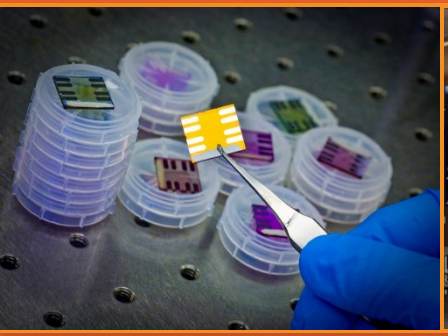
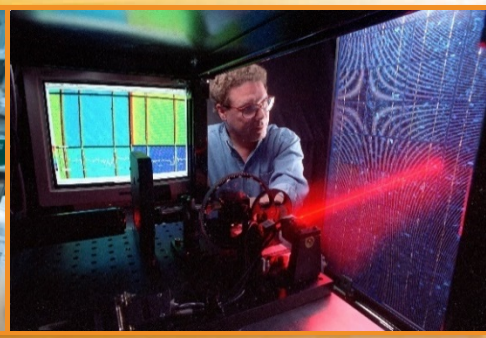
SunShot
U.S. Department of Energy



Looking to the Sky –Solar Power Today and Tomorrow

Garrett Nilsen, US Dept. of Energy

Renewable Energy Systems and Sustainability Conference

Lakeland, Florida

31 July 2017

energy.gov/sunshot

High Level Agenda

- State of the Market Today
- Role of SunShot
- SunShot 2030 Goals
- Research Areas of Interest
- Advice for Entrepreneurs

Photovoltaic effect
first discovered by
Edmond Becquerel in 1839

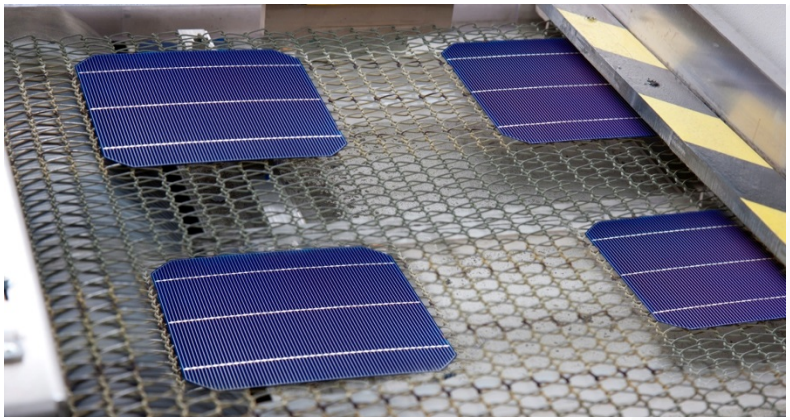
First Use of Solar Thermal?

Archimedes attacking the Romans at Syracuse in 212 B.C.?

Images: Wikipedia, www.unmuseum.org/burning_mirror.htm

Solar Technologies: Photovoltaics, Concentrating Solar Power

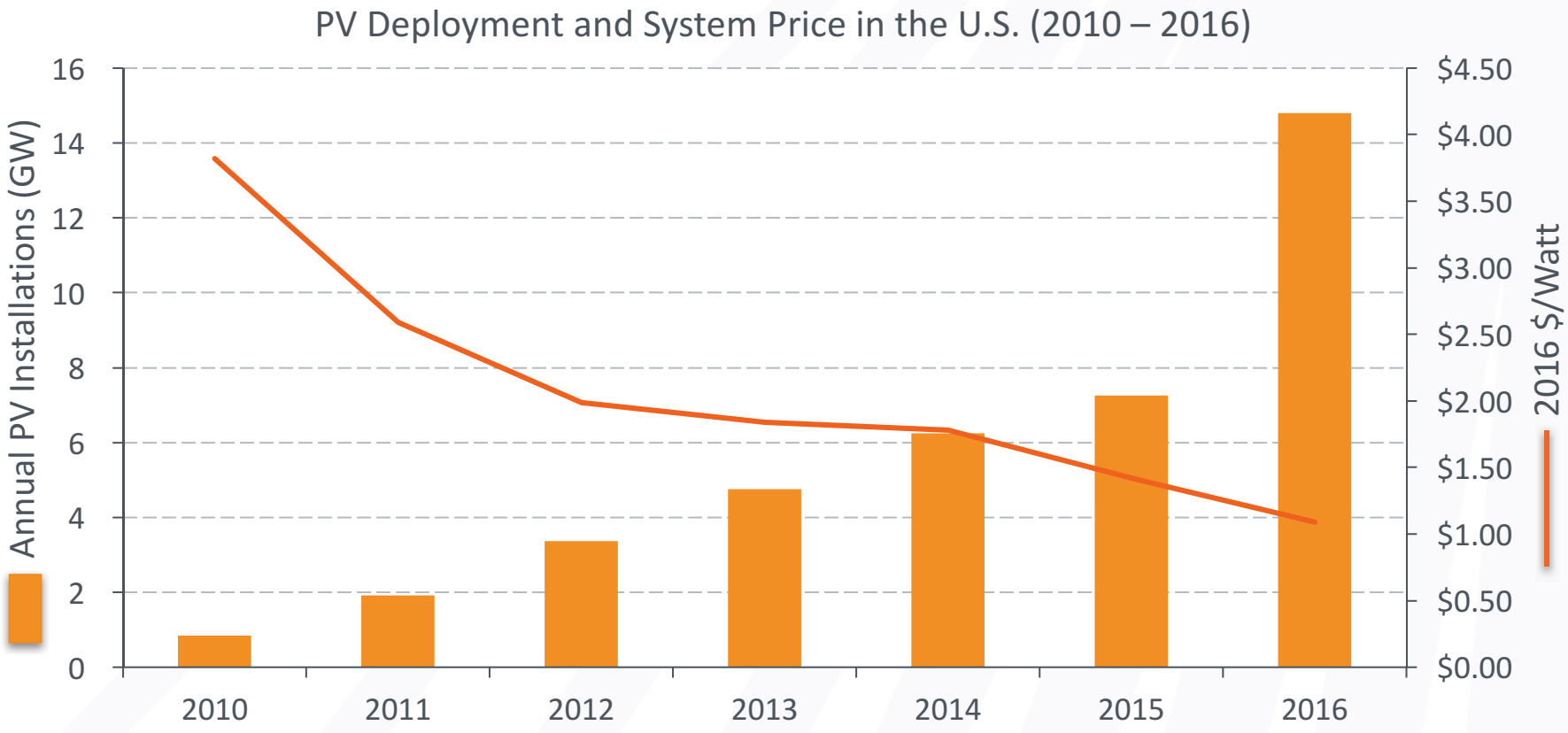
Photovoltaic (PV) technologies absorb energy from sunlight and convert it directly into electricity through a semiconductor material, such as silicon. Individual PV panels/modules are connected together to make large arrays.



