SAND2017-6343C

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PV Deployment – Motivation and Challenges

Abraham Ellis, PhD

Photovoltaics and Distributed Systems Integration

Sandia National Laboratories

SAND2016-9752 PE

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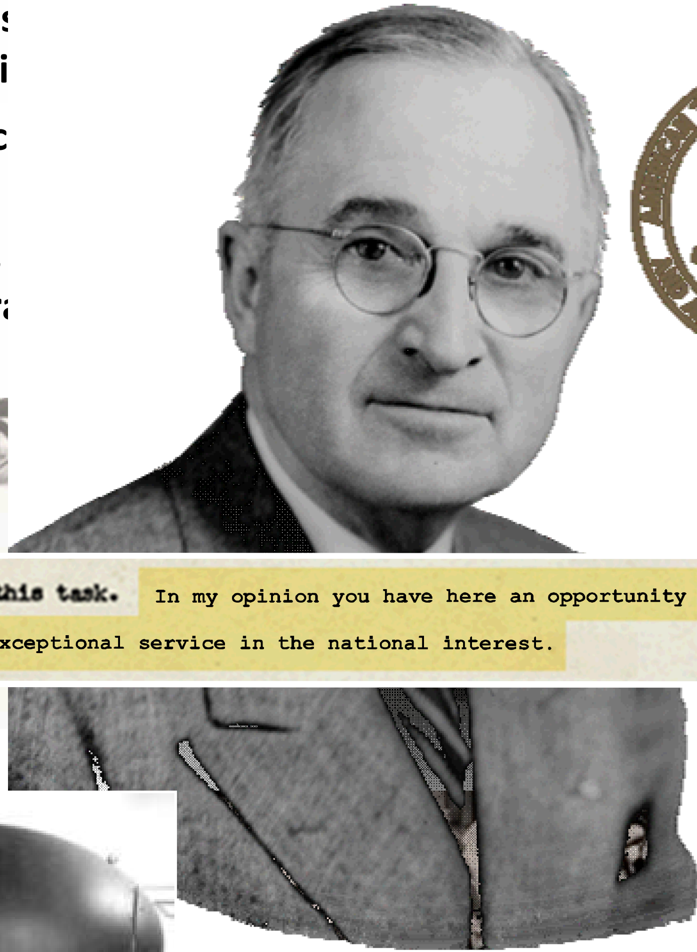
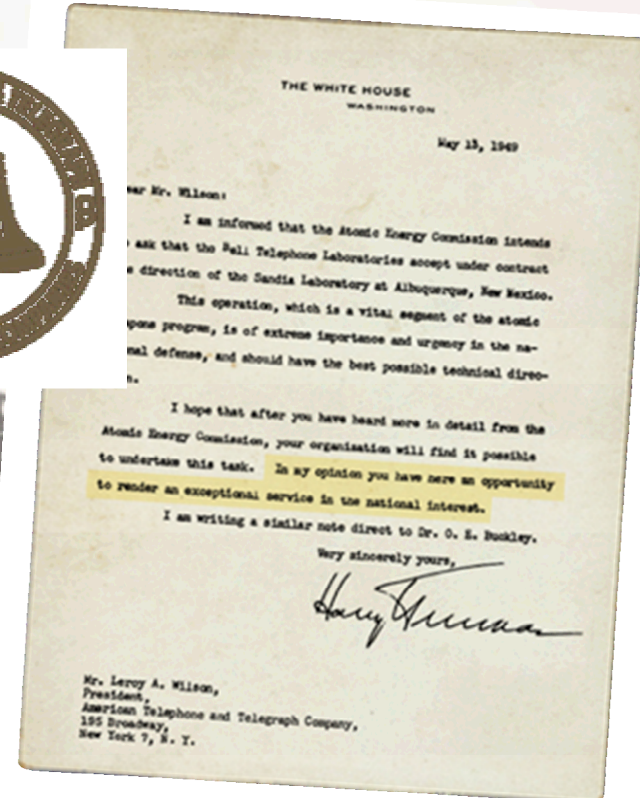
Sandia's History

Exceptional service in the national interest

- July 1945: Los
  creates Z Divi
- Nonnuclear c
  engineering
- November 1,
  Sandia Labora
  established





THE WHITE HOUSE
WASHINGTON

May 13, 1949

ear Mr. Wilson:

I am informed that the Atomic Energy Commission intends
ask that the Bell Telephone Laboratories accept under contract
e direction of the Sandia Laboratory at Albuquerque, New Mexico.

This operation, which is a vital segment of the atomic
pons program, is of extreme importance and urgency in the na-
nal defense, and should have the best possible technical direc-
n.

I hope that after you have heard more in detail from the Atomic Energy Commission, your organization will find it possible to undertake this task. In my opinion you have here an opportunity to render an exceptional service in the national interest.

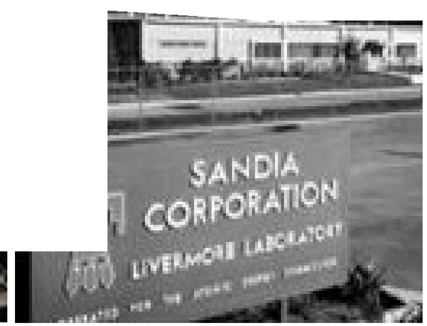
I am writing a similar note direct to Dr. O. E. Buckley.

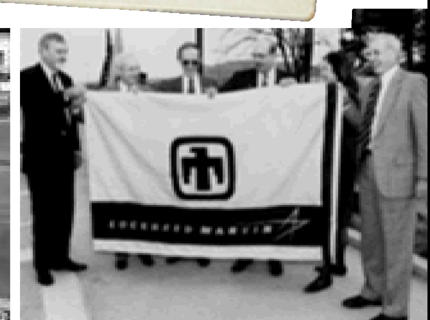
Very sincerely yours,

Harry Truman

Mr. Leroy A. Wilson,
President,
American Telephone and Telegraph Company,
195 Broadway,
New York 7, N. Y.

to undertake this task. In my opinion you have here an opportunity to render an exceptional service in the national interest.

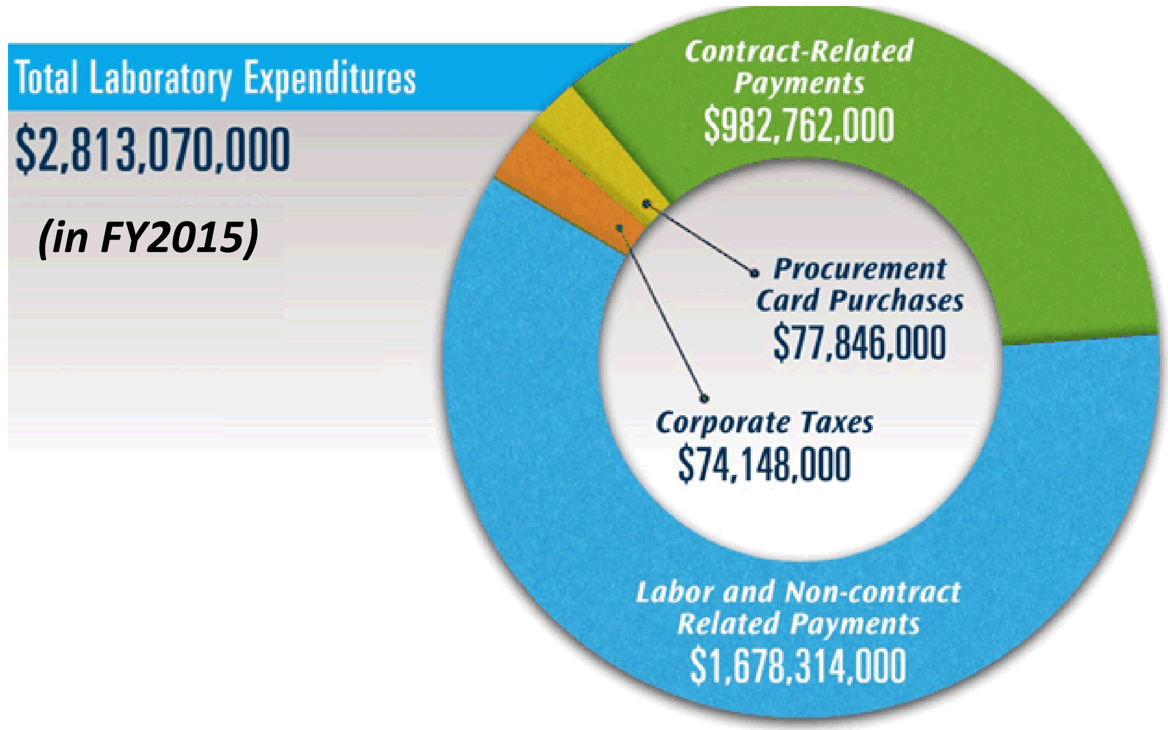




Key Sandia Figures

- Total Sandia workforce: 12,611
- Regular employees: 10,643
- Advanced degrees: 5,898 (55%)

Data as of December 14, 2015



(in FY2015)

