solar cell design using different chairs/aisles patterns. Use the same amount of time as before and run it again to observe any changes. Compare the pros and cons of different designs.

Helpful Hints to the Teacher

Students sitting in the chairs represent the electron/hole pairs. The students are the electrons and the chairs are the holes, generated within the silicon wafer when illuminated by a light source.

The aisles are the "highways" and represent the busbars/fingers of the solar cell. Depending on how many highways are available will determine how much current will pass through the device.

For the first run, fill the square with as many chairs as possible. This will maximize the amount of students in the round thus they potentially could get the highest score. After the run, we would expect not everyone to pass through. If everyone did, decrease your time. Ask the students,

> *Why didn't everyone get out? This is because there was not enough busbar/fingers to travel on. So, we can generate all these electrons, but if we can't get them out, what good is it?*

For the second run, do another extreme and have almost no chairs. Everyone will pass through. However now we didn't have enough electrons to produce current.

For the third run, find a happy medium with enough chairs but where students are still able to pass through the solar cell.

Deepen your Knowledge

In solar cells the top surface is one polarity (+ or -) and the bottom surface is another. These surfaces must be connected to make your positive and negative terminals. However, the number of connections can be varied. One way to demonstrate this is to change the number of gaps in the solar cell set up. What effect would multiple gaps have on the device performance? Solar cells are not all the same. In practice, some have 2 busbars, some have 3. What are the advantages/disadvantages to having 2 or 3 busbars?

Busbars are the large thick contacts, fingers are the small (sometimes hard to see) lines. Did you see any effect of varying your busbar/fingers thickness?

What is the difference between a semiconductor, insulator, and metal? Diagram where they are located on your solar cell.

- Semiconductors, when carefully put together, can make interesting devices. The silicon wafer is the semiconductor in the solar cell (blue part).
- The busbars/fingers are the metal in the solar cell. Metals are good conductors.
- The lamination that encloses the solar cell to protect it is an insulator. Insulators prevent current flow, ensuring your electrons flow where you want them to.

For more information on how a solar cell is made, see activity "Solar Cell Assembly Line"

Follow up this activity with the front grid optimization activity in the Classroom Lessons section.

Cycle for Science

Grade Levels: Elementary school and higher

Authors: Elizabeth Case, Rachel Woods-Robinson

The Sol Cycle is a miniature, 3D-printable bicycle that uses solar power to run a small motor that turns the wheels. We cover three broad subjects in this lesson: renewable energy (solar), physics (including speed, distance, Ohm's law), and engineering design (3D modeling and printing). This lesson plan can be tailored to your needs and the interests of your students.

The goal is to involve the students as much as possible—to have them learn science by doing, rather than hearing about it. If there is only time for one 45-60 minute lesson, the Sol Cycles should be pre-printed and pre-assembled ahead of time. There is also room for more in-depth lessons on basic CAD design using Tinkercad, a free online software developed by Autodesk, and 3D-printing.

The Sol Cycle emerged out of a cross-country bicycle trip taken by Elizabeth Case and Rachel Woods-Robinson in the spring and summer of 2015. As two female scientists, they designed the Sol Cycle to be a hands-on, creative and engaging science demonstration for students aged 4-14. Find out more about the original trip at www.cyclefor-science.org.

This lesson is flexible, and can be run in multiple ways. Here is a sample of how you can run a lesson, with some suggestions for other activities or topics that are interchangeable.

After this lesson, students should be able to

- *List the three parts of an atom.*
- *Explain how a solar panel works (briefly).*
- *Give one or more examples of renewable energy, and explain why it is important.*
- *Be able to calculate speed from distance and time.*
- *Have a basic overview of prototyping, especially in regards to 3D printing.*

Materials

Donwload 3D-printable file from QESST Education website or from: https://tinkercad.com/things/7bJwCUMnaLb

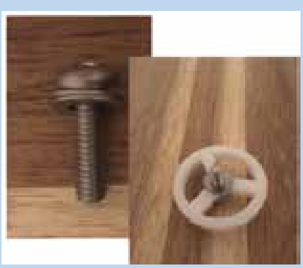
- Bicycle parts
  - (1) frame
  - (1) front wheel
  - (1) back wheel with hub
  - (2) training wheels
  - (2) training wheel forks
  - (1) motor-stop (for keeping the rubber band "chain" on the motor)
  - (1) handlebars
- Nuts and bolts
  - (1) 1.75" back wheel bolt
  - (1) 3/4" front wheel bolt
  - (2) 2 5/8" training wheel bolts
  - (3) lock nuts
  - (4-8) washers
  - (2-4) lock washers
  - (2) nuts
- Miscellaneous
  - (1) set 5-inch velcro (hook and snag)
  - (1) thin rubber band, e.g.
  - (2) thick rubber bands, e.g.
  - (1) 6V, 1.5W RadioShack solar panel
  - (2) small alligator clips, e.g.
  - (1) high efficiency motor, e.g.
  - Heat shrink wrap, e.g. (optional)
- Tools
  - (1) pair of pliers
  - (1) pair of mini scissors or Swiss Army knife
  - (1) Phillips screwdriver

How to assemble the Sol Cycle

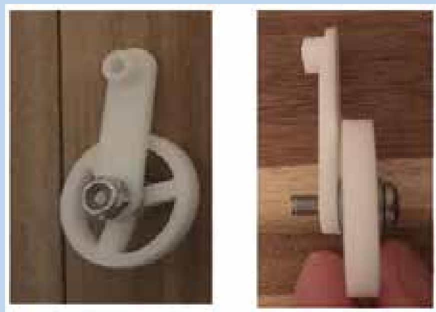
1. 3D-print all the parts you'll need, except for 1 locknut (3 needed in total: two for each training wheel and one for the front wheel).

2. Assemble the training wheels (x2) The number of washers you need will depend on the thickness of your washer – they are there to help your wheel spin, and also to make sure the screw fits snugly into the lock nut. Follow these steps for both training wheels.

2a. Add [washer(s) - wheel - washer(s)] to the bolt, so that there are washers on either side of the wheel.



2b. Screw on the training fork, making sure that the wheel is on the opposite side of the nub. Tighten on the locknut. The wheel should still spin freely – if it doesn't, remove some of your washers. You may need a screwdriver and pliers to tighten.



3a. Front wheel. Screw the bolt into the front wheel slot. You may need a screwdriver to do this. The head of the bolt should be on the opposite side of the protruding top bar (the same side as the flat face), so the front and back wheel will align.

3b. Add [washer - wheel - washer] and then tighten on the lock nut. The wheel should still spin freely. If it does not, remove one or both of the washers. If there is too much room on the screw and the wheel wiggles, add another washer.

4a. For back wheel, twist the training wheel with the open hole onto the long (1.75 or 2" screw) with the nub facing in and the wheel facing out as shown.

4b. Add the [lock washer - nut], then screw bolt into the bicycle frame. This training wheel should be on the opposite side of the protruding top bar, on the opposite side of the front wheel.

4c. Add [lock washer - nut - washer] as shown. Then add on the back wheel, with the pulley-side of the back wheel facing away from the frame.

4d. Add a [washer], then carefully tighten on the other training wheel by lightly pressing the opening of the nub against the end of the bolt. It should turn 3-5 times but can easily break if you apply too much pressure.

5. Finishing touches: it is pretty tricky to get those back wheels to stay in place. The easiest way to do it is to make sure the training wheels are aligned and touching the ground, the nut on the opposite side of the back wheel is tightened all the way up against the training wheel, and then use pliers to tighten the nut closest to the back wheel. Play around with it.

Instructions

Introduction (5-10 min)

Introduce yourself and what you do as a scientist. Then introduce the lesson material. A few tried and tested questions include:

> *How many of you ride your bicycles to school? (bicycles, mechanics, physics)? How many know where plants get their energy? (solar panel, renewable energy, circuits). And yes, the sun! Every morning, sunlight streams from the furnace of the sun's surface to the surface of the earth. Do you know how long it take light to travel from the sun to the Earth? (8 min).*

Depending on the age group, ask if anyone knows what light is:

> *Light is made of photons, which are little packets of energy that don't weigh anything at all and speed reeallllly fast through the universe.*

Introduce the idea of atoms:

> *What are the really tiny things that make up everything? What are the three parts of an atom? (Electron, neutron and proton).*

How a Solar Panel Works (10 min)

Hold up the Sol Cycle. Ask everyone what it is (a bicycle!).

Point or hold up a separate solar panel - do any of the students know what it is? How about how it works?

> *Sun emits photons, photons transmit energy to electrons, electrons get excited and move through the surface of the panel, down the red wire and into the motor, which steals the photon/energy, and the electron returns to its nucleus to repeat the pathway,*

Ask for four volunteers – (1) a **sun**, (2) an atom of the solar panel represented by an **electron** (someone who wants to run around!) and (3) a **nucleus**, and (4) a **motor**.

> *The sun is given a starburst – this is a photon! A tiny packet of energy.*

Position the four students in a line. The **sun** at one end of the space, the **electron**, walking slowly, sleepily, around the **nucleus** about 5-10 feet away, and the **motor** stands inert at the far end. If desired, lay down red and black tape/paper beforehand to represent the wires.

Set up the scenario, narrating:

> *At night, the electron is sleepy and has no energy to move away from its nucleus,*

so the student who has volunteered to be the **electron** rotates around the **nucleus**

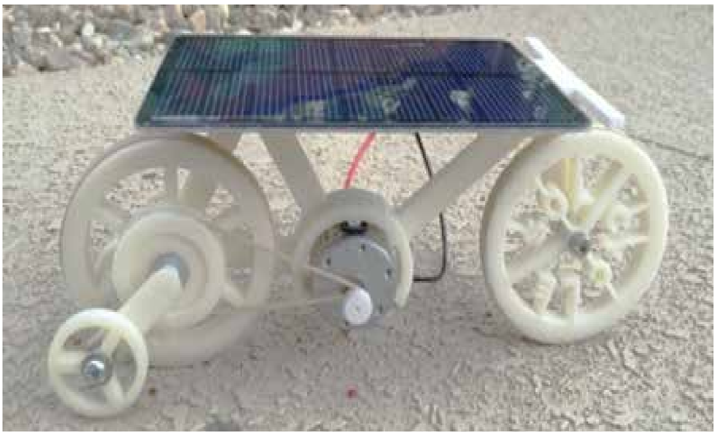
> *The sun rises and wakes up and tosses the starburst/photon to the electron. The electron now has lots of energy.*

The student runs around the room, then down the red wire to the **motor**.

> *The motor is hungry – it's breakfast time in motorland – and steals the starburst from the electron and starts spinning.*
>
> *The electron returns, exhausted, to the nucleus (its "parent") and slowly rotates again.*

<u>Sol Cycle Assembly (5-10 min)</u>

Students get in groups of 3-5. Invite one student per group to collect a Sol Cycle kit: a sol cycle (fully assembled, as shown above), a motor, a solar panel, and some rubberbands (two fat, one thin for the wheel "tire" and "chain" respectively. Final assembly should look like below:



Group assembles one cycle together. Walk around the room and help any that are stuck by asking leading questions

> *Think about a real bike. What happens when you pedal? What's moving? Are the tires plastic/metal or do they have something (e.g. a tire) around the edges?*

<u>Sol Cycle Activity (15 min)</u>

Each group receives a worksheet, a meter stick, and a timer. Each group takes five trials of how long it takes for their Sol Cycle to travel a meter.

Calculate speed, translate into miles per hour (from feet per second) and compare to: walking example, car example, bicycling example.

Have students experiment and observe. Some qualitative and quantitative questions are:

> *Does the angle of the solar panel matter? How close or far from a building? The texture of the ground? The angle of the ground?*

After doing some experiments, have students race their Sol cycles—20 feet or so is usually enough to make it really exciting.

Renewable Energy Discussion (5-10 min, optional)

What is renewable energy? Are solar panels an example of renewable energy?

What are some other examples of renewable energy?

Answer: wind, tidal, geothermal

What are some examples of non-renewable energy?

Answer: oil, gas, ethanol.

Why is renewable energy important? What is climate change?

Answer: The natural patterns and geologic ages of the earth are changing because of the pollution we emit into the atmosphere, and put into the ocean and the ground. Oil and gas release greenhouse gasses when they are burned. This traps heat in the atmosphere, and/or has torn a hole in our atmosphere, which means more radiation can reach the earth. Climate change is also affecting wildlife, causing animals and plants to go extinct. Healthy biodiversity healthy humans.

3D Printing (5-10 min, optional)

Sol-cycle design is available online to be 3D printed, so it can be a great opportunity to introduce students to 3D printing.

If a student has done any 3D printing, ask them to explain the process. In big strokes, the two steps are 1) giving the machine a design, and 2) the machine melts plastic and extrudes it onto the "drawing" board in layers microns to millimeters thick.

You can discuss with the students cool examples or uses of 3D printing. Some examples are for medical applications, like practicing surger on 3D printed skulls; for family —blind mothers receive a 3D printed "statue" or plate of the ultrasound image of their baby,— or even for printing parts for other 3D printers.

There are resources they can use to design their own bicycles (or anything they can dream of), like Tinkercad (free online software), or 3D hubs for printing ("amazon turk" for 3D printing -- someone does it for you on their own machine).

Wrap up (5 min)

Review with students how solar panels work, what the smallest element of matter is, how fast their Sol Cycle went, and how it was made.

Also, give students some take-home questions: how would they make the Sol Cycle better, or what would they like to 3D print? Have them draw out all the individual pieces that make up their design.

Next Generation Science Standards

This lesson was designed around the middle school Next Generation Science Standards (NGSS) and covers the following standards:

- **MS-PS3-2**: Develop a model to describe that when the arrangement of objects interacting at a distance changes, different amounts of potential energy are stored in the system.
- **MS-PS3-5**: Construct, use, and present arguments to support the claim that when the kinetic energy of an object changes, energy is transferred to or from the object.
- **MS-ETS1-1**: Define the tcriteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.

Designing a Solar Amusement Park

Subject: How can we use the engineering design process to create the greatest amount of renewable electricity possible?

Grade levels: 4th-8th grades

Prep Time: 15-30 min

Lesson length: 90 min

Teaching Location(s): outdoor

EFI to Group Size Required Ratio: 20:1

Author: Jenefer Husman, Christi Mendoza, Tiffany Rowlands

Students are introduced to the world of creative engineering product design. In this activity, teams work through the steps of the engineering design process by completing an actual design challenge presented in six steps. As members of an engineering design team, students choose a theme park ride that they want to build that is run ONLY by a solar panel and simple motor. As students begin defining the problem, they learn to recognize the need, identify a target population, relate to the project, and identify its requirements and constraints. They gather background information (e.g., remember a previous experience on a ride, conduct interviews with potential "customers" about what they like best in a park ride, use Google to gather information), brainstorm alternative solutions, evaluate possible solutions, create and test prototypes, and re-design to optimize their solutions.

Objectives

- *Explore how a solar cell works using a simple fan motor and multimeter.*
- *Design and build a spinning solar powered theme park ride.*
- *Understand the importance of creating detailed design plans and the use of the engineering design process.*

Preparing for Instruction

Before beginning the solar park activity, a simple lesson on how a solar cell works is strongly recommended. Students need to understand the basics such as placement of the solar cell for maximum power efficiency before building their ride. The instructor can then identify and address any misconceptions about how PV cells work.

Instructor Content Background Information

A photovoltaic cell converts radiant energy from the sun directly into electricity. Photovoltaic (PV) cells use materials called semi-conductors. When solar radiation falls on these materials, one side of a plate becomes positively charged while the other becomes negatively charged, creating a potential difference. These oppositely charged plates create a flow of electrons, or electricity.

Three types of solar panels are available: monocrystalline silicon, polycrystalline silicon (or multicrystalline silicon) and amorphous silicon (or thin film). Monocrystalline panels are the most efficient (15-18%), followed by polycrystalline panels (12-14%), then thin film (5-6%). Monocrystalline panels use individual cells to make up a module, while a polycrystalline panel is solid with flake-like pieces of silicon pressed together. Thin film comes in flat, thin, flexible sheets.

Although solar arrays are a way to free a building from fossil fuel energy, some building and homeowners do not like the appearance of roof-mounted systems (see figure below). Building integrated photovoltaics (BIPVs) use thin film technology to incorporate the PV paneling into building materials such as roofs, façades, awnings or covered walkways (see figure below), so they are hardly noticed.

Since the amount of electricity produced by PV cells is related to how much sunlight it receives, it is important to mount the panels on a surface that receives direct sunlight and is not shaded by trees or other buildings. An array has the greatest output when mounted on a roof that gets a lot of sun (in the northern hemisphere, this means a south-facing roof). An array on a roof can be angled to take advantage of how the earth tilts during its orbit around the sun.

Materials

- Materials part 1:
  - Solar cell (suggested 1V, 400 mA)
  - Hobby motor with fan blades (suggested 1.5 to 3.0 Vdc, at 330 mA)
  - Multimeter
  - Lab sheet
  - Science notebook and pencil (1 per student)
- Suggested Building Materials part 2:
  - (Required) All Materials from Part 1
  - (Required) Plastic round attachments for spinning
  - Styrofoam and/or plates, bowls, cups
  - Plastic silverware
  - Toothpicks
  - Party hats
  - Glue and tape (all kinds)
  - Wooden dowels or skewers
  - Toothpicks
  - Erasers
  - Disposable pie tins
  - Straws
  - String or yarn
  - Pipe cleaner
  - Q-tips
  - Bobby pins
  - Large white board and dry erase markers
  - Dollar store toys (miniature cars, princess rings, etc. – must be lightweight)

Word Bank

Solar (PV) cell　Multimeter　Circuit　Engineering Design process
Constraint　Shading　Architectural engineer　Electrical engineer
Solar array　Solar Power　Blueprint

Instructions

Introdution (30 mins)

Use your introduction to spark ideas and connections, stimulate wonderment and excitement. Show students a small solar panel. Use some discussion prompts so students can relate their existing knowledge to how solar panel works. Example dialogue:

> *This device is called a solar panel. It is sort of like a battery, but instead of storing chemical energy, it converts the energy we get from the sun (known as*

radiant energy) into electricity (or electrical energy). When a house or building uses a row of two or more solar panels, we call this a solar array. We see many homes in Arizona with solar panels. Where are the panels usually located? (On the roof.) Why do you think that is? (The roofs of buildings are exposed to the greatest amounts of sunlight and are better than the ground for being clear of any trees or other buildings that might cause shade.)

Here is a solar panel. Is it working right now in the classroom? (Students will say no, but it actually will put out a low voltage in the classroom.) But, there is light in this room, so why is the panel not working?

Measure the voltage of the panel. If you're inside, the light might not be intense enough to create electricity and you will need to repeat the measurement outside. If sunlight is unavailable, a 100-watt incandescent lamp provides enough radiation for each mini solar panel.

As it turns out, this light is not intense enough to create electricity. Let's go outside to see how it really works! (Take the class outside for a short demonstration.)

Have students create a circuit using the fan motor and solar panel. Have them measure the voltage of the panel outside and compare it to what it was inside.

Now we see the panel is working! This direct sunlight is perfect for creating electricity! Notice how the tilt of the solar panel and the direction the panel faces affects the brightness of the light bulb. Which direction is best? Have the students make several observations and take measurements of their panel in different directions. (Answers: In the direction of direct sunlight, which is east in the morning, west in the afternoon, south at midday, and towards the south in general.) So if you were an architectural or building engineer, where would you place the solar panels? (Answer: On a south-facing sloped roof or overhang of a building.) Great!

Planning and Designing the Solar Park Ride (30 min)

Give students time to explore and discover, to gain some experience. Have students create detailed design plans. Students will be swapping design plans; each group will build a park ride designed by a different team. Therefore, it is important that their plans be clear and complete.

1) Present students with the engineering design challenge: Design and build a spinning solar powered theme park ride that will be a major attraction in a solar amusement park.
2) Review requirements, constraints, and available materials.
3) Review the design swapping plan and discuss the importance of detailed design plans. Help students recognize the importance of professional communication in engineering design, using oral speech, written language, and charts, graphs, and sketches. Engineers work on teams with diverse members. Everyone on a team might have different about different aspects of a design. Engineers also work with customers who need to know what they are doing.
4) Allow students time to plan and sketch.
5) Swap design plans and allow groups to talk to each other and ask questions about the plans they have been given. Discuss with students procedures for getting approval to make design modifications. (Emphasize that all modifications should be minor in scope and stay true to the original design).

Before beginning the "planning" process review with the students the engineering design process. Emphasize to the students that all engineers use some form of the steps of the engineering design process to organize their ideas, and test and refine potential solution to real- live challenges. Students must be able to work together in teams. Theme park engineers work together- both architectural design engineers as well as mechanical or aerospace engineers come together to build some of the world's tallest and fastest rides. Millions of people may experience your rides, and their safety depends on your design details and building specifications.

Building and Testing the Solar Park Ride (45 min)

Focus on the iterative nature of the building and testing phases of the engineering design process. Instructional Sequence:

1) Allow students to build, test, and revise.
2) Have a board meeting allowing students to report out on the status of their rides as a work in progress. This is particularly important for those whose rides are not working. Getting constructive feedback from the class is extremely rewarding.

Share with the students that as their ride's construction advances, they may find that some elements of the ride are not working properly. Tell them that they must be willing to adjust their design plans throughout the building phase. Iterative cycles of brainstorming and testing are part of the design process. Prior to the ride's debut, the engineers coordinate numerous test runs and monitor the ride's safety. Many engineers act as guinea pigs, being the first passengers to experience their attraction.

Reflection (15 min)

Making meaning and reflecting on the activities is a very important aspect of learning. Have students analyze observations or data, construct explanatinos, and make ties to content, as well as reflect on the learning. You can organize a gallery walk for this:

1) Have students show off their rides to the public.
2) Have the original "blueprints" to show how the ride was created and modified.

At the end of the gallery walk bring all the groups back together and have a discussion that addresses these questions:

- What were some of the challenges your group faced?
- How did you overcome those challenges working as a team?
- What are some "rules of thumb" you would suggest to other teams designing building solar-powered products?

Connect beyond the classroom (10 min)

Do you think all schools, houses, libraries and supermarkets in every part of the world have electricity? As it turns out, many countries suffer from what is sometimes called "energy poverty." When no electricity is available or when an electricity shortage exists in a city or town, we say this area suffers from energy poverty. This happens because a country cannot afford or does not have enough resources to create all of the electricity it needs. Sometimes these areas are without power for hours or days! Some places exist without any electricity at all! Can you imagine what it would be like to wake up in the morning and not have any electricity? What would school be like without electricity? Do you think these areas could benefit from using photovoltaic panels?

Assessment Opportunities

Have groups make class presentations about their park rides. Require each student to participate. Require groups to describe how their rides work and why they made certain material/design choices. Also have the students explain how the solar panels were integrated into the design of their rides.

Deepen your Knowledge

Maps like the ones below could be used to help students reason about the question above: Do you think these areas could benefit from using photovoltaic panels?

- World energy map: http://www.energyhii.com/userfiles/images/437503_1--world-map.jpg
- World energy consumption map: http://burnanenergyjournal.com/how-much-energy-are-we-using/
- World solar energy map: https://s-media-cache-ak0.pinimg.com/736x/ca/88/84/ca8884a29211c8e14afb02c2d6168211.jpg
- Global solar irradiance map: http://www.vaisala.com/en/energy/support/Resources/Pages/Free-Wind-And-Solar-Resource-Maps.aspx
- Solar energy potential - find yourself!: http://www.renewableenergyst.org/solar.htm


Solar Amusement Park Reflection

Questions to think about:

1. What worked, what didn't work with your design?
2. If you could change one thing about your design what would it be?
3. If you could have 1 "dream" material that you didn't have what would it be, and how would you use it?
4. Did your ride spin? If so, why do you think you were successful? If it didn't, what could you have done to improve it if you were given more time?

Next Generation Science Standards

Grade 4–8

3-5-ETS1-1: Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost.

3-5-ETS1-2: Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.

4-PS3-4: Apply scientific ideas to design, test, and refine a device that converts energy from one form to another.

4-PS3-2: Make observations to provide evidence that energy can be transferred from place to place by sound, light, heat, and electric currents.

5-ESS3-1: Obtain and combine information about ways individual communities use science ideas to protect the Earth's resources and environment.

MS-PS3-3: Apply scientific principles to design, construct, and test a device that either minimizes or maximizes thermal energy transfer.

MS-ETS1-2: Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.

MS-ETS1-3: Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.

Adjustments (Focus) for Grade Levels

Scaling of this activity depends on the amount of interaction between the students and the teacher during the design and building process.

For advanced students, offer little to no advice and have students research different options so that they develop their own designs. Do not restrict their choice of materials or even offer examples of different devices. Have these students independently test their designs by designing their own experiments and ask them to justify their design choices either through a presentation or paper. For students who need more help, interact with them through every stage of the planning and building process. Suggest the materials to use or restrict them so they do not have to make as many choices. Offer a variety of examples or simply instruct all the students to construct their ovens based on a provided design and instructions.

Solar Oven

Subject: How do I decide which materials are best suited for building a solar oven? What advantages does solar energy provide over other types of energy? To whom could solar ovens be important and why?

Grade level(s): 3rd-5th grades

Prep Time: 15-30 min

Lesson length: 90 min

Teaching Location(s): outdoor

EFI to Group Size Required Ratio: 20:1

Authors: Tiffany Rowlands, Christi Mendoza

In this activity students learn about using renewable energy from the sun for heating and cooking as they design and build a solar oven and compare its performance to others' designs. They explore the concepts of insulation, reflection, absorption, conduction and convection. They also utilize and apply information that they have gained from a previous activity that introduces them to properties of various materials to in order to construct a solar oven.

Objectives

- *The students will conduct an experiment to investigate how color influences the temperature of an object.*
- *The students will investigate how various materials influence the temperature of an object.*
- *The students will utilize and apply the engineering design process using the information they have gained about properties of various materials to construct a solar oven.*

Instructor Content Background Information

A detailed explanation of how to construct an example solar oven can be found at

http://www.backwoodshome.com/articles/radabaugh30.html

Materials

- Part 1:
  - Each group will need 5 cans of the same color
  - Plastic wrap
  - Construction paper
  - Felt
  - Aluminum foil
  - Temperature guns (1 per group)
  - Student Data Sheets 1 and 2
  - Large white boards or chart paper
  - Dry erase markers of regular markers
- Part 2:
  - Pizza boxes or other cardboard boxes
  - Paint stirrers
  - Plastic wrap
  - Felt (various colors)
  - Aluminum foil
  - Wax paper
  - Cellophane (various colors)
  - Plastic garbage bags (black and white)
  - Construction Paper (various colors)
  - Cotton batting
  - Various kinds of tape (masking, duct, electrical)
  - Scissors
  - Temperature guns
  - Large marshmallows

Word Bank

Reflection	Refraction	Absorption	Insulator	Emissivity

Conductor Transparent Translucent Opaque Heat Thermal

Temperature Constraint Variable Renewable resource

Instructions

Introdution (30 mins)

Use your introduction to spark ideas and connections, stimulate wonderment and excitement. Propose the following scenario to the students:

> *Pretend we are going on a fieldtrip on a hot sunny day and we are going to be outside for most of the day. What type of clothing should you wear? Why?*

Ask the students to record their thoughts in their science notebooks. Working in groups of three or four, ask students to share their response with their group members. Lead the class in a discussion about what type of clothing they would wear and why.

Cans experiment, part 1 (45 mins)

Give students time to explore and discover during this activity. The purpose of this activity is to guide students towards the understanding that darker colors absorb light while lighter colors reflect light. Students should begin to understand that as light is absorbed an energy transfer occurs and we have a shift from light energy to heat energy. The activity also provides students with experience in conducting controlled experiments and using data to draw and support conclusions.

1) Review the students' previous discussion and tell them that they are going to be doing an experiment to prove that some colors cause objects to get warmer than others.
2) Show the students a set of the colored cans (one of each – black, red, yellow, green blue, white) and explain that you will be putting these cans outside in the sun and taking their temperatures to see which can(s) gets the hottest.
3) Pass out the Student Data Sheet 1 and have the students make a hypothesis about which can they believe will get the hottest.
4) Pass out the colored can sets and temperature guns to the student groups.
5) Explain to the students the procedure for the experiment.
    a. Set the cans up in a straight row in direct sunlight.
    b. Take the temperature of the cans every minute for ten minutes and record the temperatures in the data table.
6) Conduct a practice round collecting data for three minutes so that the students can get the feel for taking the temperatures and recording the data.
7) Take the students outside to conduct the experiment.

If students are not familiar with the use of temperature guns, it may be beneficial to have them practice taking temperatures of various items in the classroom before using them in the experiment.

Cans experiment, part 2 (45 mins)

This Experiment could be run simultaneously with Part 1 in order to save time. One group could complete colored cans, while one does materials.

The purpose of this investigation is for students to begin identifying materials as insulators or conductors of thermal (heat) energy. The activity also provides students with experience conducting controlled experiments and using data to draw and support conclusions.

1) Explain to students that now that they know how color affects temperature, they are going to investigate how different materials influence temperature.
2) Give each student group five cans of the same color. Have the students wrap one can in aluminum foil, one can in plastic wrap, one can in construction paper, and one can in felt. The remaining can will be the control.
3) Explain to the students that they are going to be repeating the experiment to see which material makes the can the hottest.
4) Pass out Student Data Sheet 2 and ask the students to make a hypothesis regarding which can they think will be the hottest.
5) Explain the experiment procedure to the students.
6) Set the cans up in a straight row in direct sunlight.
7) Take the temperature of the cans every minute for ten minutes and record the temperatures in the data table.
8) Take the students outside to conduct the experiment.

Designing and Building a solar oven (45 min)

This activity provides students with the opportunity to apply the science content knowledge they have gained within a real world context. The list of building materials is only a suggestion and can be added to or modified as needed.

1) Present the engineering design challenge to the students.
2) Challenge: Your challenge is to construct a solar oven using only the materials provided to heat a marshmallow. The goal is to see which group can get their marshmallow the hottest.
3) Go through the list of materials with the students.
4) Pass out drawing paper and have each student sketch a solar oven design making sure that students label the materials in their design.

5) Have students share their designs with their design groups and then have design groups work together to create a final design plan.
6) Have students construct their solar ovens using only the materials in their group design.
7) Test the solar ovens by allowing them to sit in direct sunlight for a minimum of 20 minutes and then taking the temperature of the marshmallow. Heat lamps work well if it is not possible to test the solar ovens outside.
8) Share the final temperature results with the class.

While students are waiting for the marshmallows to cook, or as an extension, student groups can work together in pairs to create a Venn diagram to compare and contrast the design of their solar oven with that of their partner team.

If time permits, teachers can further implement the engineering design process by allowing students to make improvements to their original design.

Reflection

Create meaning by reflecting on the activities. Have students analyze observations or data, construct explanatinos, and make ties to content, as well as reflect on the learning. For the can experiments (part 1 and 2), after conducting the experiment guide the students through the process of interpreting the data.

- Have the students look for any patterns (increases, decreases, fluctuations).
- Have the students calculate the average temperature, or identify the median temperature for each can.
- Have the students rank the cans in order from warmest to coolest.

Using large white boards or chart paper, have the students create a representation of the data form their experiment (one per group). The representation should include:

- A data table (average or median temperatures only)
- A bar graph using average or median temperatures for comparison
- A statement of something interesting they discovered during the experiment

After completing the data representations, have the students sit in a circle with their white boards or chart papers. Guide the students through a discussion of their data by having them compare graphs and data tables, and discussing the interesting things they learned. Challenge students to confront differences in data and to work through to a common consensus of results and understanding of content. Provide the students with direct instruction about thermal insulators and thermal conductors.

For the solar oven, have students write a reflection about what went well with their oven and what they could improve.

Connect beyond the classroom (10 min)

Solar ovens are in use worldwide, providing fuel-free and smoke-free cooking, baking and water decontamination especially helpful in remote and poor regions.

Connect to solar and photovoltaic researchers conducting experiments.

Determine how well the ovens perform in winter. How important is the season? How important is the time of day? How important is the outside temperature?

Assessment Opportunities

Have groups make class presentations about their solar ovens. Require each student to participate. Require groups to describe how their ovens work and why they made certain material/design choices. In their explanations, students should use concepts learned, including vocabulary from the word bank (e.g. reflection, refraction, absorption, insulator, conductor).

Deepen your Knowledge

For direct instruction and a connection to Language Arts, teachers may wish to incorporate the book "Light Show Reflection and Absorption" by Jack Torrence.

Next Generation Science Standards

Grade 3-6

3-5-ETS1-1: Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost.

3-5-ETS1-2: Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.

4-PS3-4: Apply scientific ideas to design, test, and refine a device that converts energy from one form to another.

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Kill-a-Watt

Subject: How much energy do you consume in your household, and how can you reduce your usage?

Grade Levels: Elementary school and higher

Lesson Length: 40 minutes

Author: Mia DelaRosa, Antoinette Brooks

Participants begin to analyze their personal use energy consumption, and how their behaviors correlate to the costs involved with selected lifestyle choices. Working in teams and drawing from the electrical grid, they plug their items into Kill-A-Watt device, take periodic readings, graph the data, report the average, and discuss how much power common electric devices require. They then discuss lifestyle changes based on their analysis of the results.

Objectives

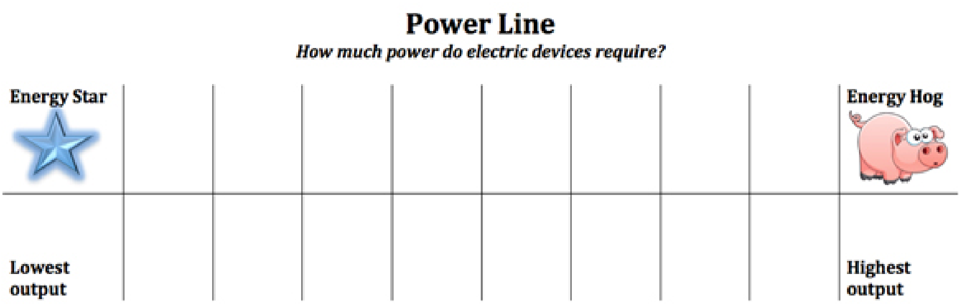
- *Students will analyze their personal use energy consumption, understand how their behaviors correlate to the costs involved with selected lifestyle choice.*
- *Students will explain the benefits and drawbacks of using photovoltaic energy to power common everyday household items, and make recommendations for lifestyle changes to encourage responsible energy consumption.*

Materials

- Common household energy using devices such as a hair dryer, Christmas lights (Regular and LED), toaster, cell phone with charger, electric blanket, incandescent lamp, fluorescent lamp, LED lamp (lamps should be of similar luminosity), electric egg beater/mixer, laptop
- Laminated photos of each of the common household energy using devices to stick on Powerline board
- Velcro with one side attached to each photo and the other side attached to the Powerline board
- Extension chords
- Power outlet
- Kill-a-watt meter
- Powerline board

Set Up

Create a Powerline board using this template (large poster-size for group settings). You may also wish to print one smaller copy of the powerline board for each individual or group to work on.



Gather household energy devices in a central location and plug them in. Be sure to check with event organizers ahead of time to be sure you will have access to a power outlet. Safety note: make sure the hair dryer, toaster, and other heat-producing items are not on the same circuit.