Concentrating solar power (CSP) technologies use mirrors to reflect and concentrate sunlight onto a receiver where it is collected and converted into heat. This heat energy can be stored and used to produce electricity whenever it is needed.

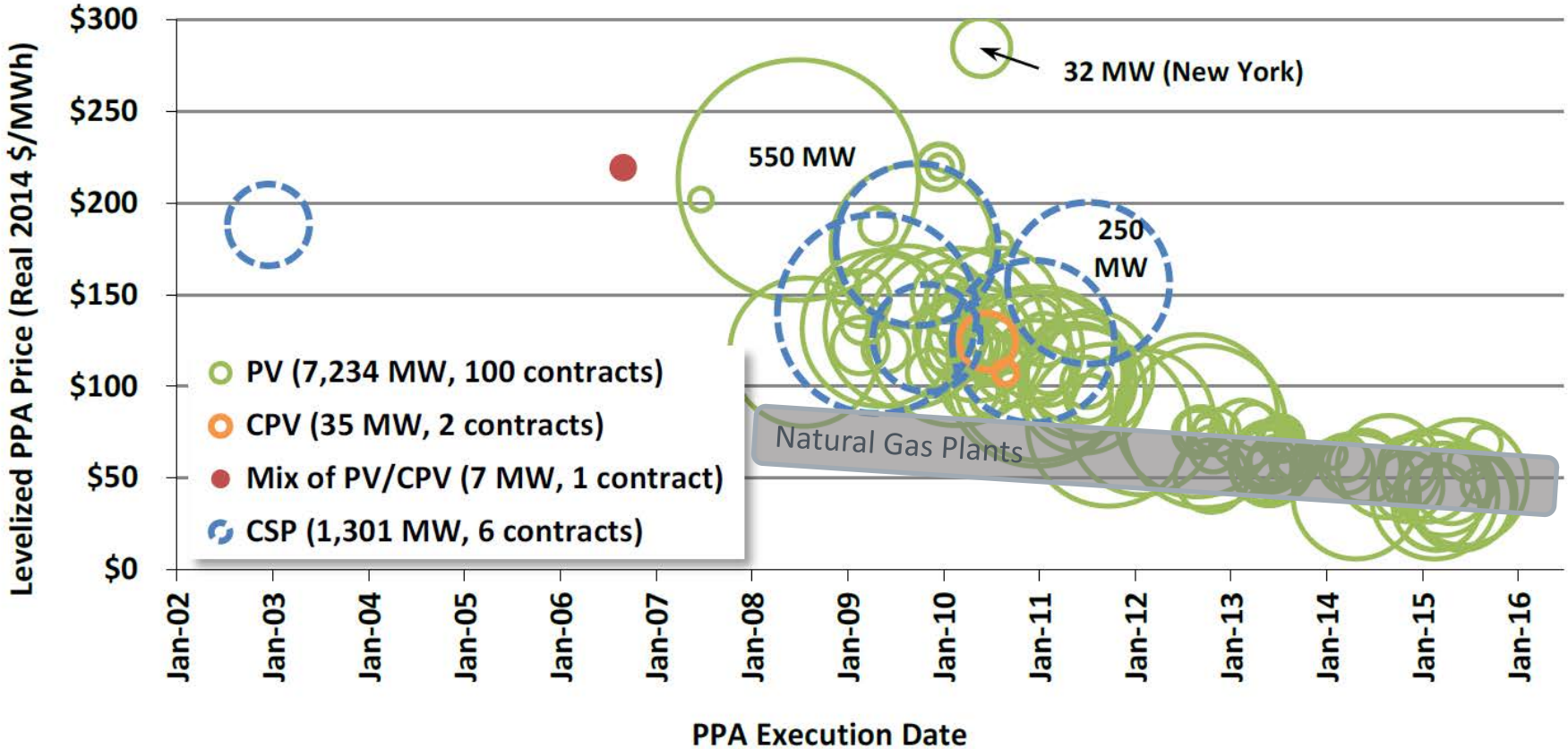
U.S. Solar: Falling Costs, Rising Deployment

The solar energy industry is one of the fastest growing industries in the U.S. Driven by falling costs, total solar installed capacity reached **42.4 gigawatts in 2016** with more than **one million solar projects** operating across the country.



Sources: National Renewable Energy Laboratory, "U.S. Solar Photovoltaic System Cost Benchmark: Q1 2016"; GTM Research and SEIA, "U.S. Solar Market Insight Report: 2016 YIR."