Sandia Sites

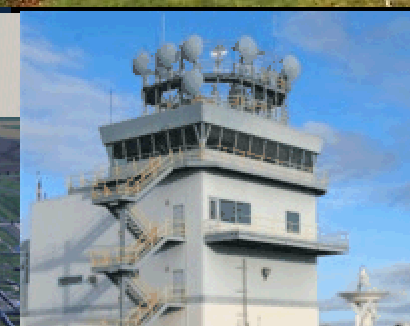
Albuquerque, New Mexico

Livermore, California

Kauai, Hawaii

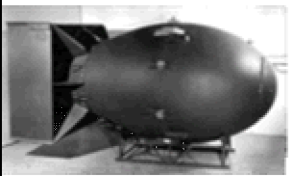
Waste Isolation Pilot Plant, Carlsbad, New Mexico

Pantex Plant, Amarillo, Texas



Tonopah, Nevada

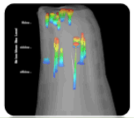
History of Sandia Energy Programs



a nuclear weapons engineering laboratory with deep science and engineering competencies

Energy crisis of the 1970s spawned the beginning of significant energy work

Strategic Petroleum Reserve – geological characterization of salt domes to host oil storage caverns



DOE's Tech Transfer Initiative was established by Congress in 1991

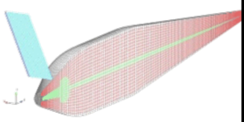
METAL HYDRIDE CENTER OF EXCELLENCE

Advent Solar

Energy Policy Act of 2005

Combustion Research Facility (CRF) & Cummins partner on their newest diesel engine

Joint BioEnergy Institute



Water Power Program

1950	1960	1970	1980	1990	2000	2007	2009	2010

Our core NW competencies enabled us to take on additional large national security challenges

Vertical axis wind turbine

NRC cask certification studies & core melt studies

Solar Tower opens

CRF opens to researchers

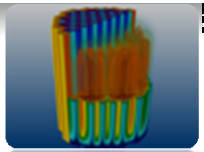
Distributed Energy Technology Laboratory (DETL) to integrate emerging energy technologies into new and existing electricity infrastructures

Power grid reliability study

SunCatcher™ partnership with Stirling Energy Systems

Sunshine to Petrol Pilot Test

Large-scale pool fire tests of liquefied natural gas (LNG) on water



Consortium for Advanced Simulation of Light Water Reactors (CASL)

Climate stu uncertainties ιυ economies

Combustion Research Computation and Visualization (CRCV) opens

Distributed Energy Technologies Laboratory

- Focus on PV inverters, energy storage, microgrids and other distributed energy technologies
- Efficiency, grid compatibility, interoperability, reliability and safety
- In operation since early 1980's, currently pace-constrained
- Constantly reconfiguring and adding new capabilities to support new industry needs

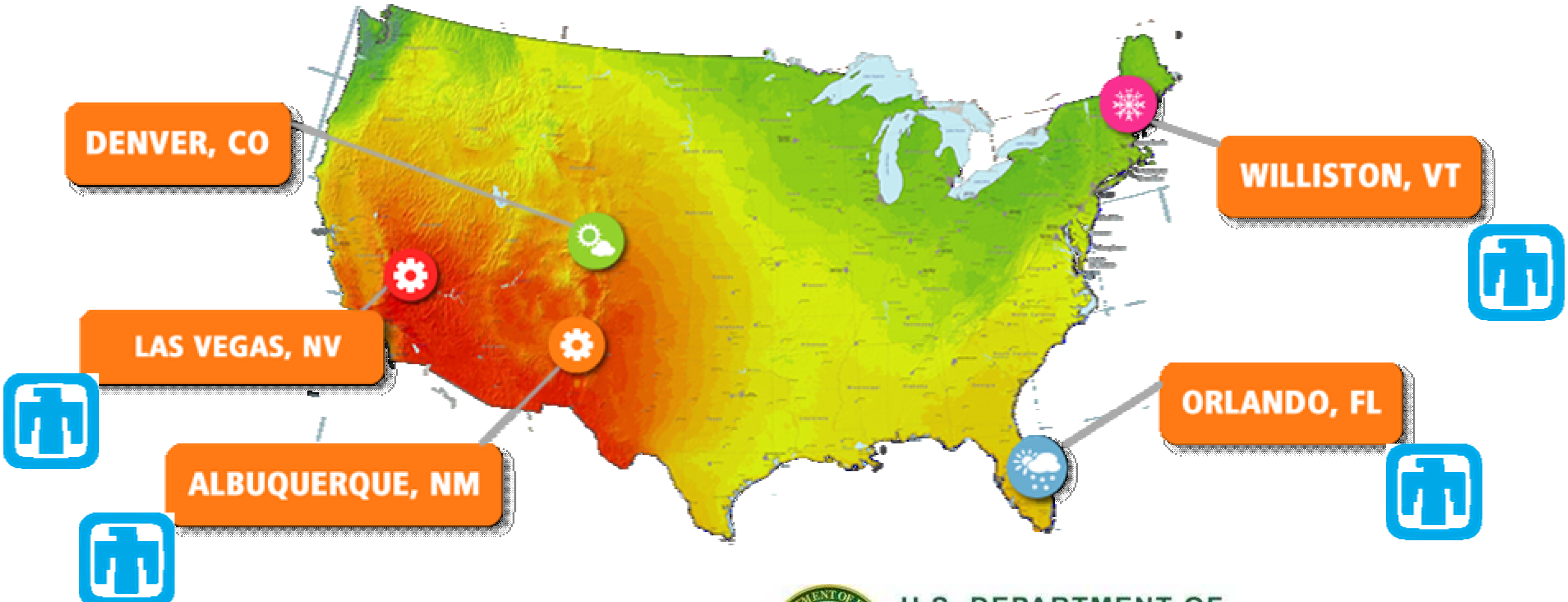
PV Systems Evaluation Laboratory

- Fully configurable test platforms for indoor, outdoor and long-term testing
- Full-scale cell and module performance characterization laboratory
- Controlled side-by-side PV system and component characterization
  - PV Systems, PV modules
  - Components such as cables, connectors, etc.

Regional Test Centers (RTCs)

- Public-Private Partnership
- Independent, rigorous PV technology validation in diverse climates
- Supports R&D and bankability

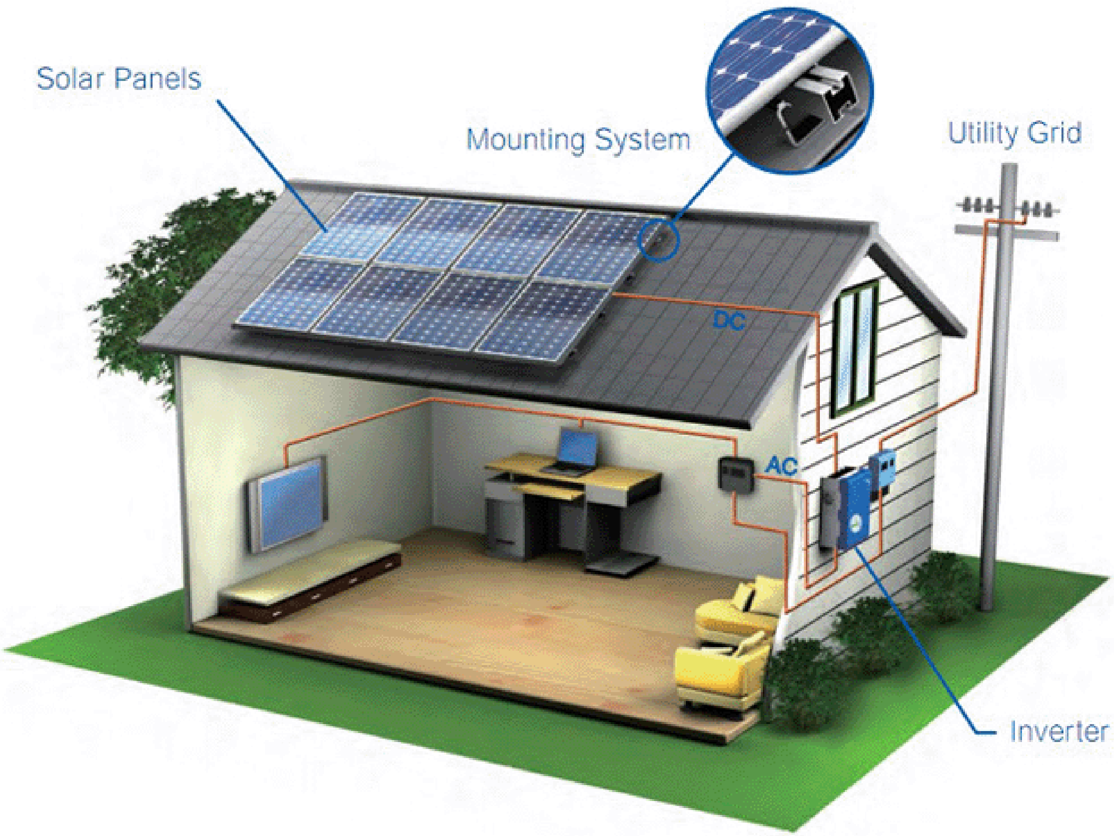
Regional Test Centers
Differentiating PV Quality



U.S. DEPARTMENT OF ENERGY

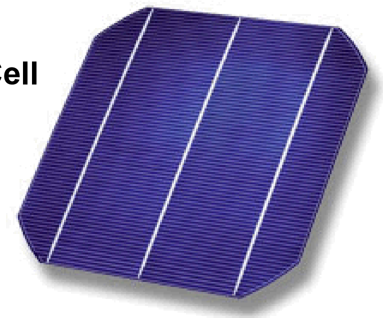
What is Solar Photovoltaic Energy?