This may be a useful video if you need to teach participants how to read the meters:

http://bit.ly/2nxecRP

You may also want to show this video on how to measure electricity:

http://bit.ly/2oy6NTa

Instructions

Either working alone, in small groups, or as a whole-group, participants take the following steps:

1) Gather common electrical devices (at least one per group).
2) Predict which appliances use the most energy and place them accordingly on the Powerline board. Be sure to ask participants to justify their answers (e.g., What makes you think the hair dryer will use the most energy? Can you explain why you think that?). Participants should be given the chance to re-arrange the items as a result of the discussion. Save this information to compare data at the end of the activity.
3) Plug in the different appliances to the Kill-a-Watt meter and observe the amount of energy used for several seconds. Record the findings.
4) Rearrange the board based on findings. If multiple readings are recorded, older participants can calculate the mean and rearrange the board based on the average reading. They can discuss any discrepancies across multiple readings.
5) Outreach leaders can lead a discussion of results, asking, for instance, why some appliances used more energy than others. (Generally, any appliance producing heat will require more power). Participants may notice as they compare results that there is a significant increase in power used for appliances that produce heat. Additionally, some participants may be surprised at some of the results. For instance, many chargers will draw power even when the device (cell phone, iPad, etc.) is off and even when the electrical device is not connected to the charger. Students will be surprised to find out that when devices they use are turned off, there is still a power demand. Participants may also be led to understand that almost all devices have a fairly constant power demand (A toaster will change between two values, minimum and maximum).

Assessment Opportunities

Lead a discussion on the question: What are the costs associated with your personal energy consumption habits? How could you be more environmentally responsible by reducing the use of just a couple electric devices? Discuss any changes in lifestyle that students would consider taking based on the results.

Follow up by estimating the energy usage of other common household devices.

Deepen your Knowledge

For a more rigorous recording of results, participants could record the power when the appliance is plugged in and turned off. Instruct them to turn on the device and record the power for a period of several minutes (for example every 30 seconds for up to 3 to 5 minutes). They could then graph the power as it relates to time.

Students could bring their results together to make a complete representation of power use versus appliance/device, for example, by reading a bar graph form of the individual results.

Student teams could bring their own devices from home. They can conduct brief research on their device, focusing on how their device operates, whether or not it generates heat, and how powerful it is.

Students could briefly examine electric bills to predict how much their lifestyle choices cost. The teacher may encourage students to bring in their own power bills or have a selection of anonymous bills prepared for students to use.

Then, they begin to examine the benefits and drawbacks of using photovoltaic energy to power common everyday household items. Finally, students will make recommendations for minor lifestyle changes to encourage environmentally responsible energy consumption.

To extend this activity to photovoltaics, participants can be led to recognize that the graphed data from the electrical outlets (generated by the electrical grid is constant). Teacher asks students to think of times when there was not reliable energy to power their common everyday devices. Students may discuss storms, power outages, experiences in developing countries, or downed power lines. Guide students to considering the need to have a reliable energy source to power devices. They then repeat the experiments outside, using solar panels as the power source. Each team takes periodic readings using the Kill-A-Watt meter, graphs the data, then reports average to class. Students will see fluctuation in reported averages. Students are led to recognize the fluctuation in averages and discuss the need for reliable energy sources to power devices. Student teams make recommendations to the whole group based on the devices they investigated, their own lifestyle preferences, and the trade-offs of using PV cells.

$1 Solar Light Hack

Subject: Electronics and solar power

Suggested Grade(s): 4th-8th grades

Lesson length: 60 min

Author: Danel Hogan, Ann Marie Condes

Guest activity from the StemAZing Project

Dollar Tree stores sell a variety of solar-powered items, like garden lamps or desk lamps. In this document, we detail how to hack two different $1 solar lights for use in science experiments and invention projects. The following instructions can be modified to other similar items. From these solar lamp/lights, the students will be able to hack for solar panels, high intensity LEDs, switches, rechargable AAA batteries, and parts.

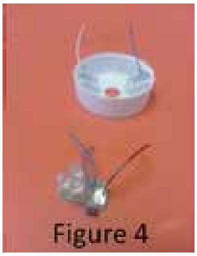
Materials

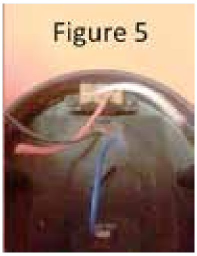
- Solar-powered white desk lamp (SKU#: 1751177)
- Stainless-steel solar-powered garden lights with stakes, 10” (SKU#: 175127)
- Philips head screwdriver
- Flat screwdriver
- Wire cutters (or scissors)
- Multimeter
- Test leads

Instructions

Solar-Powered White Desk Lamp

1) Take apart the lamp, as shown in Figure 1. The plastic cover for the LEDs is removed by twisting first. Everything else is simply press fit together so pull the pieces apart.
2) Unscrew two screws holding the solar assembly together to reveal the wires and rechargeable battery, as shown in Figure 2.
3) Cut all five wires right in the middle of their length, including the one tucked in the white plastic housing, as shown in Figure 3. This can be done either with scissors or wire cutters. The solar panel (in the black plastic housing) will now be separated from the white plastic housing. Note that the colors of insulation around the wires in each light might vary.
4) Remove the rechargeable battery from the white plastic housing, as shown in Figure 3. Remove the screw from the green circuit board to free the high intensity LEDs as shown in Figure 4. Important: do NOT remove the LEDs from the circuit board.
5) Using a flathead screwdriver, pry the switch off the back plastic housing shown in Figure 5. It is simply held on with some melted plastic and should come free with a little pressure as shown in Figure 6.





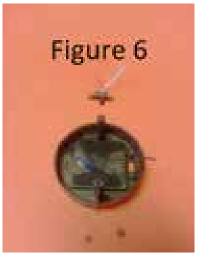
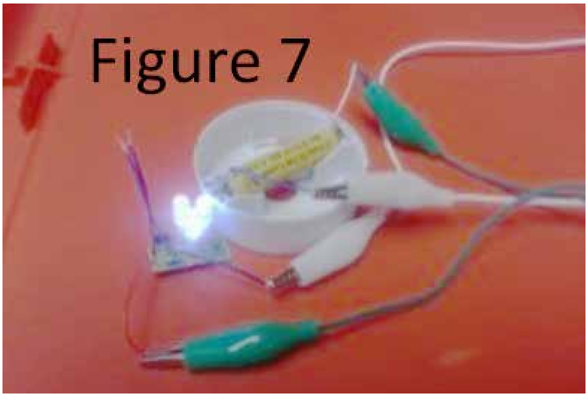
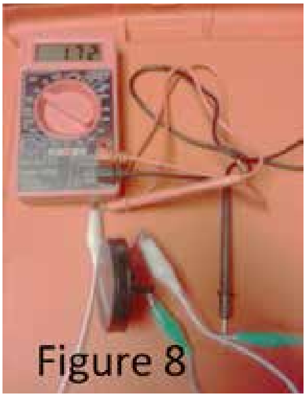


Figure 7 shows the high intensity LEDs connected to the battery using test leads to light them up. Figure 8 shows the solar panel connected to a multimeter using test leads to measure the voltage output of the solar panel.





<u>Stainless-Steel Solar-Powered Garden Light</u>

Figure 1

Figure 2

1) Unscrew two screws holding the solar assembly together as shown in Figure 1. This will allow the solar assembly to come apart as shown in Figure 2.
2) Cut all four wires in the middle of their length as shown in Figure 3. This will free the solar housing from the battery housing.
3) Unscrew the screw holding the green circuit board to the battery housing to free the high intensity LED. As shown in Figure 4, all the components should now be separate—the circuit board with LED, the solar housing, and the battery housing. Important: Do NOT remove the high intensity LED from the circuit board.

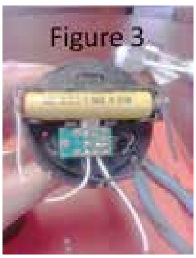


Figure 3

Figure 4

Figure 5

Figure 5 shows the extraneous parts of the garden light which can be used for all manner of invention at the will of the creativity of your students.

To connect the test leads, you will need to use the scissors to score (gently cut) the insulation a quarter of an inch from the end of each wire and pull the insulation off to reveal the bare copper wire.

Figure 6

Figure 6 shows the high intenstiy LED connected to the rechargeable battery using test leads. Please note that LEDs are directional, so if the LED does not light up, switch the test leads coming from the battery.

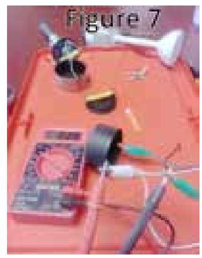


Figure 7

Figure 7 shows the solar panel connected to a multimeter measuring the voltage output. If the voltage is negative, simply switch the test leads connected to the multimeter. It should not change the magnitude of the measured voltage, only get rid of the negative sign.

Figure 8

Figure 8 shows the components all reconnected as they were originally using test leads where the wires were cut. The circuit board knows if the solar panel is in light charging the battery. For the LED to work, the solar panel must be covered.

IV Measurement

Subject: Taking IV measurements of laboratory-created PV cells

Requires special equipment

Grade Levels: College

Lesson length: 15-20 minutes

Author: Jenefer Husman, Kyle Rawlings

Photovoltaic IV testers (see fig. 1) are able to accurately give measurements of solar cells' voltage (V) and current (I) with light sources designed to recreate the sun's intensity and light spectrum. The result of these IV tests is an IV curve (see fig. 2), which is generated from a short-circuit current (ISC) (Amperes, A) point and an open-circuit voltage (VOC) (Volts, V) point. The cell's actual measurements are compared to an ideal curve, which is generated by the short-circuit current (ISC) and open-circuit voltage (VOC) and the ratio of coverage by the actual curve is the fill factor (FF) (%). For this activity, the relationship between short-circuit current (ISC) and open-circuit voltage (VOC), the factors affecting them, their effect on fill factor (FF), and the physical use of an IV tester will be explored. This activity is designed for 4-8 participants with 1-2 instructors.

OBJECTIVES

- *Participants will learn how to use the Solar Powered Laboratory's IV tester to measure their cells' optimal IV curves. Therefore, they will conceptually learn what ISC, VOC, and FF are and how they relate to each other.*

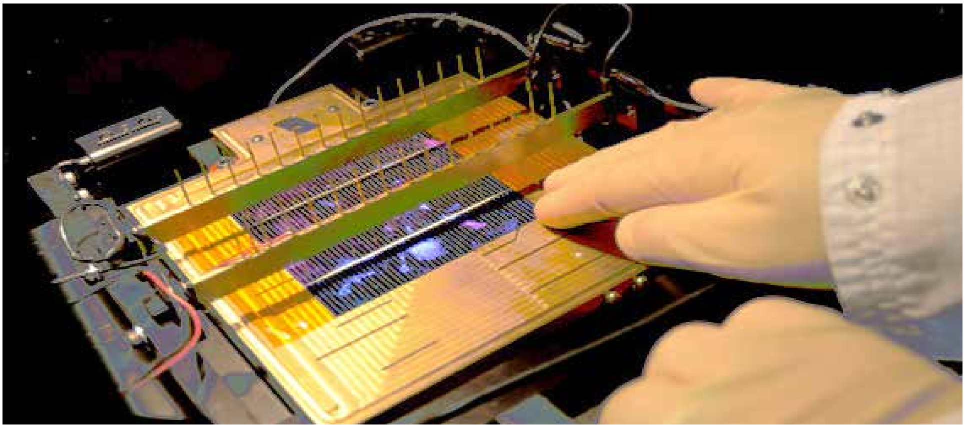
Materials

- Soldering workstation
  - Soldering wand
  - Silver ribbons
  - Wire (for actual soldering)
- Scissors
- Rubber gloves
- Solar cell(s)
- Solar Cell Measurement worksheets
- Case to transport cells to soldering workstations

Instructions

Each group will need to complete measurement for 10 cells. Six of these cells have compatible ISC's so groups can make a 4-cell module (and have two cells for backup in case of breakage). The other 4 cells will be used to make 1-cell modules.

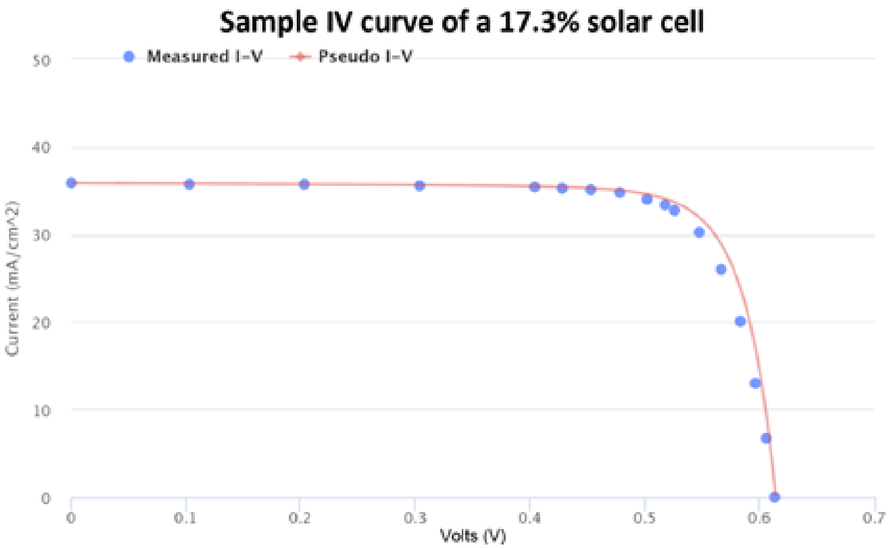
1) Begin with discussing voltage (the potential for electrons to move, similar to everyday objects' potential energy when on something like a table) and current (the flow of electrons through something conductive, e.g. metal).
2) Follow up by discussing how voltage is generated within the solar cell (energy from the sunlight is measured in the quantum "photons". These photons excite electrons within the silicon and create a voltage due to the "Photoelectric Effect").
3) Display a sample IV curve and discuss what ISC, VOC, and FF are.
4) Discuss what affects ISC, VOC, and FF. The factors affecting ISC include:
   a. area of the solar cell
   b. number of photons received (i.e. the power of the incident light source)
   c. spectrum of the incident light
   d. optical properties (absorption and reflection) of the solar cell
   e. collection probability of the solar cell



5) Demonstrate the appropriate way to handle solar cells (e.g., use of tweezers and noting how easily they break).
6) Demonstrate the steps to use the IV tester, then let students measure their own cells. Each student should measure at least 1 pre-made cell first. Have them record the results on the Solar Cell Measurement worksheet.
7) Calculate percent discrepancy with actual voltages and currents using the formula

$$|\text{Theoretical-Actual}| / \text{Theoretical} \cdot 100$$

   where the theoretical value is the given voltage and current values, and the actual value is the measured voltage and current values.
8) Separate out 6 cells which are compatible to make their 4-cell module. The additional 4 should be for their individual modules.
9) Guide students through the calculation of the expected voltage and current of their 4-cell module, explaining the effect of constructing a series circuit on voltage and current. They should record their expected voltage and current on the measurement worksheet.



Assessment Opportunities

What is voltage? What is current? Voltage is the potential for electrons to move. Current is the rate at which they move.

Construction Paper Solar Cells

Subject: Modeling the structure and manufacturing process of silicon solar cells

Grade Levels: Elementary and Middle School

Lesson length: 40 to 75 minutes

Author: Jill Murphy

After learning about how solar cells are made in a solar lab, students re-create the multi-step process of making a silicon-based solar cell. Following a diagram with labels and a key of materials used in the manufacturing of solar cells, students use construction paper and other materials (e.g., silver pens, saran wrap) to represent the materials in each layer of a solar cell. Students then make connections between their PV cell and a real PV cell.

Objectives

- *Students will demonstrate the steps involved in making a silicon solar cell and explain the purpose of each step for optimizing solar cell efficiency.*

Materials

Each participant needs the following materials to create a construction paper model representing the structure of a silicon solar cell:

- Front panel grid paper template = the metal conductor strips (found at the end of this lesson; created by Cody Anderson, QESST RET)

- Construction paper colors:
    - Aqua (bottom layer) lightly shaded with white or gray colored pencil (shade one entire side with colored pencil) = Metal Backing
    - Green & Red = Silicon Layers
    - Light Blue = Antireflective Coating
    - Dark Blue w/ Grid = Top of Solar Cell
- Silver Ribbon = Busbars (metal strips to connect to receiver to allow electricity to flow)
- Silver Pen = Metal Fingers of Silver (these can be shared)
- White or Gray Pencil = Metal Backing (these can be shared)
- Transparent sheet protector = Glass Lamination (optional)
- Glue stick
- PowerPoint file "Captain Planet_Part 2" found on the QESST Education website.
- One or more examples of a construction paper solar cell model
- One or more examples of real silicon solar cells (with varying numbers of busbars, if possible)

Instructor Content Background Information

Video Energy 101: Solar Power produced by Energy Now:

https://youtu.be/NDZzAIcCQLQ

Video Bill Nye's video on Solar Power:

http://www.discoveryeducation.com/auth/STEM-Camp/energy/video-solar-power.cfm

Richard Komp's video, "How Do Solar Panels Work?":

https://youtu.be/xKxrkht7CpY

Nova created a useful image of the layers of a solar cell:

http://www-tc.pbs.org/wgbh/nova/solar/images/insi-01.gif

There are also interactive and printable versions of the image, along with text describing the anatomy of a solar cell and explaining how a solar cell works:

http://www.pbs.org/wgbh/nova/tech/how-solar-cell-works.html

Setup

Pre-cut and make materials ahead of time to save time in class. A lot of time for cutting is required to prepare for this activity, so you may want to gain access to a paper cutter.

Print and cut out a front grid panel or copy onto a transparency sheet for each student to use as the top of the solar cell. Draw small vertical lines connecting orange squares from top

to bottom using a silver pen to represent the "fingers" of the solar cell, which are made of silver.

Cut the construction paper layers. Each layer should be wider than the next so that each later can be seen from the top. In other words, the dark blue construction paper should be slightly wider on all sides than the front grid panel, the light blue construction paper should be slightly wider than the dark blue paper, the red should be wider than the light blue, the green should be wider than the red, and the aqua should be widest of all.

Finally, cut the silver ribbons into "busbars" long enough to span the length of the widest, lowest layer of the "cell", with some overhang. Cut enough ribbon that all participants can decide whether they want to design cells with between two and five evenly-spaced busbars.

Instructions

This lesson can be divided in two parts. Part I introduces students to ways to use the sun for energy, focusing in on solar cells. Part II helps students understand how a solar cell is made.

Part I: Using the Sun for Energy

In this part of the lesson, participants learn how photovoltaic engineers design ways to generate electricity from the sun. They will then focus on one particular device, solar cells,.

Discuss questions such as the following in order to help participants orient to the task and recall relevant prior knowledge.

- What is energy?
- Who uses energy and how?
- Why do we need energy?
- Where does energy come from?
- How is energy stored?
- What do you know about solar energy?
- How do we use the sun for energy?
- What would the earth be like without the sun?

More participants will have the opportunity to talk if this discussion activity occurs in small groups of three to four participants rather than in a whole-group setting. The discussion can be organized using the Kagen structure, *Talking Chips*: each person chooses two questions or is assigned two questions to answer to the best of their ability.

Discuss the sun as a source of energy, citing fun solar facts, the optimal global locations to capture solar energy, and how photovoltaic engineers generate electricity from the sun. You might want to show the video, *Energy 101: Solar Power.* The video introduces and explains how different types of solar devices work: (~4 minutes).

1) Photovoltaic (solar) cells, panels, and arrays
2) Solar thermal electric power plants (solar concentrators)

Then, focus in more detail on how solar cells turns sunlight into energy. One place to start is Bill Nye's video on solar power and its applications (~6 minutes).

You might want to pause here for a check of understanding. Have participants talk to a partner, in small groups to answer basic knowledge questions such as the following:

- Referring to the word *photovoltaic*, what do the terms *photo* and *volt* mean?
- What is the difference between a solar cell, solar panel, and solar module?
- How does the sun's light and a solar panel work together to make electricity?
- Why aren't more people using solar panels? What are some restrictions?

Part II: How to Make a Solar Cell

In this part of the lesson, participants learn how current is generated in a solar cell. They then learn the steps involved in making a silicon solar cell. Finally, they make a model of a silicon solar cell using construction paper and other everyday materials.

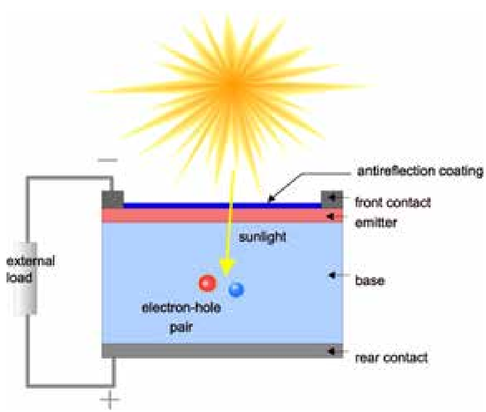
Teach participants how current is generated in a solar cell. Generating current in a solar cell involves two processes:

1) Incident photons are absorbed and electron-hole pairs created.
2) Light-generated carriers are collected by the p-n junction.

For a quick guide to a PV cell in action, see Richard Komp's TedEd video, "How Do Solar Panels Work?" https://youtu.be/xKxrkht7CpY (~4 minutes)

You might show this explanation and animation of the ideal short circuit flow of electrons and holes at a p-n junction: http://pveducation.org/pvcdrom/light-generated-current

The next step is to teach participants how solar cells are manufactured. You can use Jill's PowerPoint, "Captain America Part 2", to introduce the processes involved in manufacturing silicon solar cells. You might also use this interactive animation of how screen printed solar cells are manufactured (explains the steps modeled in the construction paper solar cell: http://pveducation.org/pvcdrom/manufacturing/screen-printed).



Another resource is Alex Killam's PowerPoint on "Solar Cells for Beginners", posted

to the QESST Education website. It includes photos of actual tools used in the pilot line of the industrial solar cell laboratory at the ASU Solar Power Lab.

Now guide participants in making a model of a solar cell. Tell participants that they are going to create a model of a silicon solar cell. Pass out materials and walk participants through each step in the manufacturing process. You can use using the “Captain Planet Part 2” PowerPoint slides found on the QESST Education website to guide participants through the steps in the solar cell manufacturing process. Do NOT explain the whole process at once. Because learners can only process a small amount of information at one time, the outreach leader or teacher should describe each step of the process along the way. It is important to connect your explanation of the processes and purposes involved in manufacturing to each action the participants make in adding a layer to their model of a solar cell. Use the supporting visuals found at the end of this lesson.

Each participant will layer the construction paper to match the Nova image. They will add another component (busbars) not featured in the diagram. On the top, students can paste the solar cell front panel grid on top or the transparency of the front panel. On the bottom of the solar cell model, students can color the entire back with a gray or white pencil. Then, they can use the silver pens to draw the three columns of dashed lines that represents the silver etching. They use the silver ribbon to represent busbars that connect on the right side and another set that connects on the top. (Note: Do not glue one silver ribbon all the way down to show silver etching on aluminum backing. Silver etching (3 dashes) are under the busbars when tabbing i.e., soldering).

Finally, participants insert the model into a sheet protector, representing glass lamination.

Along the way, ask questions to prompt thinking and check understanding. Here are some examples:

- How does the silver ribbon, "busbar" connect to the receiver, such as a lightbulb? How does this connection generate electricity? (connect to knowledge of circuits)
- Looking at the examples of real solar cells: Why are some of the busbars on different sides? How does that affect the flow of electricity? Discuss how a conductor is made of metal which allows the energy to flow (conduct)

Assessment

Jigsaw activity: Assign groups one question to reflect upon by using the Kagan structure, *Jot Thoughts*. Participants independently generate as many responses as possible by writing one response to the assigned question on a sticky note (one response per sticky note). As a group, participants pick out 2-4 essential responses to share with the class. Each group will choose a representative to share responses. Create an anchor chart ("Connections: Making a PV Cell") to post their sticky note responses.

- What connections can you make from your PV cell to a real PV cell?
- How much energy can one PV cell generate electricity?
- How much energy can an array of PV cells generate electricity?

- What items could you connect to a PV cell to generate electricity?
- What items could you connect to an array of PV cells?
- Why do solar panels cost so much? Think about the time & materials that go into building PV cells and arrays.

Deepen your Knowledge

Participants can also use the following materials to create food PV cell: bread as the wafer, mayo as the aluminum, spray butter as the phosphorus, lettuce as the anti-reflective, and mustard as silver busbars. In a science notebook, students create a Venn diagram showing the similarities and differences between the construction paper PV cell and the food PV cell. Encourage students to take pictures and email them to the teacher for a class share session.

Next Generation Science Standards

This lesson was designed around the middle school Next Generation Science Standards (NGSS) and covers the following standards:

- 4-ESS3 Earth and Human Activity

    4-ESS3-1: Obtain and combine information to describe that energy and fuels are derived from natural resources and their uses affect the environment.

    4-ESS3-2: Generate and compare multiple solutions to reduce the impacts of natural Earth processes on humans.

    ESS3.A: Energy and fuels that humans use are derived from natural resources, and their use affects the environment in multiple ways. Some resources are renewable over time, and others are not.

Designing a Solar Cell to Optimize Efficiency

Subject: Modelling trade-offs between different sources of power loss and electron transport in a solar cell

Grade Levels: Middle school and higher

Lesson length: 40-60 minutes

Author: Cody Anderson, Elizabeth Adams

Solar cells have a limited amount of space on their surfaces. The silicon wafer itself must be exposed for electron/hole pair generation, and the metal overlays are present to transport the electrons to create current. Maximizing the number of electrons that can be used in a circuit requires tradeoffs in design between electron generation and electron transport and is expressed as optimization of the total surface area of the silicon wafer versus the total surface area of the metal configurations.

In this activity, participants will examine the effects of one factor, shading, on solar cell efficiency. Their goal is to optimize the front grid design of a solar cell to minimize power loss by drawing their own custom designs on a pre-drawn solar cell front panel grid. Students use a pre-determined formula to calculate the effects of shadowing on the cells' efficiency, estimating power loss associated with their design in order to compare and improve their designs.

Learning Goals

- *Participants will learn how the metal contacts effect a solar cell's overall efficiency and how optimization must reach a happy medium between the materials' surface areas to maximize efficiency. Their goal is to optimize* *the front grid design of a solar cell to minimize power loss by designing the spacing of buss bars and fingers on a solar cell. They will draw their own custom designs, estimate power loss, then use a spreadsheet to develop a better design. Through these activities, they will come to understand some of the tradeoffs between the number of busbars and fingers and the area of exposed silicon.*

Materials

Required for each participant:

- Copies of the front panel grid paper
- Straightedge
- Black marker
- Red pen

Instructor Content Background Information

Richard Komp's Ted-Ed talk, "How do solar panels work?":

https://www.youtube.com/watch?v=xKxrkht7CpY

Richard Komp's Ted-Ed lesson:

https://ed.ted.com/lessons/how-do-solar-panels-work-richard-komp

Department of Energy's solar energy quiz:

https://www.energy.gov/articles/quiz-test-your-solar-iq

There are more resources on the QESST Education website, like PowerPoint slides on the mechanics of silicon solar cells developed Cody Anderson, or a competition spreadsheet.

Instructions

Orient students toward the design activity by checking their prior knowledge. You could use some of these questions, depending on the age and background of the participants.

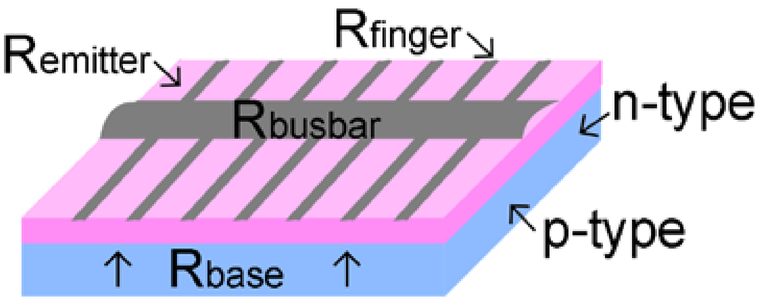
- What forms of energy do we use daily? List as many as you can think of.
- Where does this energy come from? List as many sources as you can.
- Do you think solar is a useful energy technology? Why or why not?
- What is light?
- What do solar panels do? How do they work?

Introduce participants to the mechanics of silicon solar cells. Participants should understand:

a. how solar cells convert sunlight to usable energy (electricity)
b. how silicon solar cells are manufactured

Several resources for exposing participants to this information are listed in the materials list above. You might, for instance, have them view and discuss Richard Komp's 5-minute Ted-Ed talk, "How Do Solar Panels Work", available on YouTube. You can also access his entire lesson that includes four steps: Watch (the video), Think (check your knowledge using 5 multiple choice and 3 open answer questions), Dig Deeper by exploring other online resources, and Discuss (questions in guided and open discussion forums). Another resource is Cody's PowerPoint on the mechanics of solar cells, which is available on QESST Education website. As a closing knowledge check, you might collectively take the solar energy quiz from the Department of Energy at energy.gov.

Once students have this background knowledge, lead them in discussing design considerations of a solar cell. Introduce them to the sources of power loss including optical losses (shading and surface reflection), shunt resistance (defects leading to tiny short circuits), and series resistance (base, emitter, contact, fingers and busbars).



The power loss associated with the front panel design of a solar cell can be mathematically modeled using this equation:

$$P_{loss} = P_{loss,emitter} + P_{loss,fingers} + P_{loss,shading}$$

Each source of power loss can also be mathematically modeled. Help participants interpret these equations by explaining how power loss associated with each of the sources is calculated. Point out that all three types of loss depend on finger spacing. Furthermore, power loss from shading ($P_{loss,shadin}$g) also depends on the area of the busbars:

$$P_{loss,emitter} = (S_f^2\ J_{mp}\ p) / (12\ V_{mp})$$

$$P_{loss,finger} = (L_f^2\ S_f\ J_{mp}\ \rho) / (3\ w_f\ d_f\ V_{mp})$$

$$P_{loss,shading} = A_{shaded}/A_{cell}$$

The main equation excludes power loss due to busbar resistance (which is negligible) and contact resistance (which cannot be modeled well since it is highly dependent on material variability). These equations assume equal finger spacing throughout cell. Finger Width (w_f) can be variable, but must be at least 50 μm due to manufacturing constraints.

Definitions of parameters and typical values for a solar cell

S_f = finger spacing [mm]
L = finger length [mm] (i.e., busbar spacing)
J_{mp} = current density at max power ~0.35 mA/mm^2
V_{mp} = voltage at max power ~ 0.5 V
ρ = metal resistivity ~ $3x10^{-5}$ Ω·mm
p = emitter sheet resistivity ~ 60 Ω
d_f = depth of finger ~ 0.02 mm
w_f = width of finger ~ 0.01 mm
A_{cell} = total surface area of cell (150mm x 150mm for the given cell, minus the area of the corner cutouts)
A_{shaded} = shaded surface area, estimated as
$A_{shaded} = A_{busbar} + w_f / S_f \ (A_{cell} - A_{busbar})$
Busbar width = 2 mm

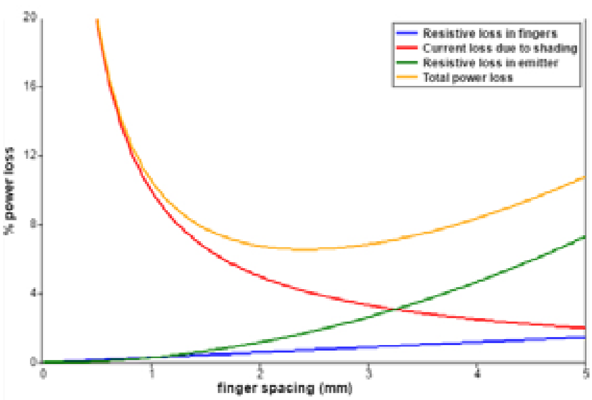
Help participants interpret these equations by explaining how power loss associated with each of the sources is calculated. Point out that all three sources of loss depend on finger spacing. Furthermore, $P_{loss,shading}$ and $P_{loss,shading}$ also depend on the area of the busbars.

Participants need to recognize that there are tradeoffs among the variables. Some examples include:

- Finger spacing (S_f): A short distance between fingers decreases losses in emitter and fingers but increases shading losses.
- Minimum finger width (w_f): The thinner the fingers, the higher the finger resistance but with less shading losses.
- Finger height-to-width aspect ratio (d_f/w_f): The higher the ratio, the lower the resistance without shading losses.
- Resistivity of metal (ρ): The lower the resistivity, the lower the finger resistance typically silver is used, which is conductive (ρ = $3x10^{-8}$ Ω·m) but expensive (cost = 1.0 $/g).

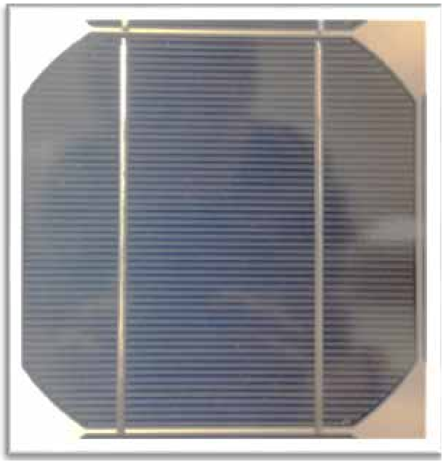
To highlight some of the tradeoffs, show this graph that represents power losses under typical conditions. Help students interpret the graph and lead a discussion on how the relative contribution of each source to total power loss depends on finger spacing. The graph is available at:

http://bit.ly/2ozGTBz



Next, focus in on the two key adjustable parameters for this activity: Finger spacing (S_f) and busbar spacing/finger length (L). Show two different front grid designs. Ask two questions:

- What is similar/different between these two cells?
- What impacts might the differences have on cell efficiency?



Discuss the impacts of each of the adjustable parameters in order to help participants check their understanding and apply their knowledge (e.g. What happens if we space the fingers further apart? How does it impact each of the three power loss terms? How does it impact the total power loss?).

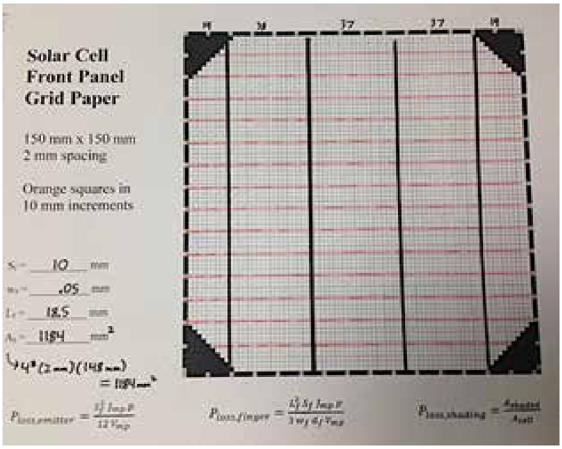
Once participants understand the parameters that affect power loss in a solar cell, they are ready for you to introduce the design challenge. In this outreach activity, participants are challenged to optimize the front grid design of a solar cell to minimize power loss. Explain that they will do this by drawing their own custom designs and estimating power loss, then comparing different designs and making adjustments to improve optimization. Participants are able to adjust two of the parameters in order to optimize efficiency of their solar cells.

- Finger spacing (S_f). Point out that this parameter plays into all three of the power loss terms.
- Busbar spacing/finger length (L). Busbars should be spaced evenly and the finger length sized accordingly.

For the optimization challenge, participants draw their own front grid designs, partner up, compute power losses from their drawings, and compare results with each other.

Working alone, participants take the following steps:

1) Take a copy of the front panel grid paper, ruler, red pen, and black pen.
2) Decide how many busbars you'd like to use (between 1 and 8). Draw your busbars in black marker. The width of each busbar is set at 2 mm, which is one cell's width on the grid paper. All the busbars you will draw should run vertically and be evenly spaced. The example on the next page was done using four busbars (black lines).



3) Choose a finger spacing (S_f) between 1 mm and 10 mm. Draw your fingers in red pen.
4) Compute power loss using the given equations. Verify that your units work out. Check a partner's work. (Note: 1 V = 1 A·Ω).
5) Compute the spacing of the busbars. Use the following table to help you (if you choose a different # of busbars, follow the pattern shown). The busbar spacing is based on a 150mm-wide solar cell and rounded to the nearest mm.

