In accordance with the Department of Labor and Industry's statute 326.0981, Subd. 11,

"This educational offering is recognized by the Minnesota Department of Labor and Industry as satisfying **1 hour** of credit toward **Building Officials and Residential Contractors code /1 hour energy** continuing education requirements."

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Minnesota Renewable Energy Society

Introduction to Solar:

Technology / Resources / Policies

February 25th , 2020

Mark Weber

markw@mnrenewables.com

MRES
MINNESOTA RENEWABLE ENERGY SOCIETY

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Minnesota Renewable Energy Society Introduction

- The Minnesota Renewable Energy Society (MRES) is a member run 501(c)(3) non-profit organization.
- The MRES was founded in Minneapolis in 1978.
- Our Mission: To advance a sustainable society and a renewable energy economy through education, leadership and example.

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Introduction to Solar Energy

Agenda

- Introduction
- Renewable Energy definition
  - Characteristics of the solar resource
- Solar Technologies
  - Thermal Technologies
  - Photovoltaic Technologies
    - History, theory, circuits, components
- Market drivers
  - Cost, Growth, Policy, Incentives
- Training and codes
- Odds and ends

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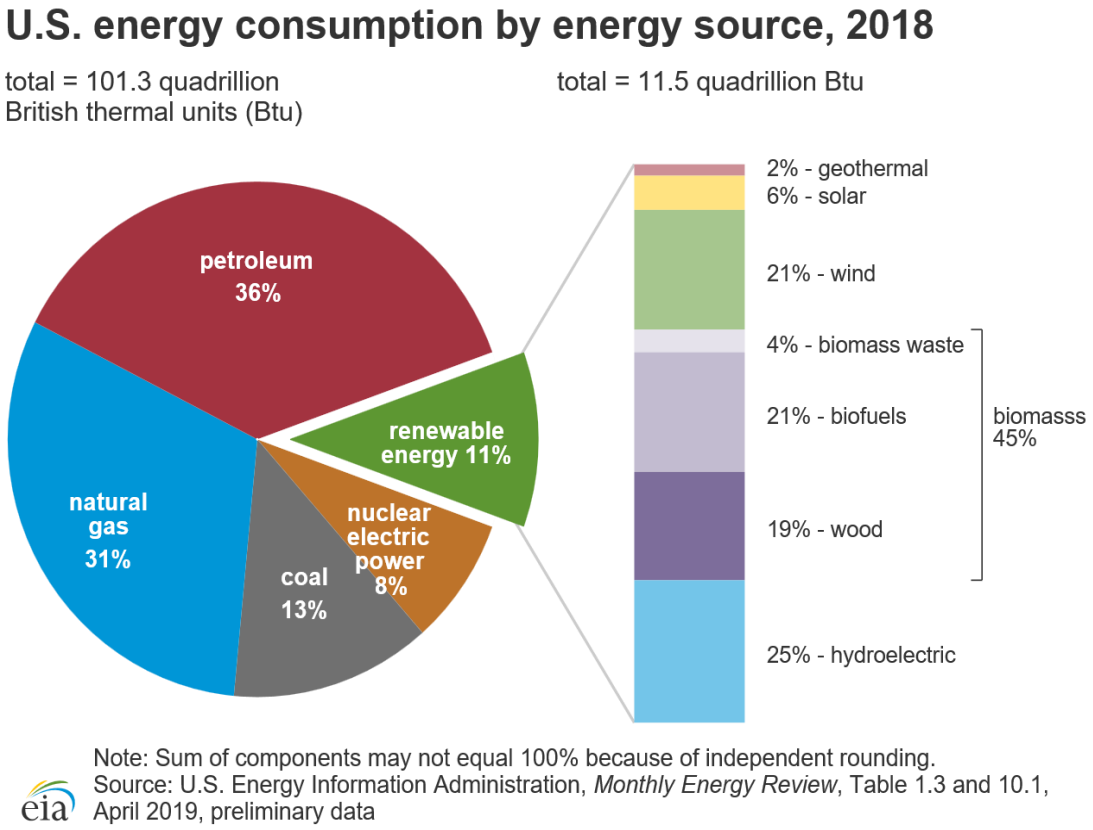
Introduction to Solar Energy

What is Renewable Energy?



- Biomass 45%
- Hydroelectric 25%
- Wind 21%
- **Solar 6%**
- Geothermal 2%
- Wave Energy - %
- Tidal Energy - %

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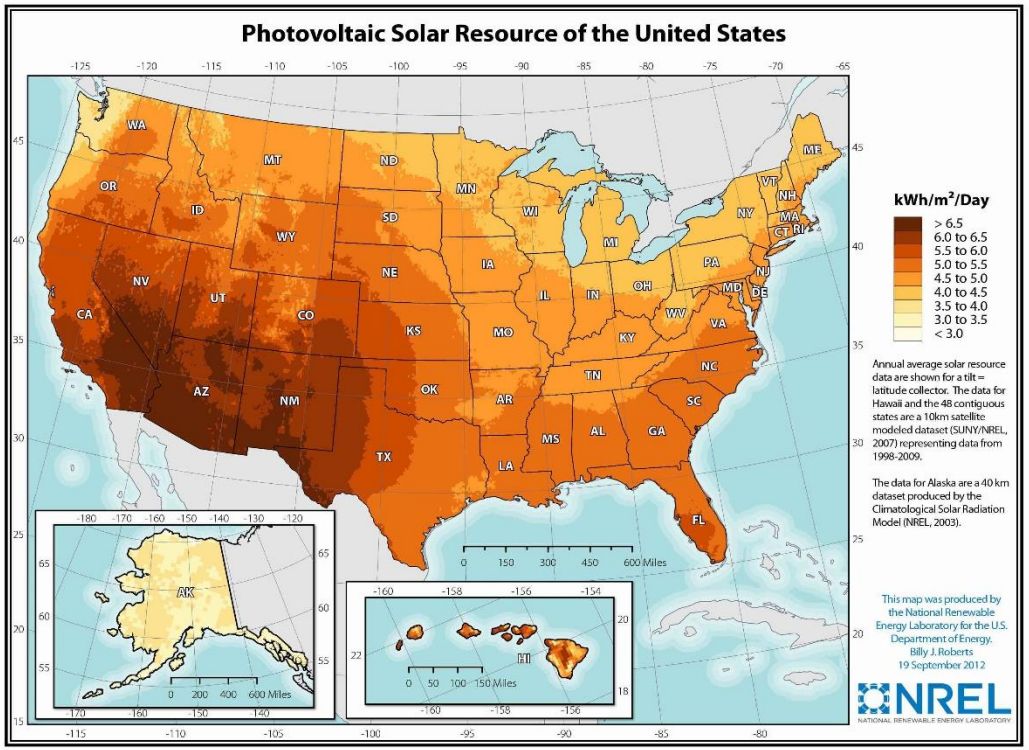
Introduction to Solar Energy

Photovoltaic Solar Resource



Minneapolis average Direct Normal Irradiance is 4.09 kWh/m2/day, 7% less if panels are flat. (DNI 7.3 kWh/m2/day in Yuma, AZ)

Solar Sense uses the PV Watts calculator

https://pvwatts.nrel.gov/pvwatts.php

10 /12 pitch is best in Duluth per Solar Sense.

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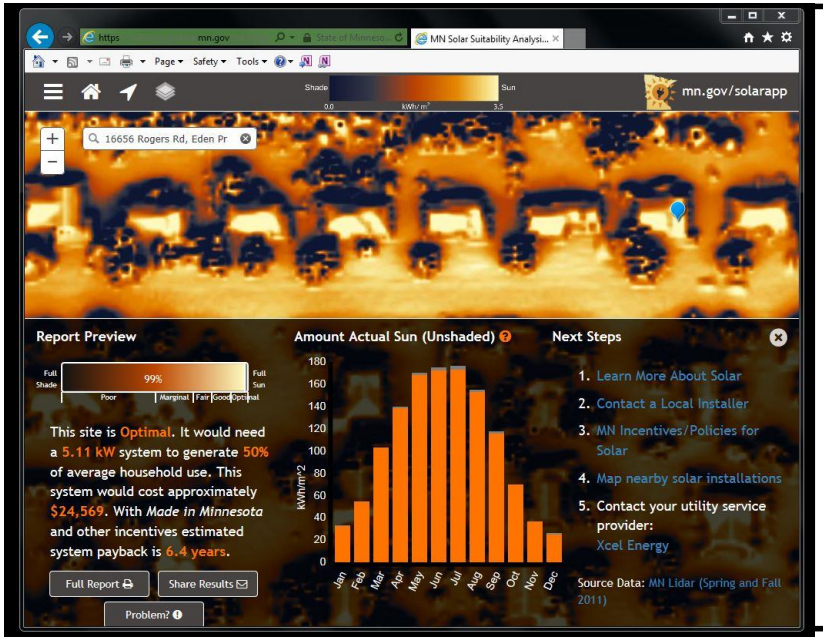
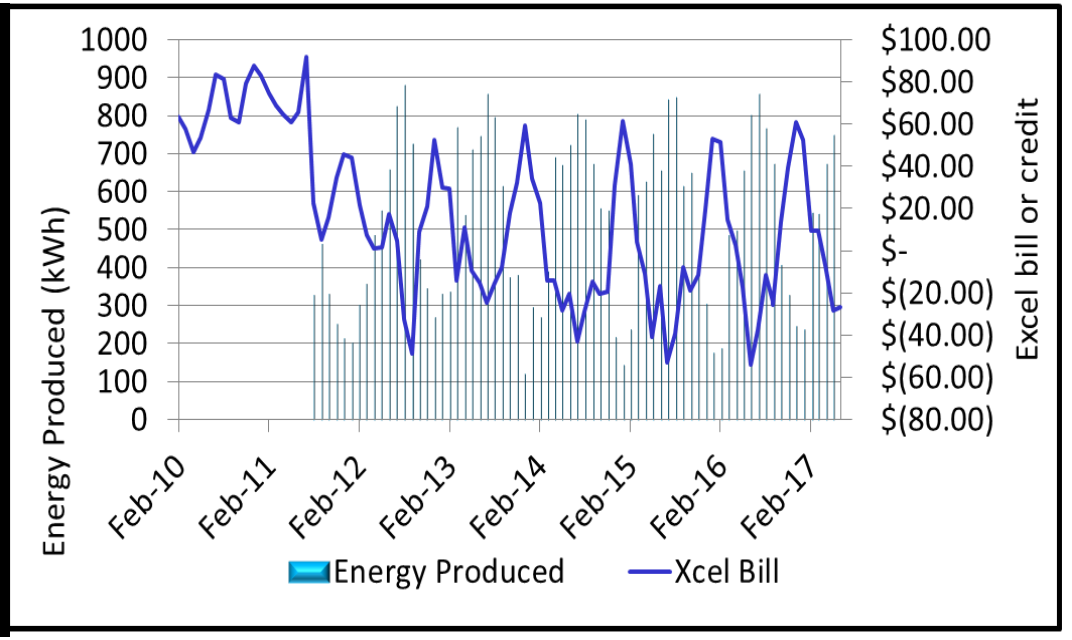
The Photovoltaic Solar Resource is Seasonal





- https://solar.maps.umn.edu/
- The Solar Resource is a seasonal resource
- Snow does not slide off an 8/12 pitch roof

