Introduction to Solar PV

Instructor note on how to use this module

You can include these as part of your online course materials. This module could also be used by science teachers, VOC tech teachers, counselors, and others to encourage students to go into this field

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Learning Objectives

This presentation covers the following learning objectives:

1. Discuss the needs for solar PV
2. Describe the emerging national trend to shift to solar PV
3. Explain the basics of how solar PV systems work
4. Explain customer benefits in using solar PV
5. Identify business opportunities and career pathways for integrating solar PV
6. Discuss educational pathways (related certifications) and their organizations related to solar PV

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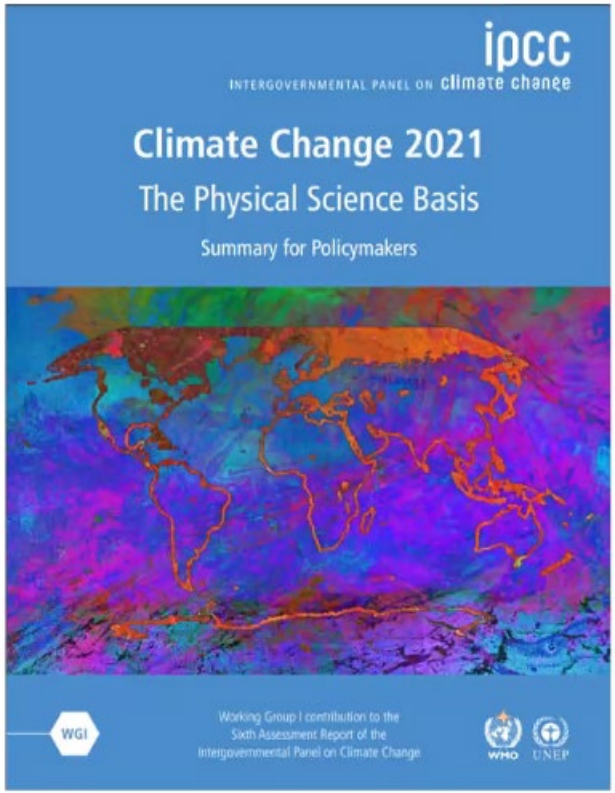
The Environmental Need:

Why solar PV is important

Why do we need a Clean Energy Workforce?

Image source: Energy.gov



We Have A Code Red for Humanity Bigger Crisis than COVID

- IPCC Sixth Assessment Report - Find all reports here
- New estimates of the chances of crossing the global warming level of 1.5°C in the upcoming decades
- Finds that unless there are immediate, rapid and large-scale reductions in greenhouse gas emissions, limiting warming to close to 1.5°C or even 2°C will be beyond reach.
- Finds “unequivocal” evidence more delays “will miss a brief and rapidly closing window of opportunity” for a globally livable future.
    - Called “an atlas of human suffering” by UN Secretary-General António Guterres because it’s a comprehensive look at recent and projected extreme weather events, ecosystem destruction, and their human toll

We are not on track to stabilize the climate. Humans need to:

- Reduce carbon emissions by reducing fossil fuel combustion (coal, oil and natural gas)

- Switch to efficient and renewable energies that are low carbon fuel sources (e.g. wind, solar)

Climate Change Paths of Destruction

- Stronger and more catastrophic weather
  - Damaging winds
  - Major flooding
- More severe wildfires
- Cycles of droughts & flooding affecting communities and agriculture
- Major health-related human impacts
- Economic and environmental disruption

Image Source: USATODAY

AAAS

NEWS JOURNALS MEMBERS CAREERS PROGRAMS GIVING EVENTS ABOUT SEARCH

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Thirty-One Top Scientific Societies Speak with One Voice on Global Climate Change

28 June 2016 Ginger Pinholster *Updated* 28 June 2016 - 11:00am

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"Observations throughout the world make it clear that climate change is occurring, and rigorous scientific research concludes that the greenhouse gases emitted by human activities are the primary driver," the collaborative said in its

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Climate Change Impacts on U.S. Budget

In just **two years**, the U.S. federal government has **paid out over $220 billion in home insurance claims** resulting from wildfires, severe storms, and other natural disasters – **more than the previous 20 years combined.**

Source: BuilderOnline

Studies about the risk of climate instability show many negative impacts:

One example - Climate Change's Deadly Combination: Heat and Humidity - Princeton Study - Source

Massive human suffering - over 3 billion lives are at risk.
80% of the planet's population have already been impacted.

Illinois Impacts From Climate Change

Agricultural impacts

- Weeds, pests, diseases, crop failure

Water accessibility

- Supply problems

Flooding

- Intense rains stress aging urban drainage systems
- Increased flooding from streams and rivers. articularly on the Mississippi and Illinois rivers
- Water borne infectious diseases and mold exposure

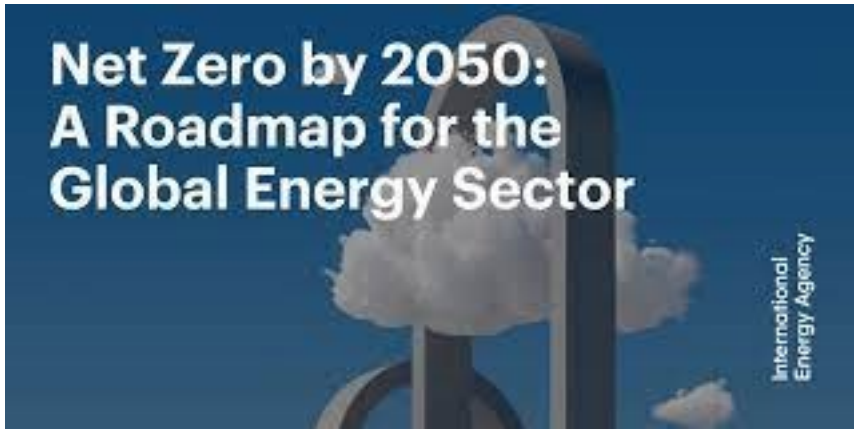
Heat & Temperature Increases

- Hotter summer temperatures will mean longer, more severe droughts.
- Hot temperatures and heat related illness, preventing outdoor work

Source: Nature Conservancy and Miller Magazine

Pathways and Roadmaps Are Available for Solutions - **ONLY IF WE TAKE BOLD ACTIONS NOW**

- International Energy Agency's Net Zero Report - We have to double renewable energies by 2030 and triple by 2050
- Cost-effective and will increase economic growth
- Clean, dynamic, and resilient energy economy dominated by renewables

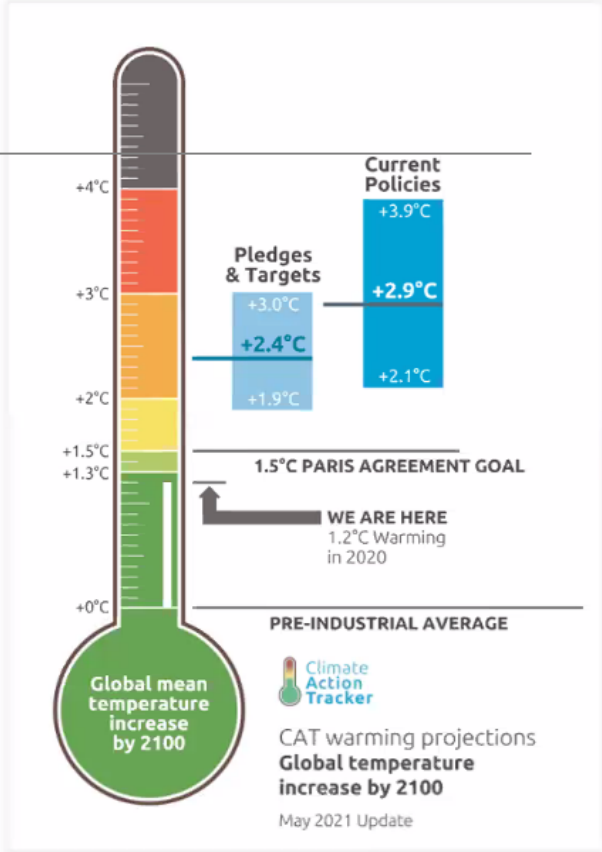


What are you most concerned about regarding climate change and the needed clean energy transition?

More ambitious action is crucial to keep 1.5°C within reach

- IPCC WG1 report confirmed that 1.5 is still within reach, but only with urgent emissions reductions this decade
- Climate Action Tracker analysis shows we're heading for:
  2.9°C under current policies and
  2.4°C under current pledges considered
- Many countries announced net-zero targets

Governments need to urgently bring forward 1.5°C aligned 2030 NDCs



More climate change findings

- Researchers studied 102,160 publications about climate impacts. They concluded that 80% of the world's land—where 85% of humanity lives—has already suffered in some way that can be connected to climate change.
- A Florida-size ice sheet off west Antarctica is called the "Doomsday Glacier" for its possibly epic contribution to sea-level rise. A crack could occur within 5 years, much sooner than expected

Climate change findings continued

- **The biggest unknown in climate science isn't any climate impact, it's <u>if</u> and <u>when</u> people will change**

There is hope!

Minor research miracles occur all the time. We have learned you can potty-train cows. With food rewards, bovines “can be trained to deposit most of their urine in a defined location.” Because separating urine from solid waste can reduce the resulting greenhouse gas emissions, the authors write, “clever cattle can help in resolving the climate killer conundrum.”

Seriously, there is hope. Prioritizing the increase of:

- electric cars
- renewable energies on the electrical grid
- deep decarbonization with building energy efficiency
- reduction of greenhouse gas emissions from the combustion of fossil fuels as quickly as possible

can get us to the science-based targets.

More good news

Increasingly governments, businesses of all sizes and other key employers are greening their job rules, products and processes. This has helped green jobs grow at a much faster pace than other categories.

LinkedIn‘s report shows that demand for green skills will be continuing to grow and outpace the supply of employees educated about green products and processes.

Science based targets, policies and Return On Investments are driving change. Scientists say we need a 50% reduction in GHG by 2030. This is deep decarbonization via:

Energy Transition

Electrification

Energy Efficiency

Cleaner Energy Sources

Many Students Care

Over a third of Gen Z says climate change is a number one concern. Multiple new reports say the climate crisis is pushing young adults to pursue more sustainability-focused career paths.

- Climate is one of the biggest concerns for 76%
- A 2020 Univ. of S CA survey found that 64% of undergraduate students are very interested" in on-campus sustainability.
  - Students Expect Higher Education To Do More On Climate Change

Green Jobs

Illinois' Climate and Equitable Jobs Act (CEJA)

- Passed in September 2021
- Commitment to 40% renewable energy by 2030, 50% by 2040, expands renewable energy by 3.5x each year. This will produce:
- $1 billion in energy bill savings for consumers
- 4,000 MW of new utility-scale solar, and 5,800 MW of new rooftop and community solar to meet 40% renewable energy goal
- Encourages a more diverse renewable energy workforce
- Over 2,000 new solar installations were initiated in the 5 months following CEJA's passing after having been significantly down, with many more to come

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Massive Workforce Development Is Needed

- New employees
- Existing workers and owners (business, community based organizations, government, etc.)

Image sources: IREC USA, GreenBiz

What we all need to know

We need to understand the crucial clean energy transition as a climate change solution that also produces jobs, better health and stronger economies. Information about clean energy can be used in our roles as:

- Consumer
- Worker
- Investor
- Community Member

Solar Workforce

According to the National Clean Energy Workforce Alliance, employers are having difficulty finding the solar employees they need.

Demand for workers is projected to continue to grow.

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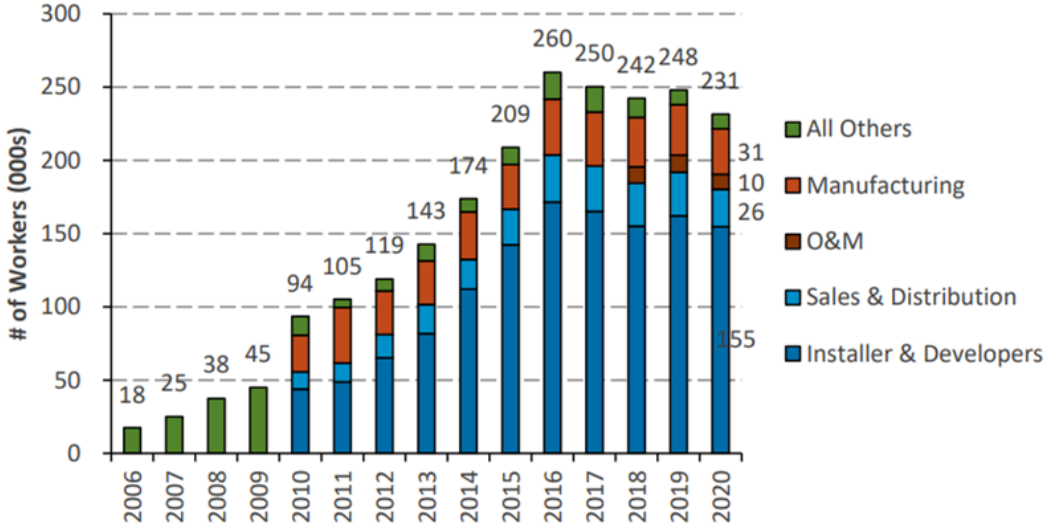
U.S. Solar Workforce

- As of Q4 2020, over 231,000 U.S. employees spent the majority of their time on solar, with another 86,000 U.S. jobs spending under 50% of time associated with solar.
- From 2016-2020, the U.S. reduced its solar workforce, despite installing more annual capacity per year.