# busbars	1	2	3	8
Fraction of solar cell reached by each side of the busbar	1/2	1/4	1/6	1/16
Busbar spacing from left edge of cell	75 mm	38 mm	25 mm	9 mm
Busbar spacing from each other	--	76 mm	50 mm	18 mm

6) Next to your design, write down the values for S_f, w_f, L_f, and A_{busbar}.
   - You have already chosen Sf and wf
   - Lf is essentially the same as the busbar spacing from the left edge of cell (minus half the width of the busbar)
   - A_{busbar} can be computed by realizing that all the busbars are rectangles; add all the areas of the individual busbars together.

Help the participants compare their results and discuss which designs were optimized. Discuss the following questions, taking special note of the tradeoffs that exist.

1) What are the impacts of increasing finger spacing?
2) What are the impacts of increasing finger width?
3) What are the impacts of having more busbars?
4) To which parameter(s) are your power losses most sensitive? Least sensitive?
5) What were the power losses for each of your designs? Why do you believe one performed better than the other?

Deepen Your knowledge

To reinforce and extend learning, connect this activity to the Electron Chairs or Construction Paper Solar Cells activity.

As an extension activity, you could use the Excel "Competition_Spreadsheet" found on the QESST Education Website to inform participants' front grid designs and help them develop

Solar Cell Front Panel Grid Paper

150 mm x 150 mm
2 mm spacing

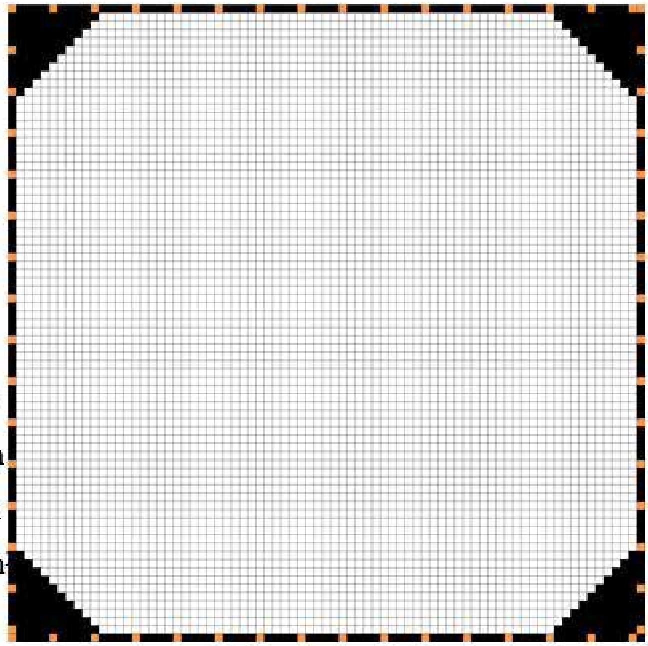
Orange squares in
10 mm increments

S_f = ___________ mm

w_f = ___________ mm

L_f = ___________ mm

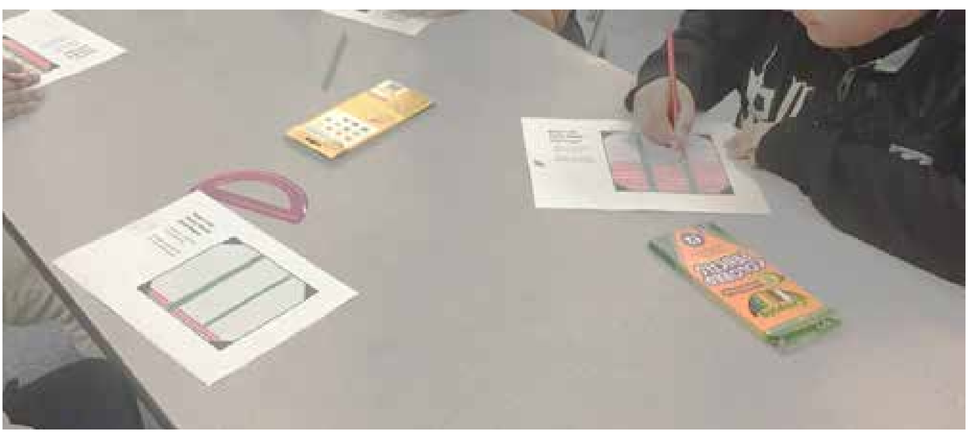
A_b = ___________ mm



$$P_{loss,emitter} = \frac{S_f^2 J_{mp} \rho}{12 V_{mp}} \qquad P_{loss,finger} = \frac{L_f^2 S_f J_{mp} \rho}{3 w_f d_f V_{mp}} \qquad P_{loss,shading} = \frac{A_{shaded}}{A_{cell}}$$

their most efficient design. Participants share the parameters for their optimal design and see who demonstrates the smallest power loss. Depending on the sophistication of participants, the outreach leader can input the data. See the community college solar engineering unit in the Classroom Lessons section for more information.

This outreach activity is adapted from a solar energy unit designed for community college students by QESST RETs Cody Anderson (SCC) and Liz Adams (CGCC), which you can find in the Classroom Lessons section of this book.



Reducing Water Contamination through Nano-Particle Solar Photocatalysis

Subject: Using photons to gather energy to purify water (QESST Testbed 3: Sustainability Pathways for TW PV); partner-developed solar lesson

Grade Levels: 5th–11th

Lesson length: 15 to 40 minutes

Authors: ASU Members of the Nanotechnology-Enabled Water Treatment (NEWT) Engineering Research Center: Harsh Ashani, Pinar Cay Durgun, Natalia Fischer, Sofia Herrera, Natalia Hoogesteijn, Tiantian Li, Mariana Lopes, Stewart Mann, Anjali Mulchandani, Dr. Onur Apul, Dr. Yuqiang Bi, Dr. Francois Perreault

In this lesson, participants explore how solar energy can be used in water treatment processes. According to the World Health Organization (WHO), 1.1 billion people around the world do not have access to safe drinking water. Often local water supplies are contaminated with chemicals or harmful microorganisms. Many effective means of treating water require expensive equipment or processes that are not available. One way to clean contaminated water is through solar disinfection, exposing the water to sunlight for 24 hours. The energy of the solar radiation destroys the contaminants, making the water safer to drink. But this process is slow and not very effective. Engineers have improved on this process for cleaning water with titanium dioxide. The purification process can be improved (made faster and or effective) using a photocatalyst, a substance that speeds up a reaction by absorbing light particles (photons) and passing on energy to other molecules. One cheap and abundant photocatalyst is titanium dioxide (TiO2), a semiconductor that can absorb photons and use them to mobilize its own electrons. Titanium dioxide is safe, cheap, relatively abundant, and found in many everyday substances (e.g., paint, plastic, toothpaste). Photocatalysis work best with nano-structured titanium dioxide (particles about 14–21nm).

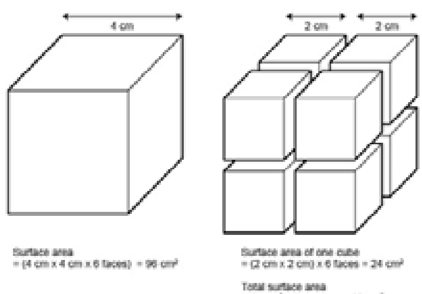
This activity is intended to help participants understand nanotechnology by enacting a model that demonstrates the power of nanotechnology for increased surface area for adsorption and light capture. Nanotechnology focuses on using particles between 1 and 100 nanometers, which are called "nanoparticles." A small cluster of nanoparticles can have the same volume as a regular particle. However, because there are more nanoparticles than there is one regular particle, the surface area is increased, meaning the cluster will absorb more photons than one particle. These photons are then used to elevate atoms from the valence band to the conduction band. For this activity, the relationship of the particle/nanoparticle sizes and their effectiveness in treating water and the energy needed to treat water will be explored. This activity is designed for 4–8 participants with 1–2 instructors.

Objectives

- *Learn how the size of nanoparticles affects their efficiency in photon absorption.*
- *Understand the importance of nanotechnology and water treatment.*
- *Participants learn about novel techniques to treat water, and how engineers are applying nanoscience for new applications.*
- *K–12 students apply science knowledge about surface area to a hands-on demonstration that proves conceptual properties.*

Materials

- Velcro-covered cubes: 1 large, 8 small; large should have same volume as small when small are put together in the same shape. Note: if possible, the small together should weigh more than the 1 large.
- Pom-poms/fuzzy balls to representing photons
- 1 large tray to hold the pom-poms
- Poster explaining the process of nano-enabled photocatalytic water treatment



Set up

Set up with the pom-poms scattered around in the tray and the small cubes are connected to a size roughly the same as the large cube.

Instructions

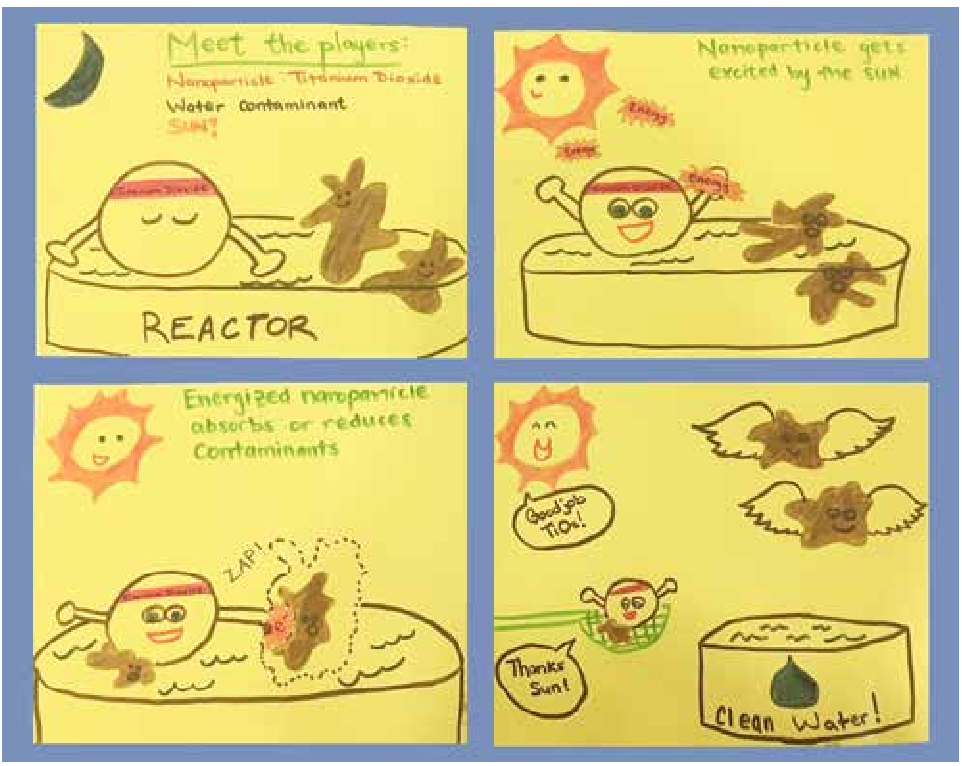
1) First, the outreach leader explains the process of photocatalysis by walking participants through the poster:

One way to clean contaminated water requires two things: titanium dioxide and light particles. Nanoparticles of titanium dioxide are added to contaminated water. At night, the titanium dioxide nanoparticles lose energy and have to "sleep." They can't neutralize water contaminants when there is no light from the sun.

During the day, when the sun is out, the nanoparticles of titanium dioxide absorb photons, gaining energy from the sun.

The absorbed photons energize the nanoparticles, which allows them to neutralize the contaminants.

The result of this photocatalytic process is clean, safe drinking water!



2) Give the participant(s) the blocks and explain that these represent particles of "titanium dioxide". Have the participant(s) attach as many pom-poms (and call them "photons") as they can to the "titanium dioxide" (TiO_2) on the surface of the cubes. Set aside the large block with all the pom-poms attached.
3) Have the participant(s) split the small "titanium dioxide" (TiO_2) cubes and call them "titanium dioxide nanoparticles", then repeat the process. Set aside all the small blocks with all the pom-poms attached.
4) Count up the pom-poms that attached to the large block. Then count up the pom-poms that are attached to the set of small blocks. Ask participants which number is higher. Very likely, the number of pom-poms (photons) attached to the 8 small blocks (nano-particles) will be higher than the number attached to the larger block. Ask participants why they think they got this result. Help them understand that objects can have the same volume, but more surface area if one large object is broken up into several small objects. In this task, the "nanoparticles" have a larger surface-area-to-volume ratio and, therefore, work better for treating water – but only when they are exposed to sun where they can absorb photons.

Assessment

1) What is nanotechnology, and how can we use it?
2) What are photons? How do they affect the titanium dioxide (TiO_2)?
3) What is a particle? What is a nanoparticle?
4) What is the relationship between surface area and volume?

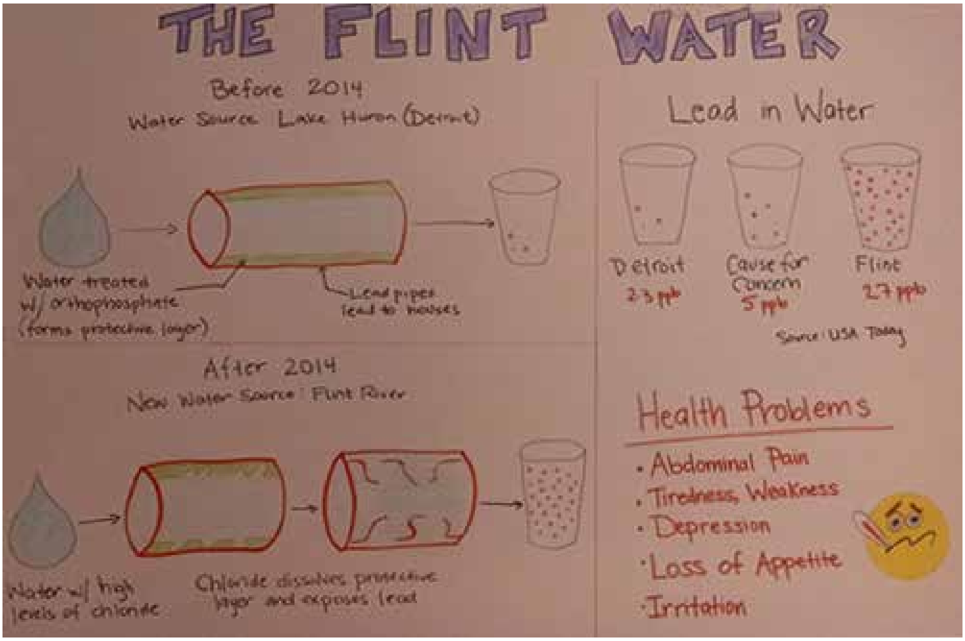
Deepen your Knowledge

One critical and recent example of why we should pay attention to centralized water treatment plants and distribution systems is the Flint Water Crisis.

Flint's original water source, Lake Huron water, was treated with orthophosphate, which formed a protective scale on the lead distribution pipes that led from the water treatment plants to homes. In 2014, the city switched to the Flint River, which had high chloride levels (almost 8 times higher than the Huron water). The corrosive water broke down the protective scalant on the pipes and began to corrode the pipes, leading to excessive lead leaching into the water (5 parts per billion lead is cause for concern, Flint water was 27-100 parts per billion lead).

In Flint, Michigan, a changed water source and cost saving water treatment measures led to leaching of toxic lead from pipes into drinking water. To visually demonstrate the phenomena that occurred, Styrofoam (scalant) was painted with nailpolish (lead pipe). The Styrofoam was first sprayed with water, and no effect was seen. The water source was changed to acetone, visually identical to tap water, but the acetone dissolved the Styrofoam (scalant) and eventually dissolved the nail polish (pipe). We spoke about the importance of water regulations and treatment plant compliance, as well as how water travels through the distribution system to homes. An accompanying poster (below) was used as a visual aid.

While many attendees may have heard about the Flint Water Crisis, many are likely unaware of the scientific cause of the problem. Through a simple visual demonstration,



attendees learn about chemistry concepts such as solubility, the importance of water treatment for public health, as well as the infrastructure problems the US faces.

Below are some pages where you can read more about NEWT research, nanoparticles, and more about this engineering research:

www.NEWTcenter.org

www.nsf.gov/nano

http://rsc.li/2o1471X

http://bit.ly/2nVdTkB

https://www.youtube.com/watch?v=e2QpT1vCD08

https://www.youtube.com/watch?v=ch9P9yFIdXE

Sunlight has ENERGY!

Subject: This lesson explores the importance of sunlight as a source of energy

Grade Levels: K-12

Lesson length: 20 minutes

Author: Tiffany Rowlands

The sun produces radiant energy (light) that travels through space to Earth. Solar energy in one form or another is the source of nearly all energy on the earth. Humans, like all other animals and plants, rely on the sun for warmth and food. However, people also use the sun's energy in many other different ways. We use the sun's energy to see and to produce heat and electricity. In this lesson, participants use UV beads and a pipe cleaner as well as a solar panel and a motor (already assembled) and go outside to observe how they work.

Objectives

- *Students will be able to identify that the sun's light has energy and by using it, we can do cool things.*

Materials

- Solar panel with alligator clips
- Hobby motor with fan blades
- UV beads

- Pipe cleaners
- Colored pencils

Instructions

1) Have the participants assemble the bracelet using 5-10 UV beads and a pipe cleaner. Sketch a “before” picture of the beads before sending them outside into the sun.
2) Have the students walk out into the sunlight and see what happens. Come back into the classroom and have them draw an “after” sketch. (The beads turn colors!)
3) Ask the students, “what happened?” “What do you think caused this to happen?”.
4) Discuss how the earth gets its energy from the sun. We call this solar energy. Solar energy travels from the sun to the earth in rays. Some are light rays we can see. Some are rays we can’t see like X-rays or UV. Energy in rays is called radiant energy.
5) Ask participants, what other devices do we use to convert the sun’s energy into something else? (Solar panels)
6) What do solar panels produce? (Electricity)
7) Show a solar panel. Outreach leaders can assemble by using alligator clips to hook the panels to a fan motor or guide the students through. Ask the students why the fan is not spinning. What do we need to do to get the fan to spin? Go outside, place assembly in diret sunlight, and watch it spin!

Deepen Your Knowledge

1) Discuss the sun’s different forms of light. Some are harmful like X-rays and UV light.
2) We wear sunscreen to protect us from the UV light rays. Students could spray sunscreen on the beads as a separate activity. This will prevent them from changing color.

Solar Cell Discovery

Subject: This lesson explores the basic properties and uses of a solar panel.

Grade Levels: 4–8

Lesson length: 45 minutes

Authors: Tiffany Rowlands, Brian Tracy

The solar panel is becoming an increasingly popular form of alternative energy around the world. Why you may ask? Simply put, solar power makes sense- it's abundant, and nearly free to use. The majority of our global population lives within 24 degrees of the Equator, making solar-harnessing opportunities plentiful and the mass production of solar energy possible. This is especially important for developing countries where approximately 1.3 billion people lack access to electricity. In this lesson, participants use a fan motor and solar panel to make measurements in different directions and angles. (North, flat; North, perpendicular; North, 45 degrees, South, flat, etc.).

Objectives

- *Students will learn which angle they should set their solar panel to obtain the maximum voltage as well as types of energy used.*

Materials

- Solar cell (suggested 1V, 400 mA)
- Hobby motor with fan blades (suggested 1.5 to 3.0 Vdc, at 330 mA)

- Multimeter
- Alligator clips
- Worksheet
- Red and black pen or pencil
- Pencil

Instructions

Using the materials provided, connect the solar panel to the fan motor using the alligator clips (colored wire clips). Once the motor begins to run, complete the questions below.

1) Draw your design that shows how the items you used are connected. On your design, label each item and the color of the wires.
2) On the diagram that you drew above, identify where each of the following forms of energy is present:
   Light   Mechanical   Electrical   Chemical   Heat
3) Where does the energy that powers the fan motor come from?

We will go outside and take measurements and observations. You will place the solar panel in various directions: North, South, East, West, NW, SW, etc. After you place the panel in different directions and angles write down the motion of the fan, as well as the reading from the multimeter.

	0°	45°	90°	Additional angles (35 °)
North				
South				
East				
West				
Additional direction (Southwest)				

4) How long do you predict the motor will remain running, if left as you have it connected? Explain why you think so.
5) What was the angle in which your panel was facing at which the fan spun the fastest? What was the reading of your multimeter at that angle?
6) If you were to hang a panel on your home, where and which direction would you hang it? Why?

7) If you were to reverse the wires (alligator clips), what do you predict will happen and why?
8) Test your prediction
9) What were your results?

Work with a partner(s), combine your clips and use more than one solar panel to power a fan.

10) What do you notice about the fan's speed?
11) What type of circuit did you make? How do you know?

Solar Panels on Ice
A Discussion of Radiant and Thermal Energy

Subject: This lesson explores people's common misconception that heat is necessary for a solar panel to produce electricity

Grade Levels: 7-12

Lesson length: 60 min

Author: Tiffany Rowlands, Jenefer Husman, Mark Bailly

Have you ever noticed how the display of your cell phone changes when exposed to extreme heat conditions? For instance, what happens when on a hot summer day you go to the pool and leave your phone in direct sunlight? Most cell phones shut down and produce a warning to the user. Temperature affects how electricity flows through an electrical circuit by changing the speed at which electrons travel. In metals, this is due to an increase in resistance of the circuit that results from an increase in temperature. Likewise, resistance is decreased with decreasing temperatures. Temperature effects the voltage of electrical devices but will it also effect the efficiency of a solar panel? A popular misconception is that solar panels do not work in cold regions. This is simply not true—in fact it's quite the opposite. Heat is the enemy of solar panels; what happens is that during the summer the days are longer which more than makes up for the impact. Not all solar panels are created equal and the impact of heat is one of the critical aspects that sets brands apart. An important module specification is called the "temperature coefficient". If the temperature coefficient rating of a panel is -0.46%, this means for each degree over standard testing conditions (STC= 25 °C) the module's output is reduced by -0.46%.

Objectives

People often have the misconception that heat is necessary for a solar panel to produce electricity, and the related misconception that the hotter the temperature the more electricity is produced. In this lesson, participants will investigate the voltage of a solar panel that has been placed on dry ice and compare it to a panel that has not been exposed to dry ice. Through these experiments, students will understand that radiant light is the driving force behind photovoltaic responses, and how temperature affects the efficiency.

Materials

- 2 Solar panels
- Cardboard to cover panels
- Alligator clips
- Dry ice
- Temperature gun
- Multimeter
- Worksheet and pencil

Instructions

Part 1: Scientific Method

Participants will answer the following questions:

Does the temperature outside affect the efficiency of a solar panel? Write down your hypothesis:

What are the independent variables in your experiment?

ANSWER: Temperature

What are the dependent variables in your experiment?

ANSWER: Voltage

What variables do you need to keep constant?

ANSWER: Time

What procedure would you use?

Part 2: Solar cell not exposed to ice

1) Obtain a solar panel that has NOT been exposed to ice from your teacher.
2) Using a temperature gun, take the initial temperature of the panel.

3) Place the panel in direct sunlight.
4) Attach the multimeter to the panel by using the alligator clips.
5) Record the voltage in table #1 every 30 seconds for 4 min.
6) Cover the panel with the piece of cardboard.
7) Record the voltage in table #2 every 30 seconds for 4 min.

Data Table #1 Uncovered solar cell (NOT exposed to ice) initial temperature of cell _______	
Time (sec)	Voltage (V)
30 sec	
60 sec	
90 sec	
120 sec	
150 sec	
180 sec	
210 sec	
240 sec	

Data Table #2 Covered solar cell (NOT exposed to ice) initial temperature of cell _______	
Time (sec)	Voltage (V)
30 sec	
60 sec	
90 sec	
120 sec	
150 sec	
180 sec	
210 sec	
240 sec	

Data Table #3 Uncovered solar cell (EXPOSED to ice) initial temperature of cell _______	
Time (sec)	Voltage (V)
30 sec	
60 sec	
90 sec	
120 sec	
150 sec	
180 sec	
210 sec	
240 sec	

Data Table #4 Covered solar cell (EXPOSED to ice) initial temperature of cell _______	
Time (sec)	Voltage (V)
30 sec	
60 sec	
90 sec	
120 sec	
150 sec	
180 sec	
210 sec	
240 sec	

Part 2: Solar cell exposed to dry ice

8) Obtain a solar cell that HAS been exposed to ice from your teacher.
9) Using a temperature gun, take the initial temperature of the panel.
10) Place the panel in direct sunlight.
11) Attach the multimeter to the panel by using the alligator clips.
12) Record the voltage in table #3 every 30 seconds for 4 min.
13) Cover the panel with a piece of cardboard.
14) Record the voltage in table #4 every 30 seconds for 4 min.
15) Collect and compare data.

Assessment

Construct 2 line graphs using Table #1 and Table #3. Use the following questions to reflect on the activity:

1) Is the panel more efficient when it has been exposed to ice or not? Use your data to explain your answer.
2) What effect did covering the panel with cardboard have on the voltage?
3) What would an engineer need to consider when designing a solar array (system) in your area?
4) Where do you think would be the best place (countries around the world) to place solar panels? Participants might plot them on a googlemap.

Young Scientist Pilot Line

Subject: Creating commercial solar cells using exact process with model materials

Grade Levels: Elementary school and higher

Lesson length: 10 to 30 minutes

Authors: Alex Killam, Tiffany Rowlands, Stuart Bowden, Danny Simonet, Michelle Jordan

Laboratories, such as Arizona State University's Solar Power Laboratory (SPL), sometimes create their own samples for research. At the SPL, silicon wafers are purchased, but all processing is done within the building's cleanroom, the main area housing the chemical baths and tools that is free of contaminants. The general fabrication steps can be broken down into the stages described below. In this activity, participants make their way through the laboratory process of making diffused junction solar cells, creating their own mock solar cell to take home. Participants follow these broad steps while learning how solar cells are manufactured, why these processes are done, and problems that that solar engineering scholars are attempting to solve via research. This activity is intended for a maximum four people per station, who move in a linear fashion down the line.

Objective

- ➢ *Participants will learn how commercial solar cells are created in laboratory settings by fabricating their own solar cell in a mock manufacturing process.*

Materials

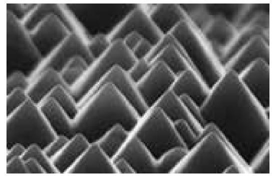
- Silicon

  Examples of silicon, as many as you can get (e.g., raw, ingets, blocks, wafers)

  Cutouts of textured silicon wafers, 5X5, printed on heavy grey paper to stand up to the assembly line process (see template in the Materials Manual on the QESST Education website)

  Grey plastic squares to represent silicon wafers for dipping in water (5X5)

  Two plastic basins, dish soap



- Furnace

  Diffusion furnace cardboard model (see Materials Manual on the QESST Education website)

- Diffusion

  P5000 wood model or a simple cardboard box (see Materials Manual on the QESST Education website)

  Blue spray paint to represent silicon nitride

  Safety goggles

  Hairdryer to dry the blue paint (and an electrical outlet to plug it in)

- Metal Screen Printing

  Printing screen with front grid panel design with QESST logo, 5X5. The screen can be created through a t-shirt company for a cost of approximately $50.00 (see template in the Materials Manual on the QESST Education website).

  Grey or silver screen printing ink

  Small cups

  Squeegee for screen printing

  Newspaper

- Belt Furnace

  Belt furnace cardboard model (and a place to plug it in) or toaster oven (see Materials Manual on QESST Education website)

  Scissors

- Testing

  Multimeters

  Real silicon solar cells for testing

- Cleanroom clothing

  Smock, gloves, goggles, mask, hair net, booties (or any combination of these)

- Cleanroom Backdrop for culminating photos

  A link to a photo of the ASU Solar Power Lab can be found on the QESST Education website. This photo can be submitted a PDF to a poster printing company. The cost is approximately $250 for room-sized proportion.

Setup

Simulations of the tools and resources of the Solar Pilot Line must first be created. You can create your own, based on your knowledge of solar cell manufacturing or you can reference the Materials Manual pdf located in the QESST Education website.

Slides and posters of the materials, tools, and processes associated with each step of the Solar Pilot Line can be found on the QEST Education website also. Posters can be made of each sub-process and placed at each station.

Please note that depending on time, knowledge, and other resources, one or more steps can be left out of your simulated silicon solar cell pilot line.

Set up the materials for each station on a separate table (if possible) in the correct sequence.

You are now ready for participants to go through the Solar Pilot Line.

Instructions

Participants prepare to "enter the cleanroom" by dressing in as much cleanroom clothing as possible (e.g., gloves, masks, booties). Many participants will have the misconception that the clothing is meant only to protect them from harmful materials. Tell them that the clothing also protects the cleanroom from the dust and skin particles that we human beings are constantly leaving in our wake, particles that can interfere with sensitive equipment and processes.

Participants are now ready to proceed through the simulated pilot line. For each of the steps below, be sure to explain to participants (1) what the step is, (2) how it is done, and (3) WHY it is done (i.e., what is its purpose).

Station 1: Preparing Silicon Wafers

Setup: Set out as many examples of silicon as possible (e.g., raw, ingots, blocks, wafers), set out the poster of silicon wafers.

1) Explain what silicon is, how it is grown (focus on monocrystalline, but multi-crystalline can be mentioned), and how it is cut. When explaining how it is cut, explain the roughness on the silicon. Let participants touch the silicon and hold the silicon so that they can perceive its qualities (e.g., texture, weight)

Background: Silicon (Si) is the eighth most common periodic element and is a semiconductor frequently used in photovoltaic (PV; solar cell) research. This is because it is cheap (due to its abundancy), and its semiconductor properties allow it to be a popular material in electronic research (e.g. computer chips are also made from silicon). A semiconductor is an element that, literally, on semi-conducts – it is not as good a conductor of electricity as an actual conductor, such as metal, but can still conduct, unlike insulators such as rubber. Conductors have a low electrical resistance, insulators have a high electrical resistance, and semi-conductors are somewhere in the middle. For more detailed information, please see reference [1]. Mono-crystalline silicon is grown via the Czochralski Process [2], in which a seed crystal (a small piece of a single crystal) is placed at the end of a thread and placed in a crucible of molten silicon. The seed grows to a large, cylinder of a single crystal of silicon. A video link is provided below [3]. The wafers are cut using a diamond-tipped wire saw – the wire cuts through the cylinder and makes the thin wafers.

Station 2: Texturing and Cleaning

Set up: Fill two white basins with water to represent chemical baths associated with texturing. Have the grey piece of plastic ready to dip in the water. Have a stack of cutouts of "textured silicon wafers" ready to pass out to participants.

1) Give each participant a cutout of a textured silicon wafer:
   a. Dip the "grey plastic" representing a silicon wafer into the soapy bath. This is saw damage removal (SDR) and texturing.
   b. Dip the same grey plastic into the water bath. This is RCA-B, piranha, and buffered oxide etch (BOE)/hydrofluoric (HF) acid.
2) Put the grey plastic away and take a cutout. Explain the creation and use of pyramids (light-trapping).

Background: The first basin represents texturing. Texturing the silicon removes saw damage from the silicon wafer and also creates pyramids to trap light (literally called "light trapping"), decreasing reflection and increasing absorption. Imagine shooting a beam of light at a mirror where the light and the mirror are perfectly perpendicular. The mirror will bounce the light back, but only at a single point. If the mirror were angled towards another mirror (imagine a valley), then the light would bounce from one mirror to the other (and possibly more depending on the angle of the light) before leaving the mirrors. The valley shape allows for the light to hit the silicon more often, hence "light trapping". Therefore, the pyramids allow the silicon wafer to absorb more light. The second basin represents cleaning. It removes the chemicals left over from the texturing step. If they were left on, the cell could degrade and/or the following steps could not work properly (e.g. the deposition layer may not actually make contact with the silicon if there are excess chemicals).

Station 3: Phosphorous Diffusion

Set up: Set up the diffusion furnace and the poster of phosphorous diffusion or a photo of the diffusion furnace.

1) Have participants put their cutout inside the "diffusion furnace" and explain what the machine is and what it is doing. Also mention the time for the process (about an hour and a half) and that it causes no visible changes to the silicon wafer.

Background: Phosphorus (P) is a periodic element frequently used in photovoltaic research. When looking at a periodic table, semiconductors are within groups IIIA to VA (or 13-15); an element in group IIIA is boron (B) and an element in group VA is phosphorus. See [4] for a representation of the periodic table. Phosphorus and boron have different electronic properties that also affect silicon, when 'combined' (i.e. when phosphorus is added to silicon or boron is added to silicon). The Solar Power Laboratory focuses on phosphorus diffusion – i.e. phosphorus is being added to silicon. The purpose of phosphorus diffusion is making one side of the cell positive and the other side of the cell negative using phosphorus. This is sometimes called the p-n junction. If the cell was never "charged" as such, it would simply not work, as the electrons would not move through the cell.

Station 4: Silicon Nitride Deposition

Set up: Set up the “deposition machine” (which could be as simple as a box to keep spray paint contained). Have the cans of blue spray paint ready. Plug in the hair drier. Have safety glasses available for participants who might not already have them. Outreach leaders should also wear goggles!

1) Give the participants safety glasses if participants are spraying.
1) Put the cutout inside the “deposition machine”, and explain what the blue spray paint represents deposition of silicon nitride (SiNx), which is the anti-reflective coating [ARC]) and why it is blue (thickness).
2) Dry with a hairdryer thoroughly before moving to printing stage. Note: apply the spray paint in as thin a layer as possible. Dry as thoroughly as possible – otherwise the paint clogs the screen in the next step.

Background: The process of silicon nitride deposition deposits an anti-reflective coating (ARC) on top of the cell. In this case, the ARC is the compound silicon nitride (SiNx) and does as its name suggests – reduces reflection and instead allows transmission, which means light can pass through to the cell. Transmission is when light can go through something, in contrast to reflection, where light is completely bounced back, and absorption, where light is absorbed into the material and nothing passes through. See [5] for a helpful visual. Silicon nitride (SiNx) deposition is was gives a silicon solar cell its blue color. The color change is due to the thickness of the layer. The long answer involves learning about something called a “refractive index”. A refractive index is a number that describes how light goes through a material. Different thicknesses have different refractive indexes, and the change in how the light goes through the material affects the color that the film is. For more detailed information, please see reference [6].

Station 5: Metal Screen Printing

Set up: Set up the screen. Have gray/silver paint and squeegee ready. Have a large tub of soapy water and paint thinner ready to clean the screen in between applications. If possible, create two screens to avoid interruption of the pilot line.

1) Place newspaper on top of a table. Place the screen over the “wafer” cutout so the pattern lines up fairly symmetrically. Gently pour a line of ink above the screen. Using the flat edge of the squeegee, pull the ink down and over the print pattern. Repeat for an even coat of ink in the shape of the pattern on the cutout. Once completed, gently peel the cutout off the screen, as it will most likely be stuck after print-

ing. Explain that the ink represents silver paste, and the paste is used to move (conduct) the electricity created by the silicon and various layers.

Background: Metal screen printing deposits the conductive metal onto the silicon via paste comprised of silver and other organics. The metal is what the electrons use to travel and, thus, generate current (current is the flow of electrons). There is a tradeoff between the amount of silver, the area of the revealed solar cell, the cost of silver, and the new prevalence of copper plating. The silver paste used in the printing process is not pure silver – it has organics. The backside of a solar cell is also printed, but with aluminum, as aluminum is cheaper. Silver tabbing can be mentioned, but is not required.

<u>Station 6: Firing and Edge Isolation</u>

Set up: The belt furnace can be represented simply using a toaster oven (no heat!), but it is also possible to construct a belt roller with a small motor and two lightbulbs if you have good mechanical skills and the right tools and equipment.