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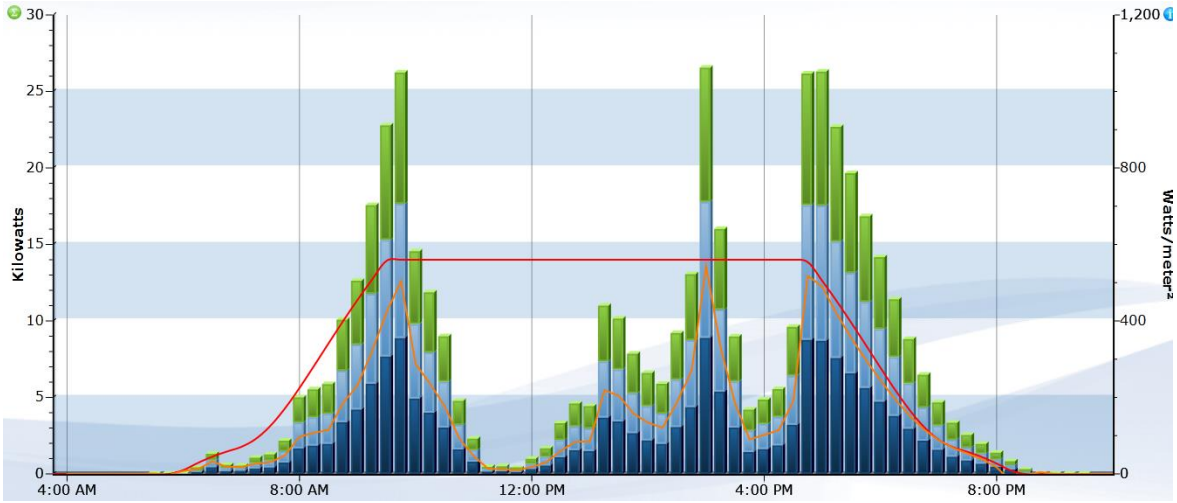
The Photovoltaic Solar Resource is Intermittent



- Power is produced when the sun is up and not when it is down
- Power curves can be erratic
- As penetration of solar increases, there can be concerning effects

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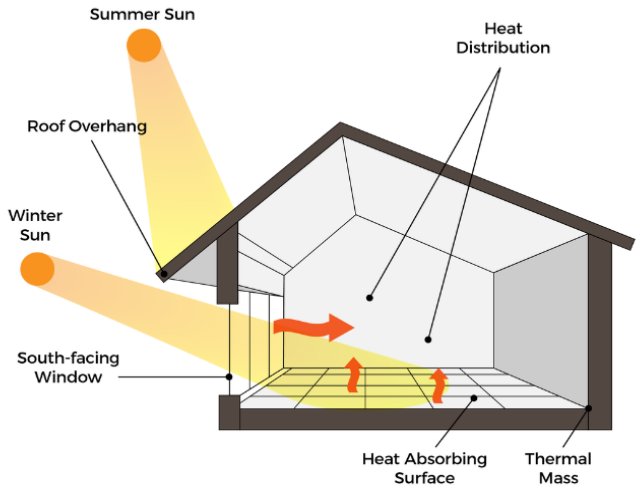
Introduction to Solar Energy

Passive Solar Architecture



- The sun angle is lowest on the Winter Solstice, 21.5 deg on December 21, 2020
- The sun angle is highest on the Summer Solstice, 68.5 deg on June 20, 2020
- Using design to control energy from the sun entering the building
- Use of overhangs and the positioning of the windows

December 21st

February 7th

March 17th

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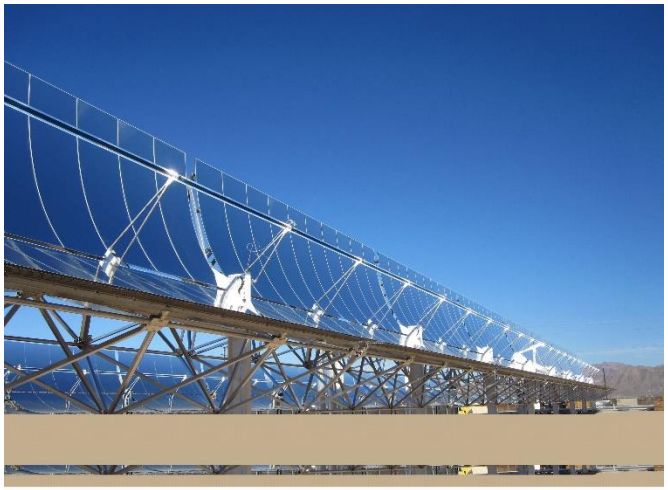
Introduction to Solar Energy
Concentrating Solar Power (CSP)

- Concentrating solar power plants use mirrors to concentrate the sun's energy to drive steam turbines to create electricity. The thermal energy can be stored.
- CSP breaks into line focusing technology and point focusing technology.
- There is approximately 1,812 MWac of CSP in operation in the USA
- Located in the Southwest portion of the country. California, New Mexico, Arizona.
- There are 11 CSP plants in the US

Introduction to Solar Energy

CSP – Parabolic Trough



- Curved mirrors are used to concentrate the sunlight onto a central receiver tube that runs down the center of the trough.
- A transparent glass tube envelops the receiver tube to reduce heat loss.
- Single and dual axis trackers
- 750 F / synthetic oil is the transfer medium
- 20 feet tall and 400 feet long

Introduction to Solar Energy
CSP – Linear Fresnel Mirror

- Flat mirrors are used to concentrate sunlight onto elevated receivers.
- Mechanically simpler and less expensive than the Parabolic Trough System.
- Can be designed to use water, thermal oil or molten salts
- Simplicity theoretically allows for higher temperatures than Parabolic Trough

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Introduction to Solar Energy

CSP – Power Tower

- A power tower has a field of large heliostats that follow the sun's path across the sky. The heliostats concentrate sunlight onto a receiver on top of the tower.
- Temperature in excess of 1000 C are achieved, molten salts are the heat transfer medium
- Energy storage is easily incorporated into this technology
- The Ivanpah Solar Generating plant uses 173,500 heliostats to generate 393 MW of electricity.

Introduction to Solar Energy
CSP – Parabolic Dish

- A parabolic dish systems uses a computer to track the sun and concentrate the sun's rays onto a receiver located at the focal point of the dish.
- Temperature in excess of 1000 C are achieved, hydrogen gas powers a 4 cylinder Stirling Engine
- Concentration factors of 2500 can be achieved with this technology.

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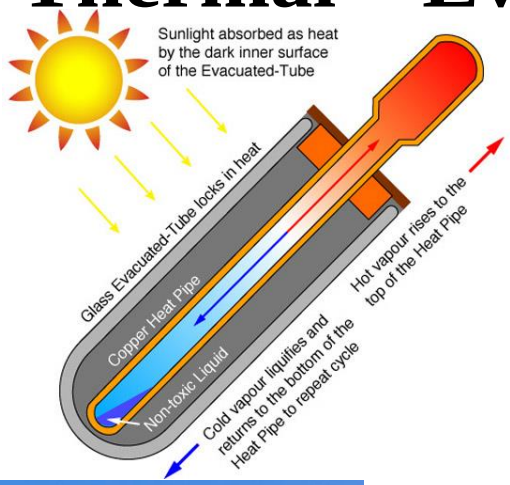
Introduction to Solar Energy

Solar Thermal – Evacuated Tube



- A set of modular tube where convective heat losses are minimized by virtue of the vacuum in the tubes.
- This technology may or may not contain a volatile fluid such as ammonia
- Temperature capability of 150 C

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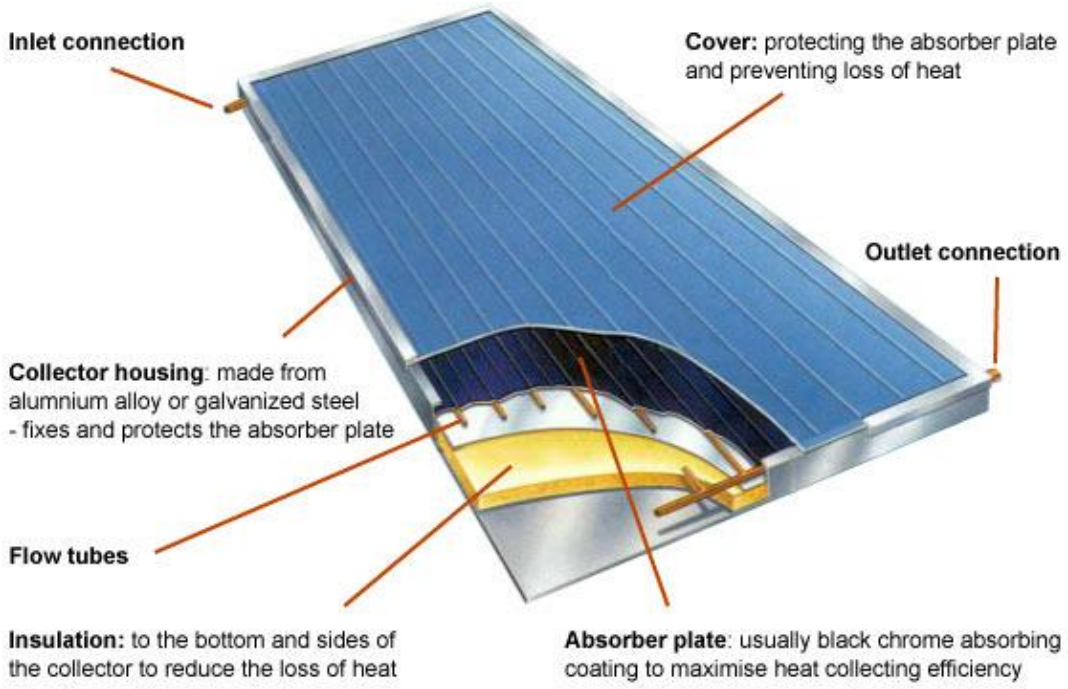
Solar Thermal – Flat Plate



- The sun heats a dark flat surface and the energy is transferred to water, air or other fluid.
- A very simple heat exchanger
- Generally used in our region with an antifreeze solution. Requires a closed loop due to its toxicity.
- Temperature capability of 100 C

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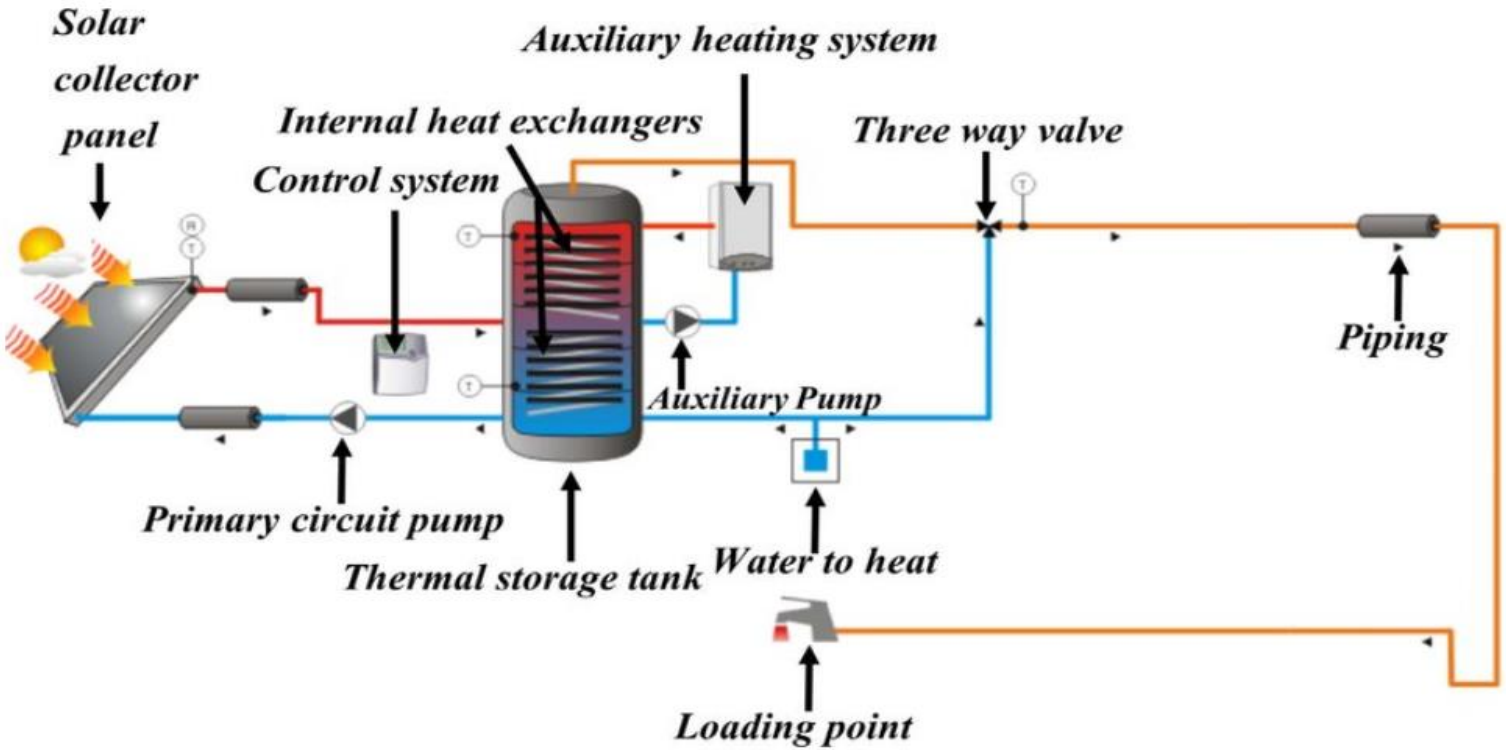
Solar Thermal – Circuit