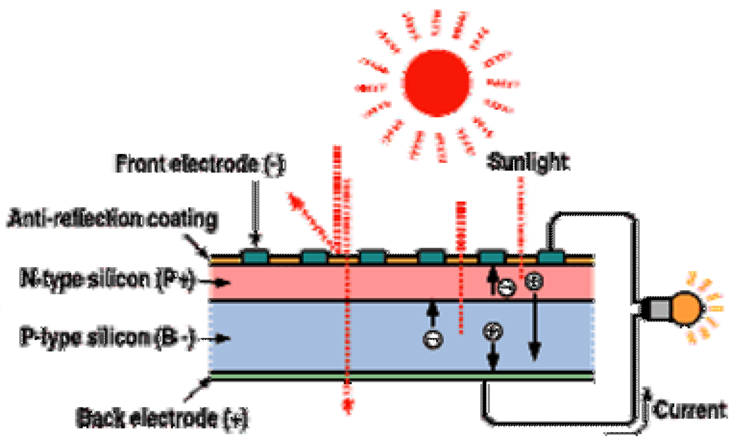
- Typical Photovoltaic (PV) Residential Installation



Typical Residential Solar Installation

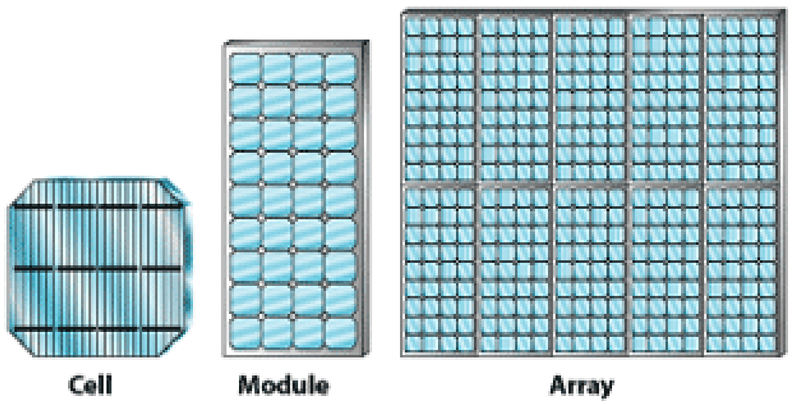
Solar Cell

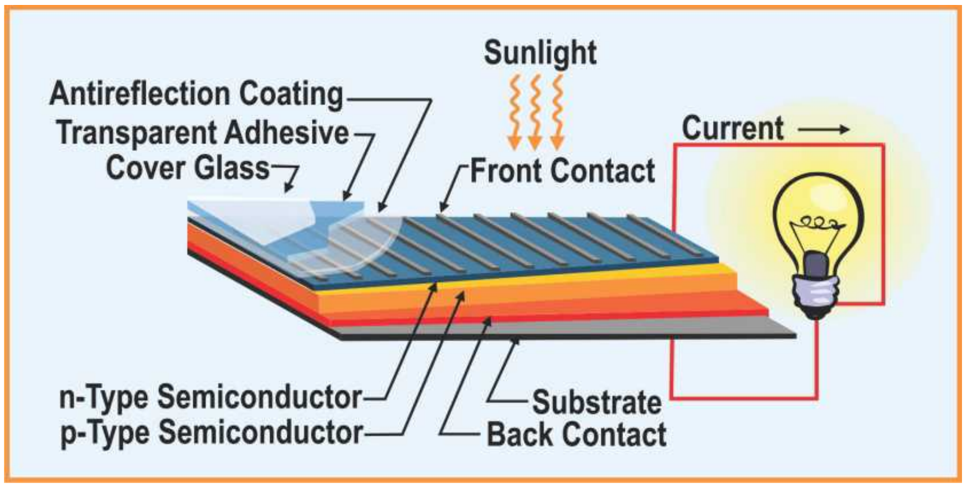




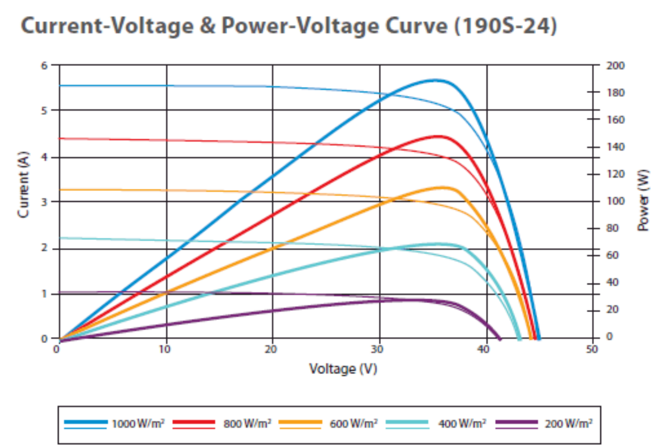
Photovoltaic Effect

PV Cells, Modules, and Arrays





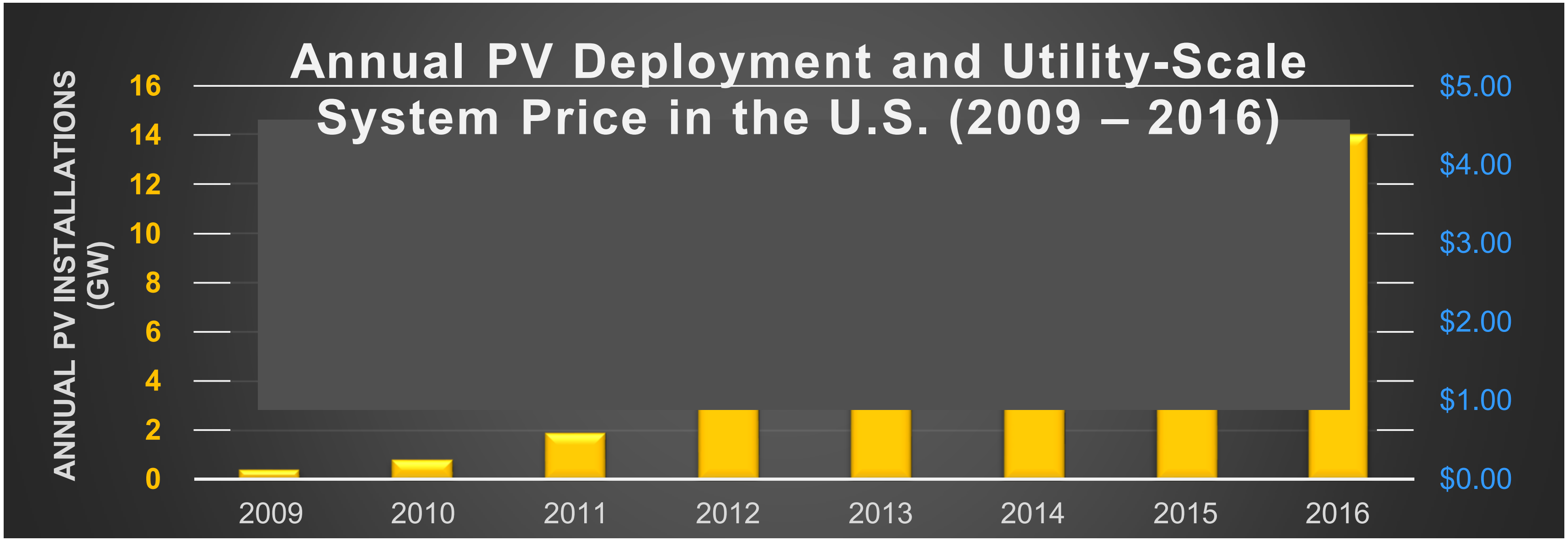
http://www1.eere.energy.gov/solar

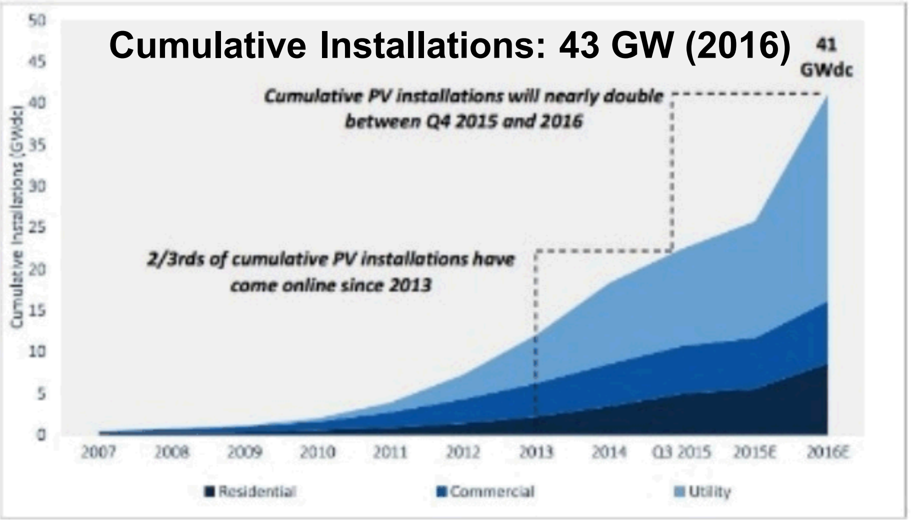


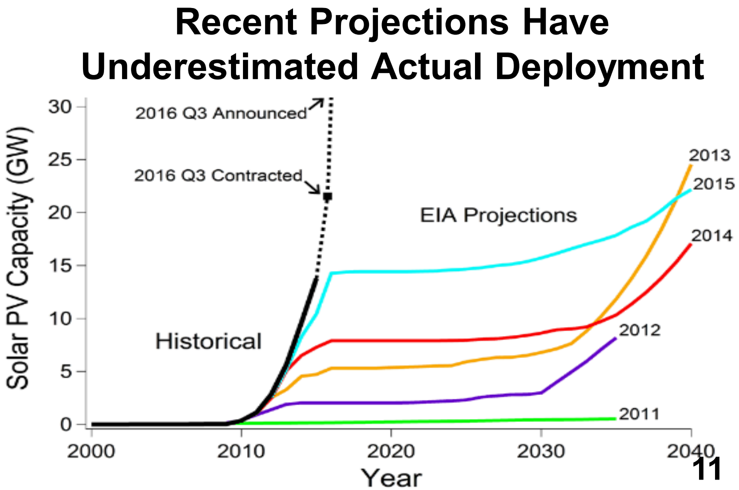
Diode-like behavior of cells and modules: higher current output at higher irradiance

Courtesy SunTech PV

PV Installation Trends in the U.S.