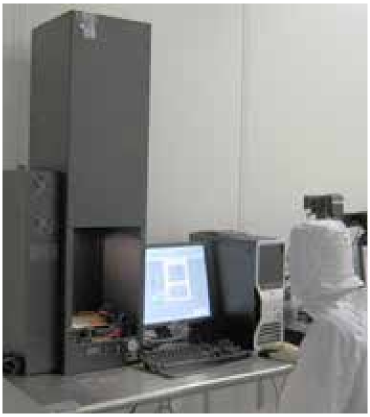
1) Take the mock solar cell to the belt furnace model. Turn on the motor and place the cutout on top of the belt. As the ink is being dried by the lamps, explain how, in the laboratory, the heat is not used to dry, but actually to push the silver through the various layers to make contact with the silicon (otherwise, it would be conducting no electricity) and to remove organics from the paste. The furnace has multiple zones, which is comparable to the model having two lightbulbs, and every zone is at a different temperature. Mention that there are a usually three different drying steps: after the backside aluminum paste, after the backside silver tabbing, and after the front side silver busbars and fingers.
2) Once the cell is dry, have participants cut off the edges. Explain this is called "laser edge isolation" and is used because of the diffusion step: phosphorus is added to the silicon, but it is added to the entire wafer. This means the entire cell is covered with phosphorus.

Background: Firing removes organic components from the printing paste and also 'punches' the silver through the various layers to the silicon. The belt furnace, in the laboratory, has different zones. Each zone has one heat lamp, and the temperature across them all varies. In the lab, laser edge isolation is literally using a laser to cut the edges and separate the top and bottom of the cell. The reason for this is because the phosphorus is added around the entire wafer, creating a path of low resistance for the electrons and giving the wafer a low shunt resistance. Because the resistance is low, that means the electrons will take that path instead of going through the cell – essentially, the phosphorus creates an extra path for the electrons to take, and, since it has a low resistance and electrons like paths of least resistance, the electrons will go around the cell through the phosphorus instead of going through the cell. To circumvent this, a laser is used to cut the sides to the top and bottom are separated. This cuts the path the electrons can take, forcing them to go through the cell as desired.

Station 7: Cell testing

Set up: set up multimeters and solar cells on a table.

1) Explain that solar cells are tested for their efficiency after they come off the assembly line. Explain how a multimeters work; include an explanation of voltage and current.
2) Explain that in the laboratory, the efficiency of solar cells can be tested using a tool called the "Flash Solar Cell Tester" (image to the right).



Assessment

Using their cell phones, participants can take a photo of themselves in front of an enlarged photo of the ASU Solar Lab Cleanroom. This makes a great souvenir to take home!

Ask participants to remember and name all the steps they took in creating their mock solar cell.

Deepen Your Knowledge

Experienced participants can act as solar ambassadors, helping to run the solar cell pilot line.

References

[1] "BBC Bitesize - Higher Physics - Conductors, semiconductors and insulators - Revision 1." BBC News. BBC, n.d. Web.

http://www.bbc.co.uk/education/guides/zppnn39/revision

[Note: there is also a short multiple choice test you can take to test your knoweldge]

[2] "Czochralski process." Wikipedia. Wikimedia Foundation, 26 Jan. 2017. Web.

[3] "From sand to silicon." YouTube. N.p., 25 Nov. 2011. Web. https://youtu.be/jh2z-g7GJxE?t=18

[4] "Semiconductor Materials." Honsberg, C., & Bowden, S. (n.d.). PV Education. http://pveducation.org/pvcdrom/semiconductor-materials

[5] "Anti-Reflection Coating Color." Honsberg, C., & Bowden, S. (n.d.). PV Education. http://pveducation.org/pvcdrom/anti-reflection-coating-color

[6] Admin. "Transmission, Reflection, and Absorption." Admin. N.p., 10 Mar. 2014. Web. https://www.chroma.com/knowledge-resources/about-fluorescence/introduction-to-fluorescence/transmission-reflection-and

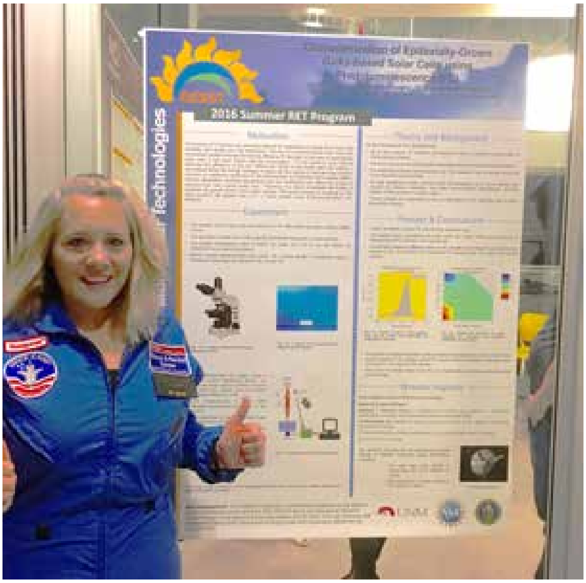
Classroom Lessons

Classroom Lessons Introduction

Jodie Guillen

The world of the 21st century is advancing at a mind-blowing pace, powered through technological marvels that were simply a figment of the imagination just a few, short years ago. This influx of incredible new resources has changed the way people live, work and play along the way. However, with great opportunities come great responsibilities, and an entirely new set of challenges that simply did not exist in years past. It is estimated that 65% of students sitting in classrooms today will one day work in jobs that have yet to be created (World Economic Forum, 2013). The question then becomes, how do educators prepare the future scientists, technicians, engineers, artists, mathematicians, and space pioneers of tomorrow? The answer is really quite simple . . . educators must teach students how to think. As said by Albert Einstein himself, "Education is not simply the learning of facts, but the training of the mind to think," and that is just EXACTLY what education is all about!!!

As an elementary science teacher, I strive to bring SCIENCE TO LIFE each and every day with the most hands-on, engaging lessons that I can, delivered through the platform of project-based learning! Through the implementation of these carefully designed projects that spark the natural curiosity in ALL students, as well as the seamless INTEGRATION of the content of Science, Technology, Engineering, and Mathematics, the pursuit of solutions to everyday problems provides the perfect scenario in which to develop innovation, creativity, and perseverance, among the qualities of most value to the world just beyond my classroom door! Not only have I have witnessed FIRST-HAND the impact Problem Based Learning has had on



student understanding, resulting in 83% of my students showing growth between short-cycle assessments, but my students are completely engaged, virtually eliminating behaviors in my Title One, majority-minority school!

Unfortunately, we live in a world where educational resources are virtually non-existent and educators are quite simply maxed out . . . and THIS is just EXACTLY where we need YOUR HELP! Please join educators around the globe on our quest for awesomeness, and help us fuse science, technology, engineering, art, mathematics, and BEYOND into a fantastical display of awesomeness, creating environments where dreams can take flight . . . forever altering the course of lives along the way!!!

I currently teach science in the MIDDLE OF NOWHERE NEW MEXICO to the most FANTABULOUS bunch of 6th and 7th graders you'll ever meet! I LOVE spending my days teaching science, and NOT so secretly hope that one of my students will be the first human to walk on Mars! However, I realize that not all students dream of becoming space pioneers, and in FACT, this is the VERY reason I am so passionate about solar energy education! It is more important to me that my students leave my classroom in May better humans than when they first step through my door in August . . . and that no matter where their journey leads, they will one-day make a positive impact on our planet through the informed votes they cast. We have ALMOST reached the point of no return here on Planet Earth due to global warming, and in order to ensure a future for this next generation to inherit, we must help them discover that the very solution lies in harnessing the energy of our very own star, the sun!

Per aspera ad astra!

The Astronaut Teacher :)

E.T. Phone Home: Fact or Fiction

Subject: Earth and Space Science

Grade Levels: 6 (5-8)

Lesson Length: 15 minutes

Authort: Jodie Guillen

In the timeless movie, "E.T. the Extra-Terrestrial," released in1982 by Universal Studios, E.T., an alien lifeform, is stranded on Planet Earth and quickly becomes friends with Elliot, the little boy who finds him. After becoming gravely ill, Elliott realizes that E.T. needs to return home in order to save his life. However, in order to arrange for his transport, E.T. must 'phone home.' Students embark on a scavenger hunt in order to discover the answer to the question, 'E.T. Phone Home: Fact or Fiction.' Just in case you're curious, E.T. DID in fact phone home . . . by bouncing a signal from satellite to satellite until he reached his home planet, powered through the miracle of photovoltaics. For this lesson, students should have a basic understanding that different forms of energy can be converted into electricity, which is then used to provide power to the world around us.

Objectives

After this activity, students should be able to:

- *Explain that the sun is used as a source of energy for power here on Planet Earth.*
- *Explain that the sun is used as a source of energy for power in space.*

Engineering Connection

Since Russia launched Sputnik 1 into space in 1957 (the first satellite in orbit), scientists and engineers have continued to develop innovative, new technological capabilities to support exploration into the vastness beyond our planet, deeper and deeper into space. Fast-forward to the year 2016, and there are now over 1,100 active satellites in orbit, in addition to the 2,600 satellites still in orbit that are no longer operational.

You might be asking what do satellites have to do with photovoltaics. The answer to that question is quite simple: satellites are powered by transforming the energy of the sun into electricity, a useable form of energy. This happens through solar arrays that are present on virtually every satellite in orbit. The innovations that have been developed by engineers in order to power the thousands of satellites in orbit today just might prove to be the very innovations that help us solve our energy crisis here at home on Planet Earth.

Materials

- Each group needs:
    - Clue Numero Uno
    - E.T. Phone Home - Fact
    - QESST World Puzzle
    - QR Code Periodic Table of the Elements
    - QR Code What is a Satellite
    - Solar Energy AWESOMENESS Crossword Puzzle
    - Tackle Box (http://amzn.to/2AFWz8b)
    - Alphabet Multilock (http://amzn.to/2EneClE)
    - Directional Multilock (http://amzn.to/2ElwxZW)
    - 3-Digit Number Lock (2) (http://amzn.to/2CQbsdM)
    - UV Flashlight (http://amzn.to/2EmtsZM)
    - Device with QR Reader
- To share with the entire class:
    - One copy per student of Small Gropu Participation Rubric Criteria and Scoring
    - Invisible Pen (http://amzn.to/2AGflft)
    - One solar-powered, dancing, flower pot for each member of the winning team
    - One package of Reese's Pieces candy for each student

Setup

- Make one copy of all of the materiasl for each group (Clue Numero Uno, E.T Phone Home – Fact, QESST Wordle Puzzle, QR Code - Periodic Table of the Elements, QR Code – What is a Satellite, Solar Energy AWESOMENESS Crossword Puzzle)
- Cut the QESST Wordle Puzzle into several pieces, and write 911 in invisible ink

pen on different pieces of the QESST Wordle Puzzle. (Make sure to write one number on three, different pieces of the QESST Wordle Puzzle.)

- Lock the UV Flashlight and the pieces of the QESST Wordle Puzzle inside the 3-digit lock box. Set the lock to 014.
- Set the following locks to the correct combinations:
  - Set the alphabet multilock to STAR.
  - Set the directional multilock to LEFT ARROW, LEFT ARROW, DOWN ARROW, DOWN ARROW, DOWN ARROW.
  - Set the three-digit lock to 911.
- Place the attachment, E.T Phone Home – Fact, inside the toolbox.
- Place the dancing sun flowers and Reese's Pieces candy inside the toolbox. (optional)
- Use all three locks to secure the toolbox.
- On each copy of the Solar Energy AWESOMENESS Crossword Puzzle circle the follow items in red marker: Circle 3 across, circle 6 across, circle 1 down, circle 2 down, and circle 4 down.
- Set a virtual timer for 30 minutes. (http://bit.ly/1foGrGh)
- Teachers should be actively involved with students throughout the course of this interactive activity, intervening when necessary in order to curb frustrations, as well as help students stay focused and on-task. In order to uncover the combinations to the different locks, students must correctly solve each clue. Two opportunities are inserted to give "hints" to groups that are struggling to come up with the correct solutions.

Introduction

As class begins, read the following scenario to students:

> *E.T. is an alien lifeform who has been stranded here on our planet. He is discovered by a little boy named Elliott, and the two quickly become friends. However, E.T. knows that in order to survive he must find a way to return home.*
>
> *The following video clip shows the moment E.T. is finally able to communicate his need to "phone home.").*
>
> https://www.youtube.com/watch?v=6xZif3WmG7I
>
> *After E.T. becomes gravely ill, Elliott realizes that E.T. must return home in order to save his life. Remember, in order to arrange for his transport, E.T. must "phone home."*
>
> https://www.youtube.com/watch?v=UUWYfNNEbyk
>
> *Is it too late to save E.T.'s life?*
>
> *Today, you will discover the answer to the question: "E.T. Phone Home: Fact*

or Fiction?" by embarking on a scavenger hunt, the answer to each clue leading your group along the way. Here is your first clue. (Hand each group the first clue, "Clue Numero Uno" and start the 30-minute timer).

Remember, the clock is ticking, and E.T.'s life hangs precariously in the balance.

<u>With the Students</u>

1) Review group norms:
   a. You have 30 minutes to find the answer to the question, "E.T. Phone Home: Fact or Fiction?"
   b. You must work together as a team. The better you communicate with your teammates, the higher your chances for success. Each time you discover the answer to a clue, make sure you communicate it to the rest of your teammates.
   c. There will be one winning team, and that team will be the first to correctly uncover the answer to the final clue which will lead them to the final hiding place where the answer, and prize, awaits them.
   d. Explain to students any places in the room that are off limits, such as the teacher's desk, book shelves, etc.
2) Hand each group a copy of "Clue Numero Uno"), Start the 30-minute timer.
3) "The answer to your first clue is hidden within the first minute of "Bill Nye – The Sun!" "The sun is the closest _ _ _ _ to Planet Earth." (Answer: STAR).
   e. Watch the first minute of "Bill Nye - The Sun!" as a whole group. https://vimeo.com/107050146
4) "Complete the Solar Energy AWESOMENESS Crossword Puzzle to uncover your SECOND CLUE!!!"
   f. As each group finishes solving the first puzzle, hand them a copy of the Solar Energy AWESOMENESS Crossword Puzzle. Remind students that we read from LEFT TO RIGHT!!! (Answer: LEFT ARROW, LEFT ARROW, DOWN ARROW, DOWN ARROW, DOWN ARROW)
5) "Read THIS awesome article in order to solve your next clue . . . what is the power source for a satellite? Remember, there are no electrical cords or outlets in space! Figure out what that power source is MADE OF, and you'll have your THIRD CLUE!!!" (Silicon: Atomic Number 14, Answer: 014)
   g. Once scanned, the QR code will take students to an article by NASA called, "What is a satellite?" If you do not have access to a QR reader, please provide students with the following link: https://go.nasa.gov/2eO1Weo
   h. HINT #1: Periodic Table of the Elements Attachment
6) Your FINAL clue to unlock the ANSWER IS . . . HIDDEN INSIDE THAT LOCKBOX!!! (Answer: 911)
   i. HINT #2: Who do YOU call when you need help???

The first team to the final location will discover the following items:

- E.T. Phone Home - FACT
- Dancing flower pots, powered by the sun. There should be one dancing flower pot for each student on the winning team. Link: http://amzn.to/2odqvqg. The flower pots are significant for two reasons:

First, the flower pots use solar energy to dance, which is the same technology that allowed E.T. to phone home.

Second, the flowers in the pot indicated the health of E.T. throughout the movie. (This may need to be explained explicitly to students.)

- Individually packaged baggies of Reese's Pieces candy. There should be enough for each student to have a packet as they enjoy the final video clips, not just enough for each student on the winning team.)

    ➛ *It is imperative that the teacher is aware of any student in their classroom with peanut sensitivities/allergies so that an alternative candy can be used in its place. This information should be indicated on the student health forms, which are completed by parents/guardians during school registration. These forms are usually located in the health office, as well as in each student's cumulative folder.*

- Many students will not have seen E.T. in its entirety. In order for students to understand the significance of Reese's Pieces, play the following video clip showing Elliot luring E.T. with Reese's Pieces candy. Give each student a bag of Reese's Pieces so they can enjoy their candy while they are watching the remaining three video clips.

    Reese's Pieces: https://www.youtube.com/watch?v=WQoRHNSarsc

    E.T. is still alive: https://www.youtube.com/watch?v=a-9990dlfvo

    Ride in the Sky: https://www.youtube.com/watch?v=oR1-UFrcZ0k

    "I'll be right here," (final scene): http://bit.ly/1klzBaM

Assessment

Activity Embedded Assessment

As the teacher circulates throughout the room, the teacher makes observations regarding each group participant's ability to work as a member of a team. Using a small group participating rubric is suggested to allow ranking their performance on a scale (for eample, 1-4). This ranking will be discussed with students individually at the close of the activity in order to have a productive dialogue regarding areas for celebration and areas for improvement, heading into the next group activity.

Post-Activity Assessment

Students will have five minutes at the end of class to explain how the use of solar energy allowed E.T. to 'phone home' using an exit-ticket format.

References

https://go.nasa.gov/2qFU3iu

https://science.nasa.gov/science-news/science-at-nasa/2002/solarcells

http://www.space-airbusds.com/en/news2/production-od-solar-arrays.html
http://talkingpointsmemo.com/idealab/satellites-earth-orbit

This curriculum was developed under the National Science Foundation RET grant #EEC1301373. However, these contents do not necessarily represent the policies of the National Science Foundation, and you should not assume endorsement by the federal government.

Houston, We Have a Problem!

Subject: Earth and Space Science

Grade Level: 6 (5-8)

Time Required: 100 minutes

Author: Jodie Guillen

Students discover how the innovative science of photovoltaics harnesses the energy of the sun in order to power the world around us by transforming solar energy into useable power, electricity, through the use of photovoltaic cells. The popular 20th Century Fox movie, "The Martian," released in 2015, highlights the important role of photovoltaics in space exploration, especially as we travel further and further away from home. The science of photovoltaics faces unique challenges when used in the harsh realities of space, and the solutions to those challenges just might help us solve our energy crisis here at home on Planet Earth.

For this activity, students should have a basic understanding that different forms of energy can be converted into electricity, which is then used to provide power to the world around us.

Objectives

After this lesson, students should be able to:

- *Define the term photovoltaics (PV).*
- *Define the term photovoltaic cell.*
- *Define the term solar energy.*

- *Explain that the sun is used as a source of energy for power here on Planet Earth.*
- *Explain that the sun is used as a source of energy for power in space.*

Standards Correlation

NGSS Standards

MS-ETS1-1: Apply scientific principles to design a method for monitoring and minimizing a human impact on the environment.

5-ESS3-1: Obtain and combine information about ways individual communities use science ideas to protect the Earth's resources and environment.

CCSS Standards

CCSS.ELA-LITERACY.RST.6-8.1

Cite specific textual evidence to support analysis of science and technical texts.

Word Bank

Photovoltaics Photovoltaic cells Solar cells
Solar Energy Solar Panel

Introduction

DAY ONE

As class begins, assemble students into groups of 3-4.

I want you to close your eyes and take a journey with me back in time . . . to 6am this morning. The loud beeping of your alarm clock wakes you from the best kind of dream ever, and after hitting the snooze button far too many times, you force yourself out of bed. You flip on the light switch in the bathroom, and take a nice, hot shower, the smell of coffee wafting through the air. You quickly finish getting ready for school, the sound of the TV droning on in the background. The bus beeps its horn and you grab your backpack, cell phone, and breakfast burrito off the table, racing to catch the bus. You put in your earbuds as you settle in for the 30 minute bus ride ahead of you, and check out the latest upload by your favorite YouTuber. As the bus pulls up in front of school, you finish the last bite of your burrito and race to class in order to beat the tardy bell. (Jolt students back to reality with the sound of the tardy bell.)

Ok, class, you may open your eyes. I would like your group to make a list of all of the things you used this morning that required some type of power source, from the moment you woke up until the moment you walked into my classroom. You have five minutes.

As you are explaining the directions, hand each group an individual white board and a dry erase marker. Make sure you circulate around the room in order to keep students focused and on-task, as well as providing support to students who are struggling to come up with ideas.

After the five minutes are up, pull students back together to have a class-wide discussion, allowing students to share their ideas, compiling them into one list on a large whiteboard or chart paper. Once the ideas slow down, ask students to name what power source they used for each item listed.

> *Now I want you to imagine that you are 238,900 miles away from home, in the vastness of space, and suddenly something goes wrong . . . very, very wrong. "Houston, we have a problem."*

Show students the scene depicting the unraveling of Apollo 13's mission to the moon in the 1995 Universal Picture movie by the same name, "Apollo 13."

https://www.youtube.com/watch?v=kAmsi05P9Uw.

> *How did the astronauts onboard Apollo 13 transmit their infamous cry for help from their lunar capsule in outer space to mission control in Houston, TX, over 200 thousand miles away with no electrical outlet in sight?*

This movie clip will help students understand the absolute critical system failures that these astronauts were experiencing, and they will be excited to share their ideas! Give students a few minutes to share their ideas with the class, limiting the number of ideas to 3-4 in order to keep everyone focused.)

> *Believe it or not, the Apollo astronauts transmitted all communication to Planet Earth over radio frequencies.*
>
> *BUT, what if you are 140 million miles from home, left behind, stranded, and far beyond the reach of radio frequencies . . . what then? How are you going to transmit a message to Earth that you need help, and then stay alive during the four years it takes for that help to arrive???*

Show students the trailer from 20th Century Fox movie, "The Martian."

https://www.youtube.com/watch?v=ej3ioOneTy8.

After watching the movie trailer, ask students to name a source of power that they saw being used by Matt Damon, aka astronaut Mark Watney. Students should quickly come up with solar power. (If students are struggling to make that connection, show them images from a Google search that capture Matt Damon using solar panels.)

Tell students that they are now going to get to see the power of the sun in action, by safely viewing the surface of the sun. Hand each student a pair of solar glasses and head outside to an area where students will have an unobstructed view of the sun. (It is important to tell students that they must never look directly at the sun. The sun is so powerful that it can cause serious damage to their eyes in just a few seconds.)

Solar glasses can be found here: http://amzn.to/2niRBr. Rainbow Symphony Eclipse Glasses - Safe Solar Viewers - Eclipse Shades.

Instructor Content Background Information

The increasing demand for the fastest, most innovative, technologies is seemingly limited only by the reaches of the imagination; that is, until the sources of electricity used to power that technology create an energy crisis like one that has never been seen before. We are quickly depleting the resources available to us here on Planet Earth, and are destroying our planet along the way. Photovoltaics is a vastly underutilized source of electricity, one that also happens to be reliable, efficient, and friendly to life here on our planet.

The Quantum Energy and Sustainable Solar Technologies Engineering Research Center (QEEST), sponsored by the National Science Foundation (NSF) and the Department of Energy (DOE), is hard at work to further the science of photovoltaics in order to find innovative, new solutions to power our world . . . ones that will ensure we have a home here on Planet Earth for many, many years to come.

It is essential as educators that we teach our students about renewable sources of energy in order to ensure that this next generation of scientists, engineers, and space pioneers, sitting right in our classrooms, will one day be able to make educated decisions regarding the way we power our world as we venture into places that no man has gone before.

As said by President Ronald Reagan, “The future does not belong to the faint-hearted, it belongs to the brave.”



DAY TWO

As students come into class, have students take out their interactive science journals and hand each student a copy of the interactive journal template, Photovoltaics – Defined (located at the end of this lesson.) After students have cut-out, folded, and glued their interactive journal template into their science journals, students take notes from the note-taking guide, also named Photovoltaics – Defined, which the teacher projects onto the interactive white board.

- Students cut along the solid line forming the external edge of the entire interactive journal template.
- Students cut along the solid lines between the words, stopping at the dashed line, creating flaps.
- Students fold along the dashed line.

- Students glue the interactive journal template into their science journals.
- Students should write the definitions provided in the note-taking guide, Photovoltaics – Defined, underneath the tab for each word.

Once students have completed the interactive journal entry “Photovoltaics – Defined,” hand each student a copy of the interactive journal template “Solar Energy Can Become.” One copy of the interactive science journal template should be provided for each student. After students have cut-out and glued their interactive journal template into their science journals, students take notes from the note-taking guide, also named Solar Energy Can Become, which the teacher projects onto the interactive white board.

- Students cut along the solid line forming the external edge of the interactive journal template, which is an image of the sun.
- Students glue the interactive journal template into their science journals.
- Students should write each example provided in the note-taking guide, Solar Energy Can Become, onto each one of the sun’s rays.

<u>Vocabulary</u>

- Photovoltaics - The science of transforming solar energy into electricity, a useable form of power. The word photovoltaic can be broken down into ‘photo,’ meaning light and ‘voltaic,’ meaning electricity.
- Photovoltaic cells (solar cells) - A device that converts the energy of the sun into electricity.
- Solar Energy - Energy that comes from the sun.
- Solar Panel - A panel consisting of many individual solar cells that work together to produce electricity.

Lesson Closure

Play the original audio recording of the astronauts onboard Apollo 13 transmitting their message of distress to mission control in Houston, TX.

https://www.youtube.com/watch?v=eco_xvkEQlg

> *“Houston, we have a problem.” The astronauts of Apollo 13 sent this now infamous cry for help to NASA, transmitted via radio signals.*
>
> *However, when spanning a distance of 140 million miles, with the necessity to spend years in space to travel to Mars and BEYOND, radio signals, electrical outlets, and extension cords are simply not an option. Thanks to the super-hero status of the sun, NASA can stay in communication with Astronaut Mark Watney, 140 million miles away, and “Bring Him Home.”*

Assessment

Pre-Lesson Assessment

Working in groups, students make a list of all the things they used before coming to school which required some type of power source, from the moment they woke up until the moment they walked into the classroom. As a follow-up question, students will list what source of power they used for each device.

Lesson Summary Assessment

Students will work in groups to develop a meme that will encourage the use of solar energy to save our planet! These memes should be displayed throughout the school in order to encourage energy consciousness. In order to further spread the message regarding solar energy as a solution to our energy crisis here on Planet Earth, these memes should be sent out to the newspapers for publication, as well as to local representatives in both Congress and the House of Representatives. Students must cite textual evidence that supports the content contained in their meme.

Deepen your Knowledge

The video clip below contains the original interview with Matt Damon did while at NASA's Jet Propulsion Laboratory located in Pasadena, California on August 25, 2015. Matt Damon provides an interesting perspective regarding the importance of continued space exploration, as well as the importance of science and engineering to the future of our planet, one that students will respect due to his celebrity status as a well-respected actor.

https://www.youtube.com/watch?v=jgIZRdeMO_I

References

http://albaenergy.com/2016/02/5-surprising-things-you-can-learn-about-solar-power-from-the-martian/

https://www.nasa.gov/feature/nine-real-nasa-technologies-in-the-martian

https://science.nasa.gov/science-news/science-at-nasa/2002/solarcells

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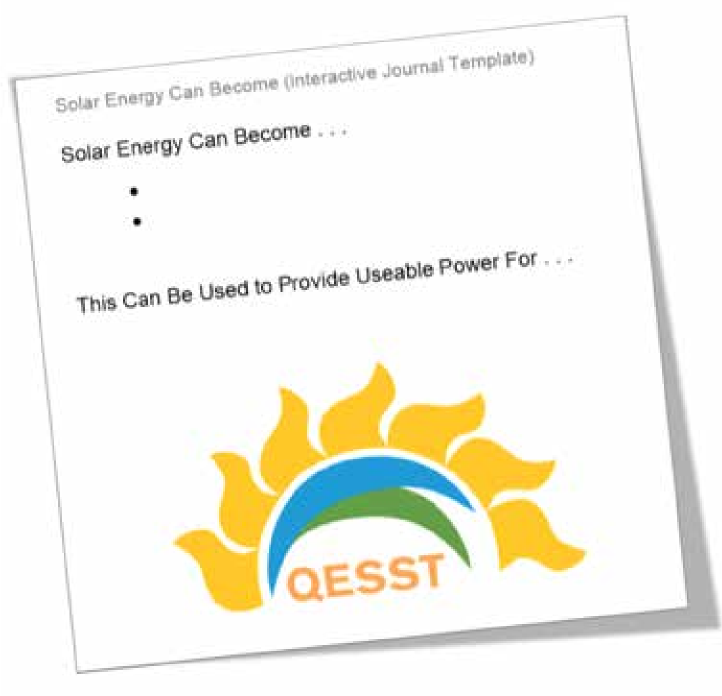
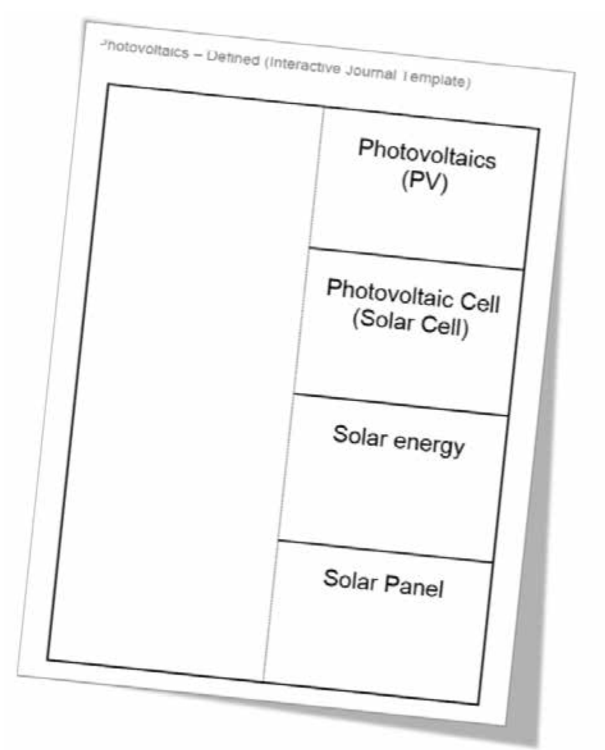
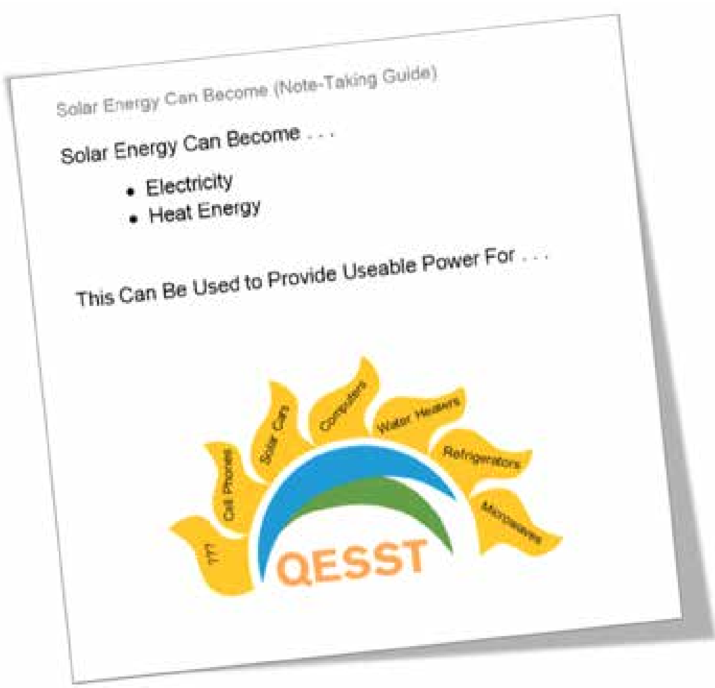
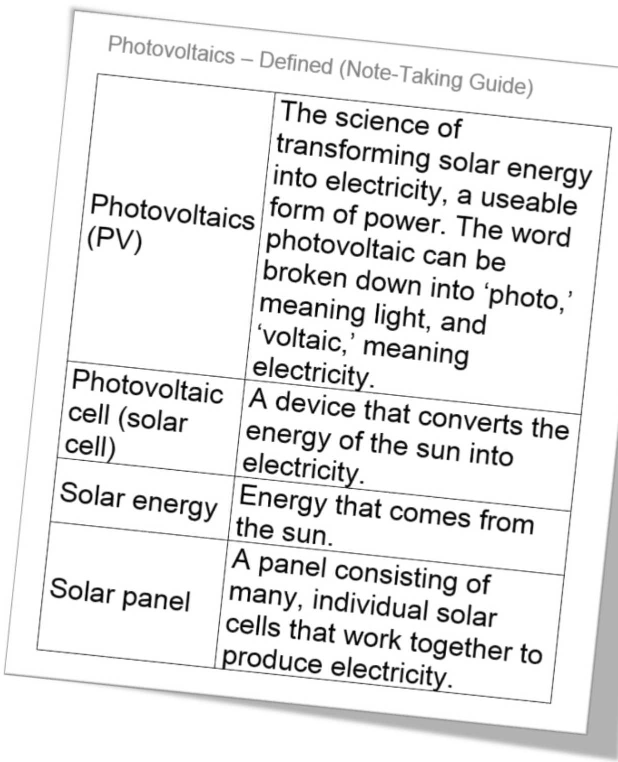

Solar Energy Can Become (Interactive Journal Template)
Solar Energy Can Become . . .
This Can Be Used to Provide Useable Power For . . .
QESST


Photovoltaics – Defined (Interactive Journal Template)
Photovoltaics (PV)
Photovoltaic Cell (Solar Cell)
Solar energy
Solar Panel





Photovoltaics – Defined (Note-Taking Guide)

Photovoltaics (PV)	The science of transforming solar energy into electricity, a useable form of power. The word photovoltaic can be broken down into 'photo,' meaning light, and 'voltaic,' meaning electricity.
Photovoltaic cell (solar cell)	A device that converts the energy of the sun into electricity.
Solar energy	Energy that comes from the sun.
Solar panel	A panel consisting of many, individual solar cells that work together to produce electricity.

Ella the Electron

Subject: How charged electrons fill holes to form a p-n junction between semiconductors in a solar cell.

Grade Levels: 8th grade through high school

Author: Rebecca Hooper

This lesson pre-supposes that students have completed a unit on atomic structure. The activity was originally developed for a classroom unit on types of energy, as part of a sub-unit on solar. This activity should only be used with participants who already have background knowledge of how solar cells convert energy from the sun to usable energy; this lesson can help them consolidate and extend that knowledge. Participants interpret an original story of "Ella the Electron" through texts and pictures, engaging in substantive interaction with peers to negotiate their understanding and refine their knowledge of how charged electrons fill holes to form a p-n junction between semiconductors in a solar cell. Participants then connect the story to an actual solar cell given an overview of the cell's structure and vocabulary terms. Students can be assigned to groups, with each group assigned a scene from the story, following by whole-group discussion.

Outreach leaders may use this lesson in conjunction with other outreach activities that first introduce students to how current is generated in a solar cell (e.g., construction paper solar cells).

Objectives

- *Participants will be able to explain how the electrons of an atom produce energy. In so doing, they will refine their knowledge of how charged electrons fill holes to form a p-n junction.*

Materials

Each group or individual needs the following materials:

- Ella the Electron story
- Blank paper, pencils, color pencils or pens for drawing
- Solar vocabulary worksheet
- Ella the electron worksheet
- A diagram of a silicon solar cell

Instructor Content Background Information

For a quick guide to a PV cell in action, see Richard Komp's TedEd video, How Do Solar Panels Work?

https://youtu.be/xKxrkht7CpY (~4 minutes)

You might show this explanation and animation of the ideal short circuit flow of electrons and holes at a p-n junction:

http://pveducation.org/pvcdrom/light-generated-current

Explanation for operation of solar cells with simple diagrams and animations:

http://www.pveducation.org/pvcdrom/light-generated-current

An animated illustration of how the p-n junction is formed:

http://www.pveducation.org/pvcdrom/formation-of-a-pn-junction

Instructions

Part 1: Review

Review with participants how a solar cell converts the sun's energy to usable energy. Use the online resources above to help students recall relevant prior knowledge. Use the vocabulary worksheet to aid the review process. Working in groups, participants could create their own definitions and explain their understanding based on content knowledge or life experience. Groups could then compare and contrast their definitions, decide which is best (most accurate and concise), and further refine a collective definition for all or some of the vocabulary. In deciding, students explain reasoning for what they include and what they exclude. The outreach leader should facilitate the discussion. Allow students to lead, only interject to keep them on topic and make them elaborate or justify weak claims.