- Over half the solar workforce was involved in construction activities.
  - In 2020, 88% of construction employers reported that it was difficult to hire.
- Despite utility-scale PV representing 68% of solar electricity generation in 2020, only 19% of installation jobs were associated with that sector.
  - Conversely, residential PV only represented 19% of solar electricity generation in 2020 but was associated with almost 55% of solar installation jobs.
- Women are underrepresented within the solar workforce, representing 30%, compared to a national workforce average of 48%.
  - African Americans and people 55 and over are also underrepresented, compared to the national workforce, while solar reports a higher representation than the national average of union members, veterans, and non-African American minorities.

Sources. The Solar Foundation, "The National Solar Jobs Census 2020." May 2021. The Department of Energy The U.S. Energy and Employment Jobs Report

Go beyond doom and gloom: **engage in climate change reductions** with the clean energy transition

Policies are driving change. For example, Illinois passed the Clean Energy Jobs Act

- **For example, Illinois passed the Clean Energy Jobs Act**
- **Other Policies too!**

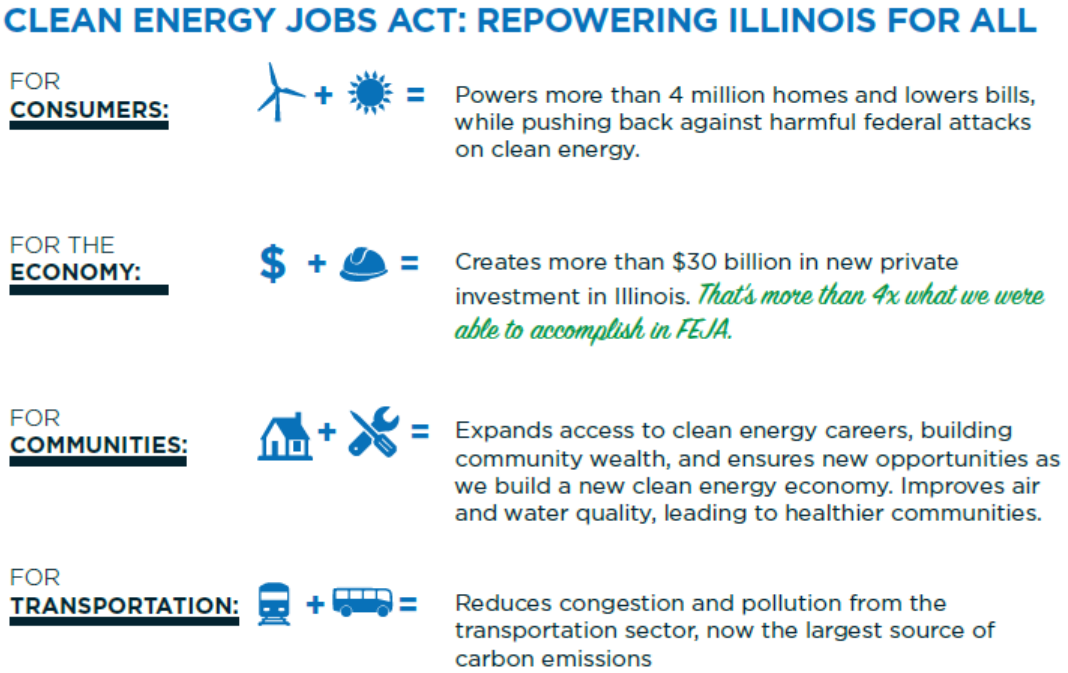


Image source: IL Clean Jobs

Parts of the transition:

Transportation

- Electric vehicles
- Cars, trucks, fleets

Building Design, Construction and Operations for Net Zero Emissions

- More energy efficiency
- Electrification of buildings including their heating systems
- Solar, wind and other clean energies (on-site or from the grid)
- Smart controls and energy storage

Other

- New products in all areas
- Embedded energy and circular economy

Image source: Cleanenergyjobs.org

The growth of green jobs and sustainability

- From MISI – 9% of the American workforce is in a green job already and that number is expected to grow enormously over the next decade.
    - From Emsi Burning Glass – job postings in the green economy were up 17% in 2021 over the previous year.
- The United States Bureau of Labor Statistics projects that employment opportunities for environmental scientists and “related specialists” will grow 8% over the next 10 years, much faster than other industries and these pay ranges are above overall median income levels

The top 2 fastest growing jobs are in wind and solar.

If it is not in your area yet, it will be soon.

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Fastest Growing Occupations

PRINTER-FRIENDLY

Fastest growing occupations: 20 occupations with the highest percent change of employment between 2018-28.

Click on an occupation name to see the full occupational profile.

OCCUPATION	GROWTH RATE, 2018-28	2018 MEDIAN PAY
Solar photovoltaic installers	63%	$42,680 per year
Wind turbine service technicians	57%	$54,370 per year
Home health aides	37%	$24,200 per year
Personal care aides	36%	$24,020 per year
Occupational therapy assistants	33%	$60,220 per year

Solar and clean energy are creating green jobs in all of these areas:

HVAC	Manufacturing
Construction	Business
Transportation	Culinary
Electricity	Agriculture
Technology	Landscaping and Horticulture
Facilities Management	&
Building Design	Many Other Industries

Some example careers in solar

- Installation
- O&M Technician
- Sales
- Project management
- Open a new division of the company
- Retail business owner
- Distribution/Wholesale
- Manufacturing

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Career Pathways

Want to explore careers in the solar electricity industry? Click on each of the dots in this Solar Career Map. This map and its accompanying resources are brought to you by experts in the field to understand what you could do, the competencies for each job role, and more about the solar industry.

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Solar careers in manufacturing

Entry Level (pre-apprentice/apprentice-level, less than 2 years post-secondary education, 1-3 years experience):

- CNC Operator
- Advanced Manufacturing Technician

Mid-Level (journey level, may require associate's degree, 3-5 years experience):

- Instrumentation and Electronics Technician
- Process Control Technician
- Quality Assurance Specialist

Advanced (master craft, bachelor's degree and above, 5+ years experience):

- Electrical Engineer
- Industrial Engineer
- Environmental Engineer
- Mechanical Engineer
- Materials Scientist

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Solar careers in systems design

Mid-Level:

- IT Specialist
- Residential PV Systems Designer
- Engineering Technician
- Utility Interconnection Engineer

Advanced:

- Structural Engineer
- Power Systems Engineer
- Solar Energy Systems Designer
- Software Engineer

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Solar careers in project development

Entry-Level:

- Solar Site Assessor

Mid-Level:

- Solar Marketing Specialist
- Solar Sales Representative
- Building Inspector with Solar Expertise
- Code Official with Solar Expertise
- Electrical Inspector with Solar Expertise

Advanced:

- Solar Utility Procurement Specialist
- Solar Project Developer
- Lawyer with Solar Expertise

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Solar careers in installation and operations

Entry-Level:

- Solar Assembler/Basic Installer

Mid-Level:

- Plumber with Solar Expertise
- Roofer with Solar Expertise
- Solar Crew Chief
- HVAC Technician with Solar Expertise
- Solar PV Installer
- Solar Service Technician (residential)
- Solar Project Manager
- Electrician with Solar Expertise
- Solar PV Technician (commercial/utility)

Advanced:

- Solar Installation Contractor
- Solar Fleet Manager
- Solar Instructor

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Why choose to work in solar? There are many reasons:

1. It feels great to help reduce pollution and care for human and planetary health each day.
2. The jobs cannot be outsourced.
3. It is a field where jobs are growing some of the fastest growing areas in the country (actually, in the world)!
4. You can be an energy hero for your country!
5. This is not only important for you for your career, but it also affects who you are as a community member.
6. Lots of job positions related to solar https://www.irecsolarcareermap.org/

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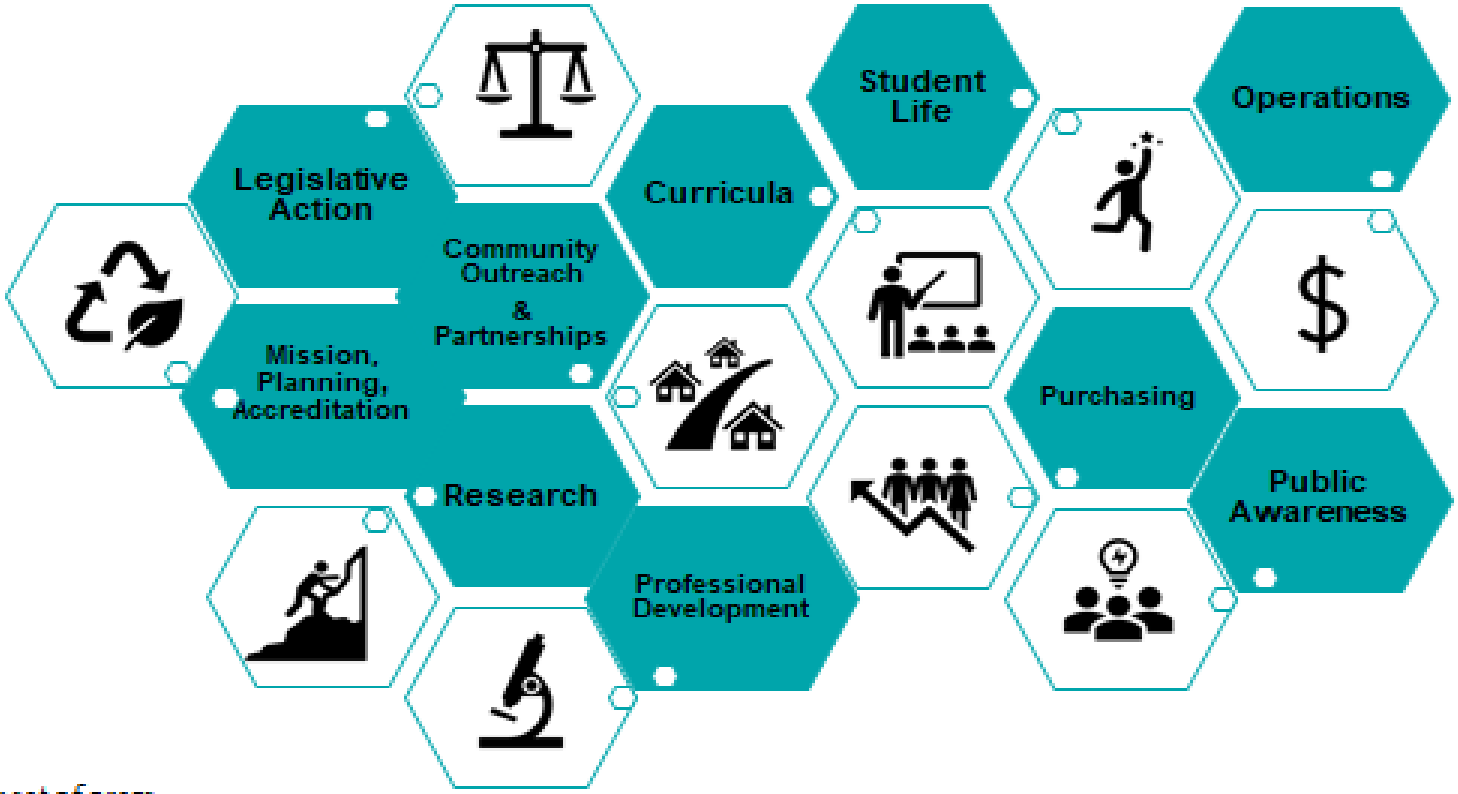
For higher education, sustainability is being integrated into:



Thanks to Wynn Calder for set of areas

Business opportunities and career pathways

Business opportunities for solar PV

1. Distributor - connect manufacturers with dealers
2. Dealer - sell to consumers
3. Installer
4. YouTuber/Consumer Education
5. Content Writer/Blogger
6. Photographer
7. Tutor/Course Developer
8. Financing Service Provider
9. Referral fees from realtors, HVAC contractors, remodelers, builders, mortgage brokers
10. Builders - add solar into the mortgage and get a net positive cash flow
11. HVAC contractor and electrical contractors - could expand to include a solar division
12. Building home performance contractors, insulation companies, remodelers, roofers and others could also expand to include a solar division

Solar PV certifications

Related certifications and organizations solar PV

1) NABCEP https://www.nabcep.org/certifications/
2) ETA https://www.etai.org/renewable_energy.html

Skills Lists/Description PV Associate Job Task Analysis

https://www.nabcep.org/resource/pv-associate-jta/

- NABCEP PV Associate Exam requires a demonstration of knowledge of the:
    - Application
    - Sales & economics
    - Design
    - Installation
    - and operations & maintenance
  - of solar PV systems.
- Knowledge on duties required is broad and fitting for a wide range of entry-level positions

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The emerging national trend to switch to solar PV

The potential of solar PV

- “Enough energy from the sun hits the Earth every hour to power the planet for an entire year.” (DOE)
- Emissions are created through the manufacture of systems, but there are no operating emissions from solar PV
  - Total lifetime emissions of solar PV in 2013: median 50 grams CO2-equivalent/kWh compared to coal at a median of 1000 gCO2-eq/kWh (NREL)
  - Advances in technology are making solar PV more efficient and longer-lasting over time, which is further lowering lifetime emissions
- Increasingly, renewable energies, including solar PV, have been replacing fossil fuels on the grid.
  - “Wind and solar energy displace fossil fuels. A 35% penetration of solar and wind power would reduce fuel costs by 40% and carbon emissions by 25%–45%—the rough equivalent of taking 22–36 million cars off the road—compared to today's system.” (Nagarajan)

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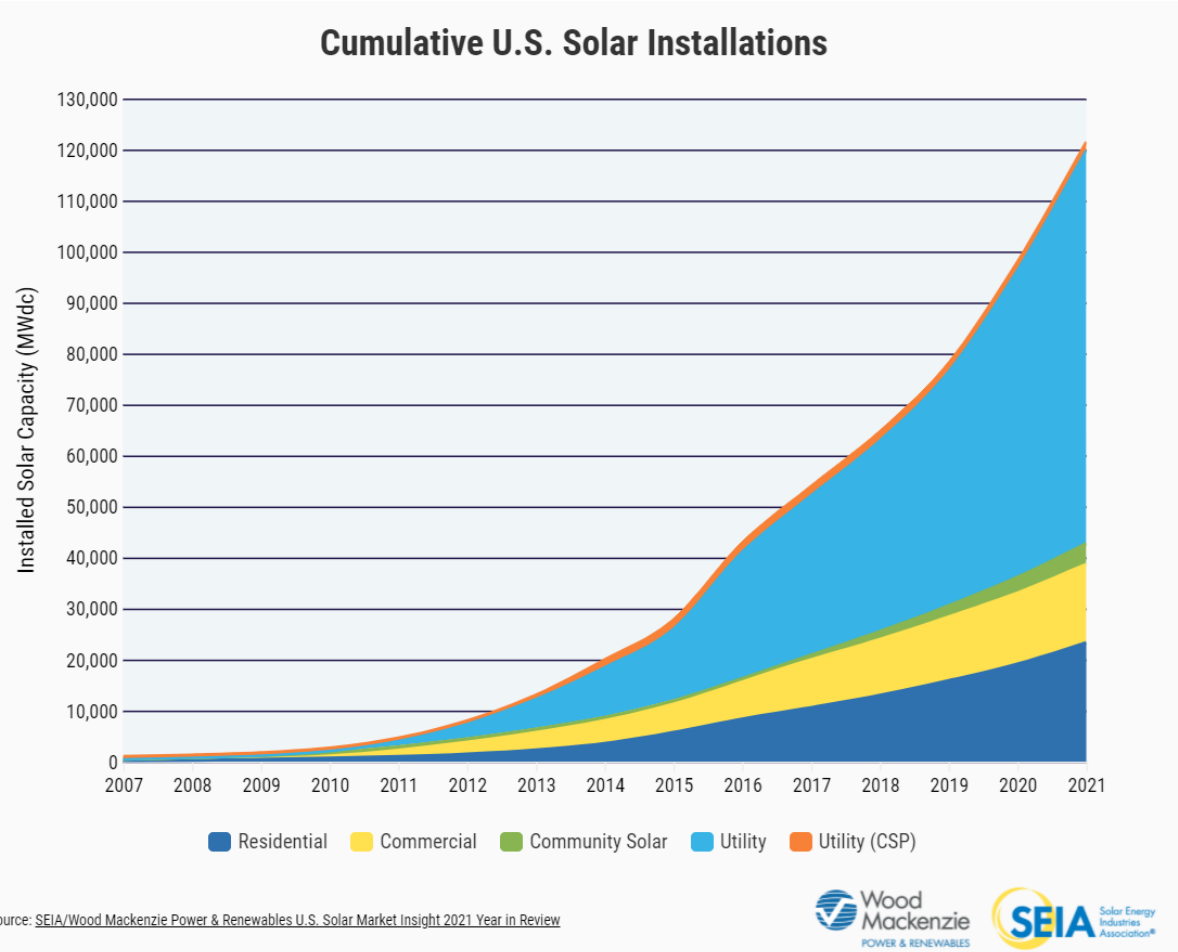
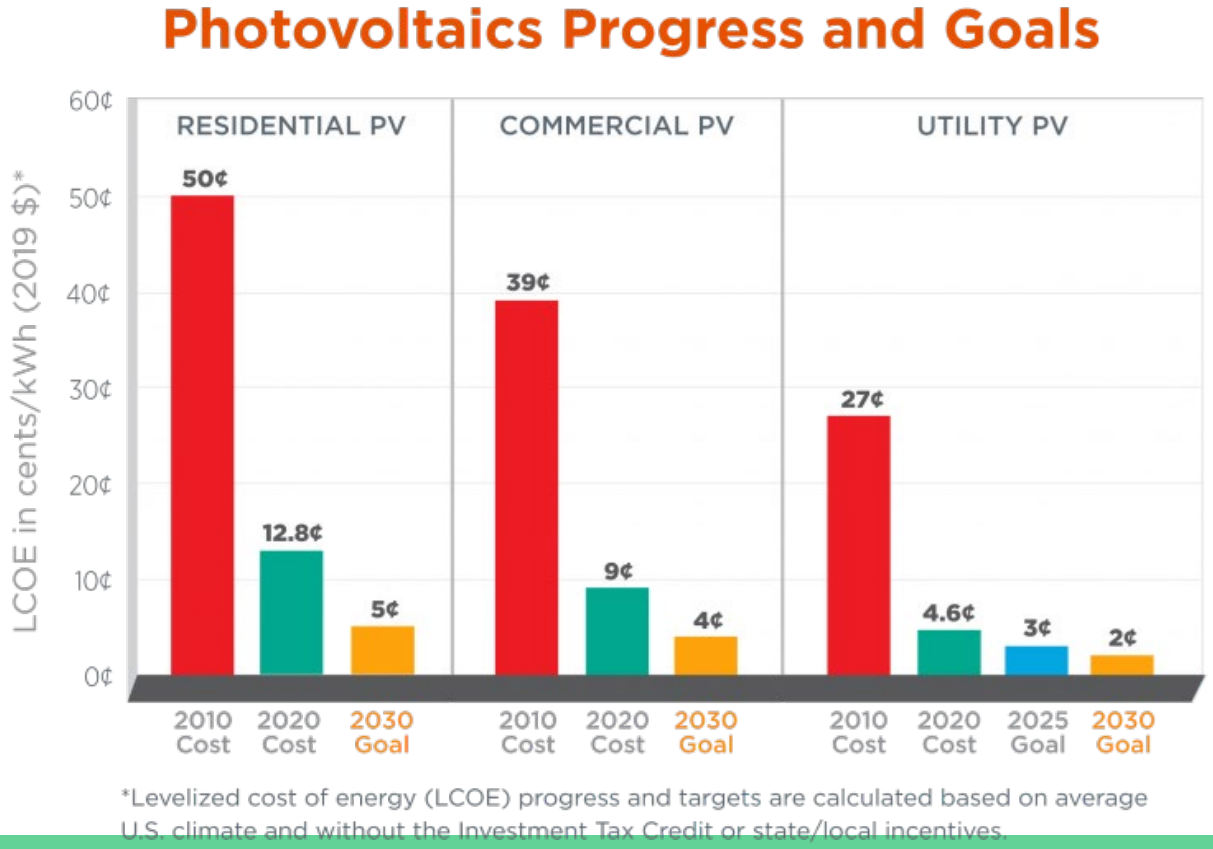
Emerging national trend to shift to solar PV

- Solar energy is growing at a rapid pace at an average annual increase of 33%.
  - Annual installation rate has doubled every 2-3 years for the past 20 years (NREL)
- Over 121 gigawatts of currently installed solar PV capacity – enough to power 23.3 million homes



Source: SEIA/Wood Mackenzie Power & Renewables U.S. Solar Market Insight 2021 Year in Review

Solar PV costs are falling and this drop is predicted to continue



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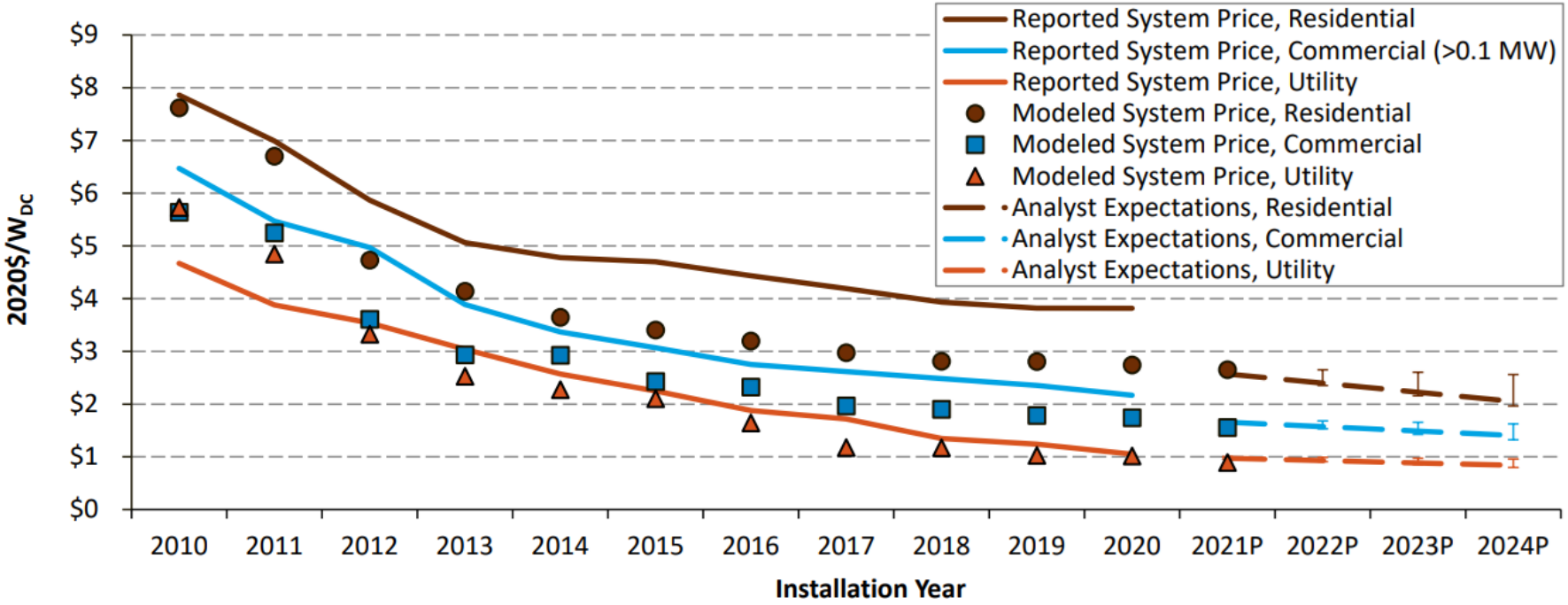
Reported, Bottom-Up, and Analyst-Projected Average U.S. PV System Prices over Time

Historically, reported pricing and modeled benchmarks have had similar results; however, residential PV system price estimates have diverged over time.

All methodologies show a downward trend in PV system pricing.