The Cost of Solar Power is Decreasing Steadily

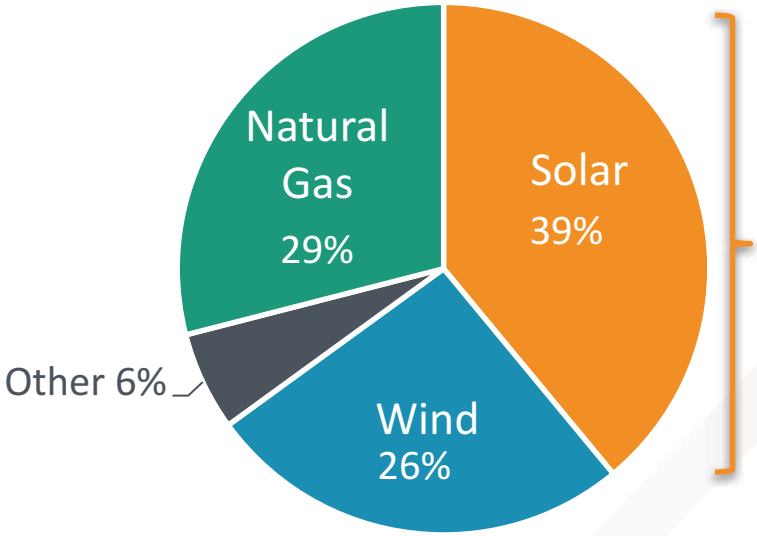


PV: Photovoltaics
CPV: Concentrating Photovoltaics
CSP: Concentrating Solar Power

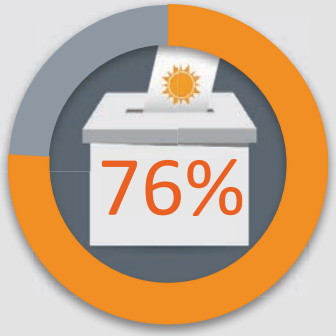
PV is already cheaper than gas in the Southwestern US, but only with 30% Investment Tax Credit.

Solar is the Fastest Growing Energy Source in America

New Capacity Added in 2016

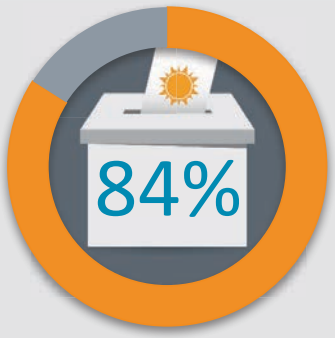


In 2016, solar represented **nearly 40%** of all new electricity capacity installed in the United States.



76% of voters support more emphasis on solar power development.

Solar polled higher than any other electricity source.



84% of voters support an all-of-the-above energy strategy, including renewables.

These voters cite cleaner air and less pollution as key reasons they support renewables.

Sources: Federal Energy Regulatory Commission, "Office of Energy Projects Energy Infrastructure Update for June 2016"; GTM Research and SEIA, “U.S. Solar Market Insight 2016 YIR." Note: Distributed PV converted to AC using .83 derate factor. Conservative Energy Network, “Voter Attitudes on Clean Energy,” November 28, 2016.

Consumers are Increasingly Choosing Solar Power

UTILITIES

26.5 GW

- About **1/3 of all U.S. utilities in 39 states** offer solar power to their customers.
- There is enough solar energy installed in the U.S. to power the equivalent of **8.3M households.**
- Utilities are today choosing solar power even **without state mandates** like Renewable Portfolio Standards.

COMPANIES (Non-Residential)

7.7 GW

- **Over 65,000 U.S. businesses** have installed solar to lower their energy costs and help to reduce prices for consumers.
- Some of the **most successful companies** and organizations in the world are deploying solar — including Apple, IKEA, Target, Costco, Walmart, Macy's, and Kohl's.