Note: The worksheet found at the end of this lesson is filled in with definitions. It can be used when time is limited. Outreach coordinators can also use the definitions to seed the conversation among participants.

Part 2: Ella the Electron.

Participants read, draw, and discuss Ella the Electron, a five-part story of how the electrons travels to produce energy in a solar cell. In an outreach setting, this is probably best accomplished in small groups. Divide participants into five groups. Each group should be assigned to draw and label each scene for one part of the Ella the Electron story. Group members should read the entire story together before drawing their section. When all groups have completed their drawing, they explain their drawing to the whole-group, taking turns sequentially through the story. The drawings can then be collected into a book. Each participant can be given a copy of the book to take home. A copy can also be donated to elementary or middle school classrooms!

Part 3: Consolidate knowledge

Participants connect the story to a diagram of a silicon solar cell, given an overview of the cell's structure and vocabulary terms. Using their illustrations for Ella the Electron and the worksheet provided, participants connect the story to the parts and processes of a silicon solar cell, identifying the pathway of the electron and purpose of each layer and important processes that occur.

A possible extension to the activity is to explore with the students what effect the following changes would have on a solar cell.

1) Use a metal instead of a semimetal for the wafer.
2) Use copper instead of silver as the metal for the fingers and busbars.
3) Use an inorganic material for the dye-sensitized cell.
4) Increase the thickness of the glass of the dye-sensitized cell.

Connect beyond the classroom

Why is necessary to harness solar power in a usable form?

Deepen Your Knowledge

This lesson is part of a high school classroom unit called Energy in Action, created by high school science teacher, Rebecca Hooper. You can find the full unit on the QESST Education website.

In Part 3 of the lesson, students could also compare Ella's story and a silicon solar cell with a dye-sensitized solar cell.

Vocabulary

- Absorption - The transfer of energy of a wave to matter
- Texturing - Roughing the surface of a substance by etching along along the face. Results in a surface of pyramids in silicon.
- Sunlight - Energy emitted by the sun incident on the earth
- Electron - Sub-atomic particle that holds a negative charge and makes up the outer volume of an atom
- Recombination - When an excited electron stabilizes to a lower energy state, removing a hole
- Photon - Packets or particles of energy that sum to the total energy of light
- Energy - The ability to do or perform work
- Electricity - A form of energy generated by the accumulation of movement of charged particles
- Busbars - Metallic top contacts necessary to collect current generated by the cell
- Fingers - areas of metallization, which collect current for delivery to the busbars
- Conductor -Material that allows electrons to flee freely or allows the flow of electrical current
- Semiconductor - A solid whose conductivity lies between that of an insulator and a metal
- P-Type - Group III elements with three valence electrons to interact with silicon's four, which results in one less electron, thus creating a hole
- N-Type - Materials made of Group V elements that have valence electrons to bond with silicon 4 and the extra electron can participate in conduction
- P-N junction - Area where a p-type and n-type meet so that electrons diffuse from the p-type to the n-type
- Wafer - A slice of semiconductor material used in electronics for solar cells
- Doping - The process of adding different add-ons to a silicon wafer in order to shift the balance of electron and holes
- Efficiency - Ratio of energy output from the solar cell to input energy from the cell
- Holes - The area of a p-type material where there is a missing electron
- Current - The flow or movement of electrical charge in a circuit
- Voltage - Measurement of the potential energy of a charge within an electric circuit at a given point

Ella the Electron : The Story

PART 1

Let's explore a world that has potential to change everything about our own world and possibly save it, starting with one little girl named Ella… Ella the Electron has a pretty normal unexciting life in Silicon Villa, a place with citizens who are referred to as particles. Before getting to know the people, here is a little history on the place, Silicon Villa. Once a flat smooth land long ago, one day a rain descended that was so heavy it was as if someone had dipped the entire villa into a tub of water. But this rain was not just ordinary water; it had other special additives. The rain eroded the land leaving an uneven mountainous terrain. Two additional periods of similar, but unique types of rain created new lands on either side of Silicon Villa, but we will share more about those areas later. Every home in Silicon Villa was exactly the same as each other, but unlike any home you would be familiar with. For example, they didn't even call a home a "home"; they called it an atom. Here's more explanation...

Every home and its land was referred to as a Silicon atom, each with the exact same floor plan and members. Every household was made of the "mothers of the house" called Neutrons. Typically, there were around fourteen Neutrons, very rarely you would see a house with one more or one less. Every house had fourteen girls, referred to as Electrons, and fourteen boys called Protons. The Protons were a very positive group of boys, they remained in the house taking care of household tasks, along with the Neutrons. Together the Protons and Neutrons made up the center of the atom, often referred to as the Nucleus. The Electrons were a different story. Despite being much smaller, they were equally as strong a force as the Protons, but had negative attitudes specifically with each other. Despite their negativity, they were vital to the structure of the atom, so instead Electrons took care of the outside of the house. They would work quickly making sure to stay out of each other's way. In fact, they worked so quickly that it was difficult to see them independently; they just looked like a cloud of Electrons. It was tough work, but each Electron had a strong loyalty to the Protons, and together with the Neutrons, they maintained the stability of the home – or as we now know, the atom.

Not every Electron was exactly the same; some electrons had greater energy than others and were able to travel farther from the house than the others. The most loyal of the electrons remained closest to the nucleus and often questioned the loyalty of those who wandered farther away. Now it's time to introduce Ella the Electron. Four of the electrons had the highest energy of them all - and Ella was one of them. They frequently roamed on the outskirts of the property line, called the Valence line. The electrons that dared to reach the valence line were, of course, referred to as the Valence Electrons. Ella the Electron had a secret desire to explore the other lands she suspected were beyond Silicon Villa, but she could never quite muster up enough energy to leave.

PART 2

One day, Ella the Electron was working around the house as normal and she noticed a bright white light in the distance just as she made it to the valence line. She noticed this white light was made of individual packages of varying colors and sizes. As she continued to work with the light shining down, she started to notice more and more of these packages. But they never quite came close enough for her to understand what they were. Ella overheard one of the other valence electrons mentioning seeing these packages as well; at least she knew she wasn't just seeing things. One day, one of the green packages got closer and closer, close enough that Ella the Electron was able to see that it was in fact a package and that on it was printed the word "PHOTON". But still, the object remained out of reach.

The next day, Ella the Electron saw in the distance, coming towards the valence line, one of the blue packages. It was getting closer and closer, close enough to grab. She could have kicked herself for not being in the right spot at the right time! Right in that instant, one of the other valence electrons snatched the package. Ella the Electron witnessed her sister receive a great burst of energy and sprint beyond the valence line, vanishing in the distance. As she continued to work, Ella the Electron's mind spun with the possibilities of what could have happened to the other electron. She wondered if her sister would ever return to the atom. The loss of a negative attitude left a positive atmosphere throughout the atom, so no one searched, no one inquired. But Ella the Electron was still curious.

Things continued to get even more bizarre. As Ella the Electron continued to work, she noticed something approaching the valence line in the distance. At first, she thought it was another package, but quickly she realized it was a different electron returning to the atom. Ella the Electron watched as the electron approached with the same unusually high amount of energy the other electron that left had received from the photon, but as she approached, the electron seemed to be losing that energy. Once the electron reached the valence line, she returned to a normal level of energy and started picking up the work the other valence electron had left behind. Despite the addition of another negative attitude, the work needed to be done. So the atom returned its neutral state with the same number of electrons and protons. The number of questions swimming through Ella the Electron's mind was staggering, but electrons never stopped working and hated to be near each other. So the idea of approaching and asking those questions was, well…repulsive. So, Ella the Electron kept her questions to herself and became determined that she would have her own experience. At the next possible chance, she would not hesitate to grab one of those photons herself.

PART 3

Ella the Electron did not have to wait long. The next thing she knew, she was at the valence line, wrapping her hands around her own package. As soon as she got the package open, she felt a surge of energy she had never experienced before. She took off past the valence line, leaving the atom behind. Ella the Electron let the energy take her to places she had never been before. She even passed other valence electrons who had grabbed their own packages. She had to be careful though. As she passed other positive silicon atoms she felt a slight attraction to get back to work and fill in the empty spot they left behind. It was difficult battling the natural urge to be with an atom. But the photon had given her the strength and energy to fight her nature.

To remove the temptation, Ella the Electron searched for a different way to get by the atoms. Unfortunately, there were so many electrons in this negative place that she kept bumping into others. It was nearly unbearable! The only saving grace was that the electrons all seemed to be moving along. Since she was in the situation, Ella the Electron took the opportunity to ask a fellow electron what was going on. The stranger she asked looked just as unhappy to be in the conversation, but complied and proceeded to answer her questions. As suspected, Ella the Electron's atom was not the only one that started seeing these colorful packages. The stranger had been on this journey multiple times since the packages first started appearing, when the bright white light shown on the land.

As Ella the Electron guessed, the key to leaving the valence line was getting the right colored package, one with a photon with the right energy, at the right time. When Ella the Electron inquired why all the electrons were huddled together heading in the same direction, the stranger replied that the discomfort they had to endure through this portion of this journey would be worth what's on the other side. They were heading towards Phosphorous Farms, one of the lands that formed after a heavy rain. Any extra electron is doing what they can to get out and travel to the other side. The atoms in Phosphorous Farms were very similar to those in Silicon Villa, except they had one extra electron, proton, and most likely neutron for a total of fifteen each. This made for a hectic border where Phosphorous Farms and Silicon Villa met, with extra electrons everywhere. At least this explained the crowdedness and discomfort. With the extra electrons from the phosphorous atoms and the addition of electrons leaving their atoms thanks to the packages, the negativity was overwhelming and many electrons fought to get out. Ella the Electron had more questions, so she did her best to keep up with the stranger as they made their way through the farms.

A shiny road in the distance caught her attention as the stranger headed straight for it. The stranger urged Ella to be ready to pick up the pace because travel on the road speeds up drastically. Once there, Ella the Electron automatically fell in line swiftly picking up the pace to travel north, but not before sensing a great source of heat as she got in line. Not sure what to think, since it was gone as fast as it was there, Ella the Electron continued in line. Unfortunately, much to everyone's distaste, it was still crowded. But the electrons were not nearly as crowded as they had been in the farms, and at least they were moving quickly. As much as electrons hated being near each other, something about this road overcame that force. So they lined up closer than any one of them truly desired to be in order to continue on their journey.

The stranger picked up their conversation, calling the road they were on Silver Fingers, one of many that could lead them to a greater purpose. As soon as the stranger mentioned this greater purpose, it seemed the reason Ella the Electron had been moving forward with this group of electrons was explained. There was a task she was meant for, they were all meant for; to carry the energy they received from the photon to produce something great. She understood why the electrons would be willing to endure such a close, negative atmosphere. Another feeling of great heat distracted her, just like when she first got in line. Looking around, Ella noticed that an electron who had been behind her was gone, off the Silver Finger. The stranger saw her confusion and explained that, despite having the additional energy, some atoms lose patience and doubt. Feeling the pull of the comfort of returning to a Silicon atom to continue the work they were used to doing. So, they go and recombine with another atom. The stranger explained that it is disappointing and pitiful, as they waste that energy. Ella the Electron wondered why they would come all this way just to return to their normal state without serving their true purpose. She hated inefficiency.

PART 4

At that time, the line turned and merged with other electrons onto a larger road. The excitement in the stranger's face was contagious; Ella the Electron asked what was going on. The stranger explained they just turned from the Silver Fingers to the Silver Busbars, so they must be getting closer. The task they were going to complete was so great and included so many electrons with energy that they required a larger road to transport them all. As they travelled, Ella the Electron grew more and more anxious to get to their destination to serve their purpose. But she was bumping into so many other electrons trying to move forward that she worried she would lose all her extra energy before she even got there. The stranger reappeared next to her and told her she would have to fight to get to the port. Before Ella the Electron had the chance to reply, she looked up and saw the sign for "Port of Electrode Out", giving her a new motivation.

As they got closer, Ella the Electron concentrated on her calling to serve her purpose and make sure the energy she obtained was used for something greater than herself. So, she repelled, collided, and fought her way closer and closer to the sign. Finally, she had made it to where the port oddly dropped off and the electrons funneled into a narrow dark corridor. They continued for a long way, what seemed like forever to Ella the Electron, being joined by other electrons along the way. Again, sensing her question, the stranger explained that their entire planet was just one of many modules that come together to serve the same greater purpose. All of the planets were made in the same way with the heavy rains and silicon atoms. Their combined task was initiated when the light shown and the packages, photons, started arriving.

They were continuing in dark silence when suddenly the stranger warned her that they were approaching the moment when they would serve their true purpose. Ella the Electron waited with anticipation as she got closer and saw the slightest hint of light ahead and where the corridor stopped, she couldn't wait to get closer. Electron after electron was drawn up and out of the corridor to somewhere she could not see. The stranger told her to get ready right as she herself was drawn up. Ella the Electron started to ascend, then quickly entered what felt like a roller coaster. Up and around, loops and spins, Ella the Electron was transported through in what probably was less than a millisecond, but felt like an eternity. In that split millisecond, as if time slowed down, she saw the most magnificent, brilliant light she had ever seen. It reminded her of the light she witnessed when the packages started to arrive. Ella knew somehow it was all connected and she was serving her purpose. Abruptly, she landed into another corridor, not exactly sure what had happened. All she knew was that she felt drained of the extra energy she had received from the package. She continued down the corridor with the other electrons that had just gone through what she had. Fortunately, the stranger was nearby and explained that the light she witnessed was in fact that bright and magnificent because of the energy the electrons were giving as they went through that roller coaster ride. This explained why she felt back to her normal self. The photons were a special gift from that light that everyone had seen back in Silicon Villa, each gift containing just the right amount of energy to meet the right electron at the right time. However, this energy was not for them to keep, but to give to provide energy for another light, a light for our world. This energy was not limited to providing light, but could also be used for cooling or heating homes, charging phones, and anything else that requires energy. The shortest moment of Ella the Electron's life turned out to be the most significant.

PART 5

Ella the Electron tried to process this information as she and the stranger continued to the end of their journey. But she realized she had no idea what was next. The stranger explained that her journey did not have to end. She could continue to serve her purpose, but she would have to make it back to Silicon Villa to start again. Before she could ask how she would get back home, the corridor opened up and the electrons exited a different port, Port of Electrode In. Ella the Electron asked how in the world she would do that if she had no idea where she was and in what relation to Silicon Villa. With a dramatic roll of the eyes, the stranger stated they were in Aluminum Alley. All she had to do was head north - but that would be the easy part. The hard part would be resisting the urge to stay. Ella the Electron couldn't imagine not wanting to go through that empowering experience again. She was already missing that extra energy after having returned to her normal self. At the same time, she did feel a sense of comfort from Aluminum Alley that tempted her to find an atom and get to work. Maybe she would stay a while... As if sensing her turmoil, or at least now beginning to anticipate and predict her many questions, the stranger turned to explain. The stranger warned her not to lose sight of her purpose. The attraction of Aluminum Alley helps a lot of electrons return from the light, but it is not the end goal. It's an alley for crying out loud, meant to be a passageway, not a home. The Aluminum houses have great appeal in that, unlike Phosphorous Farms, each atom has one less electron, proton, and usually neutron for a total of thirteen each. Since there are fewer electrons and a lot of positivity, weak-willed electrons would get distracted and remain. To the stranger, it was just another way for them to recombine to an atom and waste their potential.

Ella the Electron knew she had to resist that weakness and again fight her way back to Silicon Villa. But before she could make a move, the light, the source of the packages, disappeared. Chaos ensued as electrons returned to their normal energy, trying to find a home, any home to go to. Ella the Electron felt a push. She turned to see the stranger who urged her to find a home as well. She did as told, landing at an atom and getting to work immediately. Although Ella the Electron was okay where she was and could be content, she had a feeling it wasn't over. For some reason, she knew the light would be back, packages would start coming in again and she would have an opportunity to continue to serve the greater purpose… It was just a matter of when the white light would return.

Ella the Electron Worksheet

Directions:

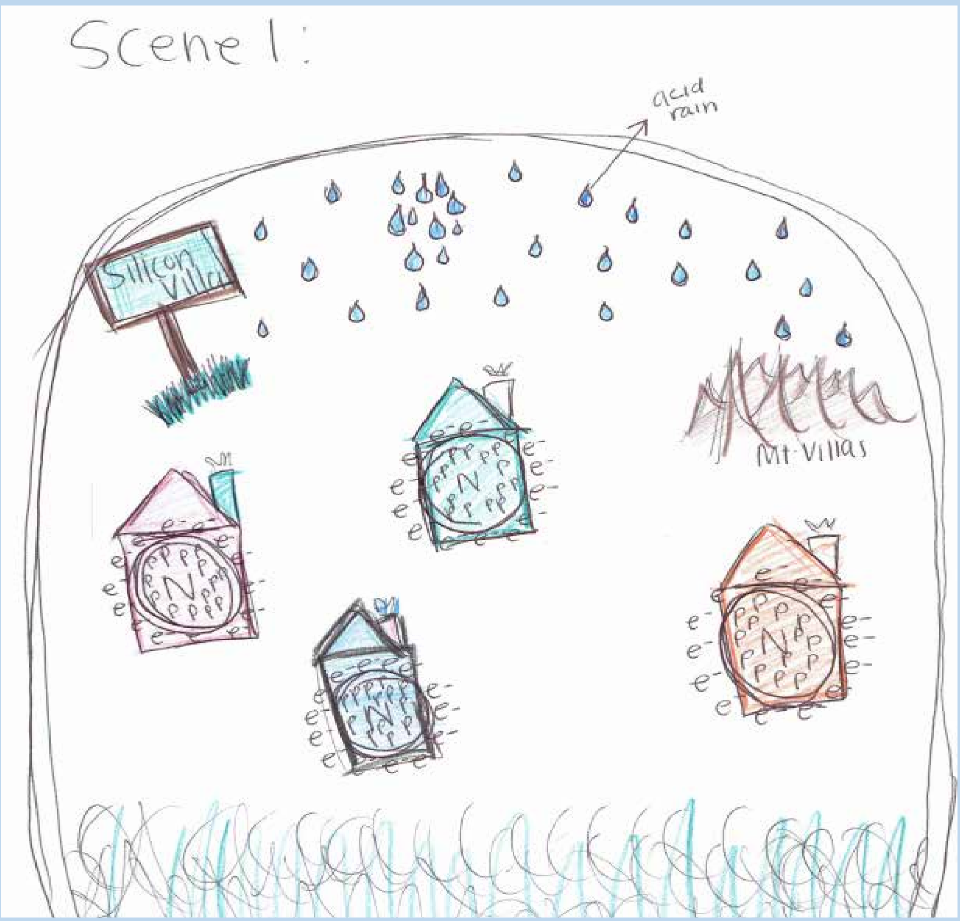
Read through the story or your group's portion of the story. Draw an illustration of what's happening, like a picture or comic book.

Use the Solar Vocabulary handout with definitions to fill in the chart below connecting Ella's journey to the structure and function of a silicon solar cell.

	Ella's Journey	Silicon solar cell
ABSORPTION		
TEXTURING		
SUNLIGHT		
ELECTRON		
RECOMBINATION		
PHOTON		
ENERGY		
ELECTRICITY		
BUSBARS		
FINGERS		
CONDUCTOR		
SEMI CONDUCTOR		
P-TYPE		
N-TYPE		
P-N JUNCTION		
WAFER		
DOPING		
EFFICIENCY		
HOLES		
CURRENT		
VOLTAGE		

Fill in the chart below, connecting Ella's journey to the structure and function of a silicon solar cell. Comparison may not be exact as long as they relate.

	Ella's Adventure	Silicon Solar Cell
Wafer structure		
Atomic structure		
How the electron receives energy		
Where the electron goes		
Electron powering a light bulb		
Electron returning		



Community College Solar Engineering Unit

Subject: Optimizing energy costs using solar energy; Modelling trade-offs between different sources of power loss and electron transport on a solar cell.

Grade Levels: Community College (may also be appropriate for some high school classes and some university courses)

Lessong Length: three class sessions

Authors: Cody Anderson, Elizabeth Adams

This unit was designed to be used in general engineering courses in the community college setting. The unit is divided into two parts. On Day 1, students are introduced to the big picture of solar applications and they design a solar array for their home. On Days 2 and 3, students zoom in to understand how solar cell engineering tradeoffs affect solar energy applications. They learn how a solar cell works and designing a cell for optimization.

Day 1 – Big Picture. Why solar? Design a solar array for your home.

Materials

- Copy of each students' recent power bill
- PowerPoint on Photovoltaic applications (found on the QESST Education website)
- "CAA_pvwatts_hourly" Excel spreadsheet posted to the course website or one copy printed for each student
- "CAA_pvwatts_monthly" Excel spreadsheet
- Access to a computer for each student

- Copy of the PVWatts Caltulator Assignment for each student (see document in Appendix for this lesson).
- Copy of the Utility Bill Review in-class worksheet for each student (see document in Appendix for this lesson).

Opener: Utility Bill Review

- Students partner up and compare their power bills. They discuss reasons for differences in energy use and cost.

Lecture: Photovoltaic applications (The PowerPoint for this lecture can be found on the QESST Education website)

Assignment: PVWatts_Calculator

- In-class, students complete Part 1, which is sizing a solar array for their home through the PV Watts Calculator
- As homework, students complete Part 2, which is using Excel to analyze the Monthly and Hourly outputs from the PV Watts Calculator

<u>Day 2 - PV mechanics. Details on how the solar cells work. Front grid design optimization.</u>

Materials

- Day 1 homework
- PowerPoint on PV Mechanics found on the QESST Education website
- Copies of the Front Grid assignment for each student (attached at end)
- Front_Grid_Optimization Excel spreadsheet found on the QESST Education website
- Competition_Spreadsheet Excel found on the QESST Education website

Students bring in: Day 1 homework

Opener: Review the Excel analysis

Lecture: PV_mechanics (The PowerPoint for this lecture can be found on the QESST Education website)

Assignment: Front_Grid_assignment

- In-class, students complete Part 1, where they draw their own front grid designs, partner up, compute power losses from their drawings, and compare results with each other.
- As homework, students complete Part 2, which is using Excel to inform their front grid designs and developing their most efficient design.
- Note: See the Designing a Solar Cell to Optimize Efficiency in the Outreach Activity section of this book for another description of how to enact this activity

Day 3 (only the first 20 minutes of class) – Front grid optimization and competition

Materials and Resources

- Day 2 homework
- "Competition_Spreadsheet" Excel
- Copy of the Front Grid Assignment for each student

Students bring in: Day 2 homework

Opener: Review the Excel analysis

Competition: Using the "Competition_Spreadsheet," have students share the parameters for their optimal design and see who demonstrates the smallest power loss

In-Class Activity - Utility Bill Review

Partner up with your neighbor and review the power bills you brought in. Provide thoughtful responses to the following questions using proper grammar and complete sentences.

A) Fill in the table with data from the two bills. For the last column, compute the true cost of the energy (remove the costs of service charges and taxes)

Location		
Date		
Total Energy Use [kWh]		
Total cost [$]		
Average cost per kWh [$/kWh]		

B) What could account for the differences between the two bills? Include as many reasonable factors you can think of. Which of these factors might be most/least important?

C) Describe (in your own words) what you are paying for when you pay this bill (Power? Energy? Electricity?). How do you know?

This assignment consists of two parts. The first will be completed in-class and the second as a homework assignment. Submit all parts together next class period.

Part 1: Construct a model solar array for your house

Access the National Renewable Energy Laboratory (NREL) PVWatts Calculator and use it to design a PV array for your home:

PVWatts.NREL.gov

If you have questions about what is required for the different inputs, look for the information icon. ⓘ

Record your input values here (including units). Write notes to justify your choices.

Zip code	
Solar resource data	
DC System size	
Module type	
Array Type	
System Losses	
Tilt	
Azimuth	
DC to AC Ratio	
Inverter Efficiency	
Ground Coverage Ratio (for 1-axis tracking only)	
Initial Economics	
System Type	
Average cost of electricity from utility bill	

Part 2: Analyze the energy output results

Output Data Analysis

Download the output results (both Monthly and Hourly). Open these files and save them as .xlsx files.

PVWatts_Monthly.xlsx

A) Define each of the output column parameters below:

AC System Output (kWh)	
Solar Radiation (kWh/m2/day)	
Plane of Array Irradiance (W/m2)	
DC Array Output (kWh)	
Value ($)	

B) Identify the month of maximum AC system output and plane of array irradiance. ______________________

C) Identify the month of minimum AC system output and plane of array irradiance. ______________________

D) Plot AC system output on the primary y-axis, plane of array irradiance on the secondary y-axis, and months on the x-axis. Label the axes in your own words (e.g. translate "Plane of array irradiance" to something more understandable)

E) In a text box near the plot, type up a short paragraph (4-6 sentences) caption for your plot. The caption must clearly describe the "story" your plot is telling.

F) Print out a page showing the plot and caption

PVWatts_Hourly.xlsx

A) Define the output column parameters listed below:

Beam Irradiance (W/m2)	
Diffuse Irradiance (W/m2)	
Plane of Array Irradiance (W/m2)	
Ambient Temperature (Celsius)	
Cell Temperature (Celsius)	

B) Use Excel functions to find the maximum ambient temperature occurring during the year. Fill in the results below.

Max Ambient Temp.	Month	Day	Hour

Does the timing of the maximum ambient temperature correspond with the month your system generated the most electricity? Below, explain why the timing of these two is close (or far) apart:

C) Create TWO scatter plots with AC system output on the primary y-axis and hours on the x-axis:

- For the month you identified producing the maximum AC system output
- For the month you identified producing the minimum AC system output.
- Set the y-axis limits to be the same on each plot. Include proper titles and axes labels

D) In a text box near the two plots, type up a short paragraph (5-7 sentences) caption. The caption must summarize the story that each plot is telling and compare results between the two.

E) Print out a page showing the caption and two plots

To turn in:

This written assignment (all three sheets) with completed definitions and all questions answered

Printed page showing caption and plot for the Monthly data

Printed page showing caption and plots for the Hourly data

Front Grid Optimization

In this assignment, our goal is to optimize the front grid design of a solar cell to minimize power loss. We will do this by drawing our own custom designs and estimating power loss, then using a spreadsheet to develop a better design.

The power loss [%] associated with the front panel design of a solar cell can be mathematically modeled as shown below. Note that this excludes power loss due to busbar resistance (negligible) and due to contact resistance (cannot be modeled well). These equations assume equal finger spacing throughout cell.

$$P_{loss} = P_{loss,emitter} + Pl_{oss,fingers} + P_{loss,shading}$$

$$P_{loss,emitter} = (S_f^2\ J_{mp}\ p) / (12\ V_{mp})$$

$$P_{loss,finger} = (L_f^2\ S_f\ J_{mp}\ \rho) / (3\ w_f\ d_f\ V_{mp})$$

$$P_{loss,shading} = A_{shaded}/A_{cell}$$

Definitions of parameters

S_f = finger spacing [mm]

L = finger length [mm]

J_{mp} = current density at max power

V_{mp} = voltage at max power

ρ = metal conductivity

p = emitter sheet resistivity

d_f = depth of finger

w_f = width of finger

A_{cell} = surface area of cell

A_{shaded} = shaded surface area

For our solar cell design, we are able to adjust a handful of the parameters:

- Finger spacing (S_f) can vary to any width you select. This parameter plays into all three of the power loss terms.
- Finger Width (w_f) must be at least 50 µm due to manufacturing constraints.
- Busbar spacing/finger length (L) can be any size you choose. Busbars should be spaced evenly and the finger length sized accordingly.

For the rest of the parameters, we will use typical values for a solar cell:

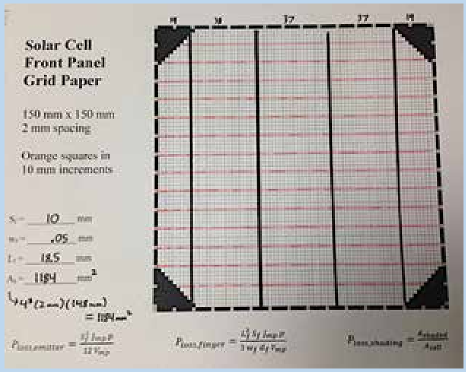
- J_{mp} = 0.35 mA/mm2
- V_{mp} = 0.5 V
- ρ = 3x10-5 Ω·mm
- p = 60 Ω
- d_f = 0.02 mm
- Busbar width = 2 mm
- Acell for the given cell is 150mm x 150mm, minus the corner cutouts
- Ashaded can be estimated as $A_{shaded} = A_{busbar} + w_f / S_f\ (A_{cell} - A_{busbar})$

Part 1: In-class assignment

1) Form a team of two
2) Discuss with your partner the impacts of each of the adjustable parameters (e.g. What happens if we space the fingers further apart? How does it impact each of the three power loss terms? How does it impact the total power loss?).
3) Each person take a copy of the front panel grid paper, ruler, red pen, and black pen. Choose the number of busbars that you will want to draw (between 1 and 8) (pick a number different from your partner)
4) Follow the instructions on the following page to draw your first front grid design
5) After drawing your design, compute power loss using the given equations. Verify that your units work out (note: 1 V = 1 A·Ω). Check your partner's work.
6) Discuss with your partner and write short answers the following questions. Take special note of the tradeoffs that exist:
    a. What are the impacts of increasing finger spacing?
    b. What are the impacts of increasing finger width?
    c. What are the impacts of having more busbars?
    d. To which parameter(s) are your power losses most sensitive? Least sensitive?
    e. What were the power losses for each of your designs? Why do you believe one performed better than the other?
7) Submit your answers with both teammates' names at the top.

Steps for drawing a front grid design

1) Acquire the following:
- Copy of the front panel grid paper
- Straightedge
- Black marker
- Red pen



2) Decide how many busbars you'd like to use (between 1 and 8). All the busbars we will draw should run vertically and be evenly spaced. The example to the right was done using four busbars (black lines).

3) Compute the spacing of the busbars. Use the following table to help you (if you choose a different # of busbars, follow the pattern shown). The busbar spacing is based on a 150mm-wide solar cell and rounded to the nearest mm.

# busbars	1	2	3	8
Fraction of solar cell reached by each side of the busbar	1/2	1/4	1/6	1/16
Busbar spacing from left edge of cell	75 mm	38 mm	25 mm	9 mm
Busbar spacing from each other	--	76 mm	50 mm	18 mm

4) Draw your busbars in black marker. The width of each busbar is set at 2 mm, which is one cell's width on the grid paper.
5) Choose a finger spacing (S_f) between 1 mm and 10 mm. Draw your fingers in red pen.
6) Don't worry about how wide the red pen lines appear on your drawing. You can simply declare any finger width (w_f) you'd like (≥ 0.05 mm).
7) Next to your design, write down the values for S_f, w_f , L_f, and A_{busbar}.
8) You have already chosen S_f and w_f
9) Lf is essentially the same as the busbar spacing from the left edge of cell (minus half the width of the busbar)
10) A_{busbar} can be computed by realizing that all the busbars are rectangles; add all the areas of the individual busbars together.

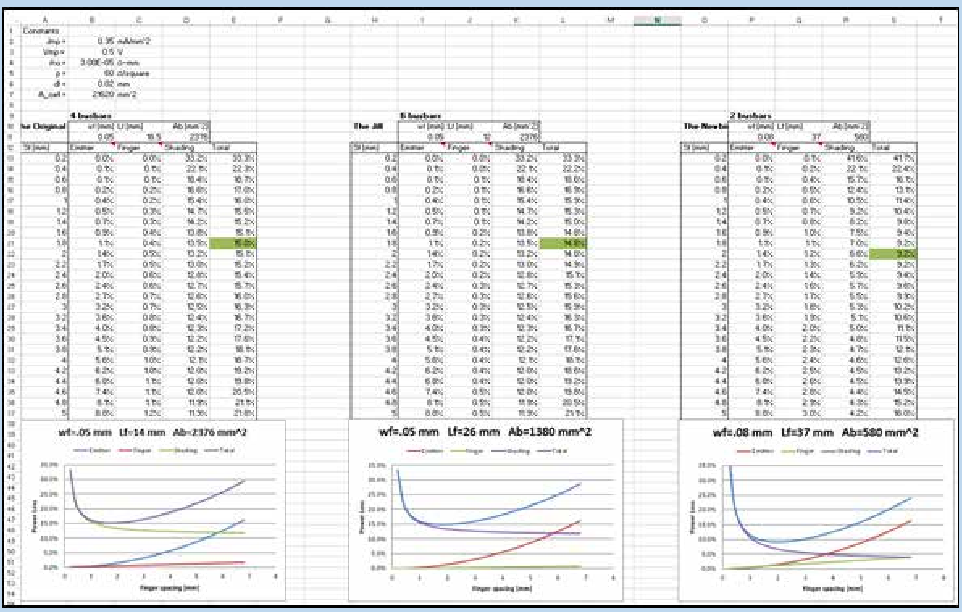
Part 2: Homework

Now that we have a feel for the grid design and the power loss equations, we will take a more systematic approach for optimizing the design. There will be a competition to see who creates the most efficient design. For you to work on individually:

1) Create an Excel worksheet. To the right is a zoomed-in view of the first table. Below is a broad view of what the overall spreadsheet will look like.

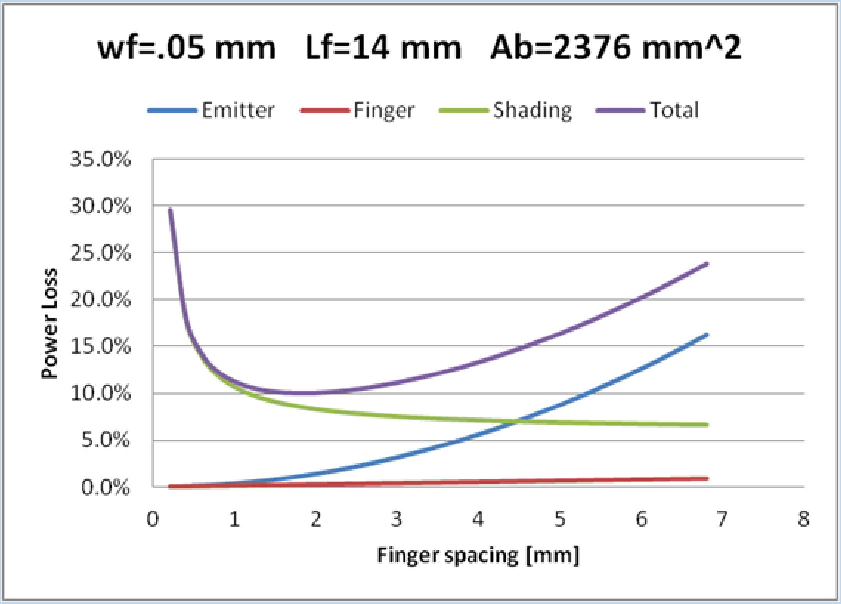
	A	B	C	D	E
1	Constants				
2	Jmp =	0.35	mA/mm^2		
3	Vmp =	0.5	V		
4	rho =	3.00E-05	Ω-mm		
5	p =	60	Ω/square		
6	df =	0.02	mm		
7	A_cell =	21620	mm^2		
8					
9		4 busbars			
10	The Original	wf [mm]	Lf [mm]	Ab [mm^2]	
11		0.05	18.5	2376	
12	Sf [mm]	Emitter	Finger	Shading	Total
13	0.2	0.0%	0.0%	33.2%	33.3%
14	0.4	0.1%	0.1%	22.1%	22.3%
15	0.6	0.1%	0.1%	18.4%	18.7%

- At the top of the sheet, define the parameters that won't change
- Within the computation table, declare the adjustable parameters (finger width, finger length, busbar area). Let finger spacing be the independent variable, as shown.
- With the parameters set, compute all of the power loss terms. Use appropriate cell references so you can easily copy & paste and also adjust the parameters easily.
- Be careful with the units and format power losses as a %



2) Create plots of P_{loss} vs. S_f.