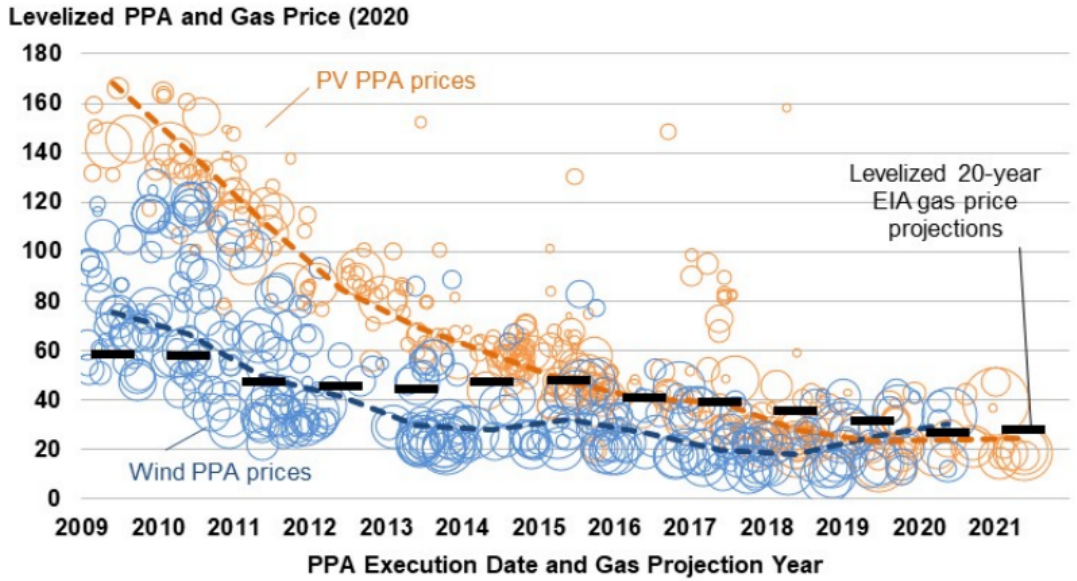


Note: Reported prices represent the median national U.S. averages. Error bars represent the high and low analyst expectations.

Sources: Reported residential and commercial system prices (Barbose et al. 2021); reported utility system prices (Bolinger et al. 2021); modeled system prices (Ramasamy et al. 2021); analyst expectations (NREL 2021 Annual Technology Baseline).

U.S. Utility-Scale PV PPA Pricing

PPA = Power Purchase Agreements
PPA is the price XXXXXX



- In 2021, PPAs for U.S. utility-scale PV systems are priced at $20/MWh for projects in CAISO and the non-ISO West, and $30-$40/MWh for projects elsewhere in the continental United States.
- Nationwide, average PPA prices have fallen by ~85% (or 15% per year) since 2009.
- Solar PPA prices are now often competitive with wind PPA prices, as well as the cost of burning fuel in existing gas-fired generators.

Source: Bolinger, M., J. Seel, C. Warner and D. Robson. 2021. *Solar Empirical Trends in Project Technology, Cost, Performance, and PPA Pricing in the United States: 2021 Edition*. Berkeley, CA: Lawrence Berkeley National Laboratory

Solar is competitive now with natural gas. This means:

- More customer demand and more jobs!
- Solar PV is more accessible to more people, further outcompeting and replacing fossil fuels
- Companies hiring the solar workforce have been experiencing difficulty finding enough people with the right skills in recent years, especially diverse workers

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From the National Renewable Energy Laboratory:

"The future is bright for solar energy. The levelized cost of solar electricity compares favorably with every other electricity generation source. The annual installation rate of solar electricity has doubled every 2–3 years for the past 20 years, and solar panel costs have dropped by a factor of 300 in the past 40 years. States such as California, Hawaii, Massachusetts, and Vermont already derive 10%–20% of their electricity from PV, and there are now more than 300,000 PV-related jobs in the U.S.

Despite these successes, PV is an emerging and fiercely competitive market, with considerable room for further improvements to capture the tremendous potential of solar energy. More than 173,000 TW of solar energy strikes the Earth continuously. This is 50,000 times more than our global energy demand. As we continue to learn to harvest the energy of the sun, these solutions will last for as long as the sun shines. "

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Solar PV in Illinois

- Illinois had enough installed solar PV capacity (as of Q4 2021) to power 176,379 homes with a prediction to triple capacity over the next 5 years
  - CEJA is accelerating the growth of solar, so this will continue to increase

- Currently, 298 solar companies operate in Illinois.
  - 61 manufacturing companies
  - 96 installers/developers
  - 141 others
  - The solar industry has invested over $2.03 billion in Illinois, with $818.15 million of that added in 2020

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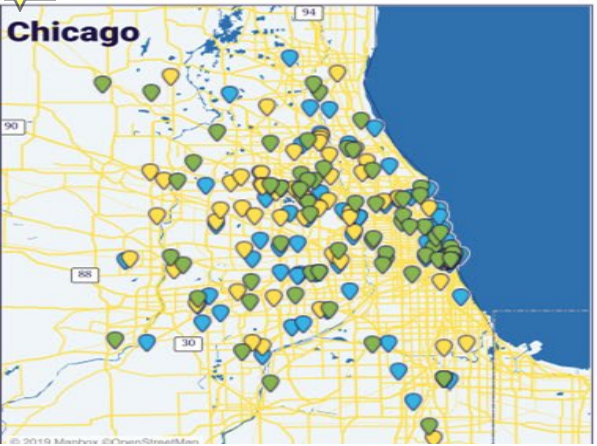
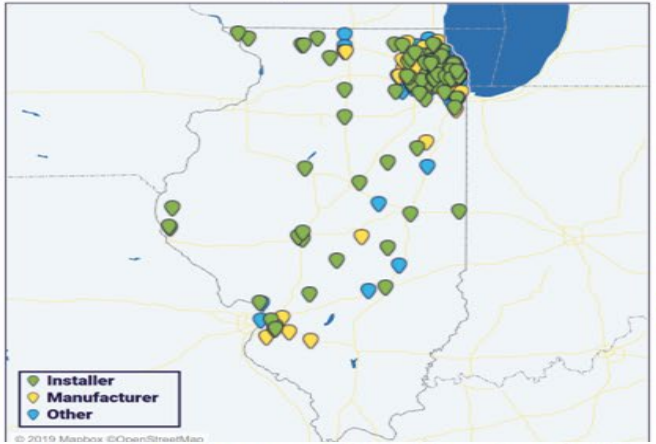
Solar Companies in Illinois

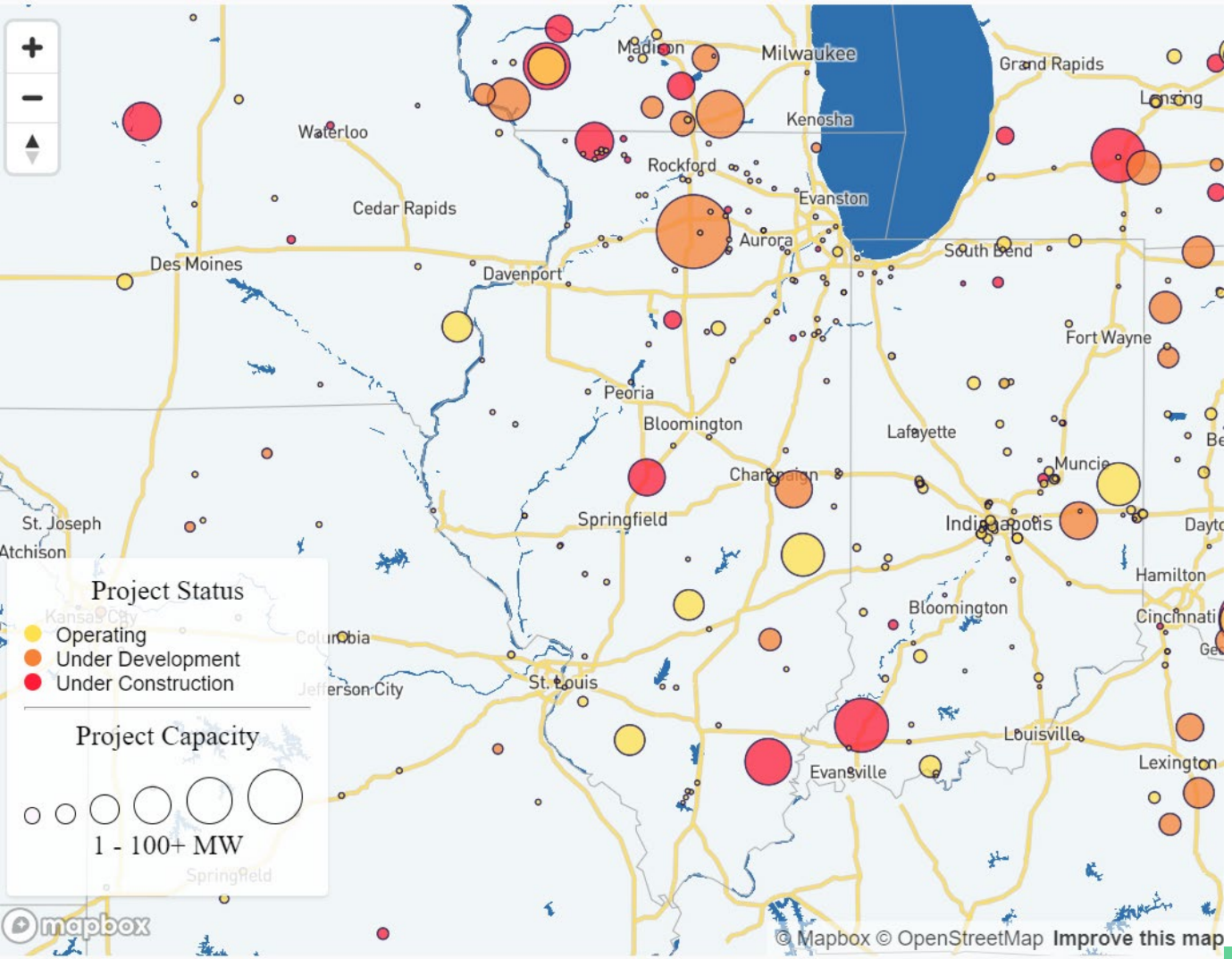




Illinois Annual Solar Installations

Notable Solar Installations in Illinois

- **Grand Ridge Solar Plant** was completed in 2012. The photovoltaic project has the capacity to generate 20 MW of electricity -- enough to power over **3,077 Illinois homes.**
- **IKEA & Walmart** have both gone solar, **IKEA** has installed a **1 MW** project at their location in Bolingbrook.
- Largest solar project in central Illinois (so far) approved in late 2021 for Sangamon County. It is planned to have enough panels to generate 592.8MW of energy, enough to power 85,000 homes – equivalent to enough capacity to power nearly all homes in the county (92,000 as of 2020 census)



From the Solar Energy Industries Association's "Major Solar Projects List" Project Location Map on April 30, 2022. See https://www.seia.org/research-resources/major-solar-projects-list for updated map

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Video: Powering Your Home With The Sun: Solar 101 from Illinois Solar Energy Association

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

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The basics of solar PV

What is solar energy?