- Two fluid circuits required in Minnesota and Wisconsin

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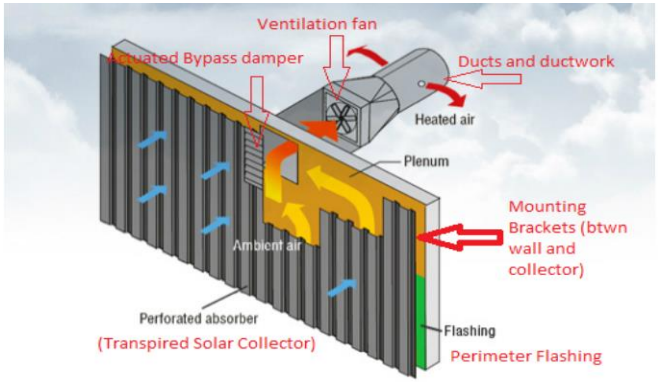
Introduction to Solar Energy
Solar Thermal – Transpired Air



- Solar ventilation air preheating technology uses the energy of solar radiation preheat ventilation air.
- Commercially available since the 1990's. Ideal for vehicle maintenance facilities, aircraft hangers, warehouses, crop drying facilities, apartment buildings, process air heating.
- No moving parts other than a ventilation fan.
- Real Solar in Backus, MN / East Side Storage and Maintenance Facility, Minneapolis

Introduction to Solar Energy

Solar Electric – History

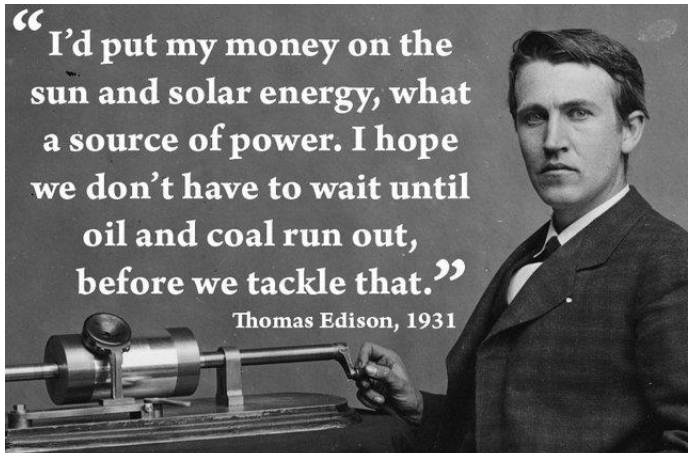


Table 1. Relative amounts of energy for various phenomena compared to the solar energy intercepted by the earth each day (After 11).

Atomic bomb exploded over Nagasaki, Japan, August, 1945	1
Average summer thunderstorm	1
Burning of 7000 tons of coal	1
Daily output of Hoover Dam	1
Average hurricane	10,000
World use of energy, 1950	1,000,000
Daily solar energy intercepted by earth*	100,000,000

*The actual amount of energy intercepted equals 3.76×10^{21} calories per day.

- 1873 – James Maxwell reports the conductivity of Selenium was affected by light.
- 1884 – Charles Fritts builds first photovoltaic array using copper / selenium / gold.
- 1905 – Albert Einstein postulates that light contains packets of energy called "light quanta" (now called phonons)
- 1953 – Daryl Chapin from Bell laboratories measures state of the art Selenium efficiency is .5%, work on silicon cell begins, initially producing an efficiency of 2.3%.
- 1954 – Atomic Energy Act passes / Atoms for Peace

Introduction to Solar Energy

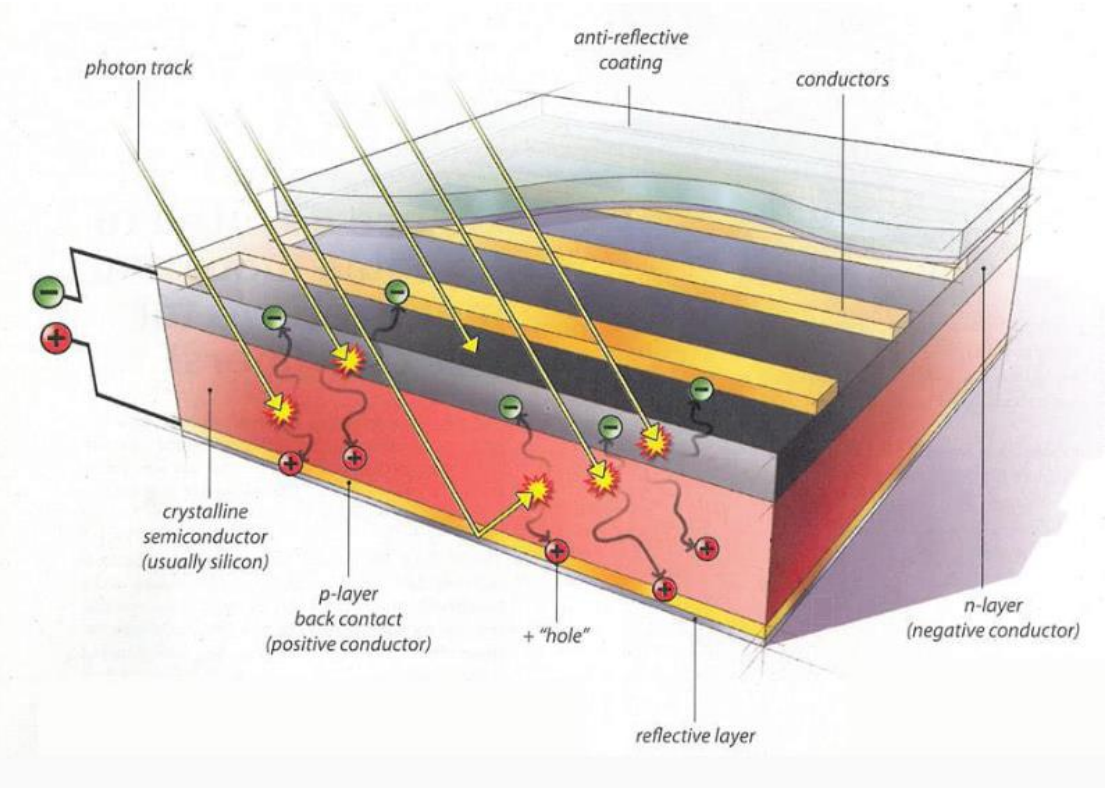
Solar Electric – History

Figure 21.8. Illustration from 1930s *Popular Mechanics* article on solar's contribution to the world's energy mix. The selenium solar cell began the dream that one day photovoltaics would power the world.

- 1954 – Bell Laboratories announces the "Solar Battery" to the press. Demonstrates technology with an Erector Set Ferris Wheel ($286 / watt)
- 1955 – The "Solar Battery" considered a possible competitor to atomic energy. RCA comes up with the Atomic Battery.
- 1958 – Vanguard Satellite launched with Bell "Solar Battery"
- 1973 – Solar Power Corporation formed / Berman / Exxon
- 1974 – Arab Oil Embargo ends
- 1977 – NREL (National Renewable Energy Laboratory) created
- 1979 – 3 Mile Island partial meltdown

Introduction to Solar Energy

Solar Electric – Theory



- A thin semiconductor wafer treated to form an electric field, positive on one side and negative on the other.
- When a photon strikes the solar cell, electrons can be knocked loose from their atoms in the semi conductor.
- If electric conductors are attached to the positive and negative sides an electric current is generated.
- The electricity is captured and used to power a load.

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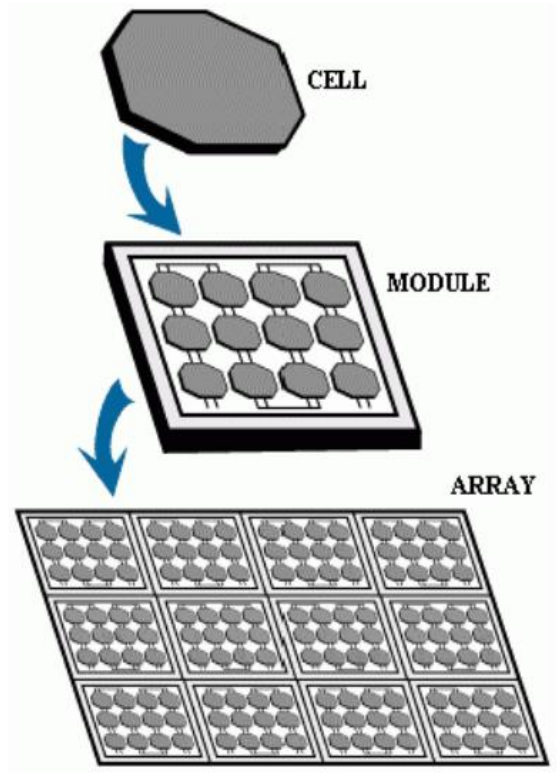
Solar Electric – Theory



- A number of solar cells are electrically connected to each other and mounted in a frame. (either 60 or 72 cells)
- Multiple modules are wired together to form an array.
- The modules generate DC current. The DC current is converted to AC current with the use of an inverter.