HOUSEHOLDS

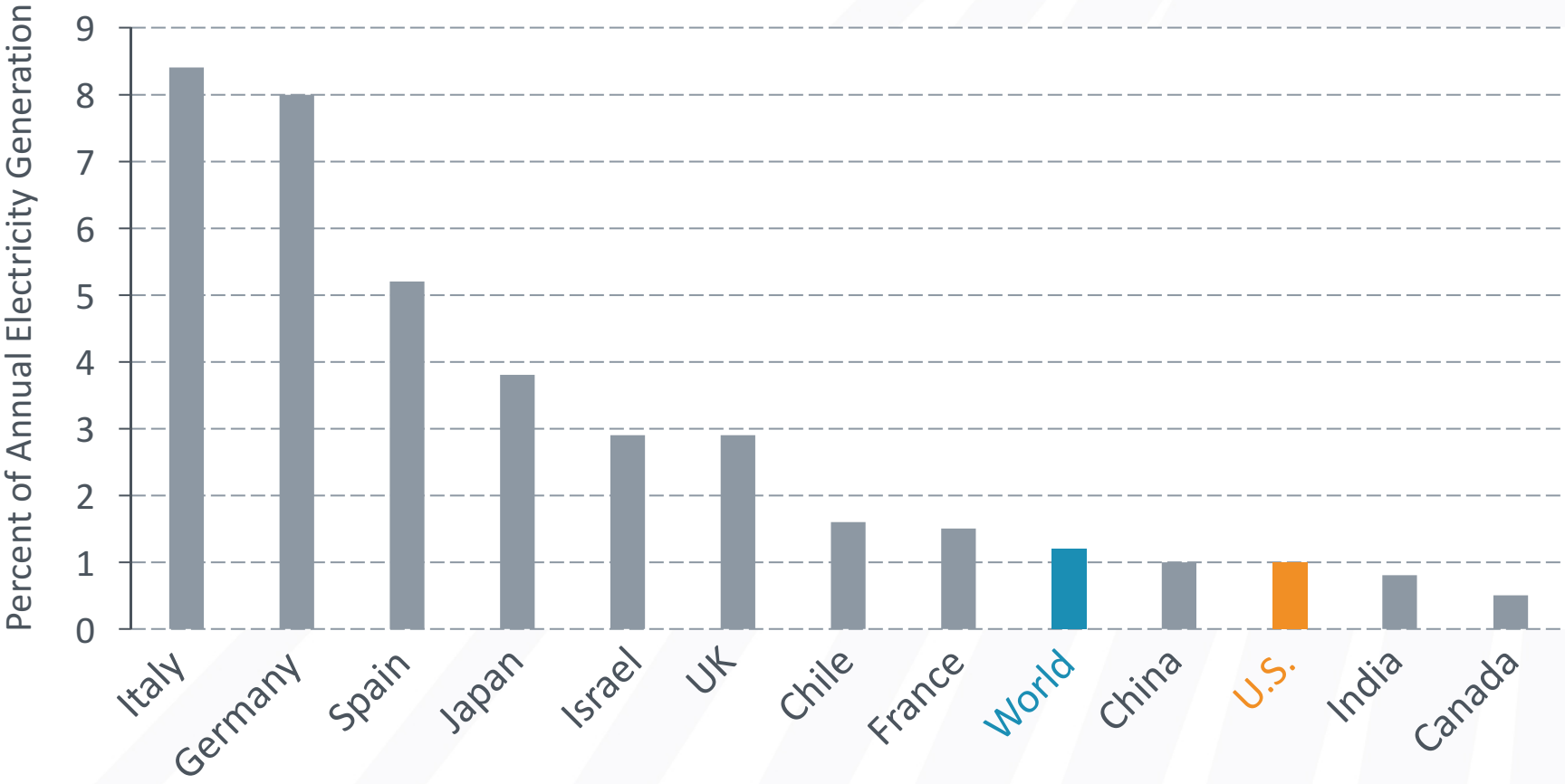
8.2 GW

- Electricity customers **across all 50 states** have chosen solar for their properties.
- Over **1.3M U.S. homes** have installed solar energy systems.
- Residential solar photovoltaic installations are **expected to grow 9%** in 2017.

Source: Cumulative solar capacity from GTM Research and SEIA, "U.S. Solar Market Insight 2016 YIR"

Solar Supplies 1% of U.S. Electricity & Growing

More progress must be made in order to take advantage of this domestic energy resource and to compete in the growing global market.



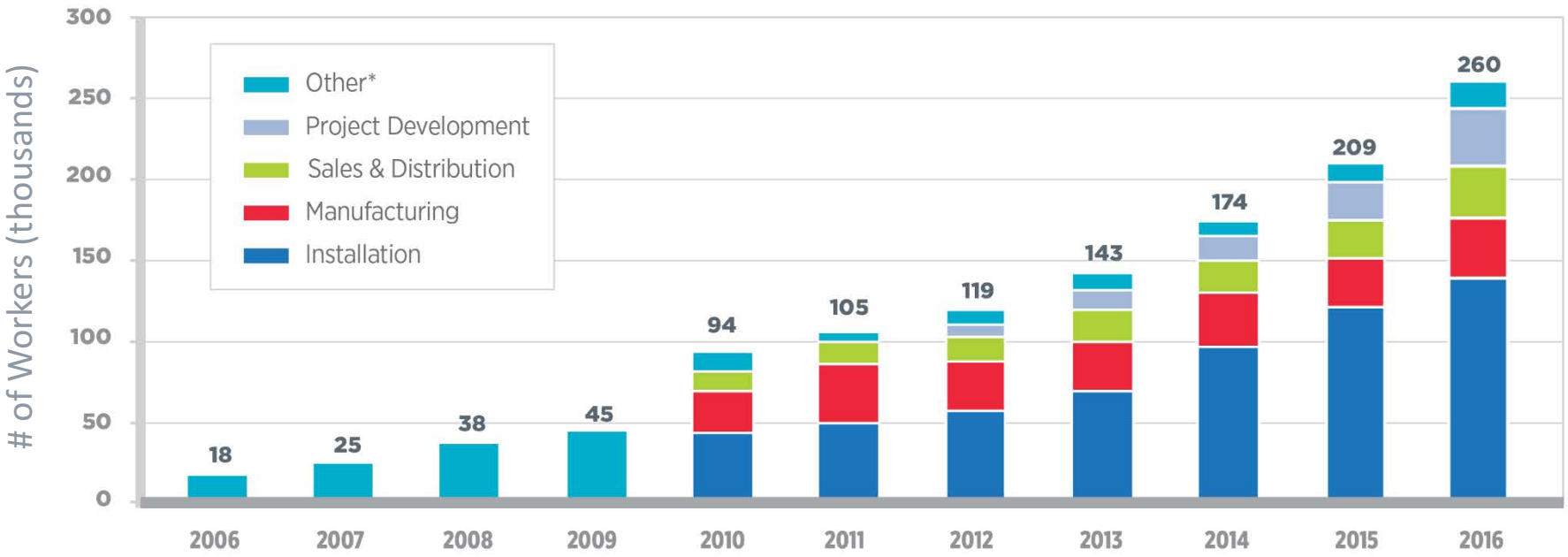
Sources: International Energy Agency, "2015 Snapshot of Global Photovoltaic Markets"; "Solar Thermal Electricity Global Outlook 2016".

The $25B U.S. Solar Value Chain

Export Focus		Domestic Focus					
Capital Equipment	Direct Materials	Module Mfg	Inverters Electronics	Sales Distribution	Financial Services	Developers Installers	Operations Services Utilities
$250M	$1.1B	$900M	$680M	$1.4B	$2.8B	$17.3B	$375M
35,000 jobs				30,000 jobs	10,000 jobs	170,000 jobs	15,000 jobs
Applied Materials Amtech GTAT	DuPont Dow Corning Hemlock Wacker REC Silicon	SolarWorld First Solar Suniva Mission Solar Energy Jiangsu Shunfeng PV Stion Miasole SoloPower SunPower Ascent Solar SolarCity	ABB SMA Enphase Siemens Fronius USA General Electric	Spruce Sungevity EnergySage Solar Pathfinder Eco-Leads Geostellar OnGrid Solar Solar Nexus Genability Soligent Solmetric Sunible	JP Morgan U.S. Bank Keycorp B of America Google GE EFS Latham & W Milbank Tweed Skadden Arps Black & Veatch Novogradac Deloitte BNEF	First Solar Mortenson Construction SolarCity E Light ES NRG Energy CSW Contact. Helix Elec. Rosendin Elec. Cupertino Elec. SunRun Vivint Solar RGS Energy	First Solar SOLV SolarCity SunPower MaxGen Sempra NextEra SunRun SMA EDF Miller Bros Vivint Solar