- “Enough energy from the sun hits the Earth every hour to power the planet for an entire year.”
  - From the US Department of Energy’s “Energy 101: Solar PV”, embedded below

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Basic Principles of Sunlight

- Sun releases energy as electromagnetic radiation
- Every area of Earth receives sunlight at least part of the year
- Amounts vary based on location, time of day, geography, weather, and time of year
- Sun hits the Earth at different angles from 0° (least recoverable energy) to 90° (most recoverable energy) due to Earth's shape and axis of rotation
- Earth's elliptical orbit around the sun with a consistent tilt allows more sun to hit different parts of the Earth during different times of the year, creating seasons.
    - Earth's tilt also creates different day lengths

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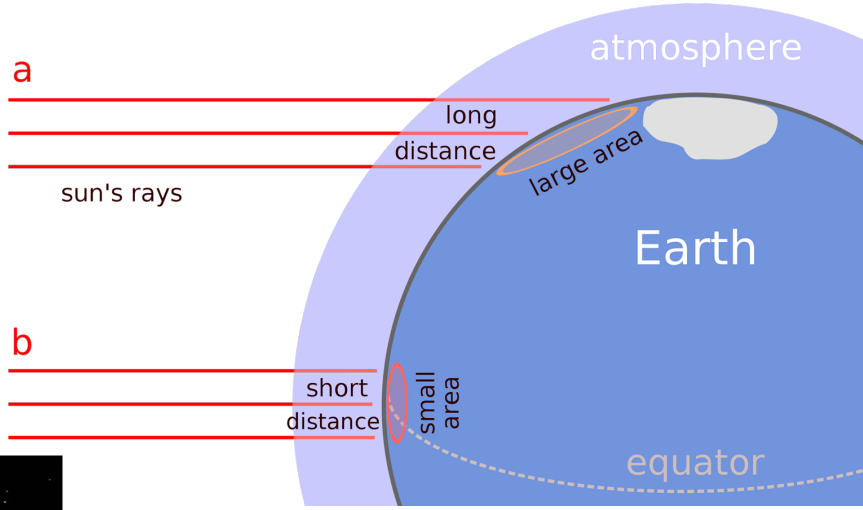
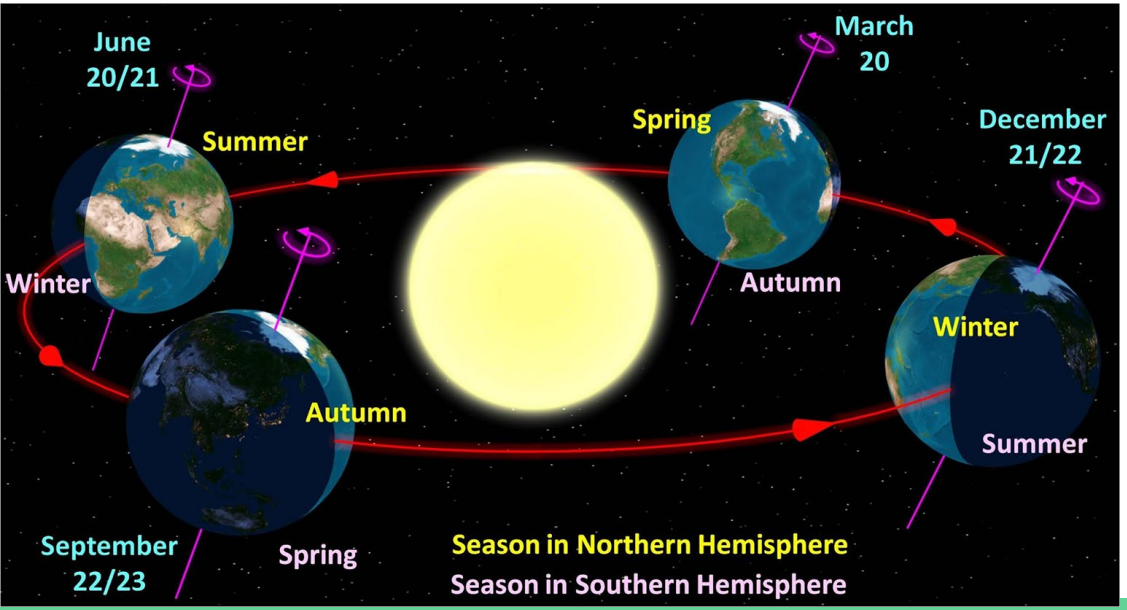
Right: How different angles of the sun's rays create different solar radiation intensities. For letter (a), a smaller angle causes sunlight to travel further and diffuse over a larger area. In letter (b), overhead sun at an angle closer to 90° creates more intensity by traveling a shorter distance and staying contained to a small area of the Earth's surface once reaching it.





Left: Earth's consistent tilt and orbit around the sun create different seasons. While Earth's orbit causes the northern hemisphere to tilt closer to the sun, we experience summer while the southern hemisphere experiences winter. Likewise, winter in the northern hemisphere is caused by the southern hemisphere being angled towards the sun.

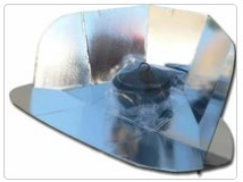
Solar Photovoltaics vs. Solar Thermal

- Both technologies take solar radiation and turn it into usable energy
- Solar photovoltaics convert sunlight into electricity
- Solar thermal technologies reflect and direct heat and light for use in other applications
  - Solar cookers
  - Solar water purification through pasteurization
  - Solar water heating
    - Solar showers
  - Passive solar heating and lighting (see passive house section in weatherization module)
  - Solar thermal technologies create affordable energy flexibility in areas where options may otherwise be slim

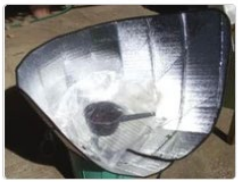
Solar Cookers

Fun-Panel

Minimum Solar Box Cooker

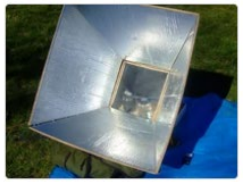


CooKit



Windshield Shade Solar Cooker

Copenhagen Solar Cooker Light



Heaven's Flame

Aluminum Roasting Pan Solar Cooker

Solar Funnel Cooker

- Reflective materials focus sunlight and heat onto food
- May be built with easy-to-obtain materials for as little as $5 and an hour of assembly time.
- Many different designs suited to different materials, generally form a funnel of foil or other reflective surface (like a reflective windshield cover or disposable foil pan) directing the sun towards food in the center

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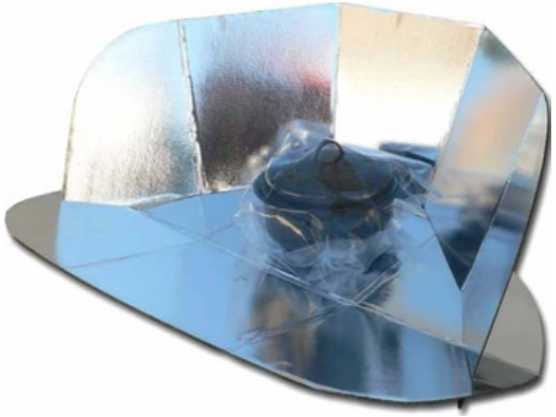
Solar Cookers - CooKit

- The CooKit is one example of a solar cooker produced by Solar Cookers International.
- Created by a volunteer team in 1994 to be an “affordable, convenient, and effective” cooking option to replace combustible fuels on sunny days
- Composed of foil-lined cardboard and an insulating bag, the CooKit folds up to the size of a book and only costs $3-5
- Cooking can happen at the same time as other activities, freeing up families to perform other tasks
- Can also be used to pasteurize drinking water, making it safe to drink



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Solar Water Heating & Pasteurization

- Water can be made safe to drink by pasteurizing – held at 165 degrees F for 15 seconds
  - Can use a Water Pasteurization Indicator to determine if water is made clean from most contaminants - vegetable wax in a tube melts at the correct temperature, hardens after removing from heat - reusable
- Water can be heated on a small scale in a solar cooker, or in a larger container, like a water heater
- Many applications that can be used by anyone who uses heated water worldwide

Water Pasteurization Indicators from Solar Cookers International. The wax inside melts around 165 degrees. Shown as solid on left, liquid on right

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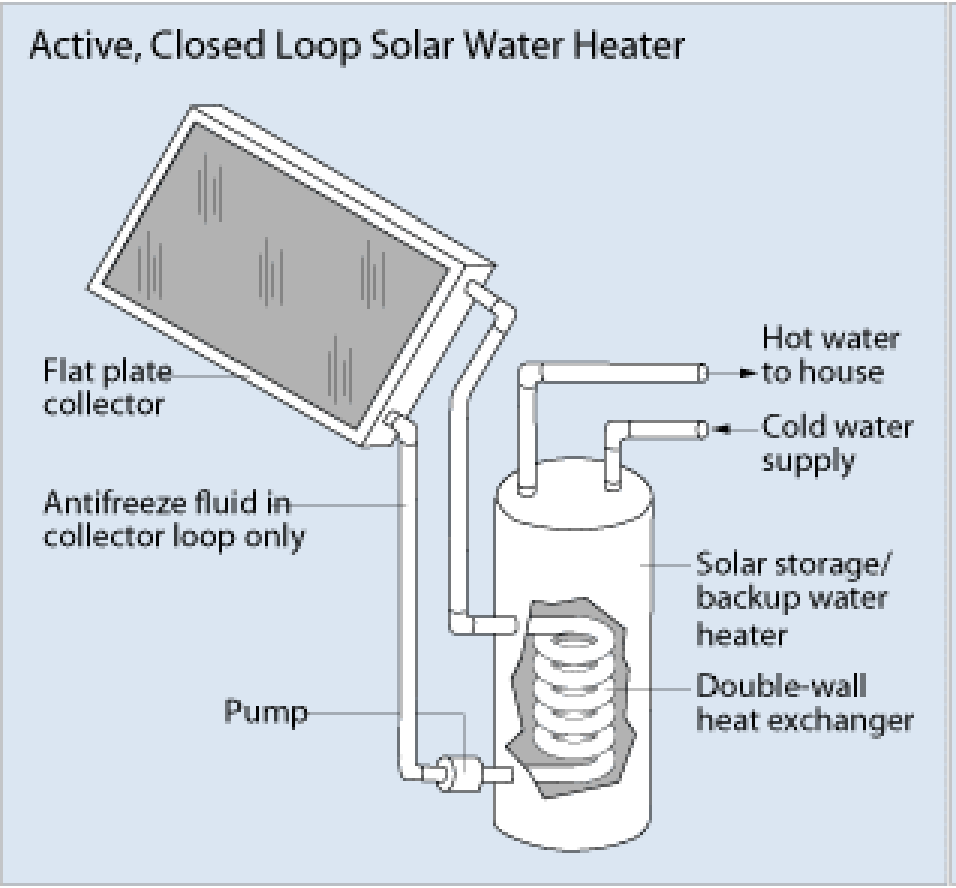
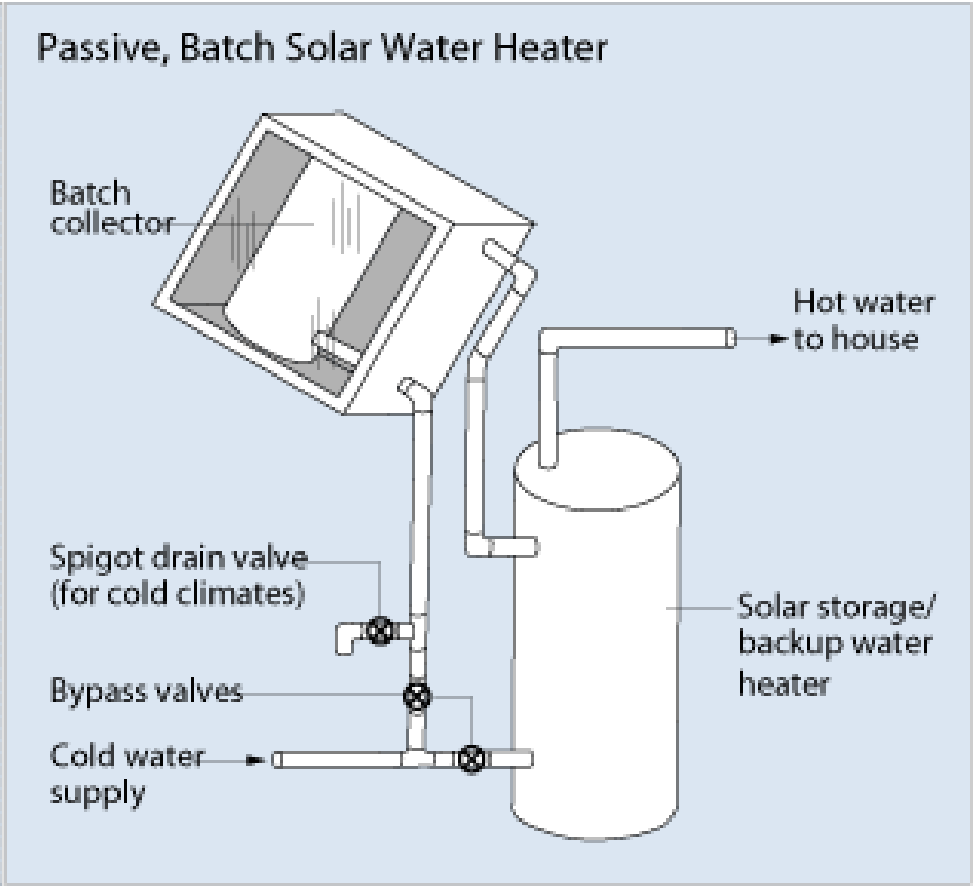
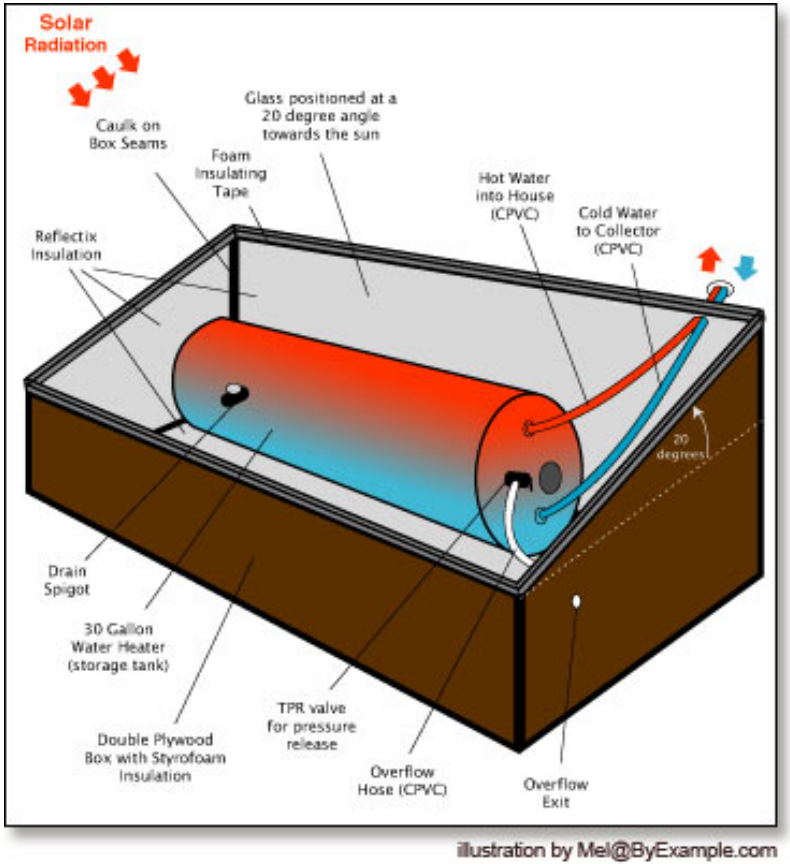
Solar Water Heaters