- See the plot below as an example. Notice how S_f is the independent variable. This allows us to see what the optimal finger spacing is for a given set of values for w_f, L_f, and A_b.
- Create at least three of these plots (use different sets of parameter values for each).



3) Competition.

- Based on your analysis spreadsheet, settle on what you believe is the optimal front grid design. Draw this design on a new grid paper. On the paper, list your values for w_f, L_f, A_b, and S_f.
- At the start of next class, we will compare everyone's results and see who has the most efficient design.

Submissions. Submit the following two items:

1) On the course website, upload your completed spreadsheet (with 3+ plots showing)
2) On paper, submit your hand-drawn optimal front grid (with parameters listed)

Solar Cell Front Panel Grid Paper

150 mm x 150 mm

2 mm spacing

Orange squares in

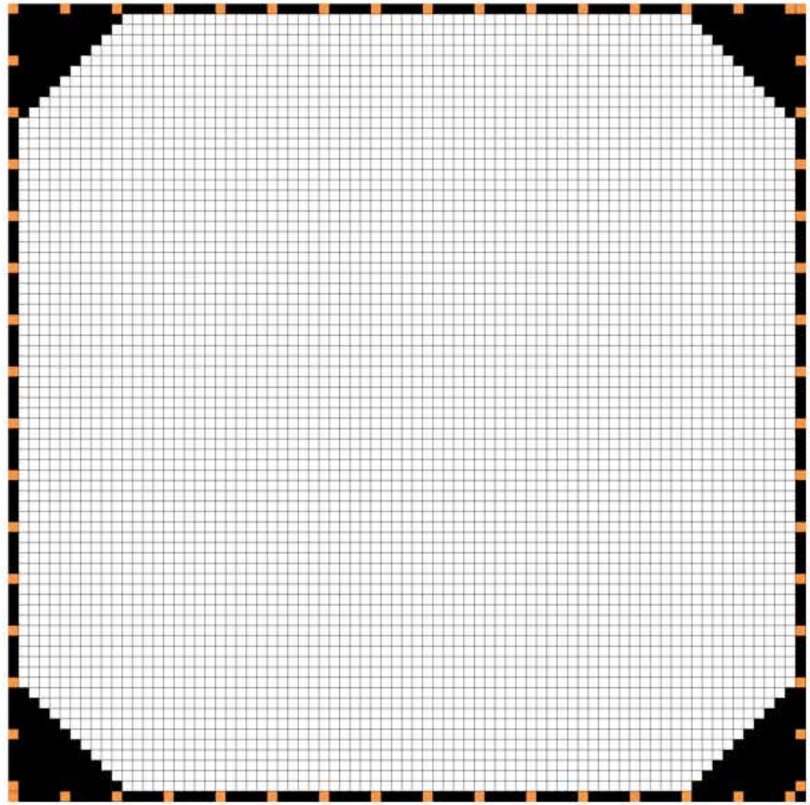
10 mm increments

S_f = ____________ mm

w_f = ____________ mm

L_f = ____________ mm

A_b = ____________ mm^2



$$P_{loss,emitter} = \frac{S_f^2 \, J_{mp} \, p}{12 \, V_{mp}} \qquad P_{loss,finger} = \frac{L_f^2 \, S_f \, J_{mp} \, \rho}{3 \, w_f \, d_f \, V_{mp}} \qquad P_{loss,shading} = \frac{A_{shaded}}{A_{cell}}$$

Enacting a P-N Junction

Subject: valance energy levels, holes and free electrons, changes in electrical charge and movement of electrons (production of current)

Grade levels: Upper elementary and higher

Lesson length: 30 to 40 minutes

Authors: Wendy Cullivan, Jill Murphy

Participants kinesthetically enact the motion of electrons and photons to form a p-n junction, mimicking the production of electrical energy in a silicon solar cell.

Participants should come to this lesson with the following prior knowledge:

- Understand that a photon is energy and creates motion.
- Identify and label the process of generating electricity using a solar cell.
- Recognize that not all photons are the same. Photons have different amounts of energy. High-energy photons are blue; low energy photons are red.

Objectives

➢ *Participants will understand how current is generated in a silicon solar cell.*

Materials

- Colored plastic balls

- Colored tape (blue, red, yellow, gray/black)
- Signs with the following labels: electron, n-type silicon, p-type silicon, hole, current, PN junction

Set up

Make an outline representing a side view of a solar cell as shown here (approximately 10 ft by 10 ft). Include a p-type layer, n-type layer, bus bars and fingers, back contact and circuit attached to an electrical device. The area or tape where the p and n silicon layers meet represents the PN junction, electromagnetic field, and band gap.

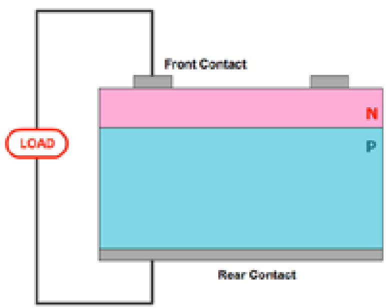
Instructions

Review the process of electrons filling holes in the p-n junction. You might want to visit pveducation.org to review how current is generated in a solar cell. A good animation that explains this process can be found at

http://bit.ly/2o5uELC

Participants can complete definitions for relevant vocabulary words. Definitions could be completed in Flashcard Stash. Participants could be asked to add supporting visuals for each term if possible. Verify definitions found in flashcard stash as accurate based on our content, with the definition in

http://thesciencedictionary.org/



Word Bank

photovoltaic current circuit voltage electricity photon conductor
insulator semiconductor free carrier electrons hole absorption
electromagnetic field visible light spectrum

Students move through the cell as electrons. Each colored plastic ball represents that color of light, wavelength and energy. For the simulation, red will represent low energy or long wavelength radiation (i.e., near infrared to infrared radiation). Red balls will not excite the electrons enough to generate and conduct current. Student (electrons) who are tossed a red ball will not be able to move through the circuit. The teacher or designated students will toss one ball (photon) red or blue to each student (electron). The student (electron) will need to decide if they can move through the cell based on the photon they caught. In order to move thru the cell students will need to have a blue ball. (These high energy photons help create the electrons and holes, and the resulting electric field helps them move across the pn junction.) The electron will move up to, through the p-type layer, and through the circuit to the load and back to the n-type layer. Assign no more than 12 students as electrons and two students to toss photons at the electrons. Each electron should be tossed one photon one at a time. Observe each electron and hole as they move through the solar cell. After the first round, ask students observing to identify correct or incorrect electron movement.

Ask students to answer some of the following questions before continuing on to the final round and clarify any misinformation.

- Electrons have what type of charge?
- What overall charge does the region we call the hole have?
- What do the different colored balls represent?
- Why are electrons who are thrown a red ball not able to move and generate current?
- What causes the electron to separate from the hole and travel through the circuit?

Repeat the simulation but choose different students to be the electrons and photon throwers. As the instructor, you may want to recognize students who move through the cell model correctly. Assign all the observers to a team and ask them to identify and explain errors in the movement of electrons.

Assessment

Students could answer questions below to check for understanding.

1) How is the p type silicon different from the n type silicon?
2) What causes the electron to move from the n-type layer to the p-type layer of the solar cell?
3) What is the relationship between electrons and holes?
4) What would cause current/voltage to vary in a solar cell or panel?
5) What factor(s) would affect the amount of electrical current produced by a solar cell or panel?

Deepen Your Knowledge

Jigsaw activity: Assign groups one question to reflect upon by using the Kagan structure, Jot Thoughts. Independently, students will generate as many responses as possible by writing one response to the assigned question on a sticky note. (One response per sticky note). As a group they will pick out 2-4 essential responses to share with the class. Each group will choose a representative to share responses.

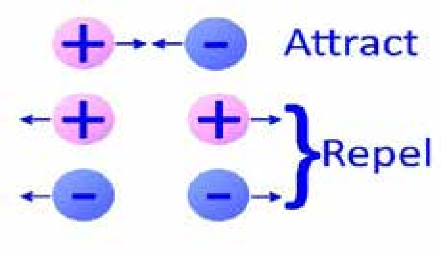
- What would happen to a PV cell if sunlight did not shine on it? Why?
- We know the light bulb won't turn on until the Sun light is shining outside. Why?
- What is the importance of creating a circuit when using a PV cell?
- Why is it important to learn about the process of making a PV cell? How does this process connect to the big picture of solar energy?
- How does creating a model of a PV Cell & acting out the process of how a PV cell works help you enhance your understanding of solar energy?
- How do we use energy in our daily lives? How can you replace those sources of energy with solar energy?

Participants could fill out a chart identifying things they found out, interesting observations, and questions they still have.

Alternative Version

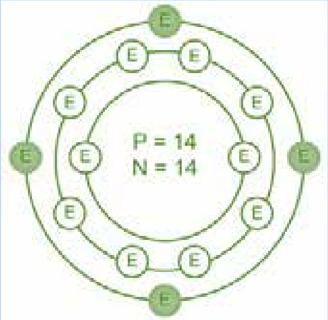
1) One student will stand at the right side of the box with 2 rectangular strips of aluminum foil (represents the metal wires/alligator clips) and a flashlight (represents the light bulb).
2) One student will stand outside to the upper left hand corner of the box with a sun (yellow construction paper of a Sun). Have a few or more students behind the Sun to act as photons.
3) Divide students into 3 equal groups – one group will stand in the N-Junction (extra electrons), another group will stand in the P-Junction (extra holes), and one group will stand behind the Sun (photons). Students should carry signs that represent their group.
4) The "Sun" students will shine light by holding up the paper sun. A "photon" student will walk over to tag the first student in the top section (N-junction/extra electron).
5) The "electron" students will link arms (across the horizontal line in the middle splitting the 2 sections) with a student labeled "hole". They will stay linked for one second then separate.
6) Once separated, the "electron" students will travel to the top & along the outside 'metal wire' line (conductors such as wire) and the "hole" students will travel down to the bottom of the P-Junction (bottom section).
7) Both "electron" students and "hole" students will link arms again (stay linked) showing the recombination of the hole and electron. They signal the flashlight holder to turn on the light which shows a complete circuit.
8) Continue this chain of movement until all students have been linked up and the energy (photons) has hit the last pair of students. Make sure that when each pair links back up again, they signal the flashlight holder to turn on the light, showing a complete circuit.
9) Students can continue this process until all the photons leave the Sun. Explain that, unlike this demonstration, the Sun never runs out of photons.

You can see a video of the game in action on the QESST Education website.



Atoms and their electrons are responsible for generating electricity. Atoms are made of three main subatomic particles. Protons and neutrons are located in the center of the atom called the nucleus. Protons have a positive charge and neutrons are neutral, they have no electrical charge. Electrons are located in the electron cloud and have a negative charge. Positively charged protons are attracted to negatively charged electrons. Opposite charges attract while same charges repel or push each other away. Atoms with an electric charge are called ions.

The electrons in the outer orbit of the atom are called valence electrons. When enough outside energy or force is present, a valence electron can escape the atom and become free. Free electrons can carry a charge and are responsible for the flow of electric current.



Elements with high conductivity can have a larger number of free electrons and are called conductors. Metals like copper, silver, and gold are usually the top choices for good conductors. An element's conductivity measures how tightly bound a valence electron is to an atom. Elements with low conductivity are called insulators. Insulators prevent the flow of electrons or electricity. Popular insulators include glass, plastic rubber, and air. A semiconductor is an element that can conduct electricity under some conditions but not others. Silicon is the most abundant semiconductor. Silicon can be altered by adding other elements (doping) allowing the flow of electrons to be controlled.

Electric fields provide the energy or force needed to generate a current flow. Within a photovoltaic cell, two semiconductor material layers are placed in contact with one another. One layer is an "n-type" semiconductor with an abundance of electrons, which have a negative electrical charge. The other layer is a "p-type" semiconductor with an abundance of "holes," which have a positive electrical charge.

Layering n-type silicon with excess electrons and p-type silicon with excess holes forms a pn junction that creates an electric field. When n- and p-type silicon come into contact, free electrons move from the n-type side to the p-type side. At the same time, the positively charged holes move in the opposite direction, from the p-type side to the n-type side. This results in the formation of the pn junction. This sets up an electric field around the junction. If there is no light being shone upon the device, then current due to electrons and holes cancel each other out and there is zero total current. When light is shone upon the device, the holes on the n side will actually try to go towards the p side.

When the PV cell is placed in the sun, photons (light energy) strike the electrons in the p-n junction and give them energy (kinetic), knocking electrons free of their atoms. Not all photons have the same level of energy; blue photons have the most energy while red have the least. Because some photons have more energy than others, not every photon is able to knock electrons free of their atoms to produce electrical current.

A simple circuit consists of a source of electricity, a path or conductor on which electricity flows (fingers and bus bars) and a device that requires electricity to operate. The flow of electricity is from the positive (+) surface of the cell through the bulb (lighting it up), and back to the negative (-) surface, in a continual flow.

Challenges & Competitions

Challenges & Competitions Introduction

Michelle Jordan

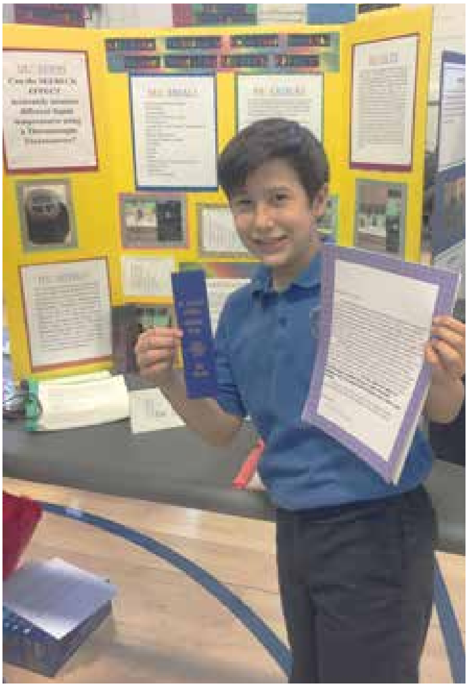
Science fairs and engineering competitions create unique opportunities for children and youth to pursue their personal interests while being mentored by supportive adults. These rich learning experiences usually occur beyond the regular school day and often beyond the school walls. QESST Scholars contribute to these efforts in several ways:

- Volunteering as judges at engineering and science fair competitions, giving feedback on projects, making suggestions for improvement, and encouraging future participation in STEM activities
- Mentoring individual students and small teams for science fairs and engineering competition projects, either in one-to-one settings or in after-school meetings
- Designing solar engineering competitions

Mentoring for Science Fair Participation

One way faculty and scholars conduct outreach is by volunteering as judges at engineering and science fair competitions, giving feedback on projects, making suggestions for improvement, and encouraging future participation in STEM activities. They also mentor science fair participants.

QESST faculty Ganesh Balakrishnan (University of New Mexico) mentored seventh-grade student Matthew Williamson After winning first place at his school's science fair competition in January 2017. Matthew took his project to the University of



New Mexico Regional Science fair competition in March 2017 where he won first prize in the Junior Division in the category of Physics- Specialty Award - with a cash prize of $75, a metal and a certificate.

Matthew's project was entitled, Can the SEEBECK EFFECT accurately measure different liquid temperatures using a thermocouple thermometer? In Matthew's own words,

"Most people do not refer to numbers very well, but they do know their comfort zone. That is why the purpose of this project is to help people understand temperatures better. The hypothesis of this study assumes that the principles of the SEEBECK EFFECT can accurately measure different liquid temperatures by using a thermocouple thermometer. Therefore, it has been predicted that heat can be converted to electricity as it is conducted through different containers and designs (i.e., metal, plastic, and vacuum). When the different temperatures connect, it forms an electrical current. The thermocouple thermometer can accurately measure this current as both heat and electricity. This is a unique ability and feature. The hypothesis of this study was developed through extensive research. Thermocouple thermometers have prompted the use of infrared thermometers with a thermocouple to measure skin temperatures, so why not assume a thermocouple thermometer can measure liquid temperatures through a container. The controls that were tested during this project utilized different liquid temperatures and the thermocouple thermometer. Various liquids (i.e., water, coffee, and milk) were heated in the different containers up to 54.4 ° Celsius. Control of the thermocouple settings and wire were monitored regularly. Interest in this project was sparked after reading a book that teaches how to build a thermoelectric generator to charge your cell phone. That study was far too hard for a seventh grader that has no experience with electrical engineering to study. However, this project is great start to future studies involving electrical engineering."

Matthew also wrote,

"I would really like to Thank my Science Fair Mentor, Ganesh Balakrishnan, with the University of New Mexico's Center for High Technology Materials. He explained things to me so I could understand them and he provided me with a thermocouple thermometer so I could do my experiment. He was so awesome!"

Advice for mentoring high school students

1) Check your students' background knowledge before beginning an activity. High school students are not as well educated college students. Sometime high school students have previous skills and experiences that may help with the upcoming project.
2) Motivation is a big part of the mentoring process. Introducing the importance and significant impact of an activity or project will help the students stay focused and positive.
3) Never ask, "Do you understand?" You will seldom get the answer that will give you the information you need. Instead, try to put the key idea into a specific question that can test if the student understands.
4) Treat students equally. A mentor often has a preference for the "good" students. This is a bad idea. Studies have shown that some students' poor performance is caused by indifference from their mentor.

Xiaodong Meng, QESST Scholar

Designing Solar Engineering Challenges

QESST has a long-standing relationship with the Arizona Math Engineering and Science Achievement (MESA) program. MESA serves middle school and high school students from Title 1 schools throughout Arizona, providing a combination of enrichment activities, hands-on competitions, academic support, industry involvement and supportive community environment. Since its inception in 1970, MESA has a strong partnership with local universities as well as industry. Math and Science teachers from low performing schools are offered free professional workshops. QESST has designed and implemented two solar car challenges for the MESA program. QESST has also provided the equipment necessary for hundreds of students to learn about photovoltaics engineering by participating in solar car challenges. The first challenge entitled, The Solar Car Race, spanned a period of 4 years. Over 300 students participated in this event. During the fall of 2016, QESST faculty, staff, and scholars designed and implemented a new MESA challenge called the Solar Car Obstacle Challenge. Through the solar car obstacle challenge, students have the opportunity to use creativity and innovation as well as engineering practices as they work together to tackle the challenge of building a solar car. QESST's new challenge is more rigorous and requires the participants to learn more PV related content.

1000 Word Challenge

If you've ever done outreach, you know how valuable it is to be able to explain your research and what you love about science in a language that all your audience can understand. This is why QESST implemented a 1000 Word Challenge for their scholars. The requirements are simple: explain your research to the public using only the 1000 most common words in the English language. But describing what you are doing as a researcher and explaining how you are doing it, with such a limited vocabulary, is not simple. Besides, when doing outreach, we should not shy away from using terminology – we should just be aware of it and find meaningful ways for students to make connections to it so they can understand it. Thus, in our implementation, we allowed for a bit more flexibility in the language, without taking the eye from the prize: showing in a manner that's easy to grasp, how Solar Energy impacts our lives and how what we do matters.

Below are three of the winners of this 1000 Word Challenge. We hope you enjoy them!

COPPER IN SOLAR PANELS

Joe Karas, Arizona State University

I'm Joe Karas, an electrical engineering researcher and student at Arizona State University. When I go to work, I try to make special panels that you can put on your roof to collect sunlight. We call them "solar panels", because in some languages the Sun is called "sol". The reason my solar panels are special is because

they turn sunlight into electrical energy. Electricity is what comes out of the plugs in your house and turns on the lights, turns on the TV, and runs the refrigerator. If I do a good job as an electrical engineer, anyone will be able to buy these panels, put them on their roof, and have all the energy they want to turn on as many things as they want.

Right now, your parents could buy some of my solar panels and put them on your roof, but they would cost a lot of money. It would almost be like buying a brand new house! One reason solar panels cost so much money is that they have a little bit of silver inside them, like buried treasure or your Mom's best jewelry. It turns out that silver is really good for helping a solar panel collect more energy from the sun and transport electricity out to where it can be used. I could use something cheaper than silver, but then my solar panels might not work as well. But that's exactly what I'm trying to do!

So, what should I use? Glass, wood, and plastic are great materials because they're very cheap. In fact, they're so cheap that sometimes when we're done with them we throw them away! Nobody ever throws silver away, and other metals cost enough money that we should recycle them instead of throwing them away. But even though those materials are cheaper than silver, they're not good for getting the energy out of the solar panels and into the wires that run through your house.

But let's think about wires for a minute: they're pretty good at carrying electricity! They run from the things you plug into the walls, through the walls of your house, and outside along poles. Those poles go all the way to a power plant, far away. So, what if we just used the same material in a solar panel as we use in a wire?

If you look at the inside of a wire, you'll see that it's made out of a thin piece of metal. Most wires are made out of an orange-colored metal called copper. We use copper for all kinds of things: wires, water pipes, and the coating on the outside of pennies. Copper isn't cheap, but it is much cheaper than silver. Pennies have just a little bit of copper on the outside, less than 1 cent's worth. But if instead pennies were covered with the same amount of silver, they'd be worth 5 cents!

Silver is great for carrying electricity- in fact, it's the best material in the world for carrying electricity. But copper is really great too - it's the second-best! And it's much cheaper than silver, which is why most people use copper instead of silver for making wires. Anybody can afford to buy a little bit of copper wire, they sell it at lots of stores. I want to do the same thing with solar panels. Right now, we make solar panels using a little bit of silver, and it makes the solar panel expensive. If I can replace the silver with copper, I can make it so that anybody, even a kid, could buy a solar panel. With your own solar panel, you could charge your phone or turn on the lights. Or we could make solar panels so cheap that we could give them away to people who need them.

But it's not as easy as it sounds! Copper is just a small part of what goes into my solar panels. We use other materials like silicon, plastics, and glass. Copper has a bad habit of reacting with those materials in ways that cause the solar panel to stop working so well after a while. So my job is mostly to make sure that the copper stays where it's supposed to and doesn't touch the silicon or the plastics. One way I do that is by covering the copper in other metals- like nickel and tin. Nickel is what nickels are made of. Food cans also contains some tin. Nickel and tin don't react with copper, so coating them around the copper in a solar panel helps everything stays right where it's supposed to be. The solar panel lasts for a long time, and if I did everything right, it will provide as much energy after 20 years as it does today.

Powering the World in Colorful Ways

Benjamin Chrysler, University of Arizona

Scientists are always coming up with ideas to make our lives better and safer. Scientists at the University of Arizona want to use the colors of the sun's light to make electricity cheap and safe. Why do they think this idea will work, and how do they plan to do it? First, let's understand how we make electricity now – and how we can already use the sun to do this.

Even though it's invisible, electricity is important in our lives. We use it to light our houses, charge our smartphones, and power our computers and TV's. You already know how to use electricity, but do you know how it's made? Most electricity is made by burning oil – which is cheap. But scientists predict that if we continue to do this, we will hurt the earth by making it hotter than normal and our air will become unhealthy to breathe. This, and the fact that we will one day run out of oil, mean that burning oil is not a sustainable way to make electricity, which means it is something we cannot keep doing forever.

Luckily, oil is not the only way to make electricity. Scientists have known how to make electricity out of sunlight for a long time. Have you ever walked outside on a sunny day and felt the sun's light warm you up? This is because sunlight has energy. Instead of turning sunlight into warmth, a solar cell uses energy from sunlight to make electricity.

When sunlight hits a solar cell, it makes tiny particles called electrons move in the same direction, like a river. This river of electrons is what we call electricity. When you put several solar cells together, you have a solar panel, which makes enough electricity to help power the things in your house. We will always have the sun, and solar panels are safe for the earth – so scientists say that using solar panels is a sustainable way to make electricity.

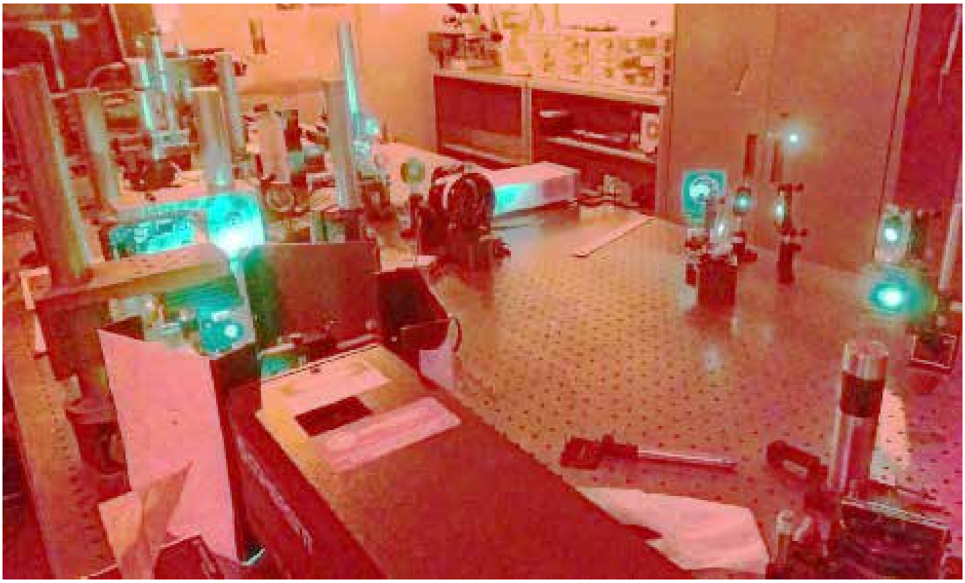
Look Familiar? Solar panels make electricity from sunlight. They can often be found on the tops of houses or parking lots.

Sounds great, right? So why do we still burn oil when we could be using solar panels to make our electricity? The answer has to do with money. It's still cheaper to make electricity from oil than it is from using a solar panel, and many people will not buy solar panels until that changes. Scientists know this, and they are coming up with new ways to make more efficient solar panels. An efficient solar panel is able to make more electricity from the same amount of sunlight. If an efficient solar panel is sold at the same price, then the cost of electricity will be cheaper – you get more electricity without spending more money!

Scientists at the University of Arizona think they have an idea to make solar panels more efficient. Their idea is colorful. But first we have to understand something about the sun's light. Sunlight looks white or a little bit yellow, but it is actually a mix of all the colors – blue, green, red, and even an invisible color of light called infrared. Scientists in the past have learned that solar cells are best at making electricity with certain colors of light. Most solar cells are best at making electricity with red and infrared light, but other types work better with blue and green light.

So why not give everyone what they want? Is it possible to send different colors of the sun's light to different types of solar cells – all within the same solar panel? That is the question scientist Raymond Kostuk and his team of students want to answer. And they think the answer is yes! But first they need to make a hologram. A hologram is a 3D photograph that can send the colors contained within sunlight to the right solar cells.

Dr. Kostuk's team of students spend their time using bright, colored light from a tool called a laser to make holograms for their special solar panel. After using science and math to help them decide how to make the hologram, they hold to show that their idea works in the near future. But first, they need to practice making holograms. They need to do this over and over again while making small changes to get it to work just right.



Scientists at the University of Arizona use lasers to make holograms. This special tool sends out bright green light that travels in a straight path.

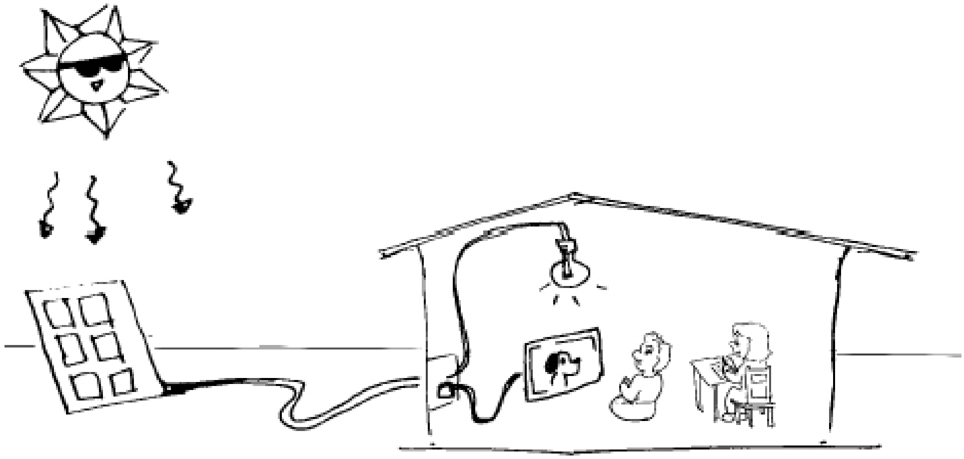
Dr. Kostuk's group is already thinking ahead to how they will set up the new solar panel to test their ideas. Since they do not make solar cells, they teamed up with scientist Zachary Holman's group at Arizona State University to get the right solar cells. With their help, Dr. Kostuk's group now has everything they need to test the new solar panel. If it is successful, the idea could be used in solar panels in the future for a cheaper way to make electricity. If it is not, the scientists will do what they always do: learn what went wrong, and change their idea to make it better.

The Favorite Color of Solar Cells

Silvana Ayala

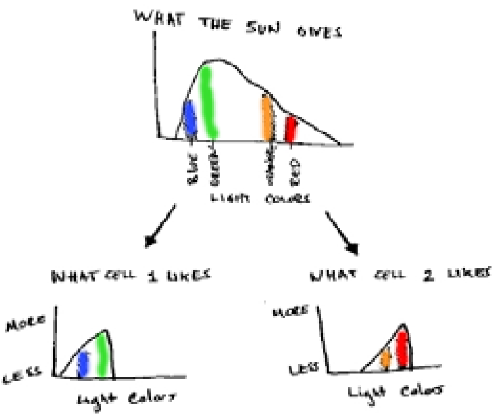
Hello, my name is Silvana Ayala. I am a solar engineering student at the University of Arizona. My work is to make the world a better place, by finding new ways to power everything in your house, like your computer, TV, lights, hair drier, cell phone charger, coffee maker. Most people today use power produced in ways that are not very safe for the world, but I want them to use the sun, because is safe and there is A LOT of it! That's why I study how to best use the sun to power everything you own.

The sun sends us light, which has many more colors than you can imagine. Blue, green, yellow, pink, red... and many colors in between. Fun fact: The sun sends us a lot more blue and green than red, that's why the sky is so blue! But how can we gather that light and make it go into your house? It's not easy: you need something to change it into power you can use. That's why engineering researchers like me created solar cells that like to eat the light from the sun and throw out power you can use in your house.



Solar cells are made from different things, and how you make them so they eat light is a big area of study. Some solar cells like to eat blue and green light, some like more pink and red light. Some like all of the light, but they don't throw out very much power. In my work, I do not make solar cells themselves. Instead, I put different kinds of solar cells together and make different colors of light go to the solar cell that likes it the best. That makes the cells give the most power.

It's like me and my brother used to do when my mother gave us dinner. If we shared our dinner, I gave him what he liked to eat and he gave me what I liked. That way both of us get to eat more of what we like. The only difference is that these solar cells eat light instead of dinner!



But the hard part is figuring out how to make the light go to the right kind of solar cell. But you can do it through Optics! You can use glasses, like the ones your dad might wear to read, with different shapes to make light go into a small, small spot (which is called "focusing"). You can also use mirrors to move light around. You can also use more complicated optics, like grids that are so so so small that they can break the light into the colors! All of this together can make a system that makes the light do what you want. If I can figure out how to make it good enough to not lose any light, and also make it easy to buy, then I'll have figured out how to make this world a better place!

Solar Cars 101

Stefi Weisburd & Joycetta Yazzie

In visits to classrooms, students make and race Pitsco SunEzoon solar cars after an interactive presentation about engineering, solar energy and solar vehicles. I adjust the content of my presentation according to age. For example, I might talk about pn junctions with high school kids and how LEDS and solar cells are essentially the same device just driven in opposite ways, but with younger students I only show them the semiconductor neighborhood of the periodic table along with a photo of a pile of sand next to a solar cell and then a slide of a silicon ingot and wafers to show how they are made.

I can do the activity without much help for 5th graders on up. For children younger than 5th grade, I need additional adults to help the students put their cars together. I also preassemble some parts for younger kids. For example, getting the big gear on the axle is very difficult, so I do that for them. Because there is not that much time in one classroom visit, I make individual kits for each student beforehand. I also show 3 slides to help with construction – one names all the parts in their kits, the second one shows a photo of a partially constructed car emphasizing the first steps (find the tiny, easily-lost 4 axle bearings and put them in the chassis plate, 2 or 3 slots from the edge) and a photo of a finished car pointing out the most critical step of the construction (sticking the motor mount on the chassis so that the motor gear and the axle gears are intermeshed only very loosely). I offer printed instructions if students prefer. I only give out the cardboard cover at the end of the class. For older students, I also leave the entire gear set so they can explore gear ratios later.

Material

- Unfortunately, Pitsco Sunezoon cars are not cheap. With an Amazon Prime account, you can often get a better deal ($11.66/student) including free shipping than going through Pitsco with an educator's discount.
- A slightly less expensive Pitsco car is the SunZoon Lite ($7.97/student in a classroom kit).
- There are alternatives for creating solar cars out of less expensive materials on the Internet, but the solar cells are still pricy. You might keep the solar cells after the activity and give the students batteries (and a holder) instead.

These are the main ideas we try to get across:

1) Engineers solve important problems and improve people's lives (e.g., solar-powered lights for 1.4 billion people who have no access to safe, affordable lighting)
2) The word photovoltaic comes from photons (packets of energy from the sun) and Count Volta (said with a vampire accent), an Italian scientist who lived in the 18th/19th centuries.
3) The first person to observe photoelectric effect was 19 years old Edmond Becquerel. Einstein received his only Noble Prize for explaining the photoelectric effect.
4) From a mere pile of sand we can make amazing devices in our everyday lives: solar cells, LEDS, and computer chips.
5) Solar energy is clean, renewable and abundant, but has some disadvantages for use in cars (clouds, night, need heavy batteries, low efficiency implies need for lots of surface area).
6) Students (not much older than you) who compete in the *World Solar Challenge* in Australia and the *American Solar Challenge* are driving remarkable advances in solar car technology.
7) One student group designed and built a car (called Stella Lux; https://solarteameindhoven.nl/stella-lux/) that is breaking all kinds of records, is the first "energy positive" family car and is street legal in the US and the Netherlands. I usually show a video about this group from YouTube (google "YouTube Stella Lux").

From making the solar car, we hope the students gain an appreciation of how the motor gear drives the rear axle gear, how switching the PV contacts on the motor change the direction of the car, that the car goes fastest when the PV panel is facing the sun, and that the car stops as soon as it goes into shadow. With respect to the latter, some students (and teachers!) sometimes confuse the solar cell with a battery and are surprised that the cars stop so fast.

Questions to Guide Thinking During Solar Car Activities

- Show a slide showing different people's attempts at making solar cars in the past and ask, "What do you notice about solar cars?" (They are flimsy, hold one person)

- Why are we interested in solar? (clean, renewable and abundant energy, climate change)
- Why do you think you don't see solar cars on the street? (panels are not very efficient so need large areas, need batteries if you want to drive at night or when it's cloudy)
- What happens if you switch the solar panel's alligator clips attached to the motor? (the car goes the opposite direction)
- What orientation of the PV panel to the sun makes the car go fastest? (Perpendicular)
- How do you think you could improve your car's speed? (additional or more powerful solar panels, lighter materials; depending on the students' background knowledge, you can bring in the ideas of series/parallel and gear ratios)

<u>What I like about Outreach using Solar Cars</u>

We have been making solar cars with students at Title I, minority-majority schools in New Mexico for nearly five years. New Mexico has the highest rate of childhood the nation poverty and always scores last or near last in the annual Annie E Casey Kids Count reports, so it is extremely gratifying to be able to send the cars home with the children. Most students cannot believe that they get to keep their car. We are now at the point where we are meeting students who say their older siblings received a car, and now they get one of their own. I also meet a lot of older students in other contexts who tell me that they still have their cars.