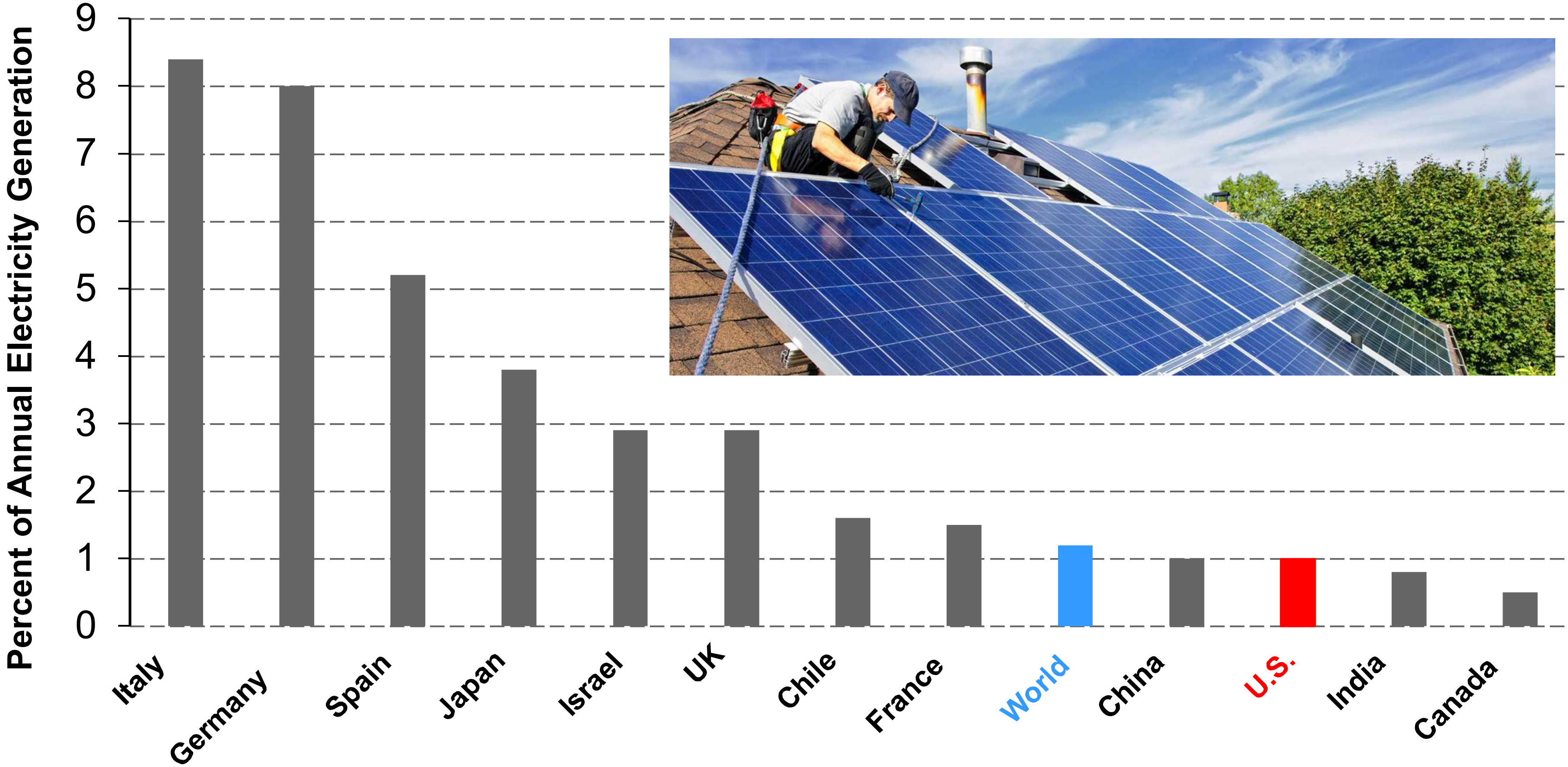


PV deployment at all scales

550 MW, Topaz Solar Farm, San Luis Obispo County. Over 8 Million PV Modules.

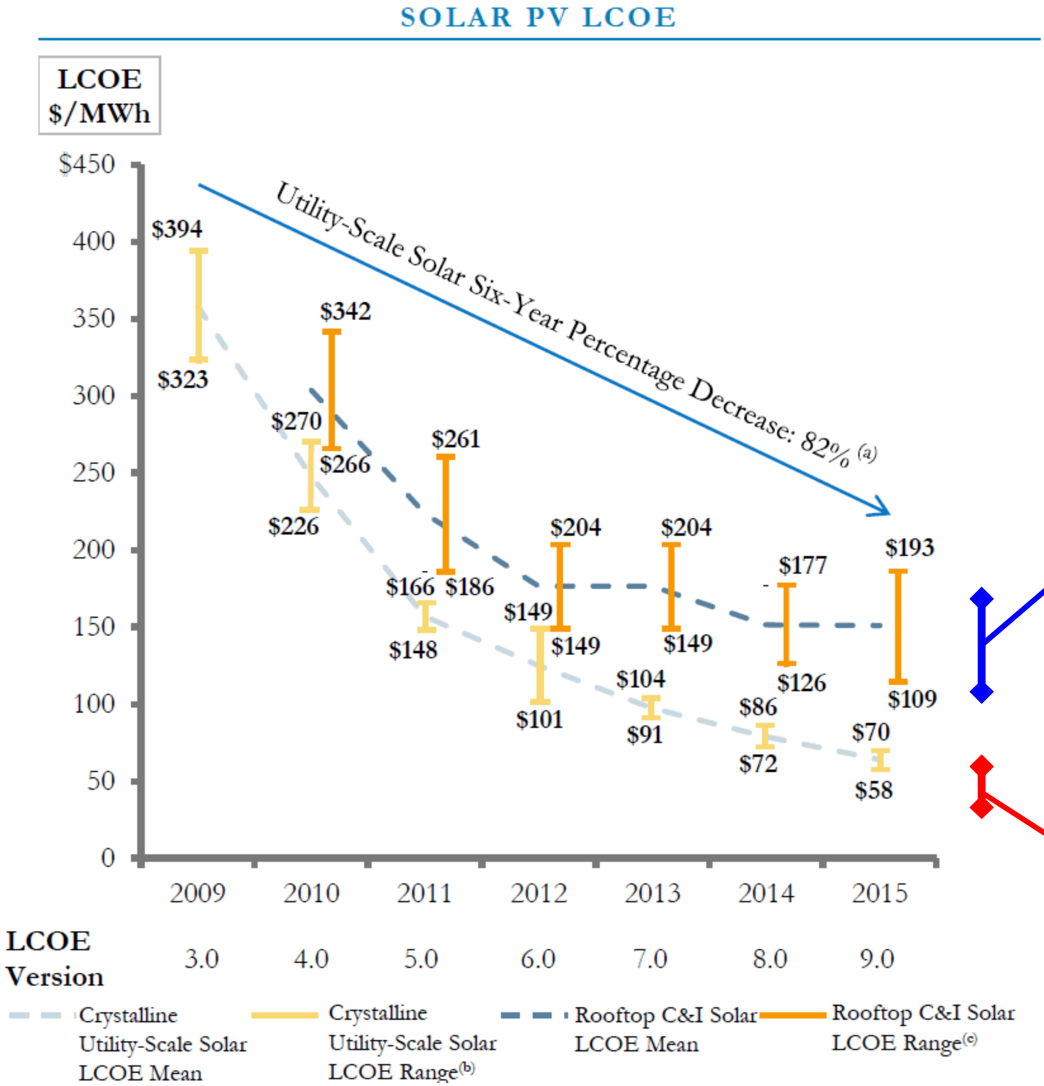
Much more room to grow

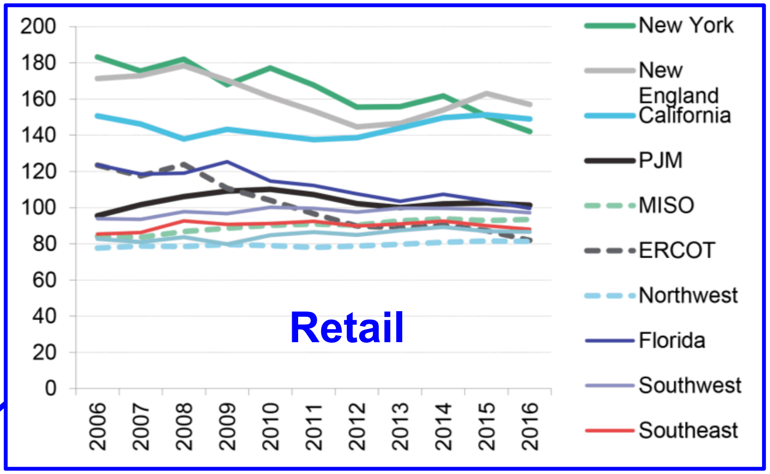
Solar supplies 1% of U.S. electricity, but very high future growth is expected. Excellent solar resource, land area and market conditions

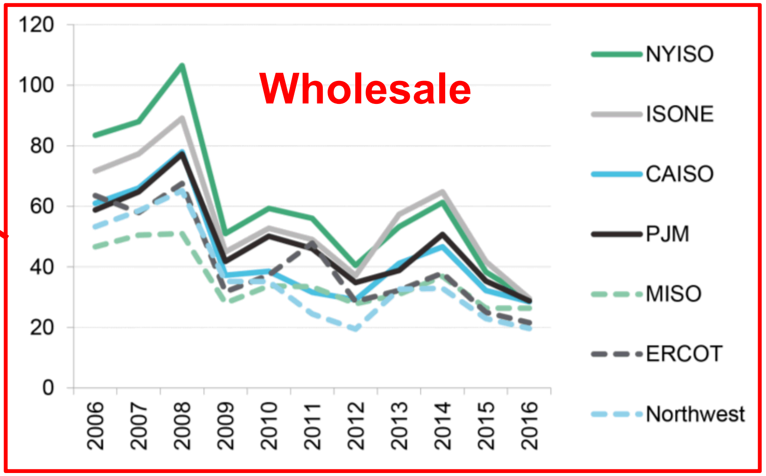


Sources: International Energy Agency, "2015 Snapshot of Global Photovoltaic Markets"; "Solar Thermal Electricity Global Outlook 2016".

Cost of PV Approaching Grid Parity