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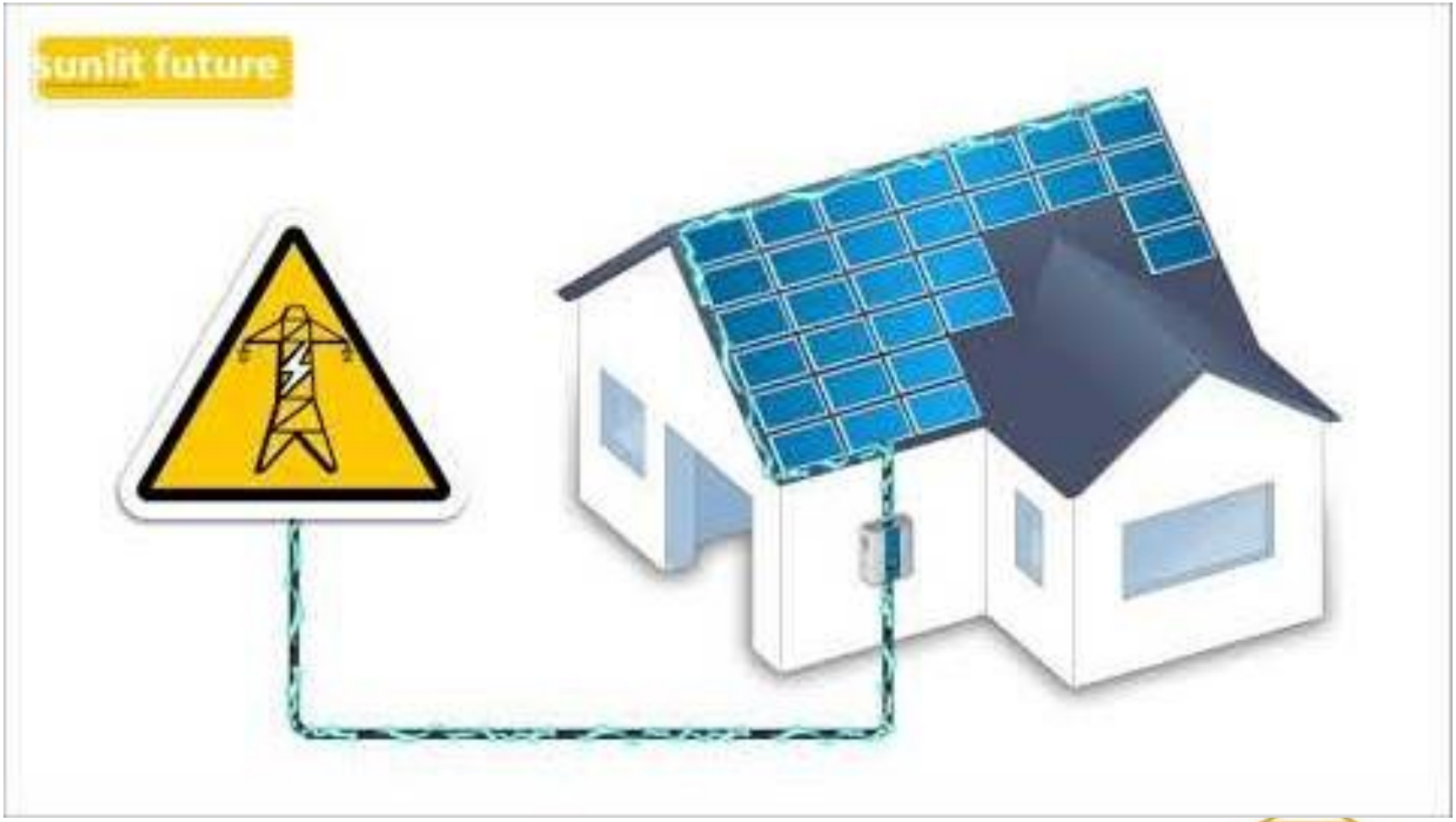
Introduction to Solar Energy

Basic Electrical Circuit



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Introduction to Solar Energy
Basic Electrical Circuit

- The inverter converts DC into AC
- There are 3 basic schemes used to do the current conversion
- Power Optimizers and Micro inverters are called Module Level Power Electronics (MLPE)

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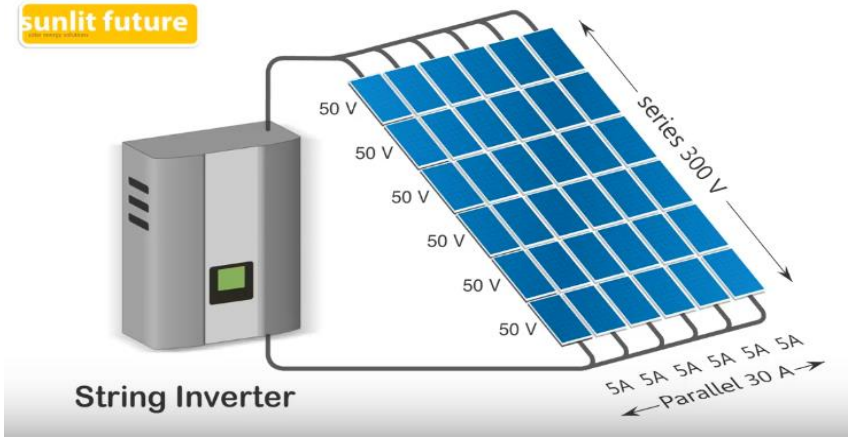
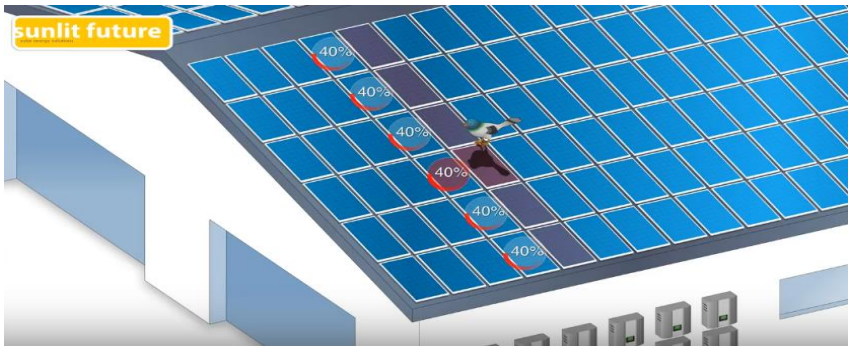
Introduction to Solar Energy

Basic Electrical Circuit – String Inverter





- With the string inverter the panels are wired in series to add voltage to the string.
- Strings are wired in parallel to add current.
- Equal # of panels in a string, all the same type, all the same angle.
- Efficiency of the string limited to the least efficient panel.

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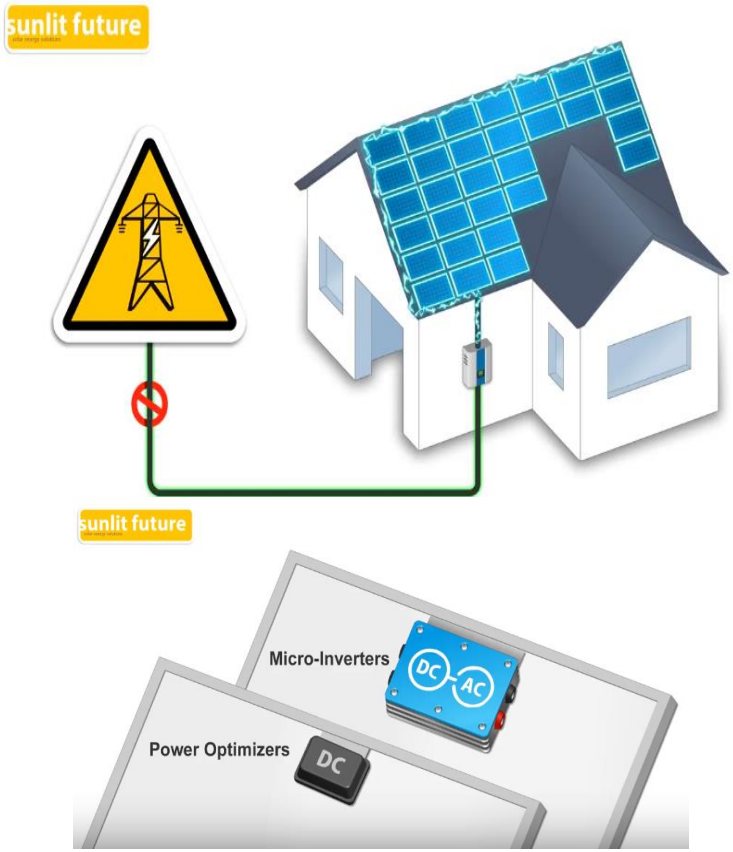
Introduction to Solar Energy
Basic Electrical Circuit – String Inverter



- For residential systems the system characteristics during a shutdown are a problem.
- When the grid goes down on a sunny day, the cables on the roof are still powered at a high voltage.
- The development of MLPE's solved this problem.

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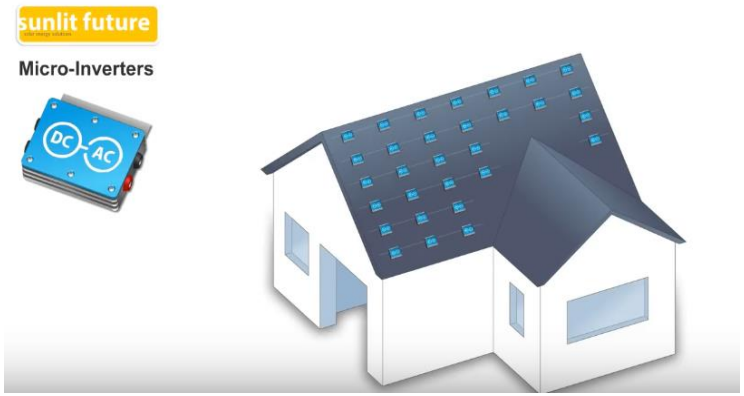
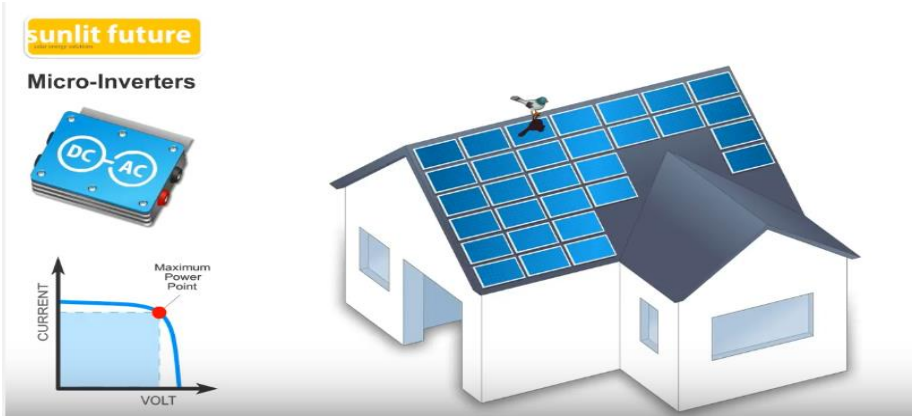
Basic Electrical Circuit – Micro Inverter

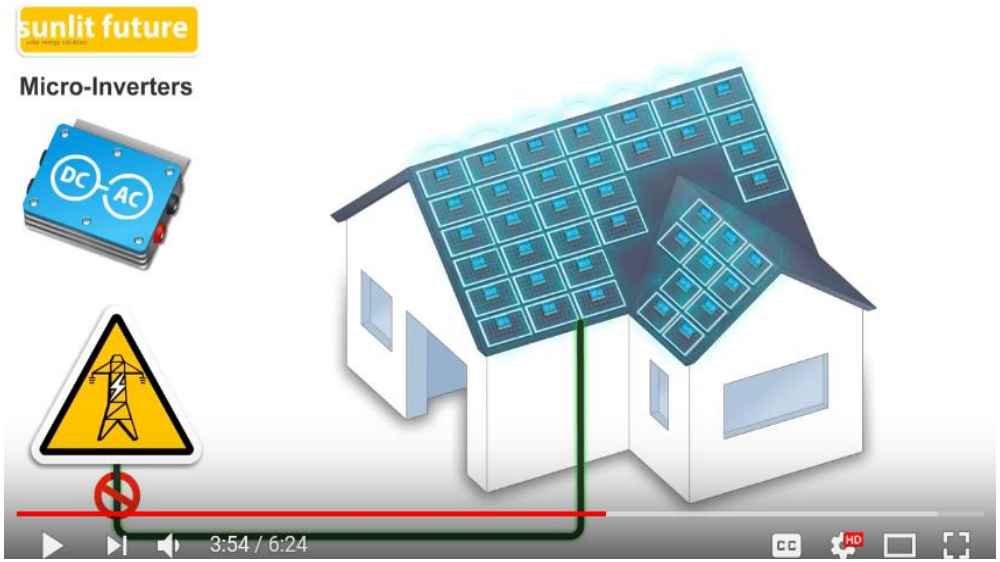




- A micro inverter converts DC to AC at the panel level.
- Each panel is independently connected to the grid.
- A problem with one panel will not affect the rest of the system.
- The micro inverter maintains the maximum power point.
- Micro inverters are the most expensive solution.