Combined value: $25B/year **Total employment: 260,000+**

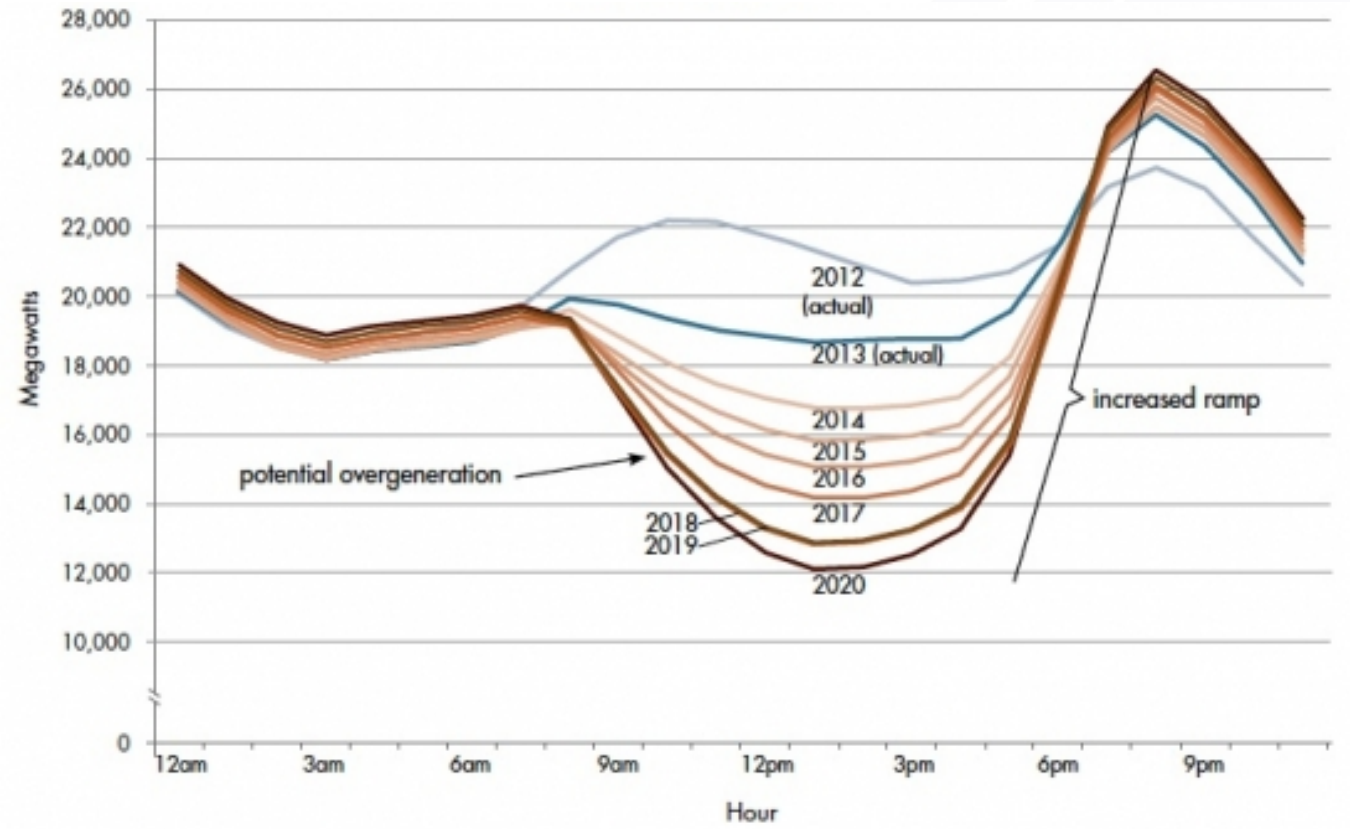
260,000+ U.S. Jobs in the Solar Industry



- Fourth straight year **20%+** workforce growth
- In 2016, nearly **1,000 new jobs** were created **every week** in the solar industry
- The median wage for solar installers is **$26 per hour**
- **Manufacturing** is on the rise and is the **2nd largest sector** in the solar industry
- **17x** national job growth rate

Source: The Solar Foundation, "2016 National Solar Jobs Census."
*Other jobs include R&D and related services, consulting, engineering, finance, legal, or other professional services and other support services.