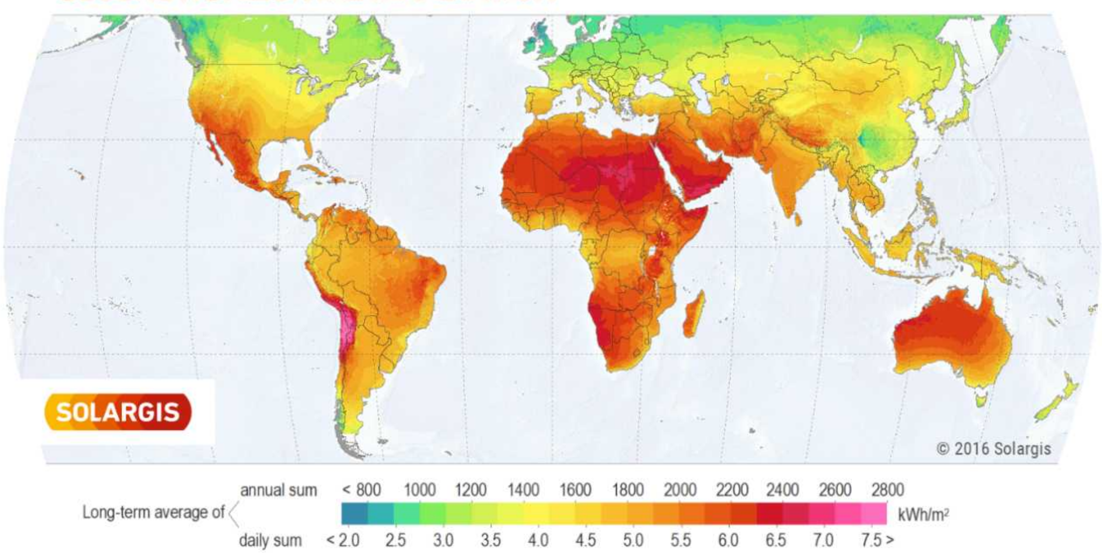
The U.S. solar resource is excellent and electricity demand is high

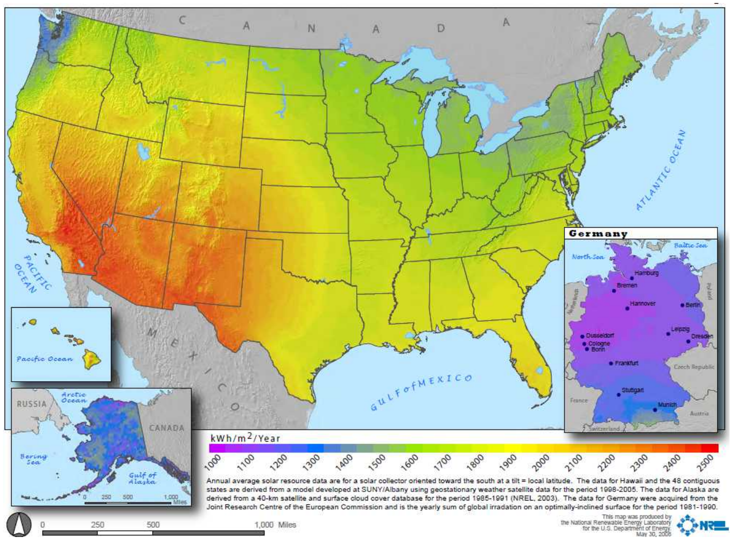
- High insolation means lower cost of PV electricity
- High electricity demand means that much more PV can be installed before reaching technical limits
  - **In some areas, like Hawaii, PV has already encountered difficult system limits**

TOP 10 COUNTRIES IN 2015 FOR CUMULATIVE INSTALLED CAPACITY

1	🇨🇳	China	43,5 GW
2	🇩🇪	Germany	39,7 GW
3	🇯🇵	Japan	34,4 GW
4	🇺🇸	USA	25,6 GW
5	🇮🇹	Italy	18,9 GW
6	🇬🇧	UK	8,8 GW
7	🇫🇷	France	6,6 GW
8	🇪🇸	Spain	5,4 GW
9	🇦🇺	Australia	5,1 GW
10	🇮🇳	India	5 GW