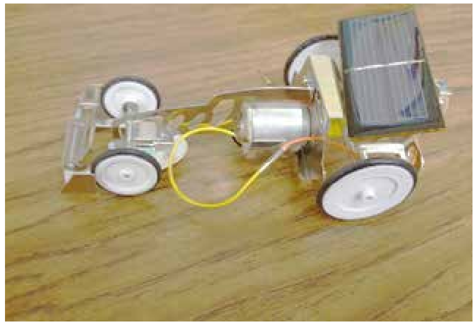
I also cherish the notes and pictures I get from kids. One of the more memorial ones was from a girl who said she did not plan on being an engineer, but she really appreciated the car because it gave her something to do with her younger brother – they took it apart and put it together a million times. Here's a note another non-engineer girl slipped into my pocket as I was leaving her class: "Hey Steffie! Thanks for stopping by our class today to give us those AMAZING solar powered cars! When I grow up I want to be a zoologist! Even though I'm not going to become an engineer I still think that building and creating things should be my part time job! :)" She drew a picture of herself and a lion standing on some boulders. It was all done in purple ink.

An alternative is Lego Solar cars, which use lego parts and gears, lego motor and small solar panels. The following solar car activity was designed by Joycetta Yazzie, a 2016 QESST RET who teaches sixth grade at Kayenta Unified School, Kayenta, Arizona.

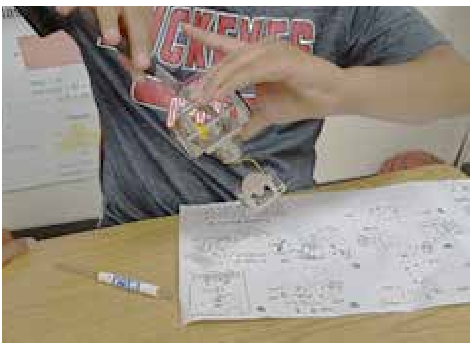
Solar Racers from Ms. Yazzie's class

There is a global demand for energy which leads to a focus on sustainability. On the Navajo Reservation, located in parts of Arizona, New Mexico, and Utah, Native American tribes are becoming more interested in methods to sustain energy. The notion of teaching renewable resources to students can broaden their understanding towards different types of renewable energy, spreading the awareness of sustainability practices related to energy generation and energy use.

Students in Ms. Yazzie's class built their Solar Racer cars using Solaracer kits. They tested their cars multiple times, graphed results, and made their analysis.

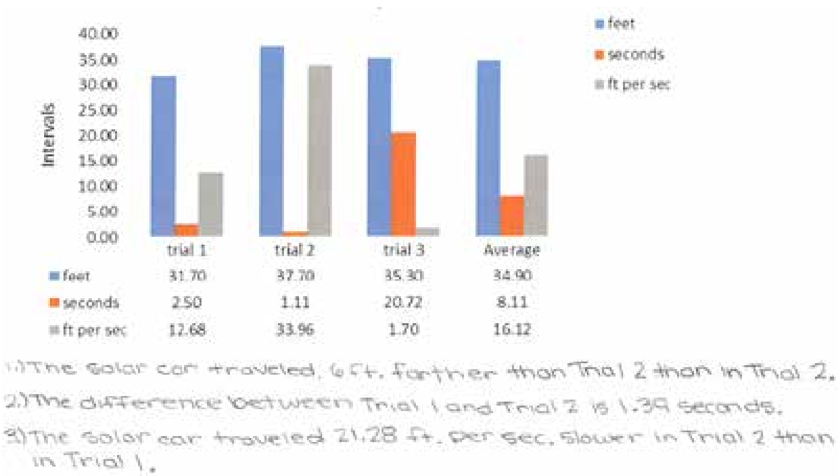


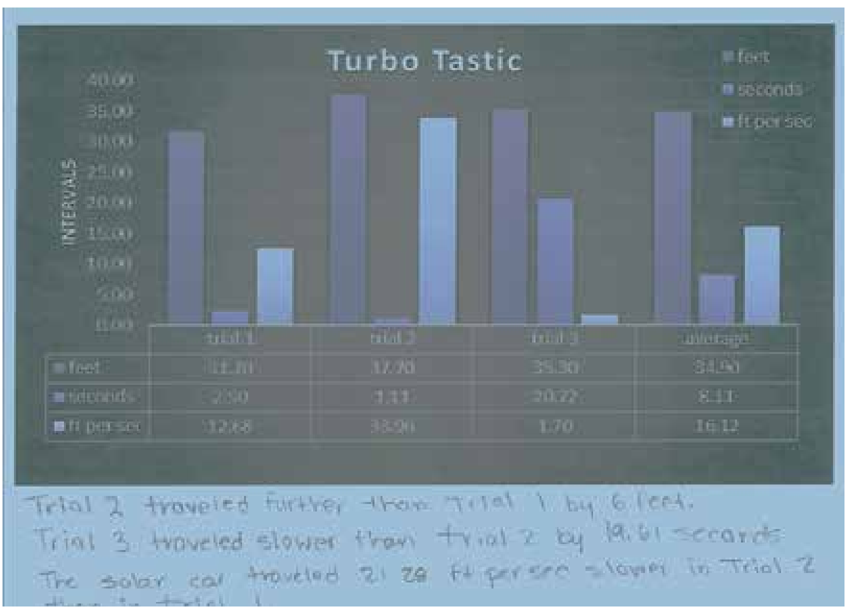
Students were EXCITED to see their Solar Racers working as they were being tested for the first time. They tested their solar cars on three different surfaces; asphalt, concrete, and dirt. The weather was not always cooperating with the activity, either. "CLOUDS, our nemesis!" As one student said.



Students tested their Solar Racer on cement in three trials. They had to measure how far their solar car went in feet and in how many seconds. Testing the solar cars on three different types of surfaces did not work out because the Solar Racer cars were starting to fall apart after testing them for three trials on the concrete. Students were starting to lose their bolts to their cars. They tried to make adjustments here and there to keep them intact, but we knew that they were going to keep falling apart. So, the teacher made the final decision to test the Solar Racer only on the concrete.

Students learned to collect and analyze data using a bar graph created in Excel. They compared their findings on a bar graph rather than a line graph because it was easier to compare the differences between feet, seconds, and feet per second.





Solar Car Challenge
Specifications for Solar Car Race, MESA Competition

Level: Middle School/High School

Number of Teams: One team per school

Team Members: Three to six students per team

Authors: Christi Foster, Katie Nelson, Jenefer Husman, Christi Mendoza

Welcome to the exciting world of the QESST Solar Car Challenge! You have taken on a fun, exciting program that captures the imaginations and creativity of young people, while providing an opportunity for volunteers to share their skills and ideas. There may be some headaches along the way (especially if the sun doesn't shine), but the result will be a great sense of accomplishment. The feedback you will receive from the students, teacher/mentors, and volunteers that participate in this program will make all your hard work worthwhile.

Objective

To design and race a solar car using commonly available materials and certain supplied materials (solar panels, DC motors, etc.) in a head-to-head competition. Performance placement and design notebooks will be used to select finalists and overall winners.

Students will also be required to submit their design budget during specification check for review and scoring.

Materials

All materials are acceptable, except materials that allow the car to be controlled remotely. Judges reserve the right to reject designs that use materials that appear hazardous or may present safety issues, including but not limited to damage to facilities or injury to persons nearby.

<u>Mandatory materials</u>

One 'Junior Solar Sprint Kit' by Solar Made (includes the required solar panel & motor) will be provided to each school committed to participating. The rest is up to each team's imagination! http://www.solarmade.com/JuniorSprint.htm

<u>Optional materials</u>

To construct the body or other parts, teams should consider using a broad variety of low-cost, re-used materials (CDs, lids from food containers, straws, rubber bands, etc.).

Background

Sustainability is the defining challenge of our time. Unprecedented global growth and consumption have created dramatic impacts for society and our planet. How we respond will determine whether the 21st century is one of rebirth and prosperity or an unprecedented disaster for people and nature alike. In the coming decades, transportation in the U.S. is expected to change radically in response to environmental constraints, fluctuating oil availability, and economic factors. The transportation systems that emerge in the 21st century will need to be innovative and will depend on the imagination and skill of today's young people. As future scientists and engineers, you could lead the development of new vehicle and fuel technologies. To do so, you will need to consider mobility, environmental, and economical needs.

Rules

1) Vehicle Dimensions. The vehicle must fit within the following dimensions: 30 cm by 60 cm by 30 cm. The body of the car must be three-dimensional. The solar cell cannot be used as the body of the car (e.g. teams may not bolt the axles and wheels to the solar cell directly).
2) Energy Sources. The sun's light is the only energy source that may be used to power the vehicle. No other batteries or energy storage devices are permitted.
3) Energy Enhancing Devices. Energy-enhancing devices, such as mirrors, are permitted, but must be firmly attached to the vehicle.
4) Safety. Judges may disqualify any entry if, in their opinion, the design might create a safety hazard for spectators, team members, or property. For instance, there must be no sharp edges, projectiles, etc.
5) Testing - Time Allotment. Teams are allowed to make minor design adjustments, such as re-securing parts or adjusting the solar panel. Adjustments before the first trial must be made before the car is submitted for the specification check. In between heats, students will be given 2 minutes to make minor adjustments.
6) Labeling. All entries must be clearly labeled with the entrant's school.
7) Materials. Vehicles are strongly encouraged to be sustainable and should be designed and constructed with mostly recyclable parts. There is no maximum amount that can be spent on the solar car. A budget sheet will be required at the time of the race that lists all materials used for the construction of the solar car and the amount spent per item.
8) Carabiner - For Guide Wire. Vehicles should include a loop able to have a carabiner loop through. It is suggested that the loop jut off of the upper edge of the solar panel or any high point of the car. The carabiner will connect the car to a guide wire so that it avoids other cars.
9) Post-Competition. Teams may claim their cars after the entire solar car competition is officially over. Any cars remaining at the end of the competition will be reclaimed by Arizona MESA and QESST to be used for educational purposes.
10) Modifications. The only aspects of design that may be modified for competition are the angle of the solar panel and any components that need to be re-secured. Students are allowed to approach or set-down their design, and make the necessary adjustments within the time allotted for each trial.

Specification Check

1) Teams will submit their solar car and their design budget for review and scoring.
2) Immediately upon submission for the competition, each design will receive a specification check to determine whether it conforms to MESA rules. Any design which fails the specification check for these 5 areas will be disqualified: 1) Vehicle Dimensions, 2) Energy Sources, 3) Energy Enhancing Devices, 4) Safety, and 5) Budget for Materials.
3) Impound. All components will be impounded at specification check. No alterations will be allowed after this time, but fine-tune adjustments will be allowed later, within the allotted time frame.

Judging

1) Tournament Style. Competition is by process of elimination. Heats of at most 10 cars will be conducted. The first and second place winners will continue on the winner's side of the ladder and eight losers continue on the other side. A car is eliminated when it has two losses. A loss can occur by losing a heat or by not racing the designated heat. It's possible that a few cars won't have two losses before the final heat, but when the final race is run, the race is formally over.
2) Gathering Vehicles. Prior to each heat, teams will be given 1 minute to collect their vehicles from impound and enter the test area. Students will then be given 2 minutes to make their minor adjustments, if they are needed.
3) Heat Inspections. Judges may inspect all cars prior to the final heat or at anytime during and after the heats.
4) Racing Procedure.
    a. Step 1. Stage
        i. The lead judge will call for a heat to "STAGE".
    a. The students will bring their cars to the start.
        ii. The judges will check each car at the start line.
        iii. The judge will indicate any "no shows".
    b. Step 2. Start
        iv. All spectators will be moved back and the announcement is made that the heat is about to start.
        v. Two students will set their cars behind the start line, turn on the motor and shield the sun from the car's solar panel by using the "cover" provided by QESST.
        vi. Start Signal. All vehicles will be started when the official signal is given by a judge. To indicate readiness, the judge will announce, "Drivers, remove your covers!" and the student will remove the cover from the solar panels. The judges will then drop a flag indicating the start of the race.
        vii. If a car cannot get going on its own, it will be permissible to let the student gently push the car to start the momentum.
    c. Step 3. Race
        viii. Students that are racing cars are not to leave their position at the start, or end, of the track during the race, even if their car has become stuck or has stopped during the race.
        ix. Judges cannot be distracted because they are required to watch every race thoroughly. Anyone interfering with a judge or the judge's eye contact with the race will be asked to leave or stay stand back during the race.
    d. Step 4. Finish (3–10 minutes)
        x. The winner will be the first vehicle to cross the finish line or the farthest car down the race track when the race is called.
        xi. At the end of each race the judges will declare the first and second place finishers and will record the time of the first place finisher.
        xii. The judge will announce the first and second winners, so as to avoid disputes later.
        xiii. The judges will begin staging for the next heat.

xiv. Should there be any disputes in each heat, the lead judge will briefly address the dispute with parties making the protest and the other judges at the time of the dispute.

e. Repeat steps *a* through *d* for each subsequent heat

5) False Starts. An early or push start may result in either a disqualification or a re-run. The determination will be left to the judges. Judges will call a false start and restage the heat, if needed.
6) Member Positioning During Heats. At race time, the vehicle will be placed by exactly two team members behind the starting line. All wheels must be in contact with the ground. A small cover, provided by QESST, will be used to cover, but not touch, the solar panel until the race begins. One team member will hold this cover while the other holds the vehicle. At least one team member must wait at the finish line to catch the vehicle. The vehicle and team member must remain at the finish line until the order of the race has been established.
7) Interference. Team members may not accompany or touch the vehicle on the track. Vehicles stalled on the track may be retrieved after the race has ended.
8) Lane Changing. Lane changing or crossing will result in a disqualification for the particular heat. The track lanes will marked with a physical barrier, such as pipes, so the cars may not cross the barrier.
9) Heat Winners. Judges will declare the heat winners.
10) Requests to Challenge Specific Teams. Challenges must be made before the judges begin the next heat. All challenges must come from the team members who are actively competing and must be directed to the judges. Teams may only ask questions concerning their own solar car and time placement. The decision of the judges is final.
11) Tie Breaking. In the event of a tie, a one-on-one race will take place. The first car to cross the finish lane or the farthest down the track after 5 minutes will be named the winner.

Testing Conditions

1) Attendance. Three (3) team members are required to be present during testing.
2) Track Specifications. The length of the race course will be a wild card in this event. It is strongly encouraged that the solar cars be able to travel a distance of a basketball court. The race will be designated with a start line and finish line. The track lanes will be marked with a physical barrier, such as pipes. The track is a hard, flat, smooth surface such as a tennis court or pavement, although teams should be prepared to deal with imperfections in the surface (i.e. cracks).
3) Measurement. Time shall be recorded to the nearest tenth of a second.
4) Ranking Overall Event Winners.
   a. The winner of the double elimination tournament will be declared the Champion Car.
   b. The car with the fastest single heat run overall will be declared the Fastest Car.
5) Design Awards. Beyond the Champion Car and the Fastest Car, the car with the best design will be awarded the Best Car Design award and the car with the most sustainable design will be awarded the Most Sustainable Design award as determined through a quorum of all judges.
6) All participants will receive a QESST Solar Car Challenge Participant certificate.

Resources

These and other resources are available on the AZ MESA website at http://azmesa.arizona.edu/Competition%20Resources

Score Sheet

See next page.

Event Specifications
Solar Care Race
MESA Day 2013

School:____

Student Names:____

____

For Official Use Only

Specification Check: **Pass** ☐ **Fail** ☐

The solar car is clearly labeled with the entrant's school?	Yes ☐	No ☐
The solar car is within the maximum dimensions?	Yes ☐	No ☐
The solar car body is not solely comprised of the solar cell?	Yes ☐	No ☐
No alternate sources of energy are used (e.g. batteries)?	Yes ☐	No ☐
Energy-enhancing devices, if used, are securely attached to the vehicle?	Yes ☐	No ☐
The solar car is safe to compete?	Yes ☐	No ☐
A budget sheet was provided for the materials used for the solar car?	Yes ☐	No ☐

Performance Ranking:

Tournament Champion Car	Yes ☐	No ☐
Final tournament rank	__________	
Fastest single race time recorded	__________	
Best Car Design	Yes ☐	No ☐
Most Sustainable Car Design	Yes ☐	No ☐

Lead Judge Signature:______________________________________

Comments/Suggestions:

Solar Obstacle Course Car Challenge

Level: Middle School/High School

Number of Teams: One team per school for state competition. Three teams for regional.

Team Members: Three to six students per team

Authors: Mark Bailly, Alex Killam, Danny Simonet, Brian Tracy, Max Cotton, Tiffany Rowlands, Michelle Jordan

Welcome to the exciting challenge of solar cars! Here you will find the opportunity to design and build a solar car that completes an obstacle course with three challenges to gain the most points and be crowned the best! Or at least have some fun along the way. Many of you are familiar with solar powered cars. These challenges will help you dive deeper into exactly what makes solar cars run and how to optimize them so they can complete the jobs we want them to do.

Objective

To design and race a solar car using commonly available materials and certain supplied materials (solar panels, DC motors, etc.) in a head-to-head competition. Perofrmance placement and design notebooks will be used to select finalists and overall winners. In these pages you will find:

- *Information about the three challenges in the obstacle course (How do I get points and win?)*
- *Requirements for the Engineering Design Notebook*
- *Extra information about solar energy and car mechanics to help you get started*

Day of Competition Expectation

1) Regional competitions will be run as workshops. They will have the same rules and guidelines as the state competition. However, the focus is on practicing in an authentic setting. NO awards will be given, but you are encouraged to scrimmage against other teams. QESST scholars will be available to help you with questions and ideas.
2) An engineering design notebook is REQUIRED. You will NOT be allowed to compete if your team checks in at the state competition without a notebook or it appears that you just began a notebook.
3) The events will be run as an open "carnival" competition. All three challenges in the solar car obstacle course will be open to compete for three hours. Your team may complete the challenges in any order you decide. You can complete up to three times in each challenge. Only your highest score will be counted.
4) You can make adjustments to your car in order to meet the specific requirements of each challenge. You do not have to change your car in between challenges, but it is allowed if you want. For instance, you can add attachments (such as a snowplow) that are only part of your car for certain tasks.

Vehicle Specifications

1) The vehicle must be safe. For instance, there must be no sharp edges, projectiles, etc.
2) The vehicle cannot exceed the following dimensions: Length: 60cm, Width: 30cm
3) The sun's light is the ONLY energy source that may be used to power the vehicle. No rubber bands, etc. allowed. No extra motors or alternative energy storage devices (such as batteries) of any kind are permitted.
4) Solar concentrators, such as mirrors, are permitted, but must be firmly attached to the vehicle.
5) The body of the car must be three¬-dimensional. The solar cells cannot be used as the body of the car (e.g. teams may not bolt the axles and wheels to the solar cell directly).
6) The vehicle must be clearly labeled with school name.
7) ALL 4 solar panels and motor must be used.

Materials

You may use all types of materials when designing your car. However, you MUST use the four solar panels and motor provided by QESST.

Overview of Obstacle Course Challenges

You will be presented with a series of challenges for your car to complete: a sprint challenge, an alignment challenge, and an impact challenge. Each challenge is worth 30 points. Additionally, you will be required to have an engineering design notebook. The notebook will be worth 24 points. At the end of the competition the team with the most points (out of 114) is crowned the "Overall Obstacle Course Champion Car" winner.

Awards

Awards will be given for the following: (subject to change based on regional competitions)

- Best Engineering Design Notebook
- Overall Obstacle Course Champion
- Fastest recorded time
- Best alignment
- Most cans knocked over during impact

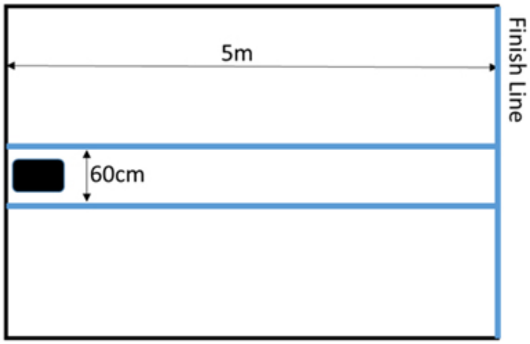
Challenge # 1 - Sprint Challenge

This challenge measures speed. Your car must move 5 meters in the shortest amount of time possible (this is a race against the clock!).

Important design criteria to consider that will help you achieve this goal: (and added to your notebook)

- How straight your car goes (e.g. if it goes sideways it will have to travel farther and thus take longer to cross the finish line)
- Good gear ratio (transfer of power, within limitations of starting)
- Solar cell placement and arrangement (more power means a faster car)
- Body and wheel design (needs to be sturdy enough to make it the distance without falling apart, but weight will also affect how fast your car will move)

Track Specifications

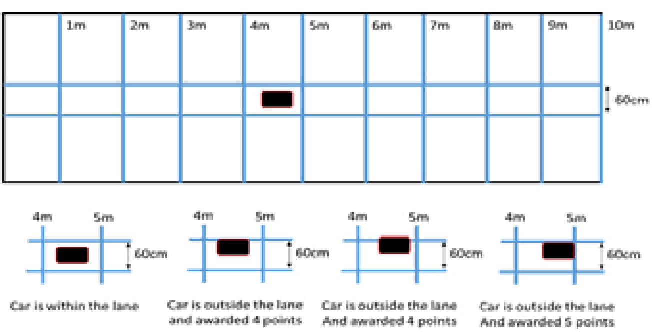


1) The length of the race course is 5 meters over flat terrain such as a sidewalk or similar surface.
2) Race lanes are 60 cm wide. It is recommended that your car stay within the lane, but it is not required for this challenge.
3) Lanes are on concrete and designated by blue painters tape.
4) Points are awarded based on the time recorded according to the chart below.
5) Time is measured from the word "go" spoken by the judges to when the first part of the car crosses the finish line.

Time	Points awarded
0-5 seconds	30 points
5-10 seconds	27 points
10-15 seconds	24 points
15-20 seconds	21 points
20-25 seconds	18 points
25-30 seconds	15 points
30-35 seconds	12 points
35-40 seconds	9 points
40-45 seconds	6 points
> 45 seconds	3 point
Does not reach 5 meters	0 points

Challenge #2 - Alignment Challenge

This challenge measures how well your car can travel in a straight line.



Track Specifications

1) The length of the course is 10 meters over flat terrain.
2) Lanes are 60 cm wide.
3) Lanes are on concrete and designated by blue painters tape.
4) Points will be assessed for every meter traveled down the course inside the lane. As soon as any part of the car is over or comes in contact with the blue tape, this portion of the competition will stop and points will be awarded.
5) Tie breaker: If car has reached the maximum 10 meters, it can continue moving down the track. However, the race lane will become narrower until it becomes 30 cm. The same rules apply (e.g. the car must stay within the lines). The car that goes the furthest distance without going outside the lane will be considered the winner.

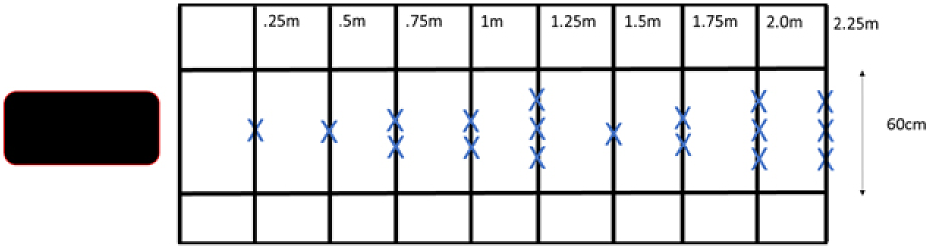
Distance car travels in a straight line	Points awarded
10 meters	30 points
9 meters	27 points
8 meters	24 points
7 meters	21 points
6 meters	18 points
5 meters	15 points
4 meters	12 points
3 meters	9 points
2 meters	6 points
1 meter	3 point
<1 meter	0 points

Challenge #3 - Impact Challenge

This challenge measures your car's ability to remove obstacles from its path, while protecting the car from these obstacles. Specifically, empty soda cans will be placed in the way of the vehicle and the challenge is to remove as many of these cans from the path of travel as possible.

Important design criteria to consider that will help you achieve this goal:

- Torque (turning power) of the wheels (is it sufficient to push the soda cans out of the way?)
- Body and wheel design (needs to push cans out of the path and also keep cans from falling on the solar panels)

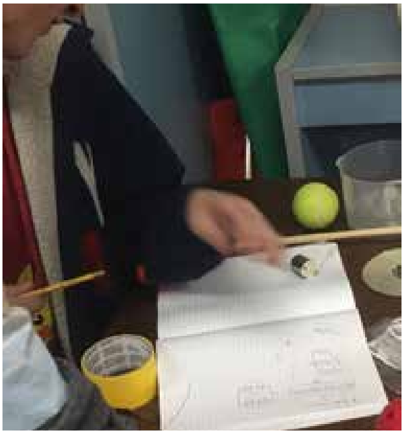


Track Specifications

1) Lanes will be 60 cm wide. Soda cans will be located every 0.25m down the lane, as shown in the figure above.
2) X's will be marked on the ground with blue painters tape, and the judges will place the cans there as shown.
3) Cans will be stacked as follows:
   a. Cans will be stacked one-high for lines 1-5.
   b. Cans will be stacked two-high for lines 6-8.
   c. Cans will be stacked three-high for the final line.
4) For example, there are three cans located at 1.25m. There are six cans (three cans on top of three cans) at 2 m, and nine cans located at 2.25 m (three cans on top of three cans on top of three cans)
5) The front of the car will start at 0 m. The car will move forward and knock over as many cans as it can without help from team members. For example, team members cannot remove a soda can if it falls on the solar panels. The competition will continue until the car comes to a complete stop, passes 2.25m, or goes far enough off course that it will not come back. All cans knocked over will count towards points: i.e. if your car passes one set of cans without knocking them over, you can still gain points for cans knocked over further down the track. Each can that falls over or moves away from the X will count as 1 point. (Total possible points for this competition are 30.)
6) Tie Breaker: The car that knocked down the most cans, traveled the furthest and knocked over the furthest can from the start line. (If you have knocked over all 30 cans and have a remaining ticket, additional cans will be set up. These cans will not count towards more points in the overall competition, but will help determine the individual winner of this challenge.)

Engineering Design Notebook

Engineers document their project work in an engineering design notebook. The purpose is to record written ideas, sketches, work session summaries, research findings, testing results and interview information in chronological order. An engineering notebook is a legal document used to prove ownership of ideas.



Using a notebook will improve documentation, sketching, research, and communication skills. A notebook protects the groups' ideas if a member leaves the project. Your notebook should document at least 3 completed design cycles.

Grading of notebooks will be based on the MESA rubric. The design notebook is worth 24 points. (See APPENDIX C for a student example.)

Notes to MESA Coaches

Teams will receive 3 different colored tickets to each challenge. There is no particular order for teams to compete. The teams will first check in with the lead judge to check vehicle specs (to ensure that no alternative energy sources have been added). They will then present their ticket to the event judge to compete.

As the competition comes to a close, teams will be given a 5-minute warning. If they are not in line during that time to compete, their ticket(s) will be forfeited. Students should be told that time is a constraint. QESST will be running several challenges at a time, so this should not be an issue.

QESST will provide one motor and four solar panels to one team at each school. If more than one team wishes to compete per school, schools may purchase the items below:

- http://www.pitsco.com/Motor_280
- http://www.pitsco.com/Solar_Mini_Panels (1.0 V, 400 mA)

Judging and Evaluation

Disputes

- Teams can only dispute their own results and not dispute or complain about other team's designs/results.
- Should there be a dispute, the Lead Judge should briefly address the dispute with parties making the protest and the other judges at the time of the dispute.

Judges

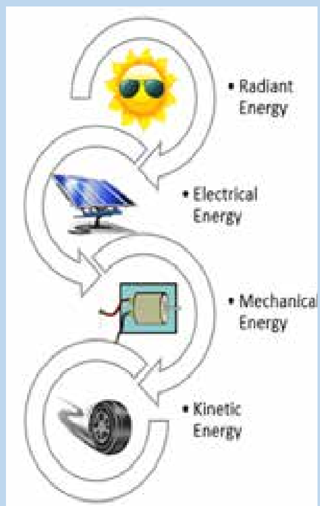
- Judges will be fair.
- Judges will discourage any interruptions to their duties, because distractions can cause a delay in the event.
- Judges will refer people to the committee chairmen, registration or other volunteers for questions and help.

APPENDIX *A*

Background Information to help you design your car

A solar car is an automobile that is powered by the sun. Recently, solar power has seen a large interest in the news as a way to help us reduce our carbon footprint and still power the technology of the future. Here at QESST, we are interested in helping further this goal. That is why we are actively involved in research improving solar cell design and manufacturing. However, once a solar cell is assembled, there is still more to consider before we can use the power to run our device. Namely, how do we connect the solar cells to our devices and how does this affect their performance? These are exciting questions, and we will discuss them more below. But maybe we are getting a little ahead of ourselves. First we need to consider: what is a solar car?

Like all cars, a solar car converts a form of energy into motion. In most automobiles today, gasoline provides the energy, and the engine and drivetrain convert that energy into motion. For solar cars, the sun's rays carry the energy. Solar energy is captured by the solar cells and converted into electrical energy. This, in turn, is converted into motion by the motor. Maximizing the energy captured by the solar panels and transferred to the wheels is crucial in designing a good solar car.

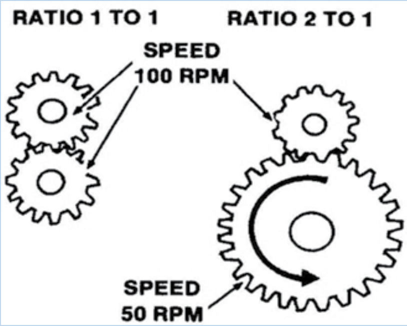


These ideas are captured by two engineering fields: mechanical and electrical. The mechanical design will consider such things as gear ratios, wheel alignment, and weight of the vehicle in order to maximize the energy transferred from the engine to the wheels. The electrical design will consider the energy absorbed by the solar cell and converted into turning power (torque) in the motor. We will treat each one of these separately below.

Mechanical Design

Each team is provided a motor for the solar car obstacle course challenges. Motors perform the important function of converting the incoming energy into rotational motion. Each motor comes with a specific power output and other specs. For this challenge this is a design constraint. (Remember to include design constraints in your notebook).

The objective is to maximize your motion given a certain amount of power. The gear ratio controls the distribution of power to the wheels. A familiar example of this occurs while riding a bike. As you are riding a bike the power is limited (that is the power of your legs). Suddenly, when you go uphill the bike doesn't want to go as fast. You cannot just switch out your legs to get larger muscles so instead you gear down.



What does it mean to gear down? Gear down means controlling the number of turns of the pedal per turn of the wheel. If there are more turns of the pedals per turn of the wheel it requires less power. How does this work? A lower gear moves you a shorter distance for each spin of the pedals, which makes it easier to pedal (but slower).

For the solar car challenge it will be important to consider the gear ratio. This is because the power from the engine is limited and might be less than you want. However, with the proper gear ratio the car can move and possibly even do so quickly.

The wheels are another important design parameter. There are two important things to consider:

1) The friction of the wheels
2) The alignment

Low friction on the wheel's axle will help transfer the most power to move your car forward. The wheels need enough friction so that they can push the car forward. Choice of wheel material and bearing type is important. Your team should experiment with these variables (and log your experiments in your notebook).

Once you maximize the rotation of each of the wheels, you need to sync them with each other. This process is called alignment. The idea of alignment is to make sure all the wheels are pointing in the same direction and not tilted in or out. Without good alignment it doesn't matter how you design your car, it will not move as desired. It is also important to make sure that all the wheels are at the same height and not tilted in the other directions (for more information, google "toe caster camber").

Electrical Power

Solar cars use sunlight to create energy. Each solar cell on your car converts light to electrical power using photovoltaics. Electrical power (P) is calculated by multiplying the current (I) by the voltage (V). We can write this as:

$$P = I\,V$$

- Electrical Power (P) is the rate at which electrical energy is converted to another form, such as your car traveling down the track!
- Current (I) is the amount of electrical charge movement.
- Voltage (V) is the rate at which you can draw or use the current.
- The more current and/or the more voltage you have, the greater the power.

Current and Solar Cells

The more sunlight the solar cell collects, the more current the solar cell generates. The more current the solar cell generates, the more potential power you gain for your car.

What happens if we double the amount of light that the solar cell collects?

Answer: The current will double.

What happens if we double the area of the solar cell (or use two solar cells of equal size)?

Answer: The current will also double.

What happens if we halve the amount of light?

Answer: We will get half the current.

What happens if we halve the area of the solar cell?

Answer: We will get half the current.

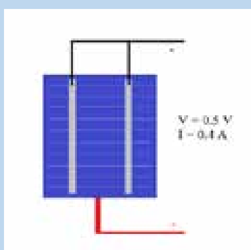
These are not the only factors that control the amount of current the solar cell generates, but they are the main factors. The amount of current coming out of a cell is proportional to the amount of light it collects. Power requires both current and voltage. Unfortunately, there is a tradeoff. The more current a solar cell has to provide, the lower the voltage will be.

The next section will show you different examples of how to connect your solar cells in order to achieve the optimal power for your car.

How to Connect Your Solar Cells for Optimal Current (I) and Voltage (V)

One solar cell looks something like this:

- In this scenario, if we generate a small amount of current, let's say 0.1 A, the solar



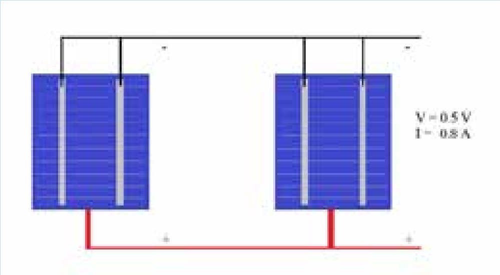
cell will run close to or above 0.5 V.
- If we generate a large amount of current, close to 0.4 A, the solar cell will run closer to 0.3–0.4 V.
- If we had multiple solar cells, how would we get more current?

APPENDIX *B*

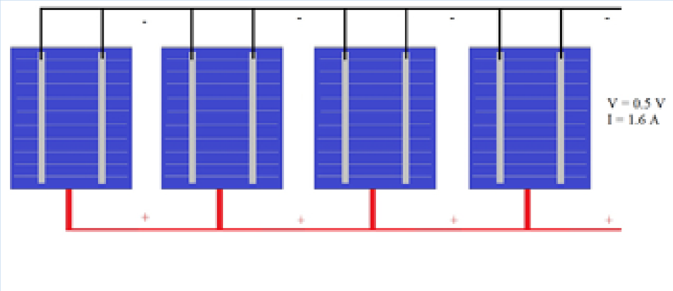
Examples of Parallel and Series Circuit

Parallel Connections

If we take two similar or identical solar cells and connect the negative terminals together (negative to negative) and then connect the positive terminals together (positive to positive), we will create a solar cell that has twice the area (collects twice as much sunlight) and generates twice as much current. This is shown in the schematic below.



Now the new, larger solar cell can provide more current without the voltage dropping as much. If we had three or four solar cells and continued to connect them in parallel, we would continue to increase the current that the solar module would generate. Again, this is shown below:



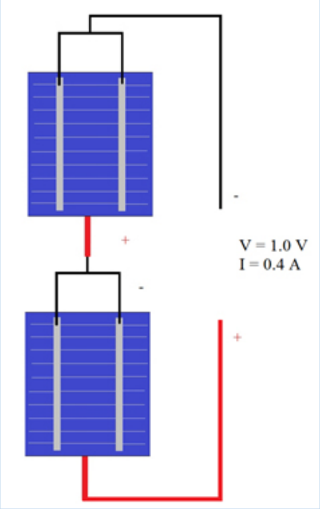
This module (made up of four solar cells connected in parallel) is capable of producing four times the current of any one of the cells. Parallel connected solar cells provide more current while operating at their optimal voltage.