Introduction to Solar Energy

Basic Electrical Circuit – Micro Inverter



- Micro inverters are the most expensive solution.
- Micro inverter systems are a very versatile solution.
- During a grid shutdown, the power shuts down at the panel level. The wires are not energized.

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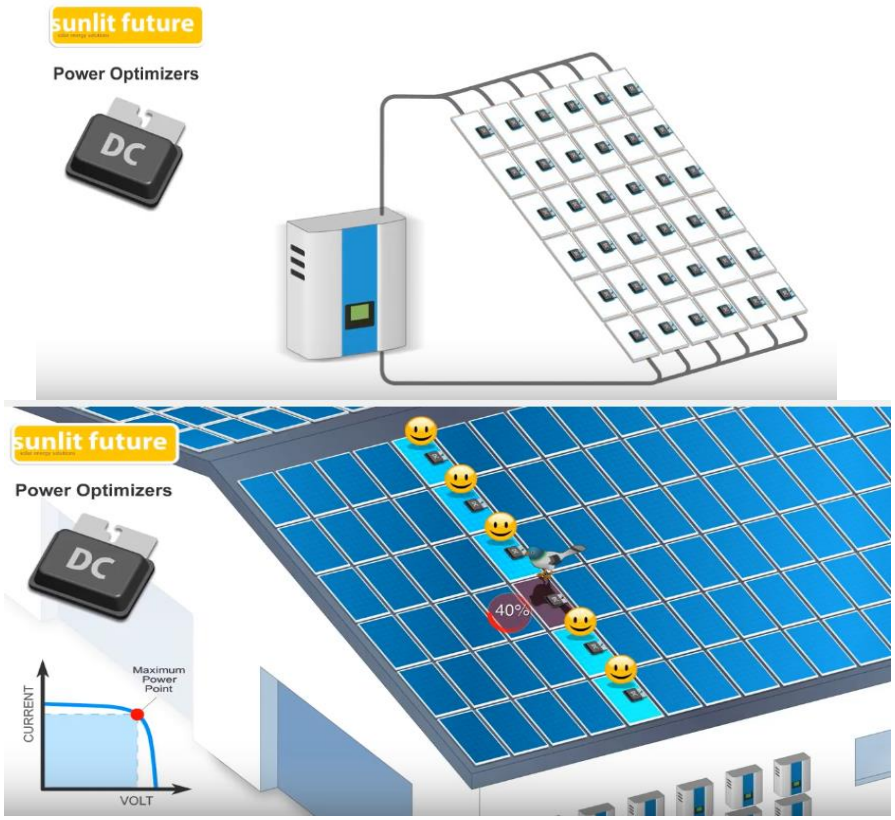
Introduction to Solar Energy
Basic Electrical Circuit – Power Optimizer



- Power optimizer and simplified inverter circuit.
- Power inverter is a DC to DC device that maintains panels maximum power point.
- A problem with one panel does not affect the entire string.

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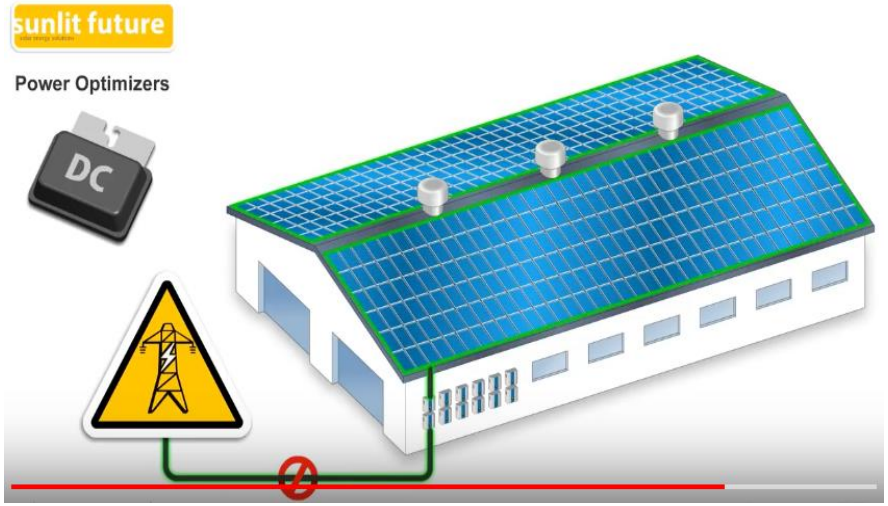
Introduction to Solar Energy
Basic Electrical Circuit – Power Optimizer



- During a grid shutdown, the voltage is reduced to a low and safe voltage.
- The power optimizer system is considered less expensive than then the Micro Inverter system.

Introduction to Solar Energy
Basic Electrical Circuit – Final Thoughts

- Both the Micro Inverter solution and Power Optimizer systems allow for the monitoring of the individual panels.
- MLPE systems are more efficient than String Inverter systems.
- MLPE are more versatile than String Inverter systems.

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Introduction to Solar Energy
Racking– Mechanical Attachment

- Mechanical fasteners attached to structural members
- Flashed mounting points
- Rails to attach modules and micro inverters
- Integrated grounding features

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Introduction to Solar Energy

Racking – Ballasted

- Can be used on flat roofs, ground mounts, capped landfills
- Vast majority of solar installers use ballasted mounting systems on low slope membrane roof systems
- Weight holds array in place
- No penetrations but more weight
- The National Roofing Contractors Association prefers mechanically attached flashed mounts due to ease of inspection

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Introduction to Solar Energy
Racking – Ground Mount

- Poles are placed in the ground and the racking system is installed on top to hold the solar panels
- Concrete piers, driven pilings, helical piles
- Soil type, wind, snow and freeze – thaw cycles need to be analyzed for this mounting type.

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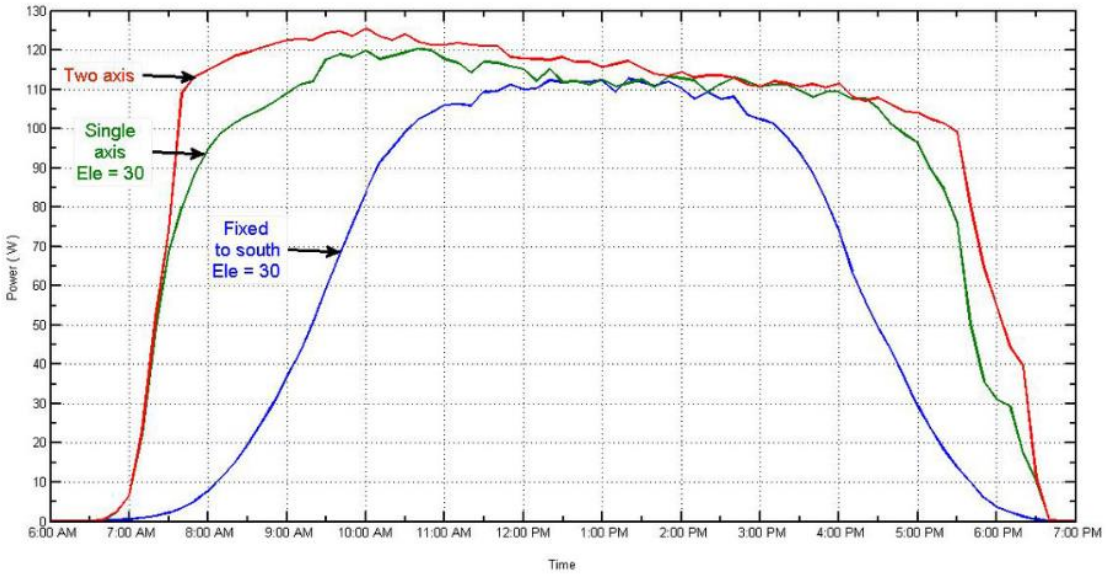
Introduction to Solar Energy

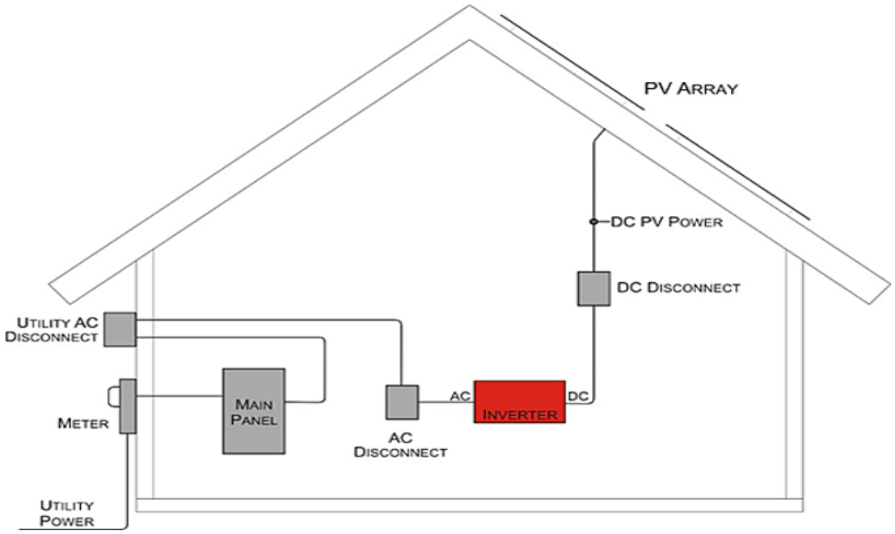
Trackers – Single and Dual-Axis



- Light Dependent Resistor (LDR) keeps the panels perpendicular to the sun. Clouds create problems.
- A single axis tracker is calculated to achieve 34% greater solar gain over a fixed solar panel.
- A dual axis tracker is calculated to achieve 45% greater solar gain over a fixed solar panel.

Introduction to Solar Energy

Balance of the System



Simple schematic showing the main components of a PV system and how it is typically incorporated into a building—in this case a home.

- Meters
- Inverters
- Disconnects
- Combiners
- Wire
- Etc.

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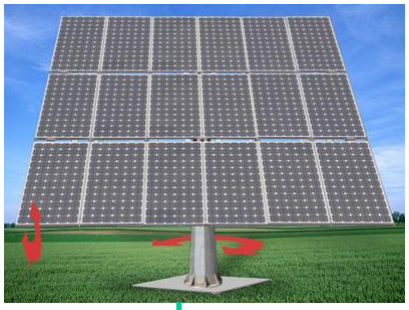
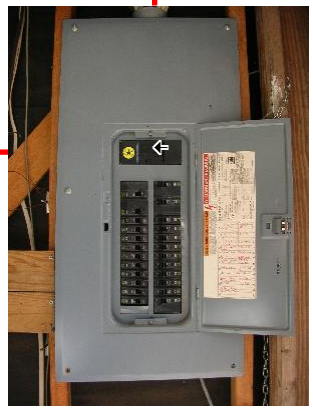
Grid Tied System Components



AC Disconnect
With in 10’ of
utility meter

DC Disconnect

Inverter



DC

AC

Introduction to Solar Energy
System Components

- Certifications under IEEE1547 for solar inverters
- UL1541 for inverters, and 1708 for modules
- New standards are emerging for inverters
  - CA- Rule 21/ IEEE1547.
  - Allow for more advance functions
    - Low voltage ride through
    - Dynamic controlling

Introduction to Solar Energy
California's Rule 21

"may be the most advanced set of requirements for the connection of solar and energy storage in United States."…." All new solar and storage installations must use inverters that have features previously reserved for larger commercial or utility applications, including Volt/VAR support functions, soft start, and displacement power support, and have inverter ride-through grid disturbances that previously that previously would have caused a disconnect."

https://www.pecanstreet.org/2019/04/what-californias-rule-21-gets-right-and-wrong-for-residential-solar/