- Active (uses pump system to circulate water) or passive
  - Active split into direct circulation or indirect
    - Direct: circulates water through collector
    - Indirect: circulates a heat-transfer fluid and uses a heat exchanger to heat water
  - Passive split into integral collector-storage passive systems and thermosyphon systems
    - Integral collector-storage passive systems: insulated storage tank with a clear surface to collect sunlight
    - Thermosyphon systems: water heated below its use or at any height when under pressure, flows to be used when faucet opened

Active and Passive Solar Water Heater Examples







Build Your Own Passive Solar Water Heater!

- Can use an old water heater as container, may be painted black for added efficiency
- Water heater held in insulated plywood box
- Can use window glass or clear plastic to capture sunlight
- https://www.motherearthnews.com/diy/solar-water-heater/

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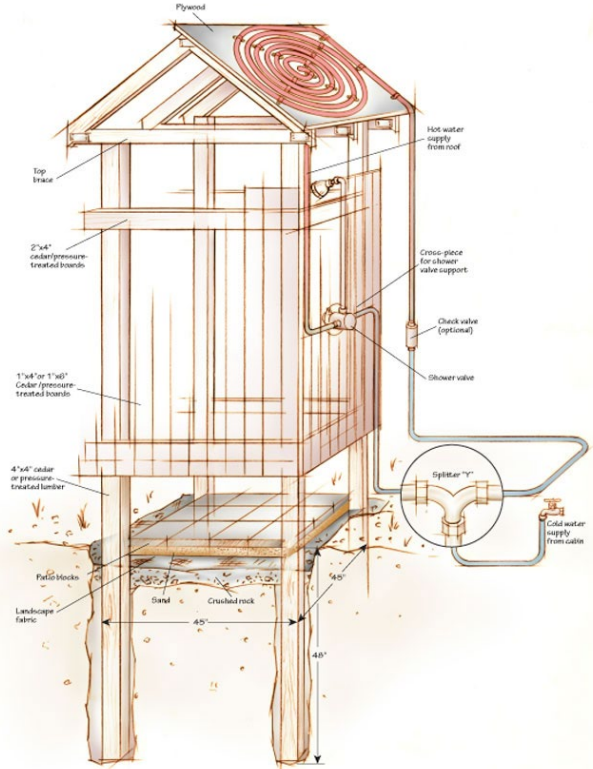
advancedelements.com/summer-shower/

Solar Showers

- Another application of solar water heating
- May be temporary or permanent
- Can use one of the previous water heater designs for a more permanent installation, or it can be its own independent structure
- Or, for temporary uses, a solar shower can be as simple as a bag of water hung in a tree



cabinlife.com/articles/how-to-build-enjoy-an-outdoor-solar-shower

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Solar PV

- Like solar thermal technologies, solar PV can also be used in areas outside of the standard electric grid, but it can also provide a choice of an efficient and renewable source of electricity in areas served by municipal electric grids
- **Solar thermal and solar PV can be used by anyone anywhere on Earth!**

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Horace de Saussure

History of Solar PV from its Solar Thermal Origins

- Magnifying lenses used to manipulate solar rays since 7th Century BCE
- Mirrors used by Romans to light torches in 3rd Century BCE
- First solar collector built by Swiss scientist Horace de Saussure in 1767, used as a cooker by Sir John Herschel on South African expedition in 1830s
- Over 100,000 solar hot water heaters in Florida in the early 1900s, according to The Golden Thread

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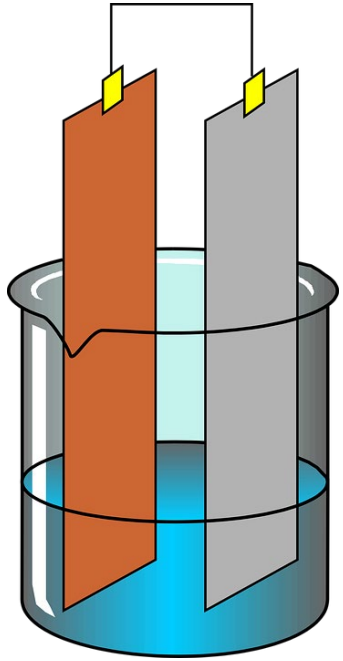
History Continued

- Photovoltaic effect discovered in 1839 by French scientist Edmond Becquerel. Electricity generation of electrolytic cell (2 metal electrodes placed in electricity-conducting solution) increased in sunlight
- 1876: Selenium first discovered to convert sunlight to electricity - first solid photovoltaic material
- First experimental solar power plant built in Olney, IL in 1902 based on design using solar energy to heat water
- 1954: First silicon photovoltaic cell created - first solar cell capable of running everyday equipment, created by Daryl Chapin, Calvin Fuller, and Gerald Pearson of Bell Labs in US. Started at 4% efficiency



Electrolytic Cell

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How Solar PV Works Today

- Converts sunlight to electricity
- Small, individual light-gathering cells connected together to form modules. Modules can be connected to form arrays to meet electrical needs for a full system
  - Arrays typically connected to the electric grid but with storage becoming more affordable and available, this may change soon
  - A residential rooftop array usually has around 30 modules
- Each cell is made of semiconducting materials and generates 1-2 watts of power

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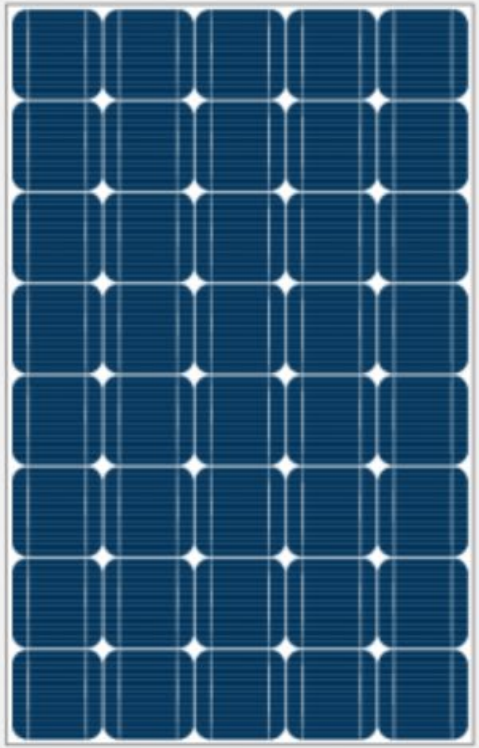
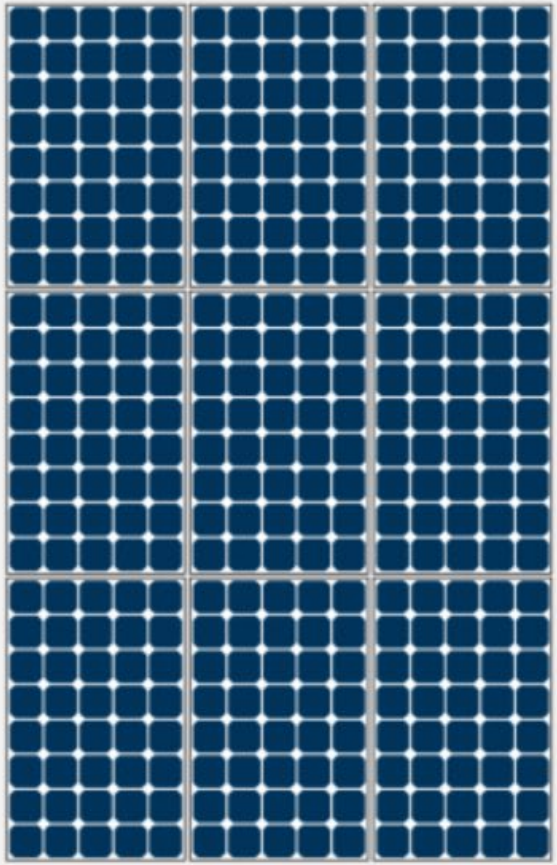
SOLAR CELL

SOLAR MODULE



SOLAR SYSTEM



There are different types of materials used to make solar pv panels.

U.S. DEPARTMENT OF ENERGY | Office of ENERGY EFFICIENCY & RENEWABLE ENERGY
SOLAR ENERGY TECHNOLOGIES OFFICE

How Solar Cells Work

- Semiconducting materials (materials that have conductivity between an insulator and conductive metal) are held between glass and/or plastic for protection
- Semiconductor converts sunlight to electrons, current of electrons/electricity travels through semiconductor to metal contacts (visible as grid-like lines on cell) and through metal contacts to inverter
- Inverter converts direct current (DC) coming in to alternating current (AC), transports AC current to electric grid or other destination

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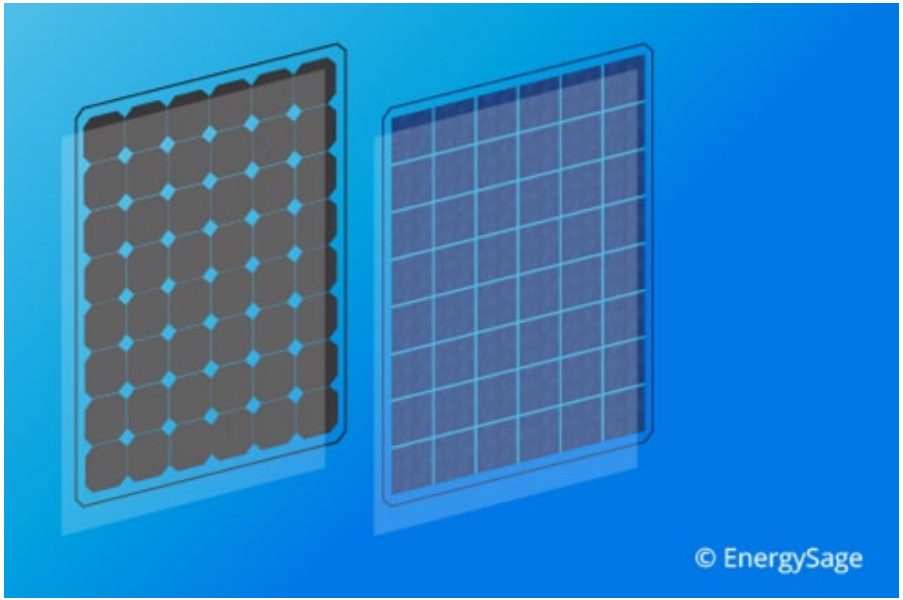
How Solar Cells Work (Continued)

- Ability of module to convert sunlight into electricity is measured in lab as photovoltaic conversion efficiency
  - Can be reduced by environmental factors - dirt, heat, reflection, shade
    - Massively improved since first use of solar PV
    - An area of continued innovation
    - Silicon cells have a theoretical max of 32%
- Silicon has been the most common semiconducting material, but there are other materials used in today's market
  - Silicon crystals cut into wafers that are processed on each side to separate electrical charges to create a diode that will only allow electrical flow in one direction
    - Diode connected to metal contacts on each side to allow electricity to flow out of cell