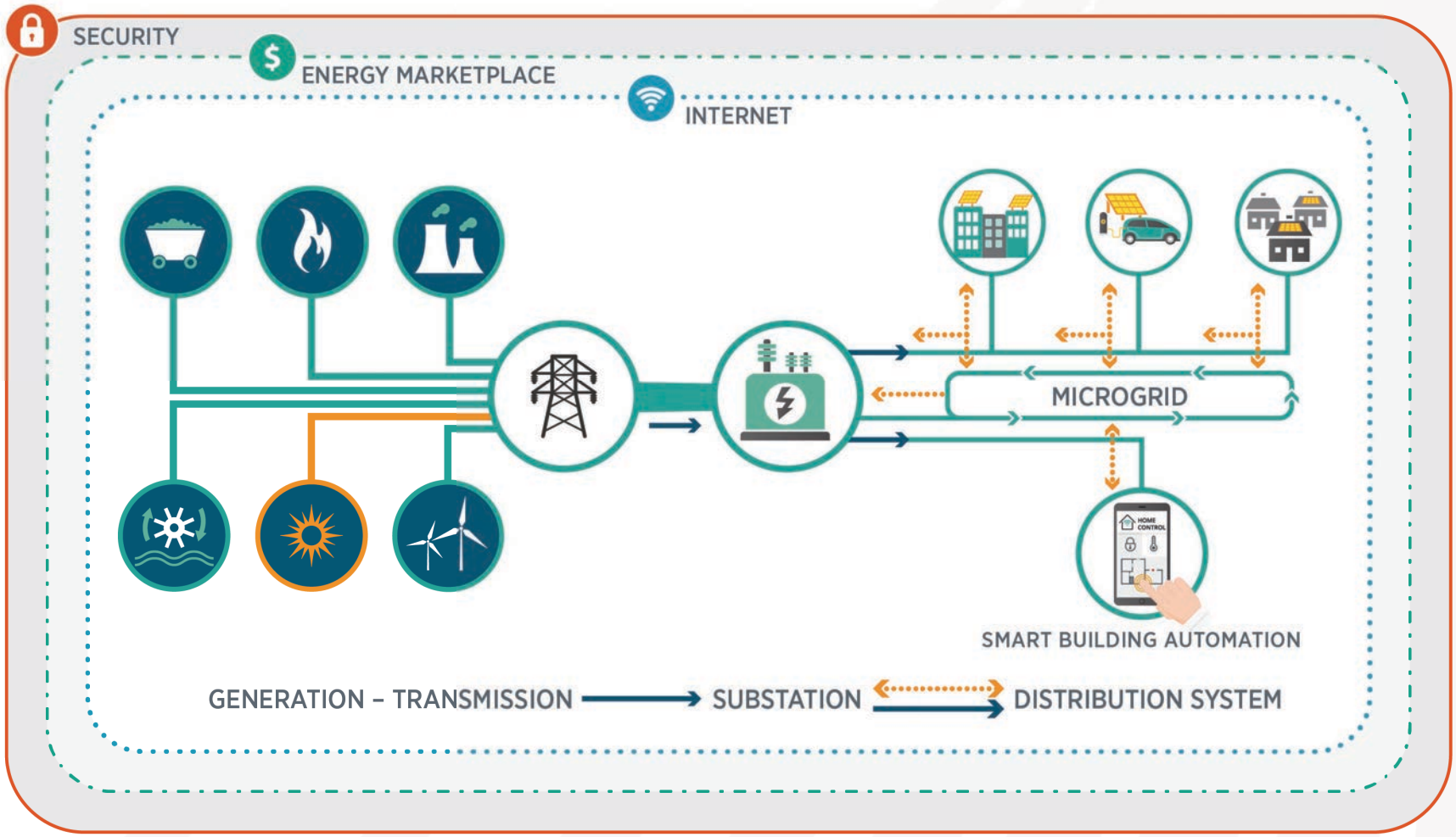
High Solar Penetration is a Worry for Utilities



Strategies for minimizing the impact of high PV penetration:

1. Storage (batteries, pumped hydro)
2. Demand-side management
3. Sun-tracking mounts
4. Increased transmission line capacity

Modern Electric Grid: Two Way Energy and Data Flow



Goal: Centralized and distributed generation optimized with finely tuned, 2-way load balancing

Potential Variables for Domestic Solar Deployment

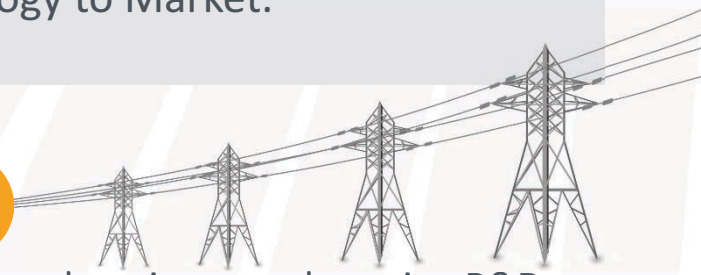
- International Trade Commission Petition
- Sunset of the Investment Tax Credits
- Policy on all levels
  - Local, Regional, National
- Global PV Appetite vs. Available Manufacturing Capacity
- The value of the marginal module
- The speed of the introduction of storage

What are my tax dollars doing about it?

SunShot Overview

WHAT WE DO: SunShot works to make it *faster*, *easier*, and *more affordable* for Americans to access solar power by making smart R&D investments to *lower costs* so solar electricity is fully *market-competitive* without subsidies.

HOW WE DO IT: SunShot drives down the cost of solar through cooperative research, development, demonstration, and deployment projects with private companies, universities, state and local governments, nonprofits, and national laboratories. SunShot funds research through its five subprograms: Photovoltaics, Concentrating Solar Power, Systems Integration, Soft Costs, and Technology to Market.



IMPACT:

SunShot has funded work to drive down the cost of solar **90%** toward the 2020 cost target, supporting the **260,000 JOBS** in the solar industry.

FUTURE:

In addition to game-changing, cost-lowering R&D, SunShot will continue to *spur solar development* and *increase grid resiliency* across the country to diversify the U.S. domestic energy supply.