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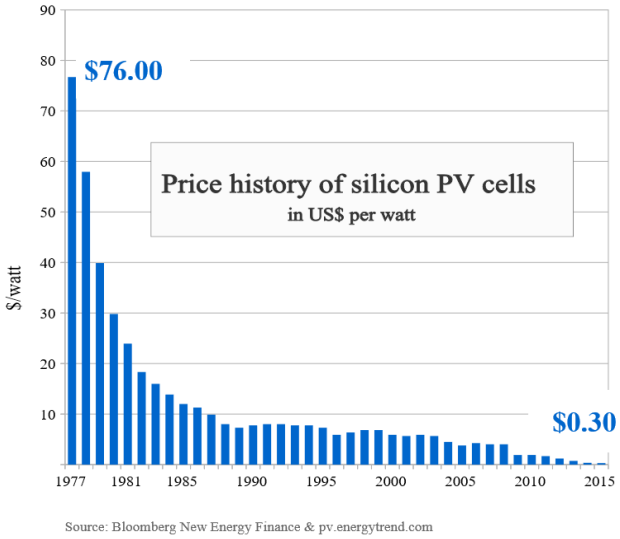
Introduction to Solar Energy

Installation Cost



Source: Bloomberg New Energy Finance & pv.energytrend.com

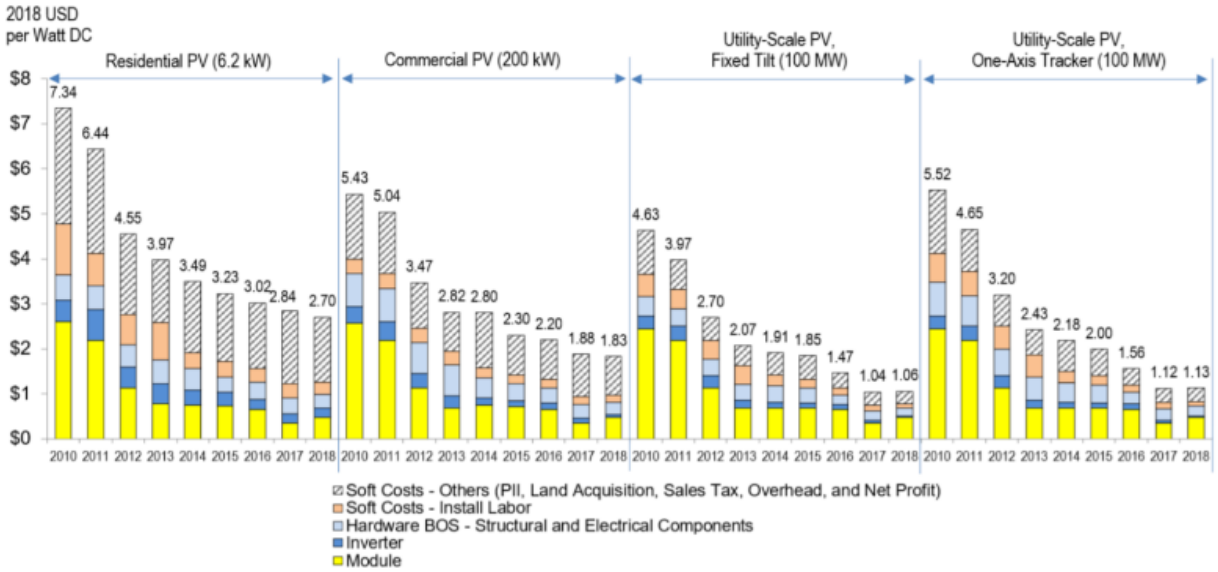


Figure ES-1. NREL PV system cost benchmark summary (inflation adjusted), 2010–2018

- Cell cost reduction due to polysilicon price reduction, economies of scale
- Average panel cost is $2.99 / watt in 2019 down from $300/watt in the 1950's
- Average system size is 6 kW in 2019
- Plan on $4.50 per watt for residential installation

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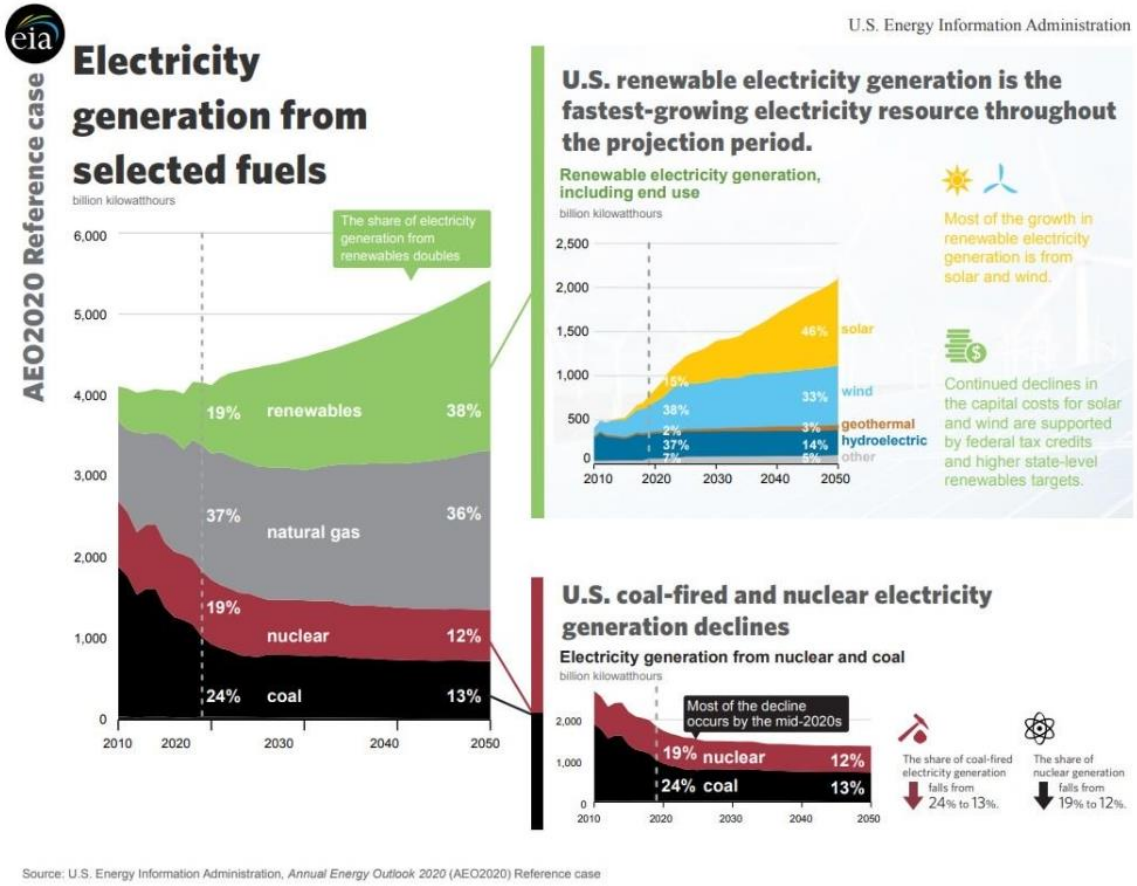
Introduction to Solar Energy

Future Electrical Generation



Source: U.S. Energy Information Administration, *Annual Energy Outlook 2020* (AEO2020) Reference case

https://www.eia.gov/outlooks/aeo/pdf/aeo2020.pdf

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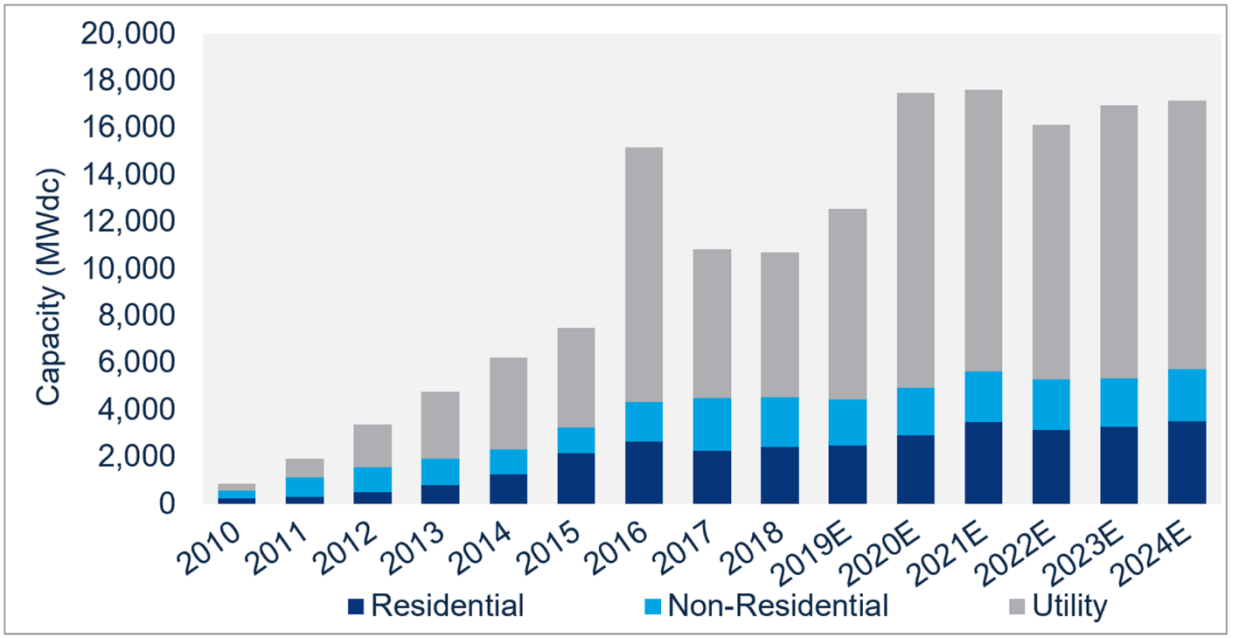
Introduction to Solar Energy

Projected PV Installation



- **Residential** – Expected growth to be between 2 to 19% depending upon location.
- **Non-residential** - growth is expected to be flat.
- **Utility** – There are currently 37.9 GW_{dc} in the pipe line and they expect at least an additional 4.0 GW_{dc} to be added to that total.

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Introduction to Solar Energy
Minnesota / Wisconsin Comparison

Minnesota

- State Mandates – 25% renewable electricity by 2025. 1.5% solar electricity by the end of 2020.
- Total Installed 1,204.4 MW
- Installed in 2018 – 352.7 MW
- Percentage of States Electricity from Solar – 2.49%
- Growth Projection over the next 5 years – 797 MW

Wisconsin

- State Mandates – None
- Total Installed – 92 MW
- Installed in 2018 – 15.9 MW
- Percentage of States Electricity from Solar – .10%
- Growth Projection over the next 5 years – 981 MW

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Introduction to Solar Energy
Solar Electric – Incentives

- Federal Tax Credit
- 26% in 2020
- 22% in 2021
- 10% thereafter for businesses
- Accelerated depreciation (MACRS) for commercial
- Storage systems may also apply with stipulations on charging source

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Introduction to Solar Energy
Solar Electric – Minnesota Power

- Solar Sense
- $701,395 set aside for 2020
- Projects need to be completed by 11/15/2020
- Estimated production to define incentive
- A Maximum of $20,000 or 60% of installed costs for each installation
- A maximum of 120% of the premises 12 month usage.
- 20 kW / 40 kW maximum system size (AC)

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Solar Electric – XCEL

- Solar Rewards
- $9,700,000 allocated for 2020
- Production based incentive
  - Payments based on production of the system
  - $.07 per kWh for 10 years for residential systems, no upfront payment, 120% cap on previous 12 months usage.
  - Systems from .5kW to 40 kW AC
- Additional plans for income qualified residential systems, non profits, solar gardens and commercial systems.
- https://www.xcelenergy.com/programs_and_rebates/residential_programs_and_rebates/renewable_energy_options_residential/solar/available_solar_options/on_your_home_or_in_your_yard/solar_rewards_for_residences

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Solar Electric – Great River Energy

- A year before Great River Energy adopted the 50% renewables by 2030 goal, the cooperative filed an integrated resource plan with the Minnesota PUC, that filling projected that Great River Energy would need to add 600 MW of energy beginning in 2029 and selected wind energy as the lowest cost option. Of the 600 MW, 100 MW would be wind energy.
- Great River's portfolio currently includes 468 MN of wind energy, 200 MW of hydropower, 4 MW of solar and 30 MW of biomass.