How Solar Cells Work (Continued) - Monocrystalline vs. Polycrystalline silicon



Monocrystalline solar cells appear black and polycrystalline cells appear blue. From EnergySage

- Cells use monocrystalline silicon or polycrystalline silicon
  - Monocrystalline silicon wafers are made of one crystal - more efficient due to free movement of electrons
  - Polycrystalline cells use many different silicon crystals
    - cheaper but less efficient, loses more efficiency than monocrystalline cells in the heat - may be better suited to colder climates

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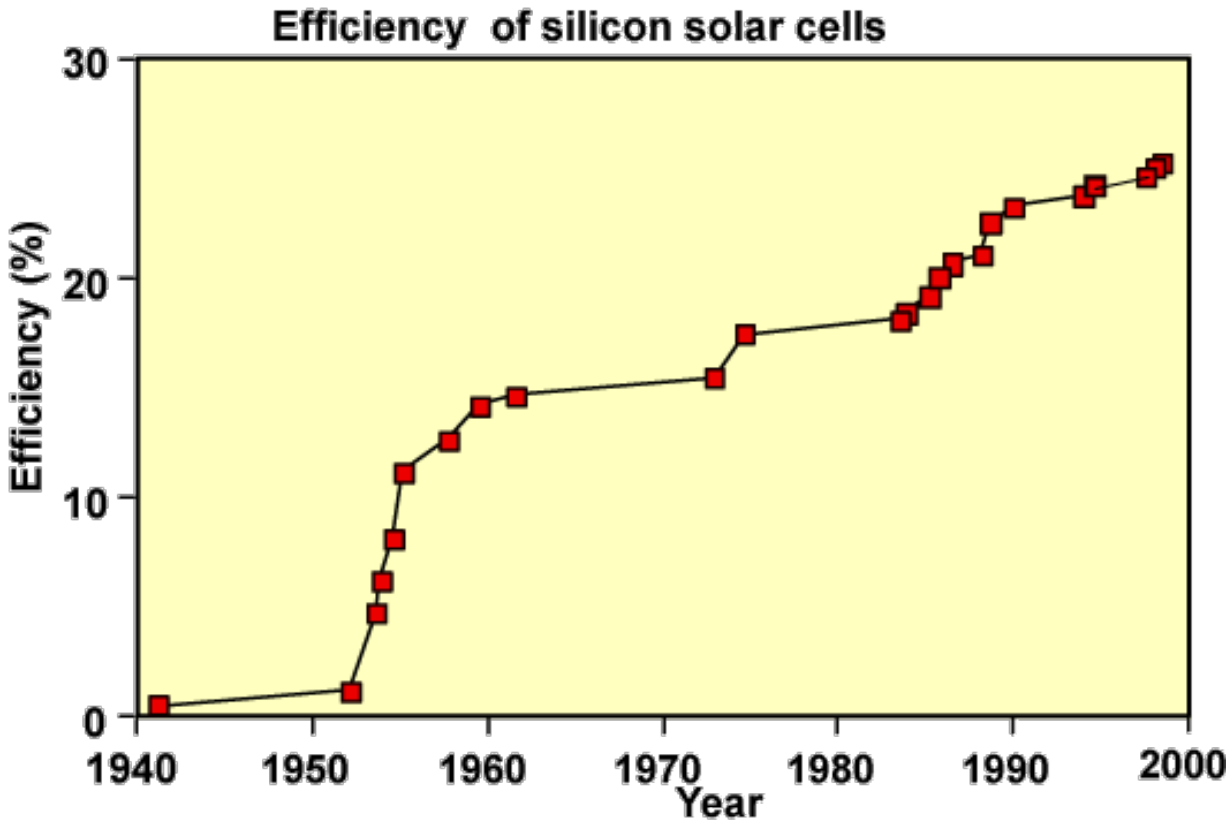
How Solar Cells Work (Continued)

- Semiconductors can also be arranged into single-junction or multi-junction cells
  - Single-junction cells use one semiconductor - cheaper but less efficient
  - Multi-junction cells use stacks of semiconductors that all absorb different wavelengths of light (have different bandgaps) and can be more efficient than single-junction cells
    - Multijunction cells reserved for space exploration for now – more efficient, but expensive and difficult to produce. >45% efficiency attained so far
- Ability of semiconductors to convert sunlight to energy determined by their bandgap. Without meeting the bandgap, the semiconductor will act as an insulator
  - A bandgap is “a property that signifies the minimum amount of energy needed to free electrons so the material can conduct electricity”



How silicon solar cell photovoltaic conversion efficiency has increased over time.

From “Solar Cell Design Principles” pveducation.org/pvcdrom/design-of-silicon-cells/solar-cell-design-principles

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Inverters

- Inverters convert incoming DC current to AC by rapidly switching the direction of the DC current
- Creates power suited for an AC-based grid, but can also help monitor solar system health by measuring load and communicating data to computer networks. Inverters can also adjust frequency to help stabilize electric grid in case of outages
    - In solar systems with batteries, inverters are needed to regulate power usage
- Systems may have one central inverter, or microinverters that convert each module's electricity separately
    - Singular inverters are cheaper and easier to service, but microinverters allow for control over each module - can be more efficient, can keep the array running when one or more panels goes offline and easier to replace if needed

System Design – The Big Picture: Mounting Systems

- Along with choosing the types of cells and inverters to use in a solar project, designers or purchasers must also consider mounting structures, project location, and if battery storage will be included
- Mounting structures must be able to withstand bad weather and maintain stable tilt to face panels towards sun. Rack mounts are most common
  - Some ground mounts are able to continually adjust panels to have the best angle – better energy production
    - While tracking systems are more expensive up-front, cost-benefit analyses continually favor tracking over static ground-mounted systems due to increased performance
- Solar arrays may also be integrated directly into building structures in building-integrated PV.
  - May be used to provide power in DC applications like lighting or powering motors, or support grid-integrated efficient building applications, like electric vehicle charging

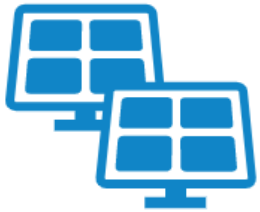
System Design – The Big Picture: Batteries

- Batteries may be used to store energy for use when solar panels are not able to generate adequate electricity for immediate use
- Becoming increasingly important for utility-scale solar PV projects for the same reason on a larger scale – can store power when generated for times when demand is higher than production
  - Helps stabilize the grid when solar PV is an important component
- New innovations in batteries and other types of storage are driving down the costs of solar PV systems while increasing its efficiency and reliability
  - Relatively new innovation, adoption of battery storage is growing

Solar PV Applications from NREL

Photovoltaic Applications

At NREL, we see potential for photovoltaics (PV) everywhere. As we pursue advanced materials and next-generation technologies, we are enabling PV across a range of applications and locations.



Solar Farms

Many acres of PV panels can provide utility-scale power—from tens of megawatts to more than a gigawatt of electricity. These large systems, using fixed or sun-tracking panels, feed power into municipal or regional grids.

Remote Locations

It is not always cost-effective, convenient, or even possible to extend power lines to locations where electricity is needed. PV can be the solution—for rural homes, villages in developing nations, lighthouses, offshore oil platforms, desalination plants, and remote health clinics.

https://www.nrel.gov/pv/applications.html

Stand-Alone Power

In urban or remote areas, PV can power stand-alone devices, tools, and meters. PV can meet the need for electricity for parking meters, temporary traffic signs, emergency phones, radio transmitters, water irrigation pumps, stream-flow gauges, remote guard posts, lighting for roadways, and more.

Power in Space

From the beginning, PV has been a primary power source for Earth-orbiting satellites. High-efficiency PV has supplied power for ventures such as the International Space Station and surface rovers on the Moon and Mars, and it will continue to be an integral part of space and planetary exploration.

Building-Related Needs

In buildings, PV panels mounted on roofs or ground can supply electricity. PV material can also be integrated into a building's structure as windows, roof tiles, or cladding to serve a dual purpose. In addition, awnings and parking structures can be covered with PV to provide shading and power.

https://www.nrel.gov/pv/applications.html

Military Uses

Lightweight, flexible thin-film PV can serve applications in which portability or ruggedness are critical. Soldiers can carry lightweight PV for charging electronic equipment in the field or at remote bases.

Transportation

PV can provide auxiliary power for vehicles such as cars and boats. Automobile sunroofs can include PV for onboard power needs or trickle-charging batteries. Lightweight PV can also conform to the shape of airplane wings to help power high-altitude aircraft.

https://www.nrel.gov/pv/applications.html, National Renewable Energy Laboratory

Future Directions of Solar PV

A screenshot from a video filmed by NREL researcher Peter Hacke shows the interior of one of the combined, accelerated testing chambers in Golden, Colorado. The "donut" rings periodically press down and flex the modules to provide mechanical stress, while the chamber subjects them to water, heat, cold, electrical loading, and ultraviolet light.

Continuing to increase lifespan, efficiency, and applications in all weather conditions

- Current lifespan of standard panels around 30 yrs, goal of extending lifespan to 50 yrs
- Improvements in testing and modeling techniques along with prototypes create more frequent innovations

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NREL Breaks Solar Panels (So Yours Won't): Accelerated Testing

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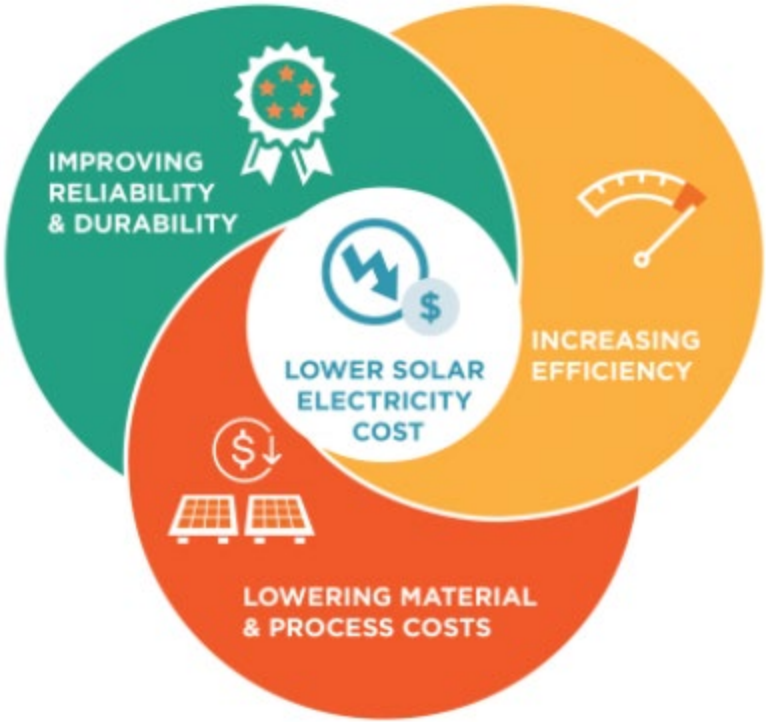
2030 Goal

- Department of Energy aiming to achieve a levelized cost of energy of $0.03/kW-hr by 2030 after reducing cost by 90% since 2011
  - Will maintain cost-competitiveness with other energy sources even with costs to address dispatchability and grid effectiveness – more demand and more jobs!
- May lower cost by improving lifespan, efficiency, or lowering production costs
- Working to lower whole systems costs
- Lots of improvements occurring in storage options