GLOBAL HORIZONTAL IRRADIATION

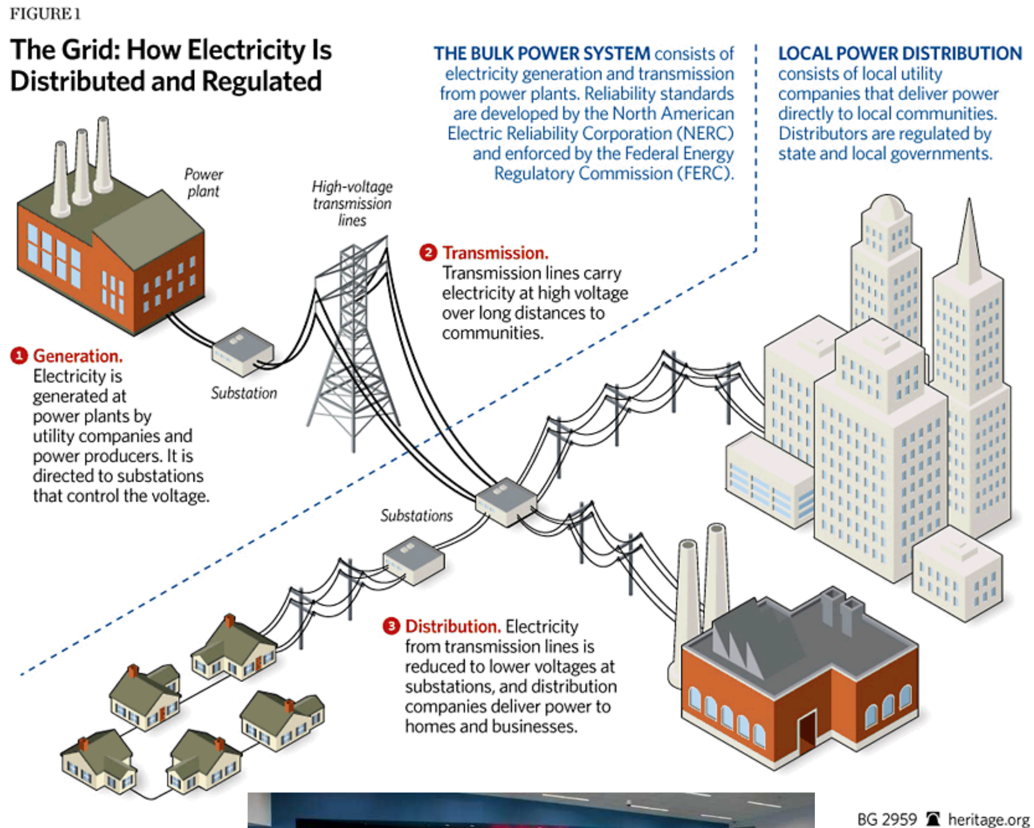




How can PV affect the power grid?

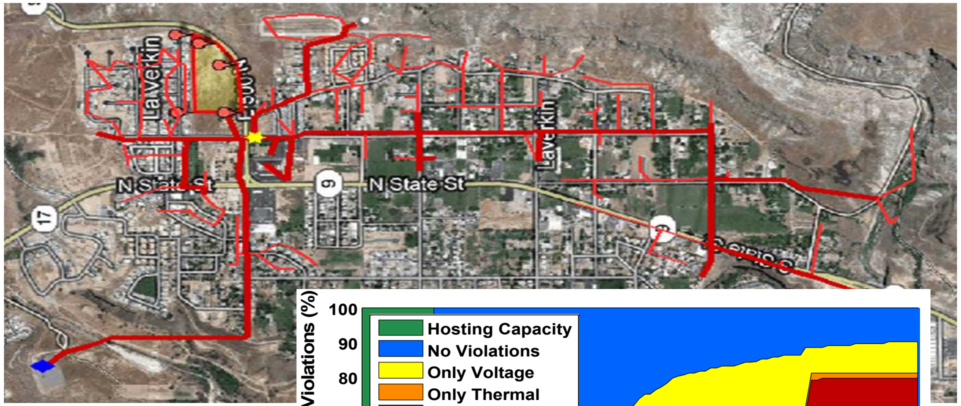
- Modest changes have been required to install PV so far
  - Updated technical standards
  - Better forecasting
  - Better markets
  - Better policies
  - Improved planning and operations methods and tools

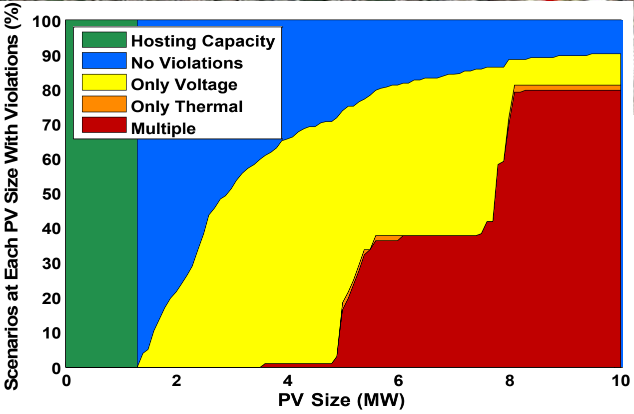
- To install 3 or 4 times more PV, fundamental changes and new technologies will be needed
  - Fitting demand to supply
  - Large-scale energy storage
  - Advanced grid controls

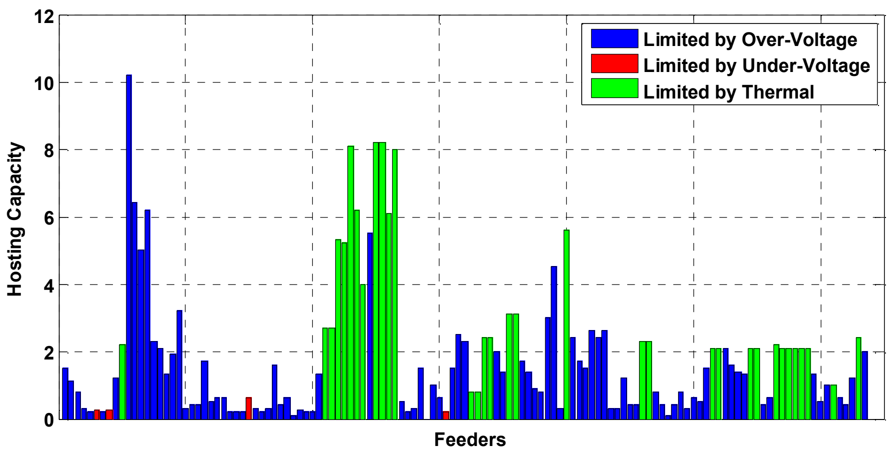


Possible technical impacts of PV on distribution systems

- Difficult voltage regulation
- Increase maintenance on voltage control equipment
- Challenging protection
- Equipment overload





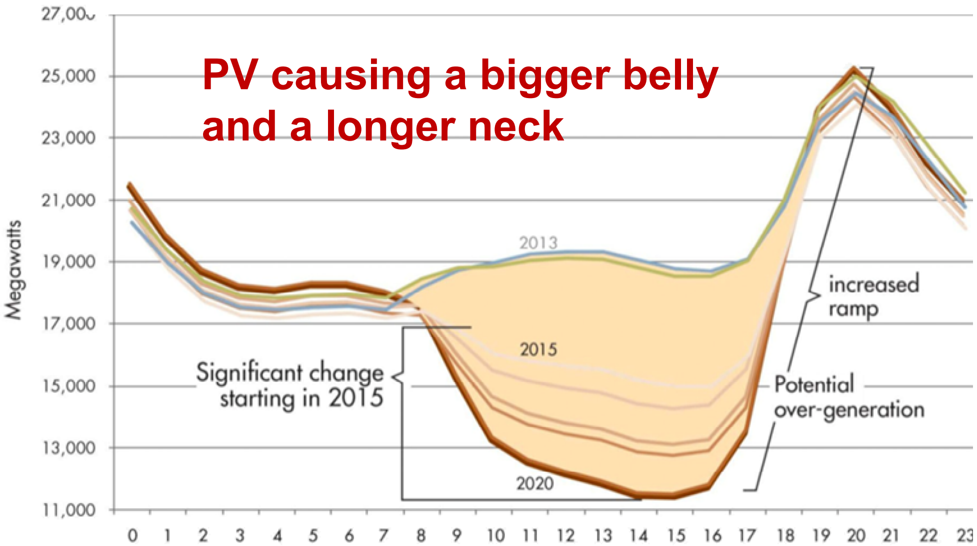


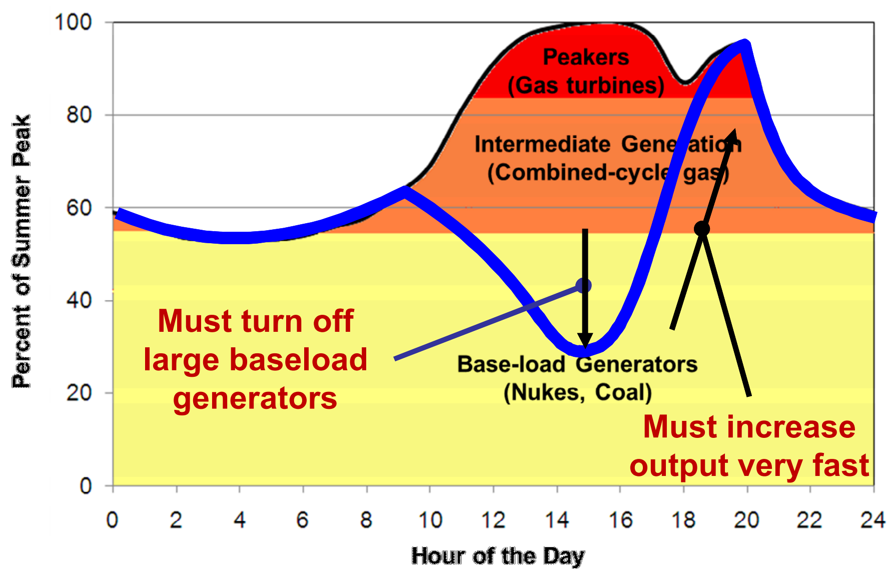
- Many types of distribution systems have been studied
- The amount of PV that can be installed without causing problems is highly dependent on the type of feeder