All we've done so far is increase the current of the system. Is there a way to increase the voltage? Yes there is! We can use series connections.

Series Connections

If we take two cells with the same current and connect one negative terminal to one positive terminal, then the remaining two connections will produce two times the voltage with the same current as before.

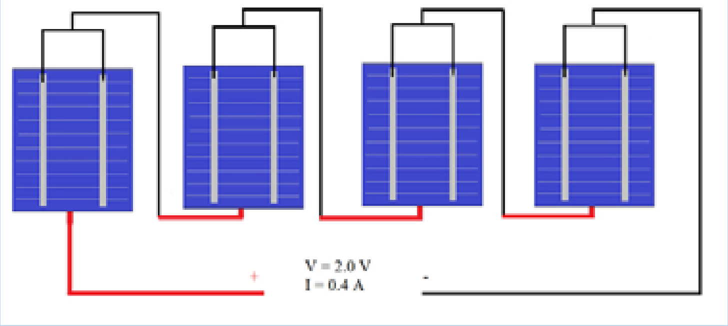
This new module is capable of producing more voltage than the single solar cell, but it does not have more current than the single solar cell.



What would happen if we connected three or four solar cells in series?

Answer: The voltage would increase proportionally.

Can we increase the current and the voltage at the same time? Yes! We have to use a series-parallel configuration.



Series-Parallel Connections

So far, we have dealt with identical solar cells, so we haven't had to match currents or match voltages. However, when you create series-parallel connections, it gets a little tricky.

In a series connection, each solar cell has to produce the same amount of current. If one produces a little less, then the new module will produce less. This is called current mismatch.

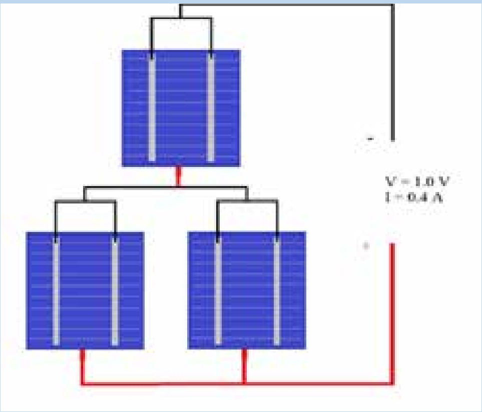
In a parallel connection, each solar cell has to produce the same voltage. If one produces a little less, then the new module will produce less. This is called voltage mismatch.

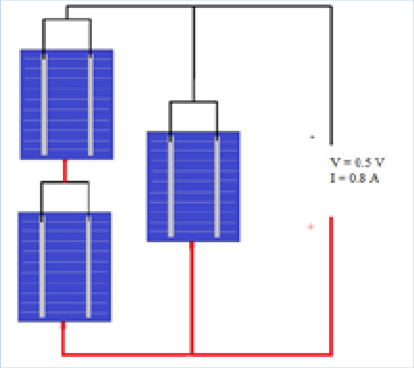
Let's look at some configurations that have these problems.

Current Mismatch

This is when the current of the system is limited by one or more solar cells.

Here, the top cell only wants to produce 0.4 A of current, even though the bottom two cells are trying to produce 0.8 A. Ultimately, this makes a solar module that is limited to the least performing part of the circuit, the 0.4 A solar cell.

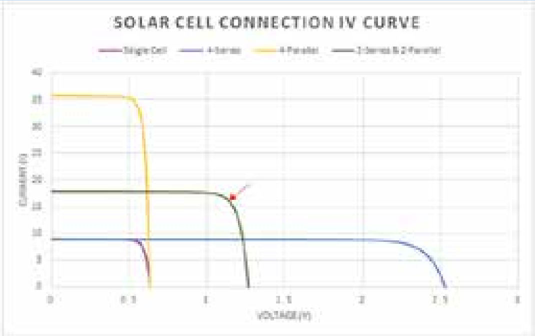




Voltage Mismatch

This is when the voltage of the system is limited by one or more solar cells. Here, the cells on the left are connected in series and want to produce 1.0 V, but the cell on the right only wants to produce 0.5 V. Ultimately this makes a solar module that is limited to the least performing part of the circuit, the 0.5 V of the solar cell.

Cell Connection Summary

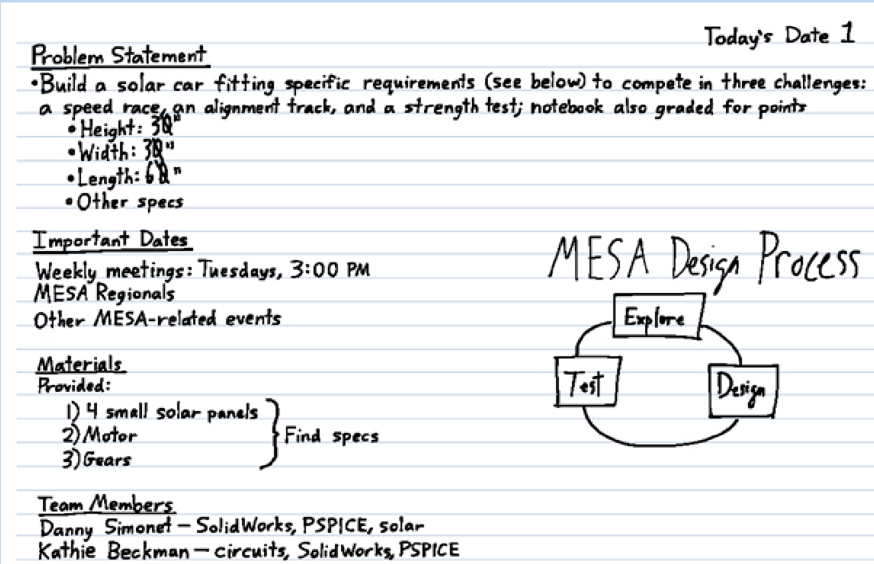


The graph represents how electrical performance is dependent upon the connections of your solar cells. The purple curve shows the electrical performance of a typical solar cell, with a small current (I) and small voltage (V). The blue curve shows that when four solar cells are connected in series the current will remain the same while the voltage increases. The yellow curve shows how current increases and voltage remains the same when you place all four cells in a parallel connection. The dark green curve shows how the current and voltage adds together when you place two series-connected cells in parallel (series-parallel connections).

To get the maximum power you need the maximum product of current and voltage, not just one or the other, where does that happen on the graph? The red arrow shows the place with highest power given the solar cells available. However, this would be something that you could easily test and verify for yourself (and record in your notebook.) Which setup works best for you?

APPENDIX C

Example of Student Design Notebooks



Today's Date 1

Problem Statement

- Build a solar car fitting specific requirements (see below) to compete in three challenges: a speed race, an alignment track, and a strength test; notebook also graded for points
  - Height: 30"
  - Width: 30"
  - Length: 60"
  - Other specs

Important Dates

Weekly meetings: Tuesdays, 3:00 PM
MESA Regionals
Other MESA-related events

Materials

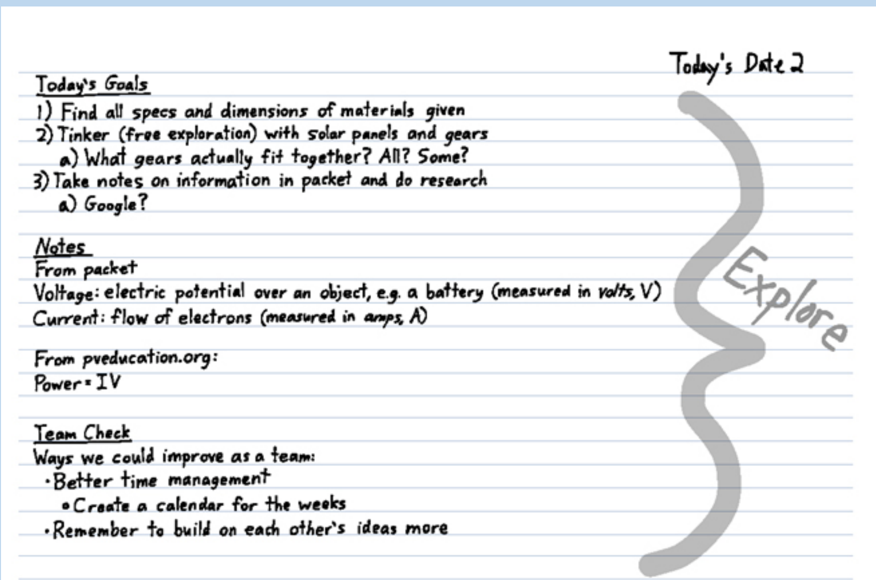
Provided:

1) 4 small solar panels
2) Motor
3) Gears

} Find specs

Team Members

Danny Simonet – SolidWorks, PSPICE, solar
Kathie Beckman – circuits, SolidWorks, PSPICE



Today's Date 2

Today's Goals

1) Find all specs and dimensions of materials given
2) Tinker (free exploration) with solar panels and gears
   a) What gears actually fit together? All? Some?
3) Take notes on information in packet and do research
   a) Google?

Notes

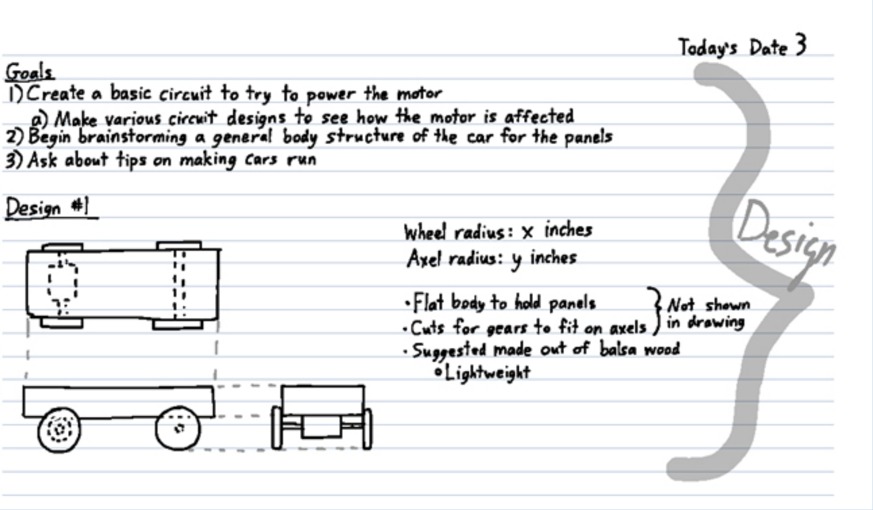
From packet
Voltage: electric potential over an object, e.g. a battery (measured in volts, V)
Current: flow of electrons (measured in amps, A)

From pveducation.org:
Power = IV

Team Check

Ways we could improve as a team:

- Better time management
  - Create a calendar for the weeks
- Remember to build on each other's ideas more

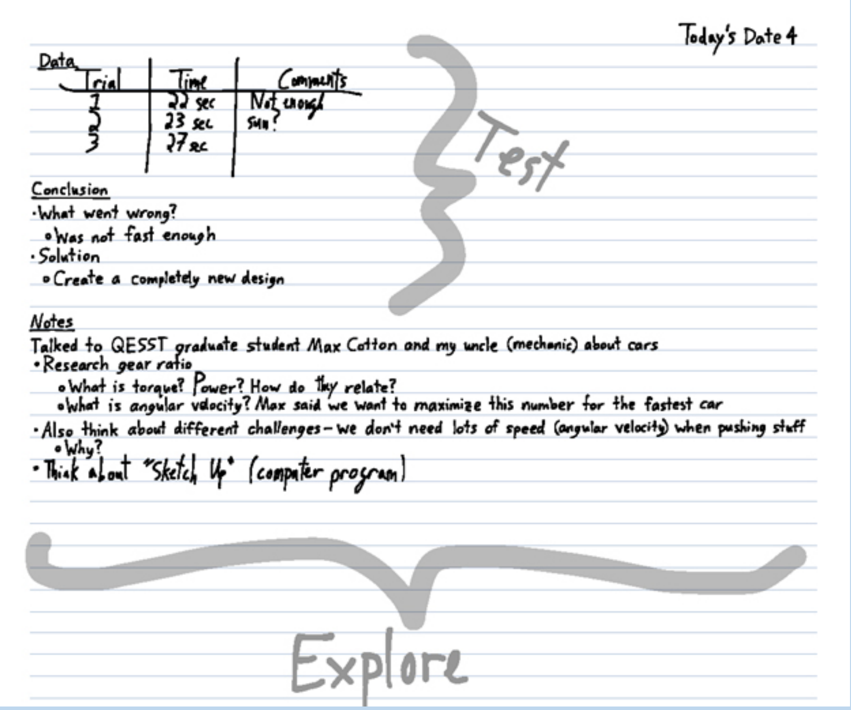

Today's Date 3

Goals
1) Create a basic circuit to try to power the motor
a) Make various circuit designs to see how the motor is affected
2) Begin brainstorming a general body structure of the car for the panels
3) Ask about tips on making cars run

Design #1

Wheel radius: x inches
Axel radius: y inches

- Flat body to hold panels } Not shown
- Cuts for gears to fit on axels } in drawing
- Suggested made out of balsa wood
  - Lightweight


Today's Date 4

Data

Trial	Time	Comments
1	22 sec	Not enough sun?
2	23 sec	
3	27 sec	

Conclusion
- What went wrong?
  - Was not fast enough
- Solution
  - Create a completely new design

Notes
Talked to QESST graduate student Max Cotton and my uncle (mechanic) about cars
- Research gear ratio
  - What is torque? Power? How do they relate?
  - What is angular velocity? Max said we want to maximize this number for the fastest car
- Also think about different challenges – we don't need lots of speed (angular velocity) when pushing stuff
  - Why?
- Think about "Sketch Up" (computer program)

APPENDIX *D*

Helpful links to information about solar energy

- *Conduct experiments related to designing solar cars: http://www.nrel.gov/docs/gen/fy01/30826.pdf*
- *Get ideas for designing solar cars: http://www.nrel.gov/docs/gen/fy01/30828.pdf*
- *Learn more about photovoltaics and powering DC motors. Plus, find ideas for solar science fair projects! http://www.makeitsolar.com/solar-energy-information/07-solar-cells.htm*
- *Understand how a solar cell works: http://www.explainthatstuff.com/solarcells.html*
- *See a video explaining how a solar panel works: https://www.youtube.com/watch?v=xKxrkht7CpY*
- *Here is a lesson on solar concentrators: https://www.teachengineering.org/lessons/view/cub_pveff_lesson04*
- *See a video about why we do solar engineering research at QESST: http://pv.asu.edu/*
- *This is a challenging read, but good information about solar energy and photovoltaics: http://pveducation.org/pvcdrom*
- *AND of COURSE to learn more about what we do at QESST!! https://qesst.asu.edu/*

STEM Profiles

Yongjie Zou

Country of Birth: China

Ph.D. student, Electrical Engineering, Arizona State University

Educational Background: M.S., Materials Science and Engineering, University of Florida

In the first year of my middle school, I borrowed a book from the school library. It's a book about materials that can change our daily life. Some types of metal have "memories". They can be bent or twisted. But after they are heated up to certain degrees, they get back to their shapes before being deformed. Another type of materials, called semiconductors, can absorb sunlight, and convert it into electricity. Some people predicted that cars can be powered using these materials in the future. These materials and technologies all sounded (and still sound) fascinating to me. The pictures painted by this book planted a seed in me, which grew into my interests in science and engineering.

Maybe one day, I can use science and engineering to help improve our lives. I grew up in China. I remember I was sick one day, and my mother took me to the city to see a doctor. We still needed to take a bus to get to the hospital. Cars were running closely after one another, like a troop of ants. Waiting at the station made me even sicker. I didn't want to breathe, trying to hold my breath as long as I could. I have always wanted to protect the environment for us living on earth, and I believe solar power is a great way to achieve this goal. But the thing that hit me hard and drove me to determine to pursue that study of solar energy is a number. A number I learned when I was an undergrad: in China, more than 6,000 people died each year from mining coal so that we can use electricity in our daily lives. I want to change our energy structure into one which relies mostly on clean and safe energy solutions.

Currently, I am doing research on solar energy at Arizona State University. I use physics models to predict the properties of materials, and simulate solar power conversion using these materials. Hopefully my effort can help expedite our search for materials and device structures that give higher solar conversion efficiencies. With higher-efficiency solar devices, we can get the same amount of solar power with smaller area (of land or of vehicles, etc.), less transportation waste, less labor needed. It could also make some impossible applications possible, e.g., solar powered cars, which has a limited surface area. My study here involves reading journal papers, doing derivation of equations, computer programming, and getting my programs to work on a cluster of high-performance computers. Given internet connection, I can basically work anywhere.

Ben Chrysler

PhD Student in Optical Sciences, University of Arizona

Place of Birth: Longmont, Colorado

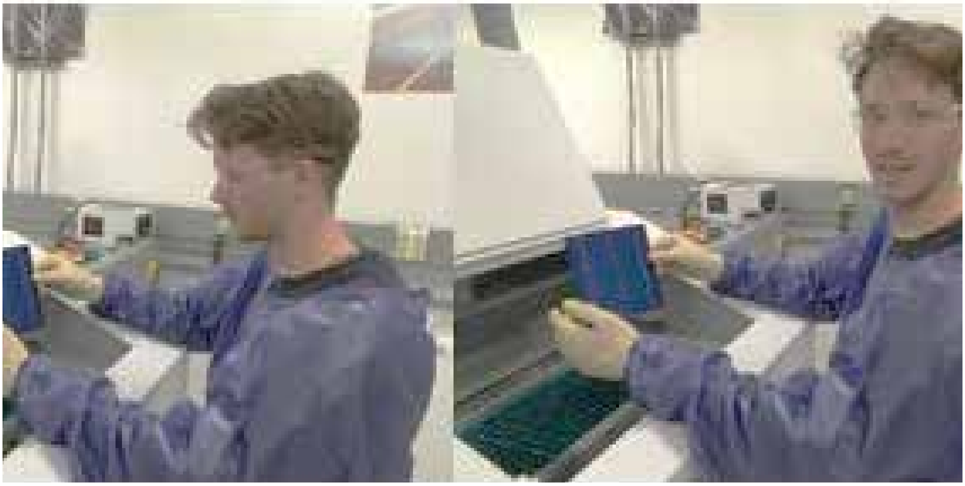
Educational Background : BS, Electrical Engineering, Colorado State University

I have always loved using my imagination. As a kid, I would design buildings, spaceships, and video game worlds in my head as I walked home from school. Math was my favorite subject and I dreamed of combining it with my creativity to solve problems in the real world. My career in science and engineering has given me this opportunity!

As a student in Optical Sciences I study light and invent ways to make light do useful things for the world. As a researcher in solar energy I apply my study to a special type of light – sunlight! Sunlight is important because we have a never-ending supply of it and we can use it to make electricity to power our homes and electronics. I work on understanding sunlight and solar cells better, so that I can make solar panels that produce more electricity from the same amount of sunlight. Solar cells have a “favorite color” that they are best at converting light into electricity. The sun’s white light is collection of many different colors of light. By splitting the sun’s white light into a rainbow of colors and placing the best solar cell under each color of light, we can make more electricity from the same amount of sunlight!

Unfortunately, when I was younger I was told it was very difficult to become a scientist and I did not consider this as a career until I became older. I have since realized that being excited about what you are doing and finding enjoyment in your work is the most important part about choosing your job. These have moved me past the challenges I’ve faced – mostly that there’s not enough time in one day to do everything!

My interests have changed a lot over the past few years – from computer programming to electrical circuit design to lasers and now solar energy. Part of why I love my job as a researcher is that I am free to study the things that interest me. Instead of planning out my whole future, I take it step by step and just make sure I am enjoying what I am doing now.



Joe Karas

PhD Student in Materials Science & Engineering, Arizona State University

Place of birth: Pittsburgh, PA, USA

Education: B.S., Polymer Science & Engineering, Case Western Reserve University

Every day enough sunlight hits the earth to power all of our homes and cars for years and years, if we can turn that sunlight into useful energy. Think about that! The sun rises every day and sunlight is always free, we just have to harness it. That's my dream and that's what I work on every day. Right now, we know how to turn sunlight into electricity, using solar panels like you might see up on a roof. I'm trying to make solar panels affordable enough that every house and building in the world can have them.

I do that by studying Materials Science & Engineering. I look at ways to make solar panels out of common, everyday materials so that they'll be affordable for anyone. Metals like copper and nickel are more common and much less expensive than some of the other materials used in solar panels right now. I try to take the expensive materials out of the solar panel while making sure they do just as good a job at converting sunlight to electricity. Sounds easy, but it's a lot of work!

I got my start in science from my dad. He's a science teacher- in fact, he taught my 8th grade science class! But my dad didn't push me to become a scientist, he just wanted me to be happy. I am happiest when I'm working on big, important problems. Science always gives us the chance to work on big, important problems. Even if my work is just a small part of the solution, I want to work on things that really matter to everyday people. To me, figuring out how to power our homes and cars seems like a really important thing.

That's the way I think about my job, but it applies to almost anything. First, pick a big problem, one that everybody agrees is a really vital problem. Then figure out a small way you can do something about it.

Jacob Clenney

Electrical Engineering student, Arizona State University

I started my career as a nuclear trained electrician in the US Navy for a period of 8 years, serving in the field onboard a fast attack submarine and stateside as an instructor. There I learned how to operate in environments around the world with one of the most highly regarded operating teams in the US. As time passed I garnered the skills necessary to succeed as both a leading member of the crew but also in my future in academics. In the spring of 2014 I separated with an honorable discharge and began my undergraduate degree at ASU in the fall of that year. Since joining, I have excelled in the pursuit of a Bachelors in Electrical Engineering. Maintaining a 3.8 GPA, I have compressed a 4-year degree in only 3 years while also making excellent use of an early opportunity to work under QESST faculty Dr. Bertoni starting my freshman year.

Since my addition to the QESST family, I've has worked on many different projects ranging from construction of laboratory setups to my primary research involving Induction Annealing. Using an Induction Furnace, I have conducted a wide variety of experiments. One example being my work on defect reduction in multi-crystalline silicon which was funded through the Fulton Undergraduate Research Initiative (FURI). Another example is my work on localized contact annealing as presented at MRS 2016. As I finish my final semester as an undergraduate I am also finishing what is to be my first paper of many. Starting in the fall 2017, I will begin yet another project as I embarks on the path to a PhD.

Elizabeth Case

I didn't always want to be a scientist, but caught on to its wonder taking college physics. I'm wrapping up a master's in mechanical engineering at Cornell and moving to Columbia University to study glaciers and ice sheets for my Ph.D. I love the outdoors, and I'm thrilled to have a chance to use the tools I've developed to study the earth and better understand huge, complex, climate-related systems. Plus I'll probably get to go to Antarctica!

I'm drawn to science for its elegance and its ability to both clarify and complicate, and because I find the challenge enticing. Math never came easy to me; I was always a writer. Despite growing up with privilege and resources, I still didn't believe I was capable of being a scientist. This is the kind of thinking I hope I can dismantle among the younger generations through outreach, education and exploration.

Antony Aguilar

Place of Birth: California

Following high school, I enrolled in community college with an interest in forensic science, but soon switched to electrical engineering. Bouncing between four colleges to fulfill credit hours, I took a lot of classes while working at Dave & Busters to support myself. I worked there way too long and decided if I was going to do anything with my life I had to quit. After successfully applying to and participating in the QESST Research Experience for Undergraduates, I transferred to Arizona State University and began working in the HESSC lab. There I became known for fixing lasers, designing Arduino circuits, and installing new safety measures for lab equipment. That's when Stuart (my advisor from QESST) asked me if there was a way to contact probes to a solar cell. Little did I know that would become an IEEE paper and even my dissertation research. I was also invited to present the extended oral talk at the 2016 IEEE Photovoltaics Specialist Conference in Portland, Oregon, which is an unusual honor for an undergraduate student. I nearly passed out before presenting on the day of the conference because I was so nervous – but some people stayed after to talk to me about my research. They wanted to know what future work I was doing. They approached me like an experienced researcher.

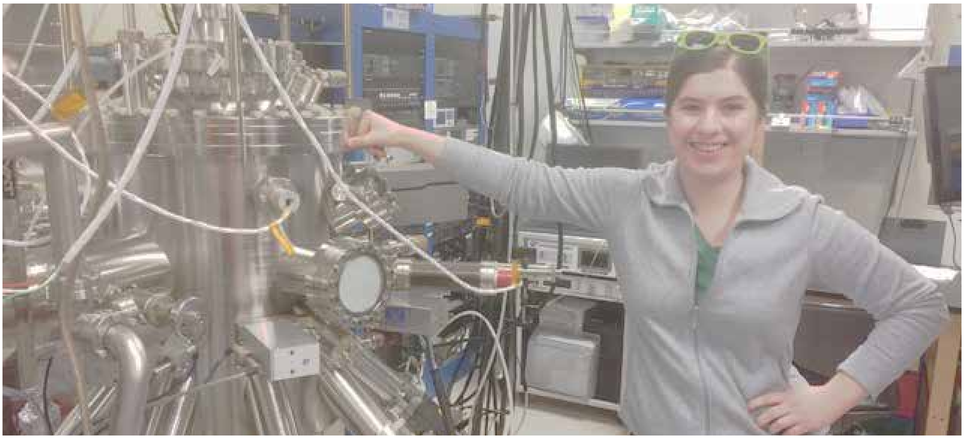
In addition to being a committed scholar, I volunteer often in QESST outreach events. I think it's important to inspire the next generation. I know for a fact if we were missing one of these brilliant people who work at our lab, there would be a huge gap in research. Everything we do here at QESST is important; the more people who do it the more chance we have of developing better solar cells, better, safer, cheaper products. If my high school would have had more outreach programs I probably would have gotten interested in science long before I did. I was good at math and science, but there wasn't much to hold my interest. If I had some inspiration like that, seeing what you could do with science, I might have got here a lot sooner.

Abhishek Iyer

Electrical Engineering student, University of Delaware

I work under Dr. Robert Opila and I've been part of the QESST family since 2015. I did my bachelors in Electrical engineering from SRM University in India. I joined UD in the fall of 2014 and the reason I chose UD from other universities was merely due to the presence of strong solar energy (renewable energy) based curriculum. The presence of the oldest solar dedicated research lab in the world, Institute for Energy conversion at UD made my decision easier. A semester after joining UD, I started working under Dr. Opila in the "hybrid solar cells" project. They're called hybrid because these solar cells incorporate the traditional benefits of both organics and silicon. These induced junction solar cells can be fabricated under lab environment in contrast to high temperature processing involving humongous sized tools in the conventional environment. We have an alternate and innovative way of making a solar cell through solution processing. This was further validated by the NSF I-sites and NSF I-corps program where we ventured on understanding the commercial applications of low-temperature solution-processed based solar cells. During the 7 week program I and my labmate, Jimmy Hack ended up visiting 6 states and talking to over 60 companies in the solar manufacturing, tool manufacturing and related industry. I was chosen the best entrepreneurial lead from the NSF I-corps program for the fall cohort.

Personally, I've always wanted my research to have potential commercial impact and I have had the opportunity to work in that direction under Dr. Opila. One day, I wish to spin off a startup with the cutting edge research we do at Opila lab. With this motive on my mind, I believe I have enough fuel to finish my PhD.



Rebecca Glaudell

PhD Student in Physics, Caltech

Hometown: Glen Ellyn, Illinois

Educational Background: BS, Engineering Physics, University of Illinois at Urbana-Champaign

I have always planned my life far in advance, preferring to know the answer before the question is asked. When I started learning about climate change in high school, I had an answer for what I wanted to do with my life: save the world. At that point, I didn't know how, but as my dad always said, "If you get a degree in physics, you can do anything."

Following my dad and my sister before me to the Physics Department at the University of Illinois, I dabbled in superconductivity research, with the idea of using superconductors in the power grid to reduce power loss at all levels. As I neared the end of my undergraduate degree, I knew I wasn't done learning about physics, but I started to realize that while the basic physics research I was doing fulfilled my need to work with my hands, I wanted to work on the actual devices that would change the world. And so I found myself working on solar cells at Caltech, studying for a PhD in Physics.

Silicon solar cells dominate the market and are approaching their theoretical efficiency limit percent by percent. One of the reasons they aren't at their best yet is some light doesn't make it to the power-producing silicon in the cell, getting absorbed in the current-collecting layers the sunlight first hits. I've been working on using zinc-based semiconductors to redesign the top layers of high-efficiency silicon solar cells to increase the amount of light that hits the silicon and the amount of current then collected from the cell. I get to grow my own samples in a large air-free vacuum-chamber, basically by boiling whatever material I'm interested in, then condensing it on a cooler silicon wafer, just like steam on a pot lid. I love getting to touch and create the science I'm studying, eventually making devices like the ones people have on their houses, or that utility companies use to provide power to the masses.

While my original vision of the future didn't pan out, I know I have found the best place for me right now: I'm doing work I enjoy on something important, I have the freedom to create my own schedule and design my own experiments, and I'm constantly learning more about the world, about physics, and about myself.

Contributors

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Elizabeth Adams is a teacher at Chandler-Gilbert Community College. She participated in the Research Experience for Teachers from QESST 2016.

Cody Anderson is a teacher at Scottsdale Community College. He participated in the Research Experience for Teachers from QESST 2016.

Silvana Ayala Pelaez is a 5th year PhD-track graduate student in Electrical and Computer Engineering at the University of Arizona. She is also pursuing an MS in Optics at the same institution. Her research focuses on the use of holographic optical components to improve photovoltaic performance in concentrating and spectrum splitting systems.

Stuart Bowden presently heads up the silicon section of Arizona State University's Solar Power Laboratory. Dr. Bowden has extensive experience in the characterization of silicon materials for photovoltaic applications. He is also the author of the Photovoltaics CDROM (http://www.pveducation.org/pvcdrom) that has been used extensively as an educational tool in industry and academia throughout the world.

Nereyda Carlos is an undergraduate student at the University of Arizona, pursuing a Bachelor degree in Social Sciences. In collaboration with faculty, she assists in the development of effective laboratory exercises for students at Pima Community College. Occupied as a Lab Specialist and Bio-technician for nine years, her goal is for students to enjoy natural science through positive and memorable experiences.

Benjamin Chrysler graduated from Colorado State University with a B.S. in electrical engineering. He is currently pursuing an M.S. in electrical engineering and PhD Optical Sciences at the University of Arizona. Outside of the university he is an outdoors enthusiast and spends many weekends camping and exploring.

Ann Marie Condes is a physics/engineering teacher at Palo Verde High School, in Tucson AZ.

Maxwell Cotton, seeing a world in need of help while growing up in the southwest, decided to steer his life towards saving the planet with solar power. He earned his bachelors of science degree in electrical engineering and is currently working towards a Ph.D. also in electrical engineering.

Wendy Cullivan is an eighth-grade teacher. She participated in the Research Experience for Teachers from QESST 2016.

Mia DelaRosa is an 8th grade Science Teacher at Sevilla West Middle School. She participated in the Research Experience for Teachers from QESST in 2016.

Ruben Diaz's home has been New Mexico since he was three years old. He grew up in Roswell, a small town known for extraterrestrial speculation, and received a phenomenal education from local public schools. He left New Mexico to attend college at Emory University in Atlanta, GA but ultimately decided to return and serve his community as a science teacher. He has been teaching in Las Cruces, NM for five years now and looks forward to a lifelong career in education.

Emily Finan is in the Ph.D. program at the College of Optical Sciences at The University of Arizona. Her research focuses on optical engineering including the development and testing of a novel microscope and spectrometer system. She is passionate about encouraging women to pursue STEM education and enjoys participating in outreach with the Women in Optics organization.

Jodie Guillen is sixth grade science teacher at Moriarty Middle School in Moriarty, New Mexico.

Danel Hogan is the Director of the STEMAZing Project www.pimaregionalsupport.com/STEMAZing.

Rebecca Hooper is a high school Science Teacher. She participated in the Research Experience for Teachers from QESST in 2016.

Isela D. Howlett is a graduate research associate at the University of Arizona in Tucson, Arizona. Her academic background includes a BS in Optical Sciences and Engineering from the University of Arizona, an MS in Electrical Engineering from Colorado State University, and she will receive her PhD in Optical Sciences in August 2017. Outside of academia, Isela is a certified baker in the state of Arizona for Cakes for Causes and has a house full of rescued animals.

Jenefer Husman received a doctoral degree in Educational Psychology from the University of Texas at Austin, in 1998. She serves as the Director of Education for QESST. Dr. Husman has been a guest editor of Educational Psychology Review, has served on editorial board for top educational research journals, currently sits on the editorial board of Learning and Instruction.

Michelle Jordan is the QESST Education & Outreach Director.

Alex Killam is originally from Newport News, Virginia. He is a 2nd year PhD student in Electrical Engineering conducting research under Dr. Stuart Bowden. His bachelor's degree is from Norfolk State University in Electronic Engineering. Alex's current research project is under PV module performance and characterization.

Jennifer Lumbres is a PhD student at The University of Arizona in the College of Optical Sciences. Her research is in astronomical adaptive optics. A first generation Filipina-American, her dream is to work at NASA as a research scientist. In her precious off-time, she enjoys making green tea flavored chocolate.

Jill Murphy is a fourth grade Teacher. She participated in the Research Experience for Teachers from QESST in 2016.

Kyle B Rawlings is a Physics Professor and Acadmic Advisor at Scottsdale Community College. He participated in QESST's Research Experience for Teachers during the summers of 2013, 2014 and 2015, with projects on solar cell design and fabrication involving laser edge isolation, anti-reflective coating variations, and fabrication techniques.

Tiffany Rowlands is the Pre-College Education and Outreach Coordinator at QESST. Prior to QESST, she taught middle school science for 12 years in Houston, TX as well as Chandler, AZ. In May of 2014, Ms. Rowlands received her Master's Degree in STEM education. Pedagogically, she approaches teaching through the use of modeling instruction. Her experience also includes leadership roles in modeling workshops hosted by Arizona State University.

Liliana Ruiz Diaz was born in Matamoros, Mexico, a small city located next to Texas. This geographical factor allowed her to study physics at The University of Texas at Brownsville, while crossing the US-Mexico border every day. Now, she is pursuing a Ph.D. in Optical Sciences at The University of Arizona where I work with solar energy systems.

Dr. Parikhit Sinha is a Senior Scientist and Director of Sustainable Development, Environmental at First Solar, where he leads the company's research on environmental product safety and life cycle assessment. He has a Ph.D. in atmospheric sciences from the University of Washington, Seattle, and a B.A. in environmental engineering from Harvard University.

Stei Weisburd is the University of New Mexico Outreach Coordinator.

Also contributed to this book: Raymond K. Kostuk, Christi Mendoza, Brian Tracy, Rachel Woods-Robinson, Mark Bailly, Danny Simonet, Tom Fraker, Xiaodong (Leon) Meng, Emily Finan, Emma Renteria, Xuesen Tan, Luca Febbraro, Melisa Jane Bohlman, and Poorva Milind Rajguru. Bios for copy readers Yongjie Zou and Rebecca Glaudel are included as STEM Profiles in this section.

QESST is an Engineering Research Center sponsored by the National Science Foundation and Department of Energy. We are an interdisciplinary team of scientists from universities partnering with solar industry leaders. Our mission is focused on advancing photovoltaic science, technology, and education to address one of society's greatest challenges: helping meet the growing energy needs of the 21st century. QESST is developing new technologies that will make solar energy sustainable, cost-effective, and available to everyone. Want to learn more about photovoltaics and solar energy? Check out this handbook for information and fun activities!

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