Introduction to Solar Energy
Solar Electric – NABCEP

- North American Board of Certified Energy Practitioners (NABCEP)
  - MREA course's required to take the NABCEP test (32 hours)
    - PV201 Basic Photovoltaics ($135, online, 8 hrs.')
    - PV201 PV Site Assessor Training ($195, online, 8 hrs.')
    - PV202 PV System Design ($315, online, 16 hrs.')
    - NABCEP PV Associate Exam
  - Six months of full time work with photovoltaics, solar heating or small wind and then pass the NABCEP PV Associate Exam

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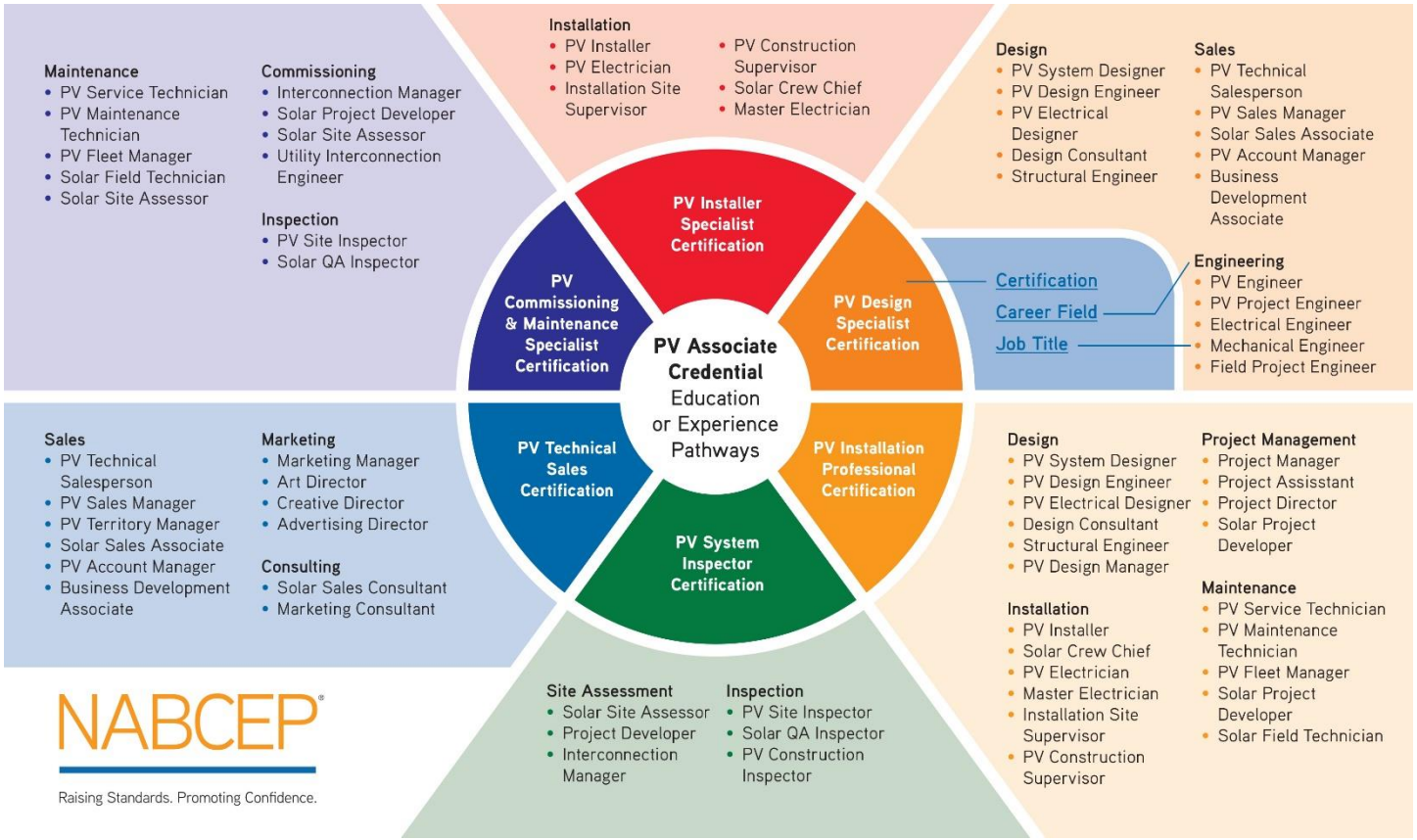
Solar Electric – NABCEP



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Solar Electric – NABCEP

- **Why should I achieve a NABCEP Certification?**
  - 60% 0f EPCS consider NABCEP Board Certification essential or very important when Hiring employees
  - $11,000 is the average salary increase after earning a NABCEP Board Certification
  - 26% of NABCEP Board Certified Professionals end up starting their own business
- **Minnesota Power – Solar Sense**
  - Select a contractor

    Selecting a contractor that meets your needs is an important step in the process. While Minnesota Power does not require that you choose a specific installer to participate in the SolarSense program, an installer certified with the North American Board of Certified Energy Practitioners (NABCEP) or Underwriters Laboratory (UL) is required. Click here to find a NABCEP certified installer in your area.

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Solar Electric – Codes and Rules

- The Department of Labor and Industry requires electrically trained persons to perform the work associated with PV installation
- NEC codes that guide the proper installation of electrical components
  - 690 Solar Photovoltaic Systems
  - Other associated NFPA 70 sections
- NABCEP and UL certifications
- State interconnection Standards
  - 2004 standards currently being updated
  - Small Generator Interconnection Process

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Squirrels and Solar

- Squirrels damage is expensive
- Install a squirrel guard?

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Snow

- The biggest aggravation to residential customers is that they expected the snow to slide off their panels
- The snow will not slide off an 8/12 pitch roof without mechanical help
- Does the snow have a place to go?
- Be careful what you tell the customer

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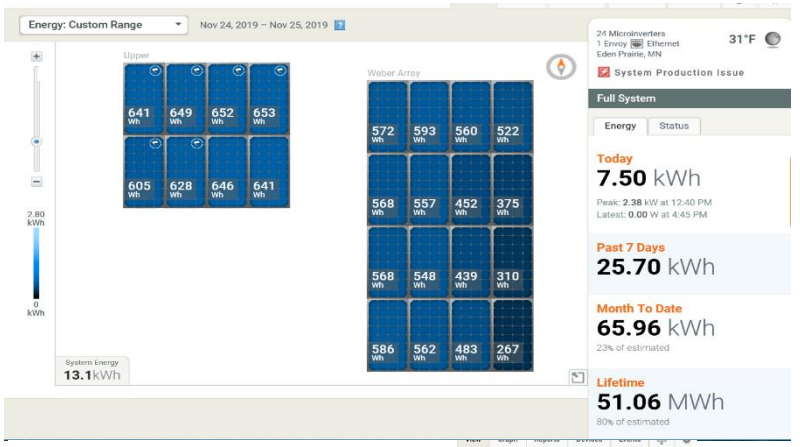
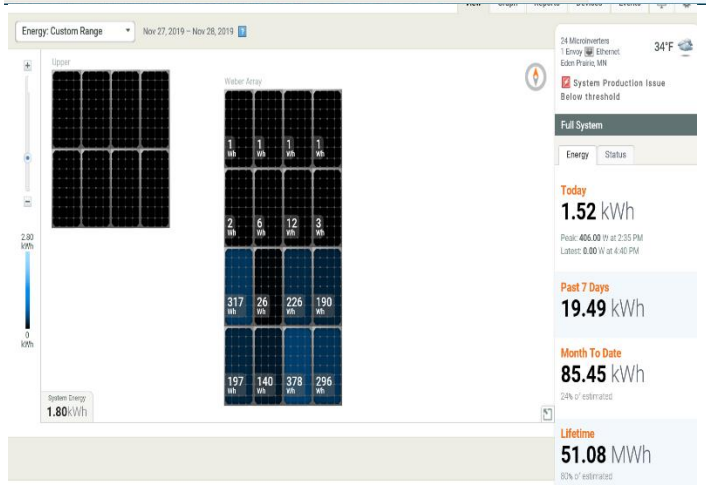
Snow Example – 11/26/2019 Storm



Day 1



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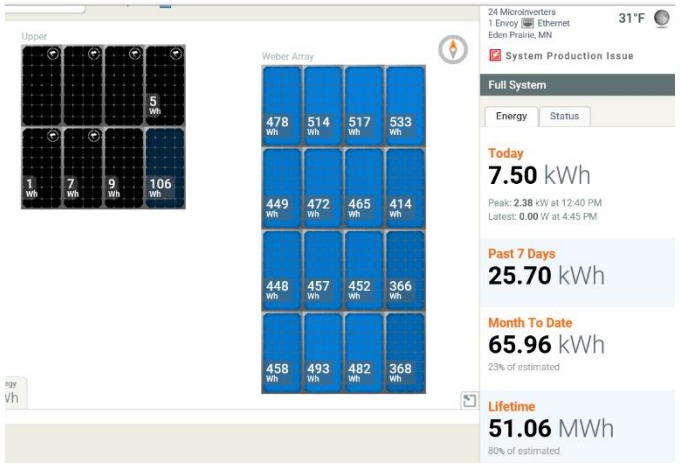
Snow Example – 11/26/2019 Storm

Day 27



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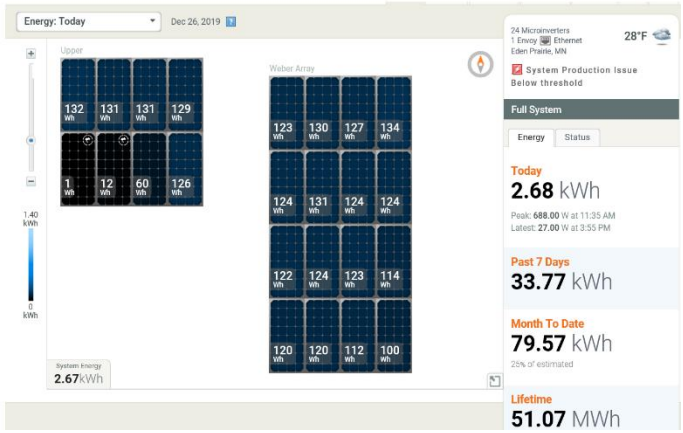

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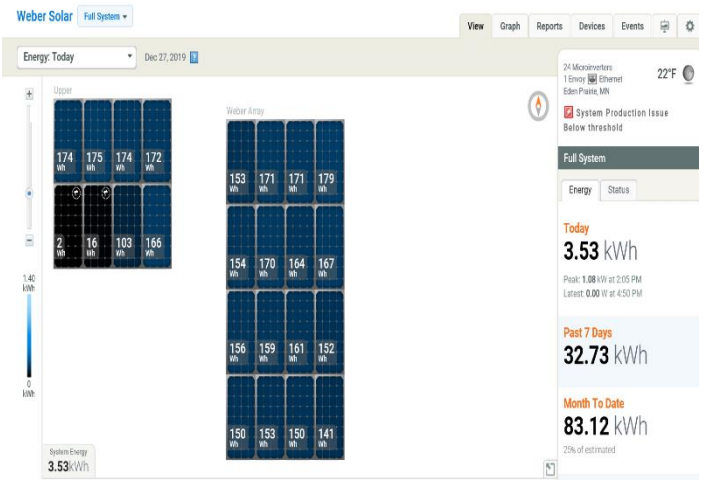
Snow Example – 11/26/2019 Storm