Possible technical impacts of PV on overall power systems

- More PV during the day makes it more difficult to efficiently operate the power system
  - It can be done, but it is more expensive

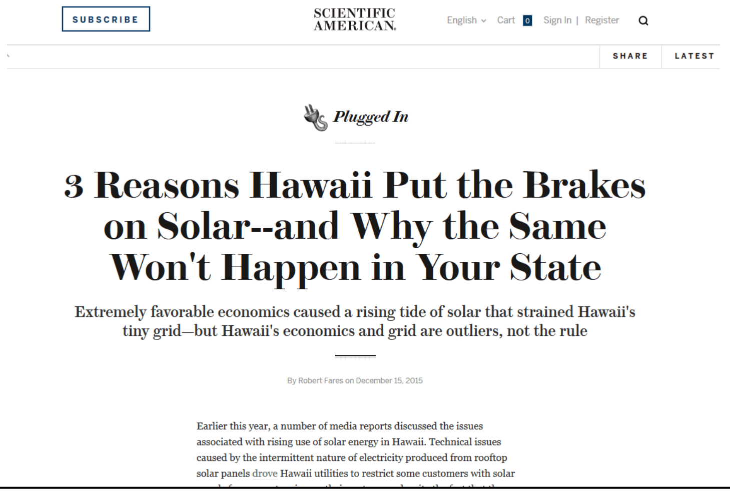
California Duck Curve Problem





A Living Laboratory in Hawaii

- PV growth in Hawaii driven by economics – retail customers pay ~$0.4 kWh!
- 2003: PV on distribution circuits limited to 100 of minimum daytime load
  - Reverse power flow could affect operation of **protection** systems
  - **Transient overvoltage** when feeder disconnects and generation > load
- 2016: Additional PV at system level limited to 5MW in Big Island and Maui, 25 MW in Oahu
  - Insufficient **inertia** could lead to system instability due to a generator contingency
  - Beyond that, PV installations must be "self-consumption"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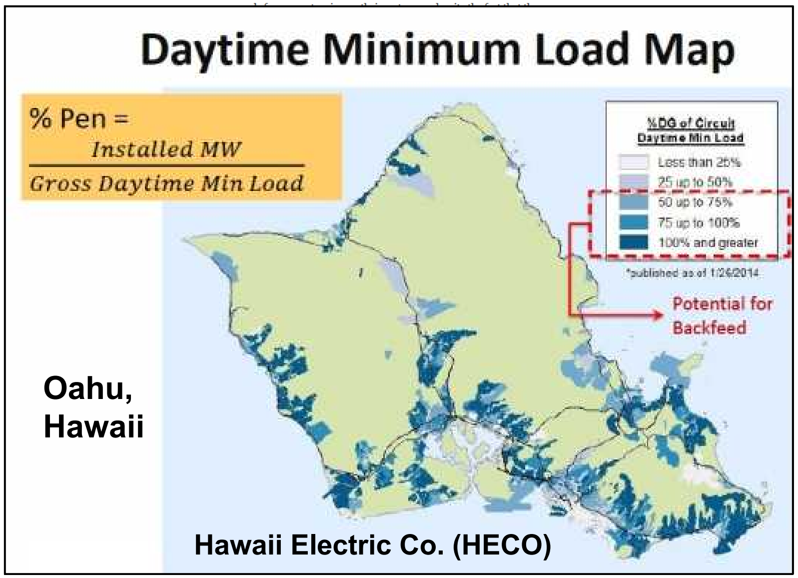
Plugged In

3 Reasons Hawaii Put the Brakes on Solar--and Why the Same Won't Happen in Your State

Extremely favorable economics caused a rising tide of solar that strained Hawaii's tiny grid—but Hawaii's economics and grid are outliers, not the rule

By Robert Fares on December 15, 2015

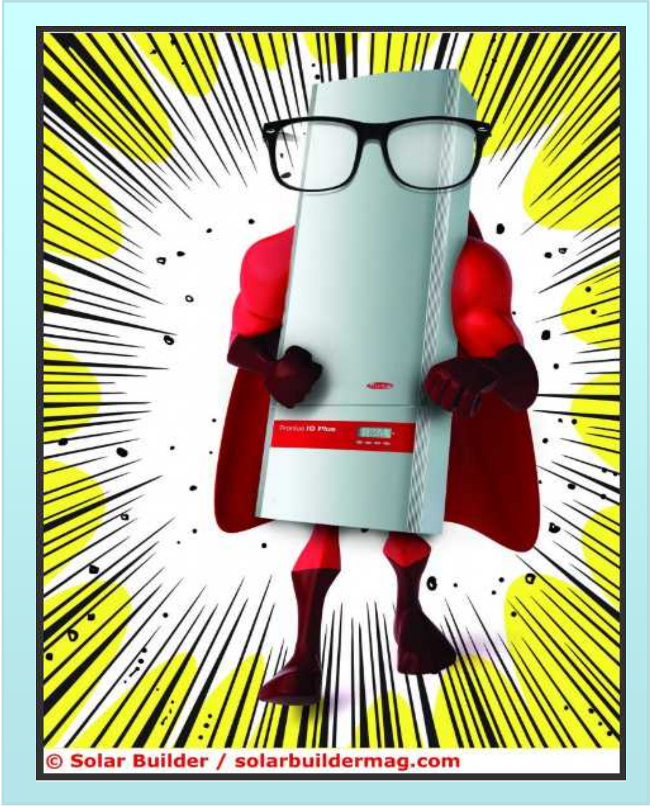
Earlier this year, a number of media reports discussed the issues associated with rising use of solar energy in Hawaii. Technical issues caused by the intermittent nature of electricity produced from rooftop solar panels drove Hawaii utilities to restrict some customers with solar



http://www.renewableenergyworld.com/articles/2014/02/the-interconnection-nightmare-in-hawaii-and-why-it-matters-to-the-u-s-residential-pv-industry.html
http://www.utilitydive.com/news/hawaii-utilities-hit-rooftop-solar-caps-for-grid-supply-tariff-on-maui-big/425087/
https://blogs.scientificamerican.com/plugged-in/3-reasons-hawaii-put-the-brakes-on-solar-and-why-the-same-won-t-happen-in-your-state/

Advanced PV inverters can help…

- Deployment of Smart Inverters are an effective way to solve the challenges
  - Can help solve the challenges caused by PV installations
  - Can increase the amount of PV that can be installed without causing problems
  - Could generate financial benefits for the PV system owners
- We are updating standards and policies so that smart inverters can be required in the future