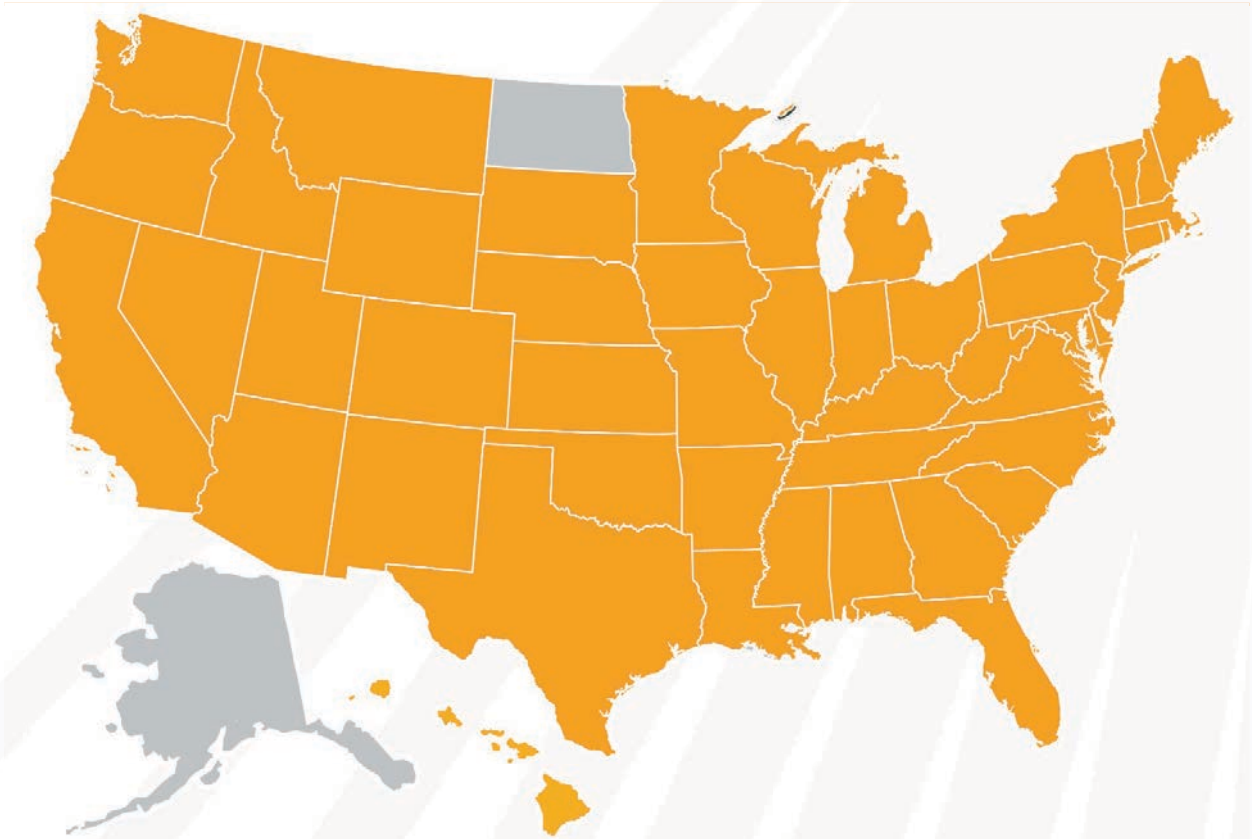
*NREL Site-Wide Facility Support

energy.gov/sunshot

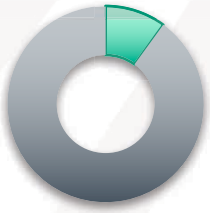
SunShot U.S. Department of Energy

SunShot Funds 250+ Active Projects

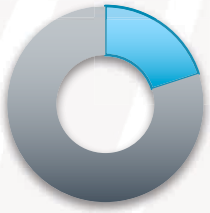
Projects and partners in
48 states plus the
District of Columbia



70% of projects at **national labs & universities**



10% of projects with **non-profits***



20% of projects with **companies**

Note: SETO has funded past projects in North Dakota and Alaska.
*1% of state and local government
energy.gov/sunshot

SunShot U.S. Department of Energy

Sandia National Laboratories

University of Central Florida

Ultrasonic Technologies, Inc

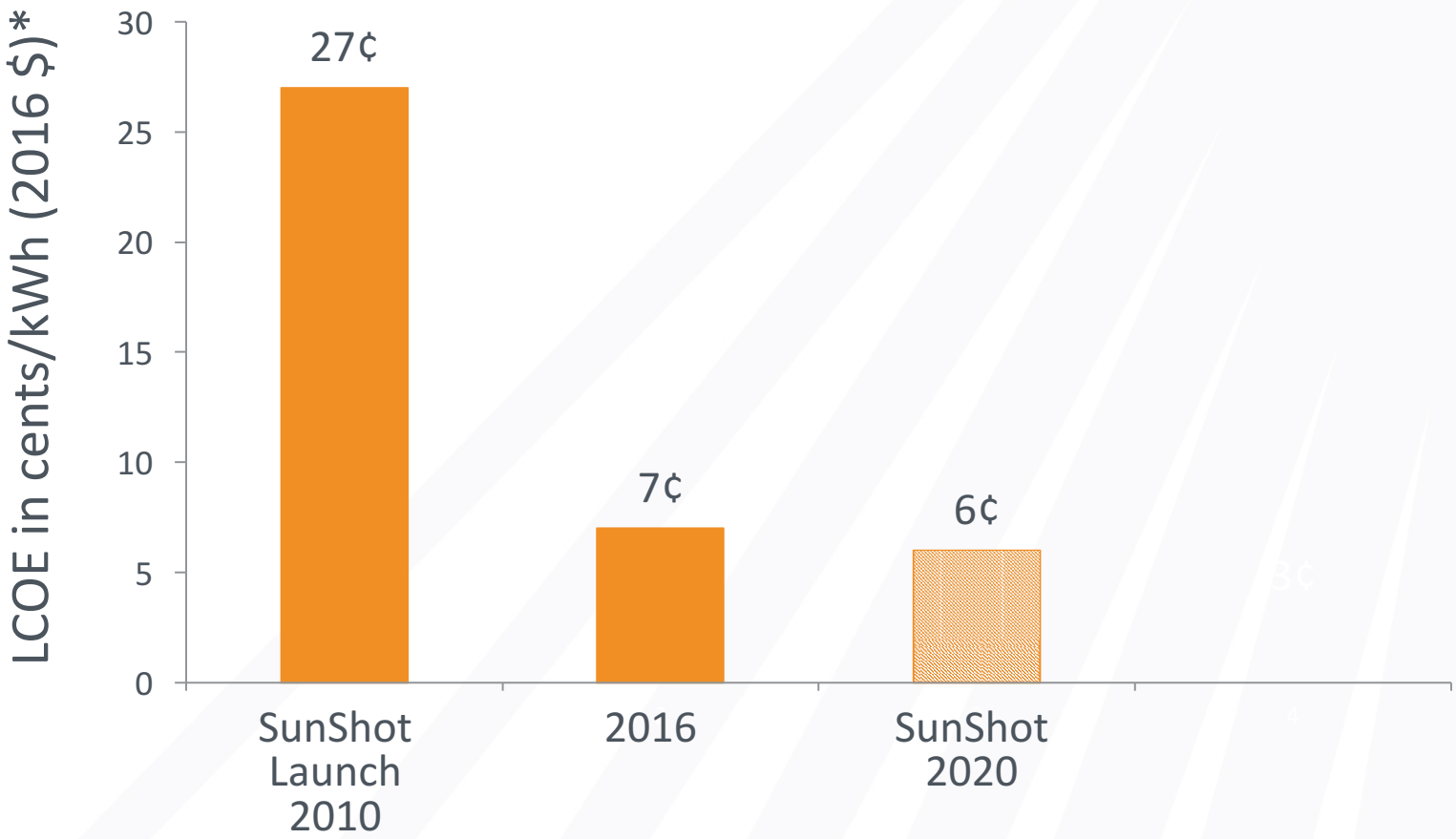
Nhu Energy, Inc.

