DOE OFFICE OF INDIAN ENERGY

Foundational Courses
Renewable Energy Technologies
SOLAR

Presented by the National Renewable Energy Laboratory



U.S. DEPARTMENT OF ENERGY | Office of Indian Energy

NREL's Presenter on Solar is

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Introduction

- **Purpose** – define different solar technology, applications, cost, and performance
- **Key Takeaways** – solar technologies work in all parts of the United States, economics of solar are dependent on first cost (including incentives), solar resource, and cost of energy being displaced

Maps of Resources

- http://www.nrel.gov/gis/maps.html
  - Biomass
  - Geothermal
  - Hydrogen
  - Solar
    - Photovoltaic (PV)
    - Concentrating Solar Power (CSP)
  - Wind
- State and national level maps

Photovoltaics System (Grid Connected)

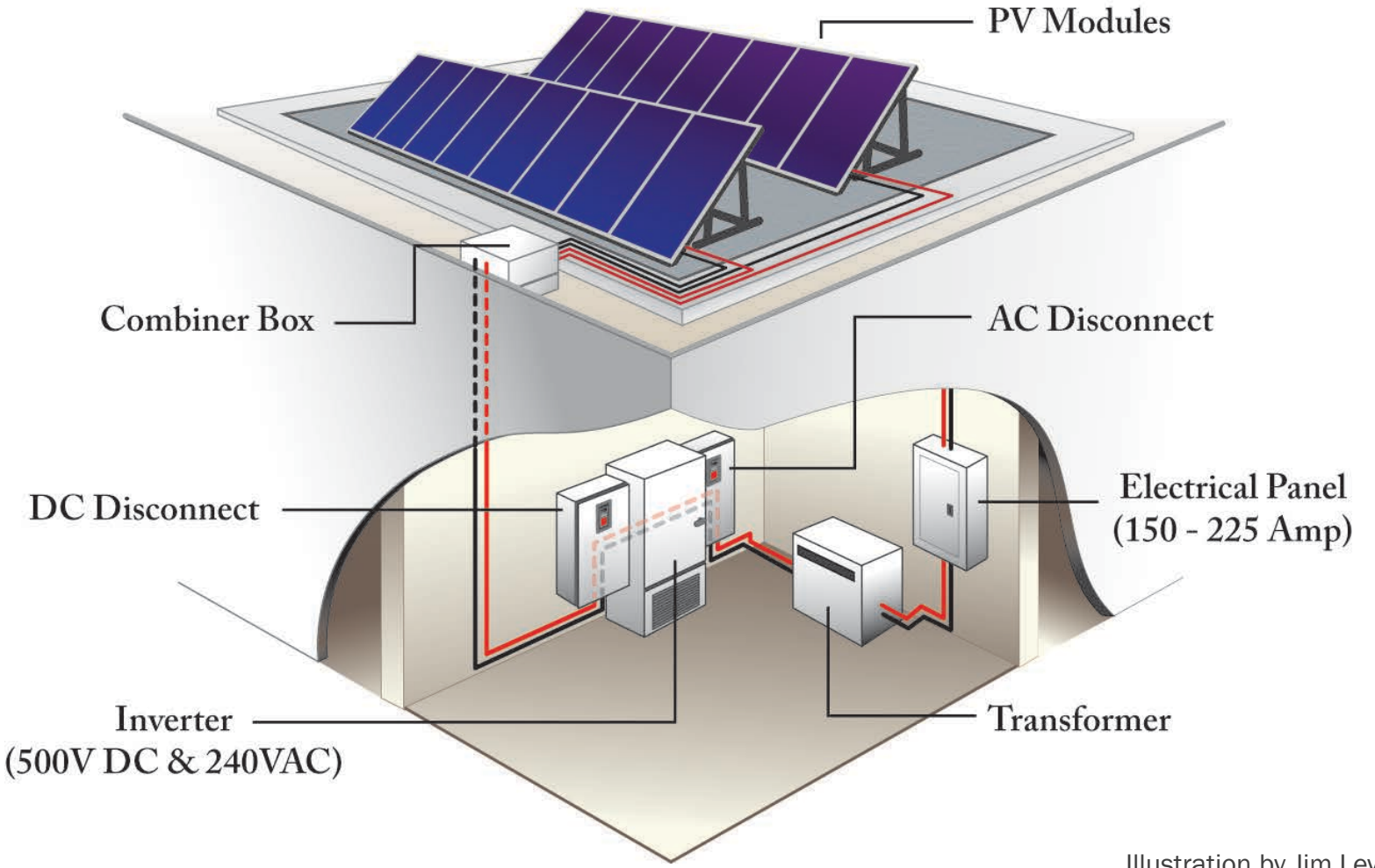

Illustration by Jim Leyshon, NREL

PV Technology

- Direct conversion of sunlight into direct current (DC) electricity
- DC converted to alternating current (AC) by inverter
- Solid-state electronics, no-moving parts
- High reliability, warranties of 20 years or more
- PV modules are wired in series and parallel to meet voltage and current requirements