Day 32



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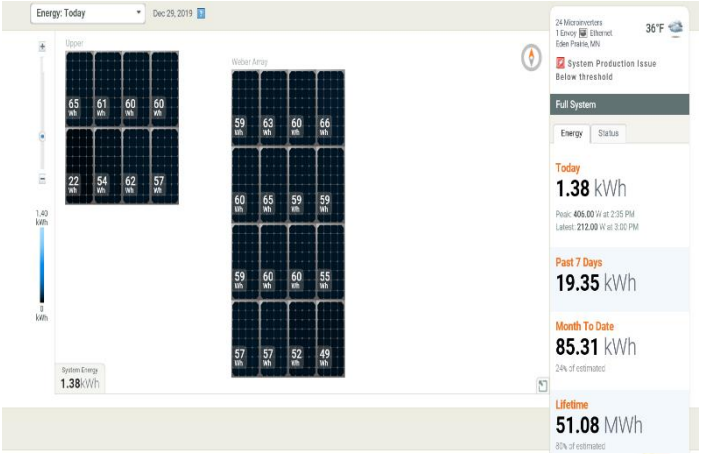

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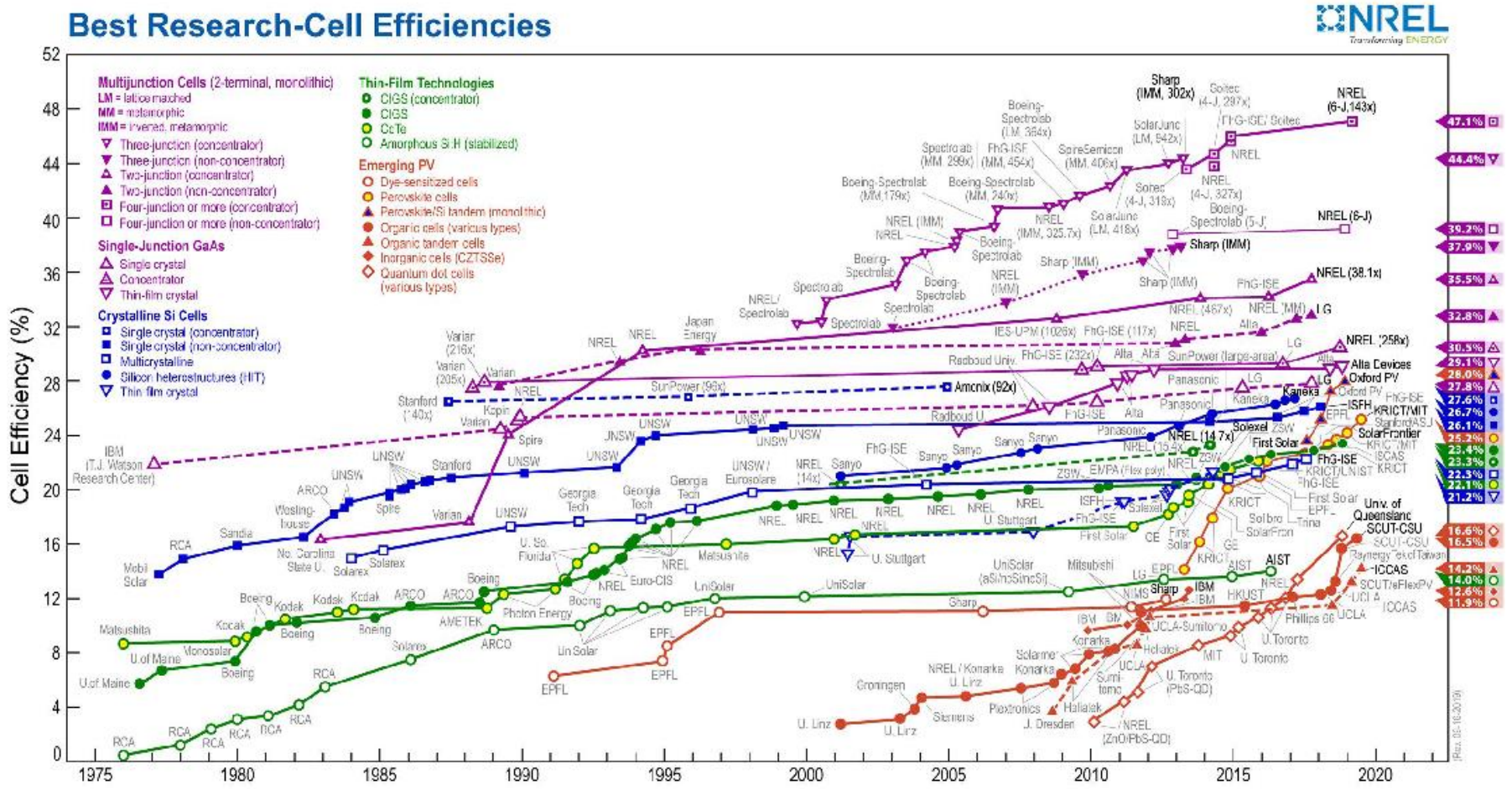
Solar Electric – Cell Research



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Introduction to Solar Energy
Solar Electric – BIPV Definition

- Building-integrated photovoltaic (BIPV) electric power systems not only produce electricity, they are also part of the building. For example, a BIPV skylight is an integral component of the building envelope as well as a solar electric energy system that generates electricity for the building. These solar systems are thus multifunctional construction materials.

Introduction to Solar Energy

Solar Electrical – BIPV Types

- **Facade Systems**
  - Curtain wall
  - Spandrel panels
  - Glazing
- **Roofing Systems**
  - Tiles
  - Shingles
  - Standing seem products
  - Skylights

Introduction to Solar Energy

Solar Boat Races

- **28th Annual MRES Solar Boat Regatta**
  - Middle school / High school age
  - Eden Prairie, MN – May 16th, 2020
- **27th Annual Solar Splash**
  - University age
  - Springfield OH, June 9th – June 13th, 2020

SOLAR BOAT 28th ANNUAL Regatta MAY 16, 2020

SOLAR SPLASH

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Solar Car Races

- **American Solar Challenge**
  - Endurance race from Independence, MO to Boise, ID
  - July 10th – July 25th 2020
- **Solar Car Challenge**
  - High School age STEM
  - Texas Motor Speedway
  - July 20th – July 23rd 2020

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Introduction to Solar Energy
Volunteer Opportunities

- **MREA Energy Fair**
  - Custer, Wisconsin
  - Beer, Training, Exhibits, Fun
  - June 26th – June 28th , 2020

- **MRES Eco Experience at the Minnesota State Fair**
  - Minnesota State Fair
  - Help educate 320,000 fair goers
  - 150 volunteers needed
  - August 27th – September 7th, 2020

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Introduction to Solar Energy

Carbon Dioxide (CO2) Sources

Why is carbon capture important?

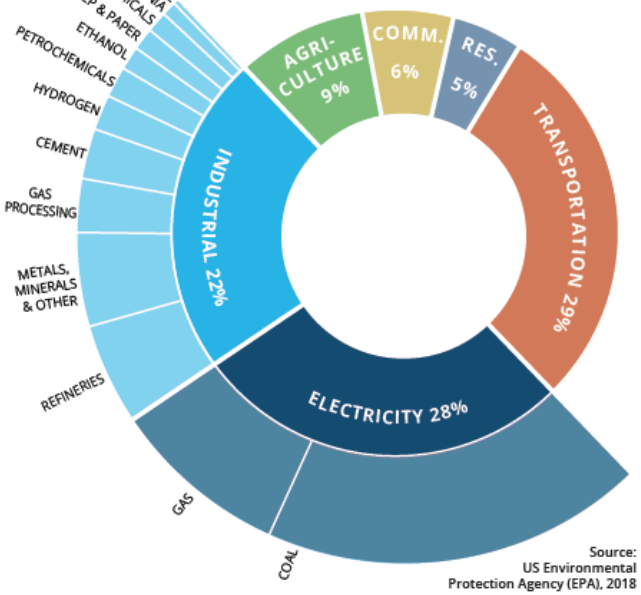
Authoritative analysis by the International Energy Agency and Intergovernmental Panel on Climate Change (IPCC) shows the critical role carbon capture must play in achieving US and global carbon reduction targets by 2050. Carbon capture enables many industries to reduce or eliminate their carbon emissions while protecting and creating high-wage jobs.

Moreover, for key carbon-intensive industries such as steel and cement, significant CO_2 and CO emissions result from the chemistry of the production process itself, regardless of energy inputs.

Thus, carbon capture is an essential emissions reduction tool for major industrial sectors that are otherwise difficult to decarbonize.

Figure 1 illustrates that emissions from the US industrial sector are as significant as the electric or transportation sectors.

Figure 1. Percentage of total US CO_2 emissions by sector



Source: US Environmental Protection Agency (EPA), 2018

GREAT PLAINS INSTITUTE Better Energy. Better World.

BETTERENERGY.ORG

Carbon capture refers to a group of technologies that prevent industrial and electric power facilities CO2 emissions from reaching the atmosphere or remove CO2 from the atmosphere.

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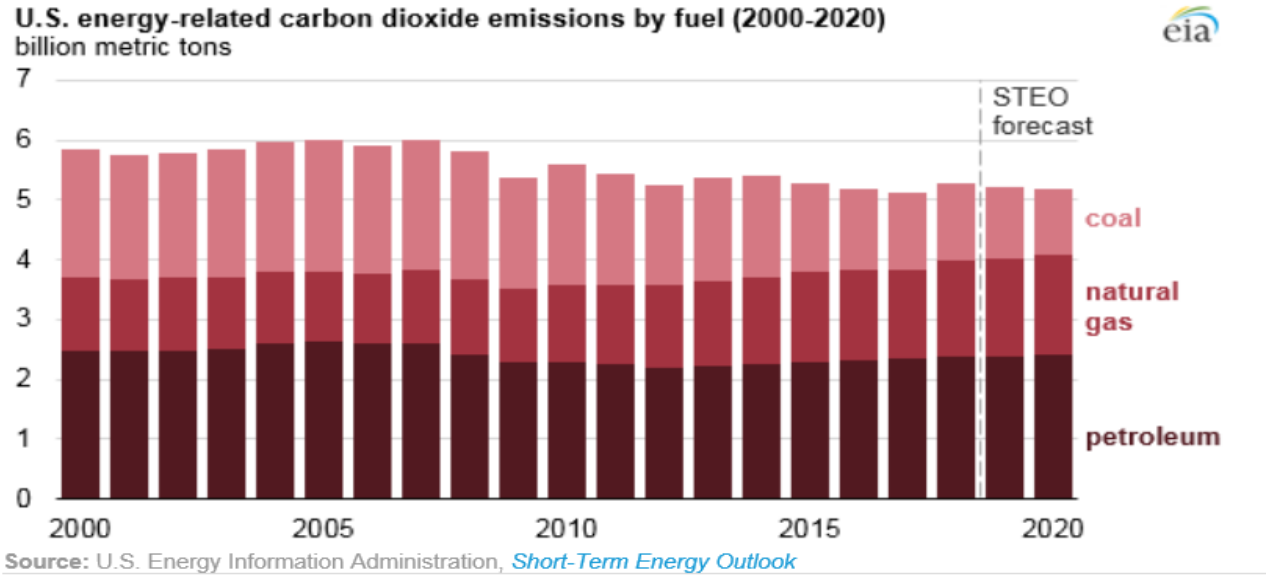
Carbon Dioxide (CO2) Emissions



After decreasing by 2.1% in 2019, EIA forecasts that energy – related CO2 emissions will decrease by 2.0% in 2020 and by 1.5% in 2021. Declining emissions reflect forecast declines in total U.S energy consumption combined with assumptions of relatively normal weather.

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MRES

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