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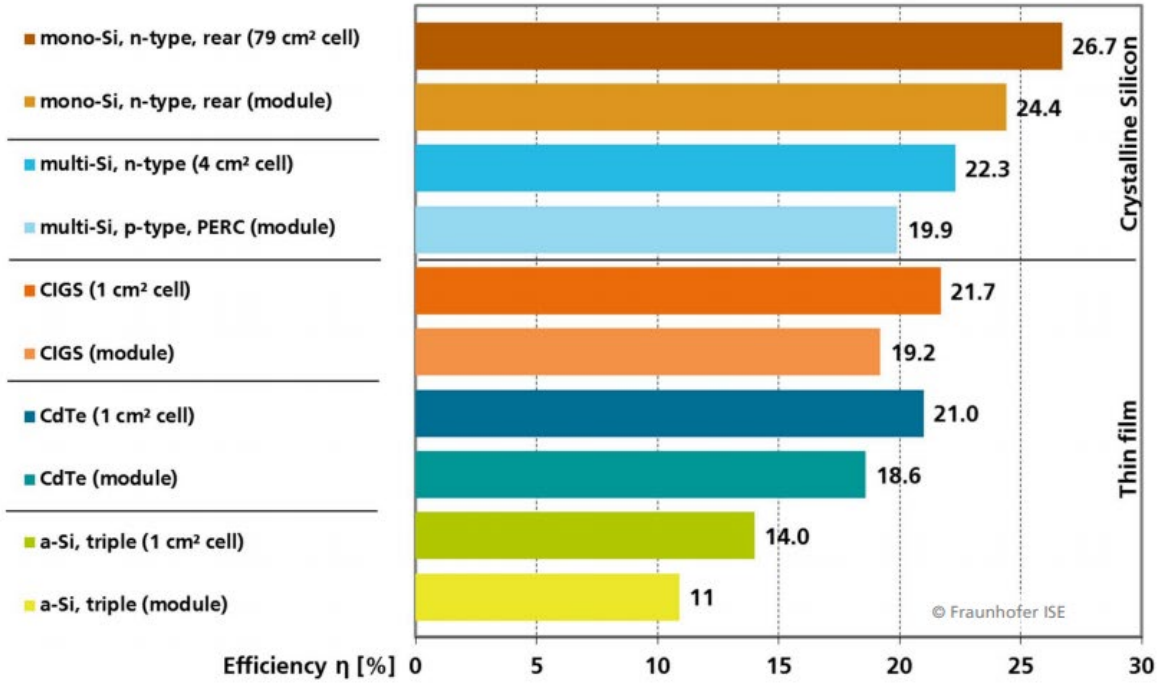
Examples of Further Innovations to Handle Environmental Stresses

- Arizona State University is researching different back sheets to improve efficiency on hot days and reduce heat degradation
- Different surface treatments may repel dirt and reduce soiling, maintaining efficiency
- University of Michigan - Ann Arbor is researching how to balance power between cells across solar modules to reduce damage that may occur from consistent shade on module

Future Directions of Solar PV - Thin Film Solar Cells

- Thin film solar cells - cheaper, more versatile, and easier to produce than standard silicon solar cells, but less efficient - standard crystalline silicon cells held 90-95% of the global market share as of 2018
  - Made by coating a thin layer of semiconducting material on a substrate - sheet of glass, plastic, or metal foil
    - May be flexible if a flexible backing is used - increases possible mounting surfaces
  - Often 20x thinner than crystalline silicon cells
  - Current varieties include amorphous thin-film silicon (a-Si), cadmium telluride (CdTe - most popular and efficient), and copper indium gallium diselenide (CIGS)
- Crystalline silicon is more dependable and efficient, but thin film solar modules may be better suited for surfaces that need flexible or more lightweight panels
  - Thin film may be used on surfaces like vehicles, tiny homes, commercial roofs that need lower-weight arrays, or in marine applications

Efficiency Comparison of Technologies:
Best Lab Cells vs. Best Lab Modules



Data: Green et al.: Solar Cell Efficiency Tables (Version 51), Progress in PV: Research and Applications 2018. Graph: PSE GmbH 2018

2018 in-lab efficiency comparison between different types of PV cells and modules. From top down: monocrystalline silicon (mono-Si), multicrystalline silicon (multi-Si), copper indium gallium diselenide (CIGS), cadmium telluride (CdTe), and amorphous thin-film silicon (a-Si).

Source: Fraunhofer ISE, Solar Power World

Fraunhofer ISE

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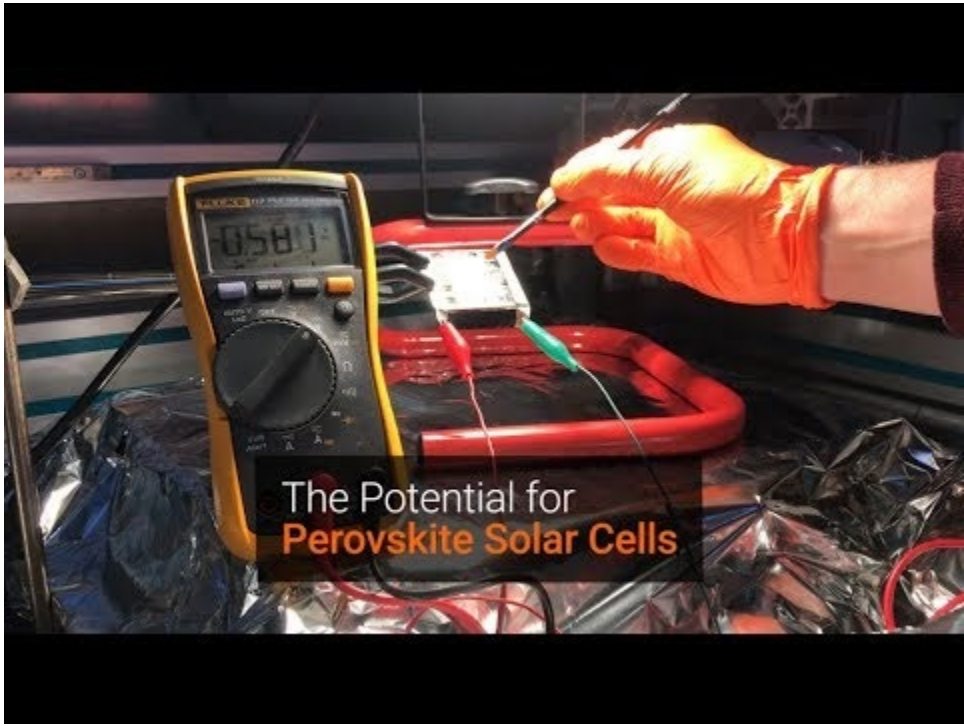
Future Directions of Solar PV - New Materials

- May further reduce costs, manufacturing difficulty, and expand applications
- Some new emerging technologies include perovskite solar cells, quantum dots, and organic photovoltaics
    - Perovskite solar cells - thin film cell with a different crystal structure (ABX3) that is deposited on a substrate like other thin film solar cells, but are high-efficiency. Researchers are working on making perovskite cells more durable and stable over a 20 year lifespan outdoors. Also developing low-cost manufacturing techniques that can be used on a large



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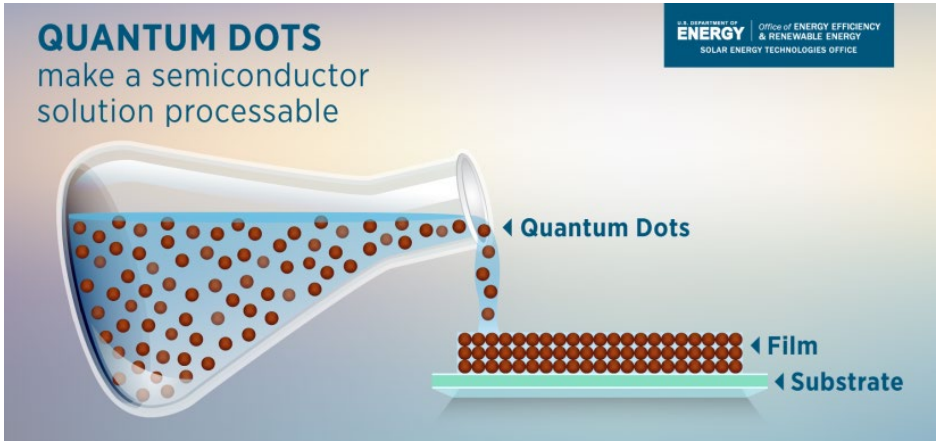
New Materials - Quantum Dots

- Quantum dots - Semiconductor particles only a few nanometers wide
- Can be sprayed or printed onto surfaces
- Have a customizable bandgap that can allow for usage of difficult-to-collect light
    - May be paired with other semiconductors
- However, quantum dots have a low efficiency due to the difficulty of establishing an electrical connection between particles.



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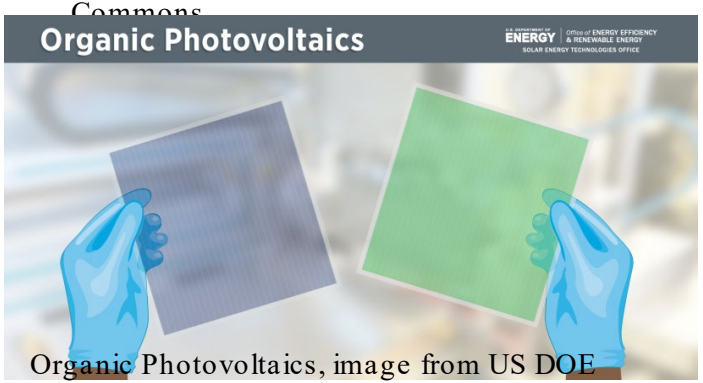
New Materials - Organic Photovoltaics

- Made of carbon-containing compounds that are dissolved and solution-processed to reduce costs
  - Polymers with similar conducting properties to those used in OLED displays
- Compounds may be customized - may allow for different colors or transparent solar cells
  - May be used in building-integrated systems to make windows and facades
  - Researchers working to improve efficiency, durability, and reduce visual effects of aging

OLED TVs, image from Wikimedia Commons



Organic Photovoltaics, image from US DOE

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Conclusions re: Jobs and Future Directions of Solar PV

- Don't wait to get into the field – Solar PV technologies are already efficient and cost-effective, competing and excelling in lowering costs compared with all fossil fuels (coal, oil, natural gas)
- In addition to solar's cost-competitiveness, it is also much better for the environment and climate in terms of climate change and other pollution issues

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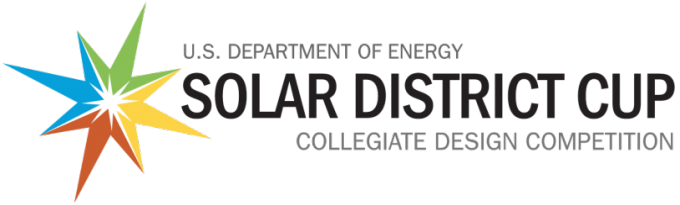
Do you want to further optimize solar PV?

You can enter the Solar District Cup!



- Held by the US Department of Energy
- “challenges multidisciplinary student teams to design and model optimized distributed energy systems for a campus or urban district. These systems integrate solar, storage, and other technologies across mixed-use districts, which are groups of buildings served by a common electrical distribution feeder”
- Goal to model the most innovative and cost-effective system
- Teams structured into divisions within districts
- Final results of each team presented to judges at live event

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Solar District Cup

"The Solar District Cup is designed to inspire students to consider new career opportunities, learn industry-relevant skills, engage with the professional marketplace, and prepare to become leaders in distributed solar energy. As competitors, students:

- Build experience with innovative distributed energy design
- Develop innovative solutions to real-world, district-scale challenges
- Engage with industry professionals to forge relationships and connections that aid participating students' transition to the distributed energy workforce upon graduation
- Compete to earn national recognition upon winning a Solar District Cup and/or being selected as an industry choice winner or pitch champion.

The Solar District Cup encourages collaboration between academia and industry. The program seeks to establish public-private partnership and demonstrate corporate and nonprofit industry co-sponsorship."

Learn more at: energy.gov/eere/solar/solar -district -cup

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Customer benefits of solar PV

Customer benefits to switching/using solar PV

1. Reduce your dependence on the utility company
2. Reduce your pollution
3. Increase your energy independence
4. Contribute to solving climate change and the Clean Energy Transition

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Benefits to Society

Benefits from the clean energy transition:

- Safer and healthier ecosystems
- Protection of clean air and clean water
- Production of healthier communities
- Reduction of toxins within our buildings for our families health and comfort
- Reduction in greenhouse gases that reduces climate change
- Jobs

Test Questions

Will write 10-20

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Reading Materials

IREC's Solar Careers Map - students can explore career options they may be interested in more in-depth (there are also career maps for green building and HVAC/R accessible here)

Department of Energy's pages on Solar Energy Basics found on this page. Each linked page has other links for more related information.

Solar Energy Industry Association's "Solar Industry Research Data"

National Renewable Energy Laboratory's "Fall 2021 Solar Industry Update" (may need updated occasionally)

The Nature Conservancy's *Illinois Climate Assessment* (the release page's summary or sections from the full report may be useful)

Links from slides 47 and 48 on certifications and NABCEP's solar associate exam

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Shared Materials

We will write descriptions for additional resources/materials instructors might use to offer more content

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SEED center

Sustainability Education & Economic Development

Sustainability Education and Economic Development

National support for community colleges in building a green campus and a sustainable, green economy. You can explore solar and more in the resource center at www.theSeedCenter.org

Tie in your current educational materials

Instructors will input their own educational pathways that relate to their offerings

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