Ground mount PV

Arizona Public Service, Prescott, Arizona
Photo from Arizona Public Service

Dangling Rope Marina, Glen Canyon National Recreation Area, Utah
Photo by Warren Gretz, NREL

Alamosa PV System, Alamosa, Colorado
Photo by Tom Stoffel, NREL

Single Axis Tracking PV

- Increases energy production by ~20% depending on climate
- Large ground mount only >300kW
- Costs more to build, higher O&M
  - But not much more
  - Increasingly more systems have 1-axis tracking

Photo by Warren Gretz, NREL

Rooftop and Carport PV

Rooftop

- No additional greenspace taken
- Ballasted systems very common
  - No penetrations
- 5 to 20 degree tilt common

Carport

- Dual use of land, no additional greenspace taken
- Adds shade as an amenity
- More expensive

Photo by Andy Walker, NREL

Photo by Dan Olis, NREL

PV General

- Very sensitive to shading
- Approx. 0.5%/year annual performance degradation
  = 13% in year 25
- Best performance when tilt = latitude and system is oriented south
  - But performance is relatively insensitive to some deviation
  - Economics might drive these parameters off 'ideal'

Impact of Tilt and Azimuth on Annual PV Energy Production in St. Paul
Values in the table are deviation from maximum production (100%) with a 45-degree tilt and azimuth set to due south.

Tilt Angle (degrees)	45 Deg. West of South	30 Deg. West of South	15 Deg. West of South	Due South	15 Deg. East of South	30 Deg. East of South	45 Deg. East of South
20	92%	94%	96%	96%	96%	94%	92%
33	94%	97%	99%	100%	99%	98%	95%
45	94%	97%	99%	100%	99%	98%	95%

- Panel efficiency determines system footprint, not energy production

$$\text{Area } (m^2) = \frac{\text{Power out (W)} \times 100\%}{\text{Solar cell efficiency (\%)} \times 1000\ W/m^2}$$

Total Area Required for PV

- Varies by technology, tilt, and location
- For crystalline silicon
  - Roof mount - sloped roof, flush-mounted power densities of 11 watt-DC (W)/square foot (ft^2) crystalline
  - Flat roof = 8 W-DC/ft^2
  - Ground mount: 5 to 6 acres per 1000 kW (1MW)

Priorities: Where to Install Solar

- On the "built environment" where unshaded
  - On existing building roofs that have an expected life of at least 15 more years and can accept added load - typically 2-4 pounds (lbs)/ft^2. Reduces solar load on building
  - On ALL new buildings – all new buildings should be "solar ready"
    - See http://www.nrel.gov/docs/fy10osti/46078.pdf
  - Over parking areas, pedestrian paths, etc. – energy generation and nice amenity
- On compromised lands such as landfills and brown fields
  - Saves green fields for nature
  - If installed on green fields, minimize site disturbance; plant native low height vegetation as needed

Important Policies

- Interconnection limit
  - Sets maximum size of system that the utility will allow to interconnect
- Net metering
  - Net-metering limit is the max size system that qualifies for the net-metering policy
  - Gives system owner/host credit for excess generation that is sent back to utility
  - Virtual net-metering, if available, allows system owner/host's to transfer credits to other meters/accounts they may have

PV Installed Costs

- Residential $3.30/Watt-DC
- Commercial $2.50/Watt-DC
- Utility scale $1.80/Watt-DC

Photovoltaic System Pricing Trends: Historical, Recent, and Near-Term Projections. 2014 Edition (Presentation). Sunshot, U.S. Department of Energy (DOE)
NREL/PR-6A20-62558
D Feldman; G Barbose; R Margolis; T James; S Weaver; N Darghouth; R Fu; C Davidson; S Booth; R Wiser; Lawrence Berkeley National Laboratory. 2014
http://www.nrel.gov/docs/fy14osti/62558.pdf

Solar Concentrating Technologies

- Captures direct beam sunlight only
- Heat used in conventional steam cycle
- Dispatchable when coupled with thermal energy storage
- Uncommon
- Disadvantages:
  - Viable only for large (50 MW+) plants
  - Most viable in the desert Southwest
  - Normally requires water for cooling towers

Parabolic trough

Power tower

Useful Resources

SOLAR ENERGY RESOURCES	• NREL: http://www.nrel.gov/rredc/ • TMY or Weather Data: http://rredc.nrel.gov/solar/old_data/nsrdb/1991-2005/tmy3/
SOLAR PV ANALYTICAL TOOLS	• System Advisor Model (SAM): https://sam.nrel.gov/ • PVWatts: http://pvwatts.nrel.gov/
STATE UTILITY POLICIES & INCENTIVES	• DSIRE: http://www.dsireusa.org

Thank You & Contact Information

For Technical Assistance:

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DOE Office of Indian Energy Website:

www.energy.gov/indianenergy

NREL Technology Websites:

www.nrel.gov/learning/re_basics.html

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