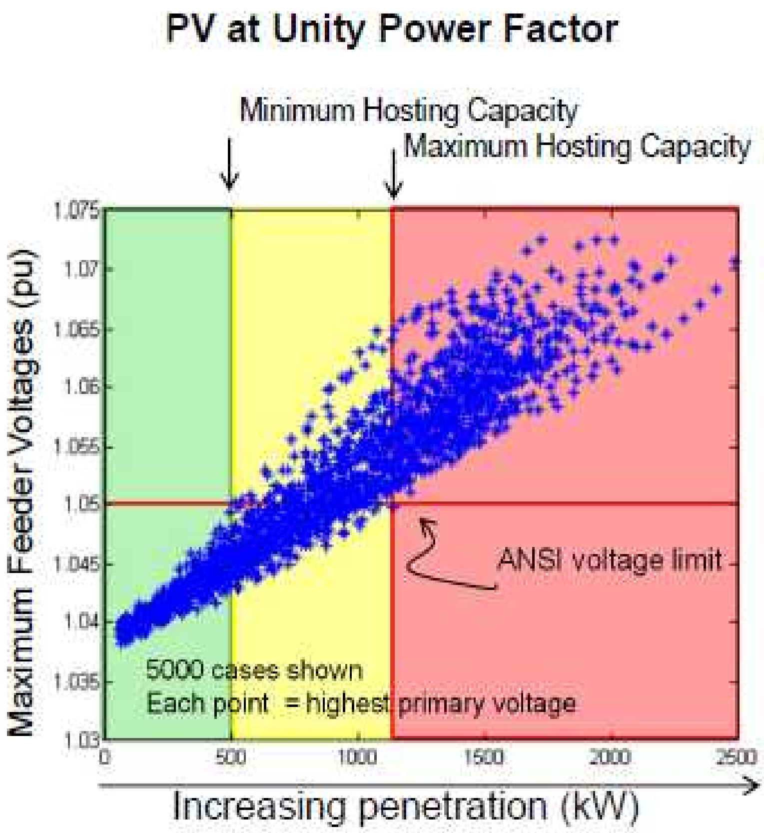


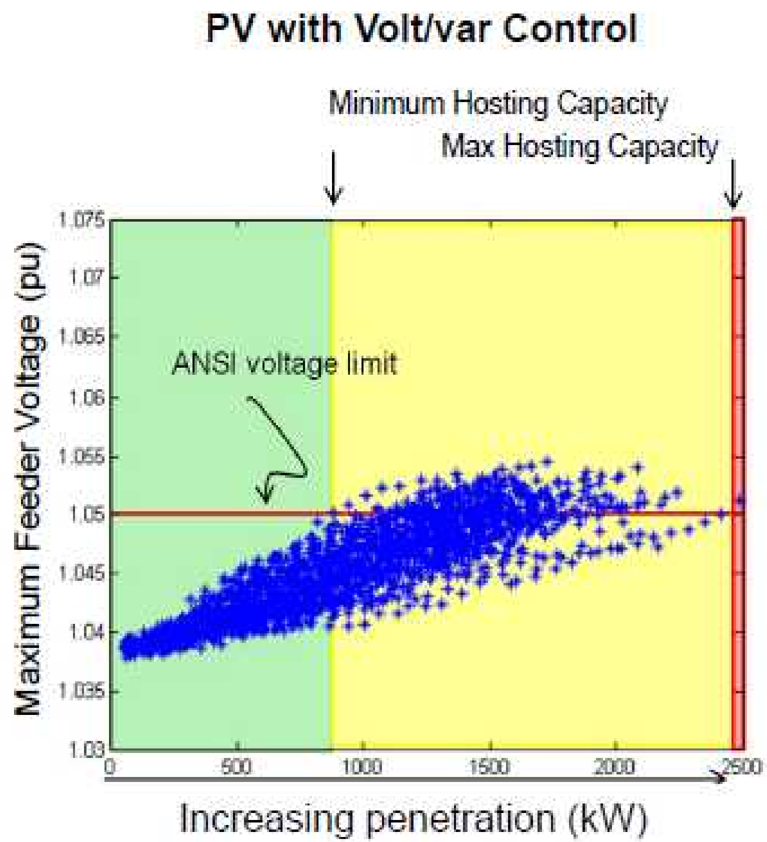
What is a Smart Inverter?

- Actively support the grid operation
- Tolerate grid disturbances
- Interact using communications

Advanced inverters can help…

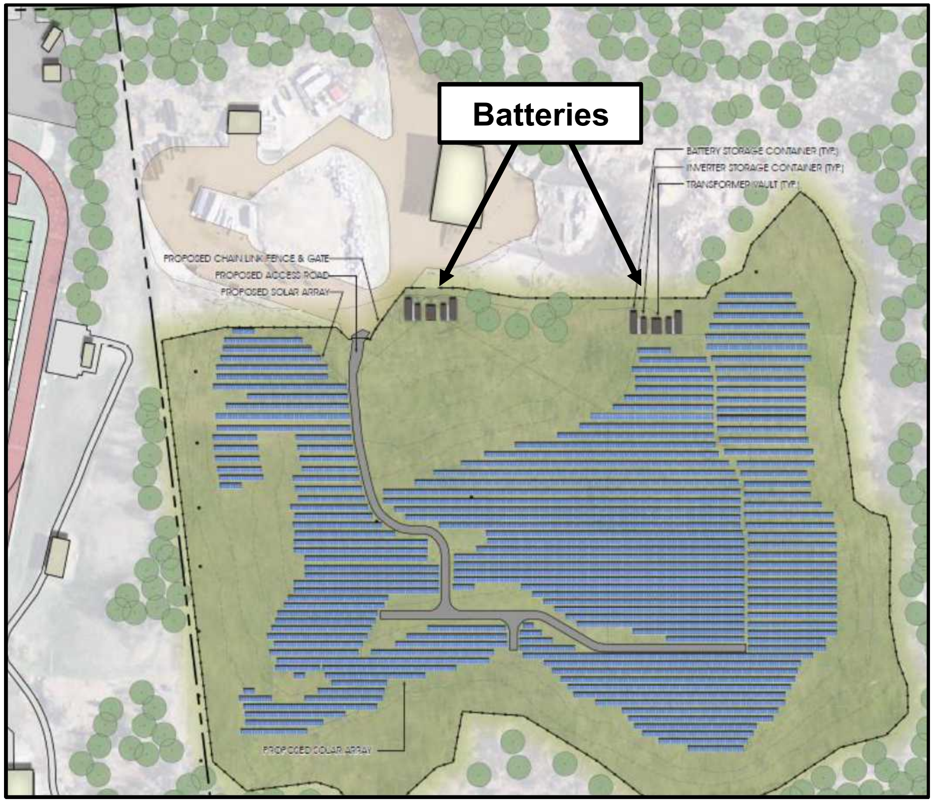
- Smart Inverters that control voltage could **DOUBLE** the amount of PV on distribution circuits without causing high voltage



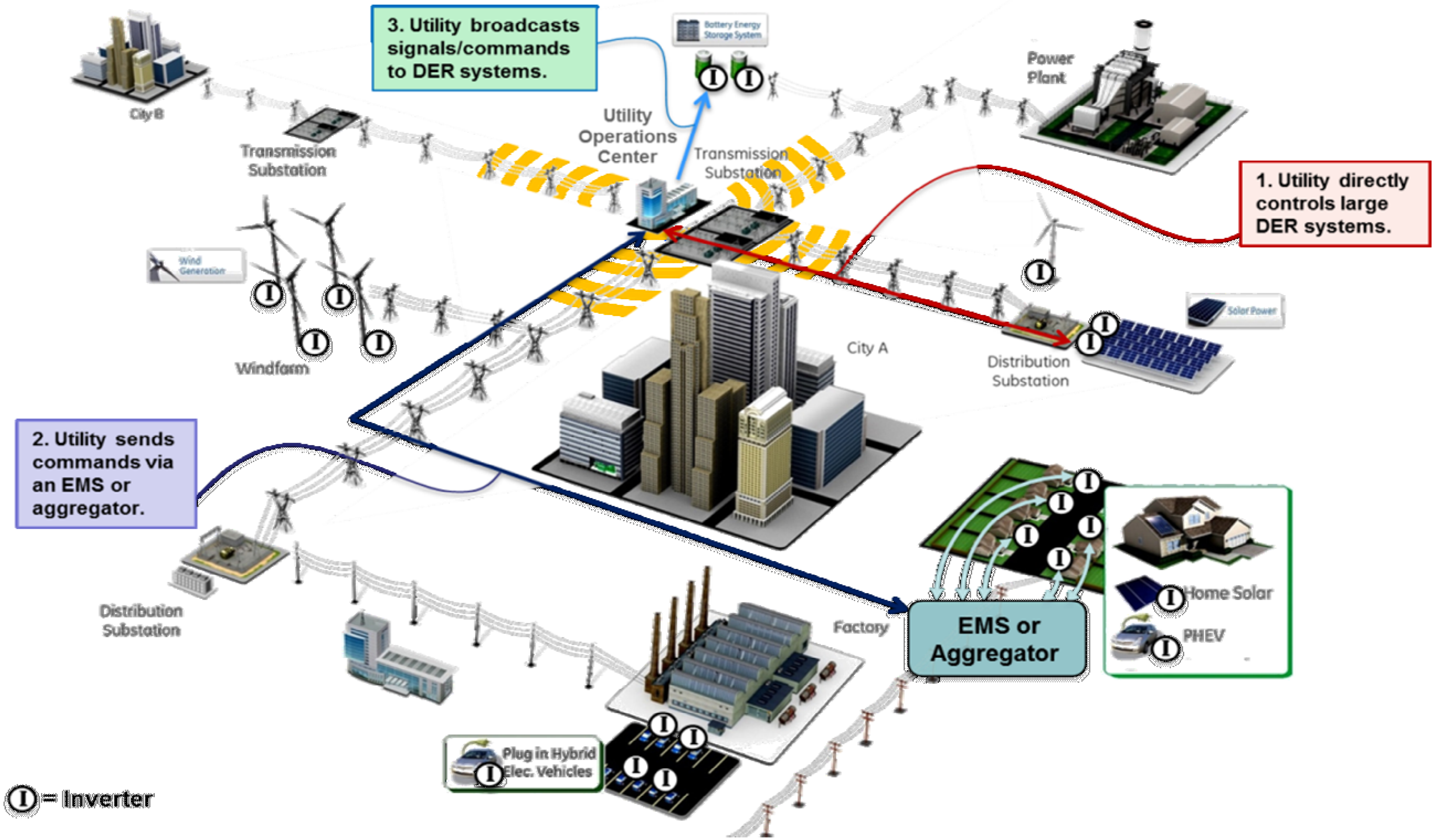


More flexibility will be needed to deploy 5 times more PV in the future

- Advanced controls such as Virtual Power Plants
- Demand Response
- Energy Storage
- Large-scale transmission



Communications/control architecture



Emerging challenges: Interoperability, Cybersecurity

Summary

- The amount of PV installed in the U.S. and worldwide is increasing, expect much more in the future
  - Reaching grid parity in many regions
- Difficult technical challenges in the distribution system as well as the overall power system
- There are feasible solutions for both the near term and the long term
  - Standards, policies and technology (advanced inverters)
  - Future: Advanced controls, communications, energy storage
  - Emerging challenges: interoperability and cybersecurity

Questions?

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