BROWARD COUNTY FLORIDA

SunShot Accelerates the U.S. Energy Economy

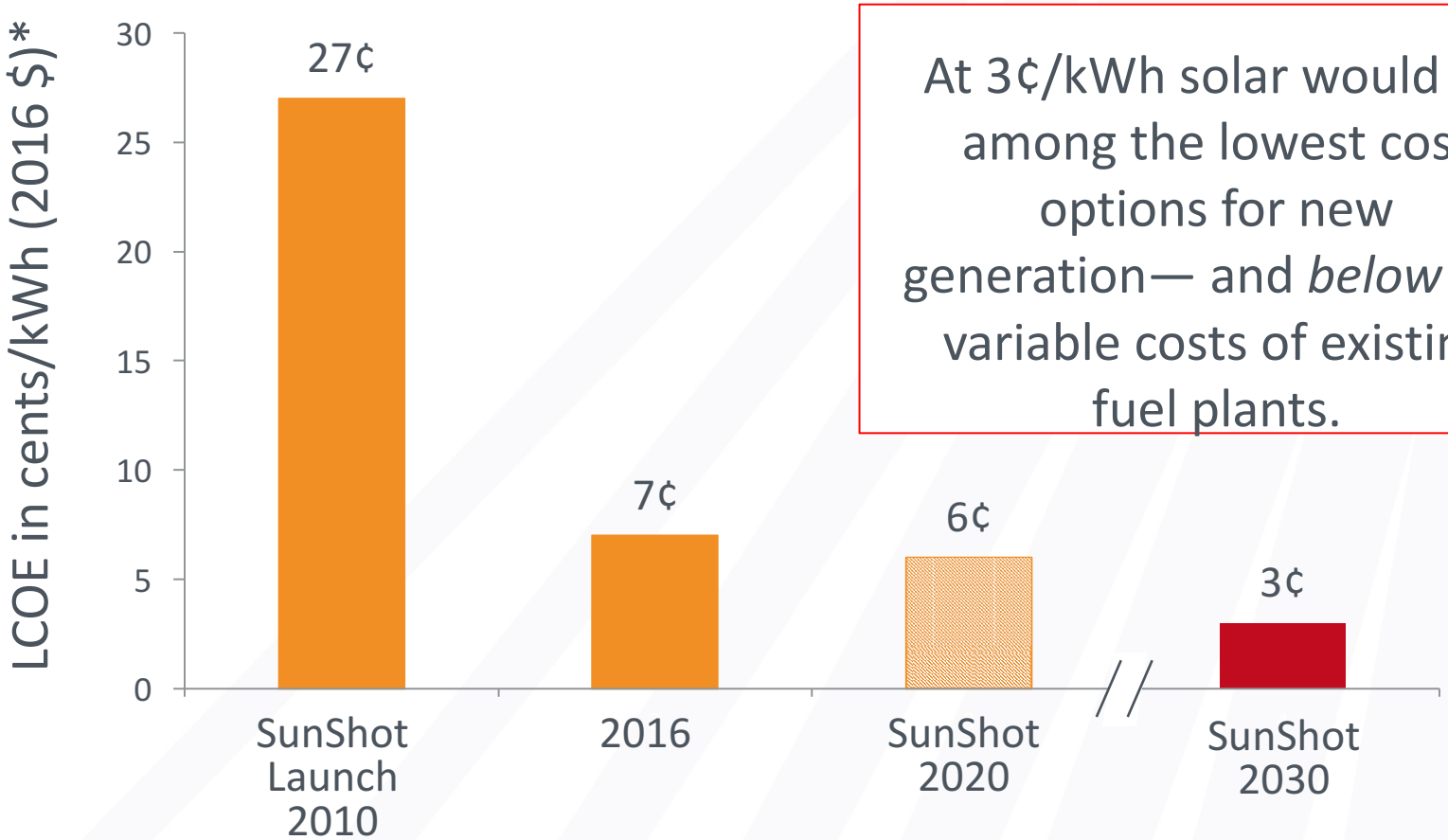
ECONOMIC IMPACT ENTREPRENEURSHIP	• Supports innovations across the full $25B/year U.S. solar PV supply chain • 250+ active R&D projects across 48 states impacting the 9,000 U.S. solar businesses • Small businesses attract $22 in private investment for every $1 of public support
JOB CREATION	• 260,000 total employed in solar • The median wage for solar installers is $26 per hour • Supported training for 60,000 U.S. workers including power systems engineers
INFRASTRUCTURE & RESILIENCY	• Supports diversification of domestic energy supply with affordable homegrown power • Enables improved resiliency, reliability & security of our national electric grid
RESEARCH & INNOVATION	• Creates a long-term innovation pipeline • Private sector R&D budgets are only 2% of revenue • 10-yr planning horizon and research beyond private-sector capacity
CLEAN AIR AND WATER	• Achieving SunShot's goals would reduce air pollution by as much as 14% and reduce power-sector water consumption 10% by 2030
INTERNATIONAL COMPETITIVENESS	• Supports U.S. product & manufacturing innovation in order to keep pace with the 11 countries spending a greater percentage of GDP on energy R&D • DOE funded >50% of all world records for solar cell efficiency

SunShot 2020 Targets in Reach — What's Next?



* LCOE progress and targets for utility-scale PV are for average U.S. climate and without the ITC or state/local incentives. The 2016 number is for a system with one-axis tracking.

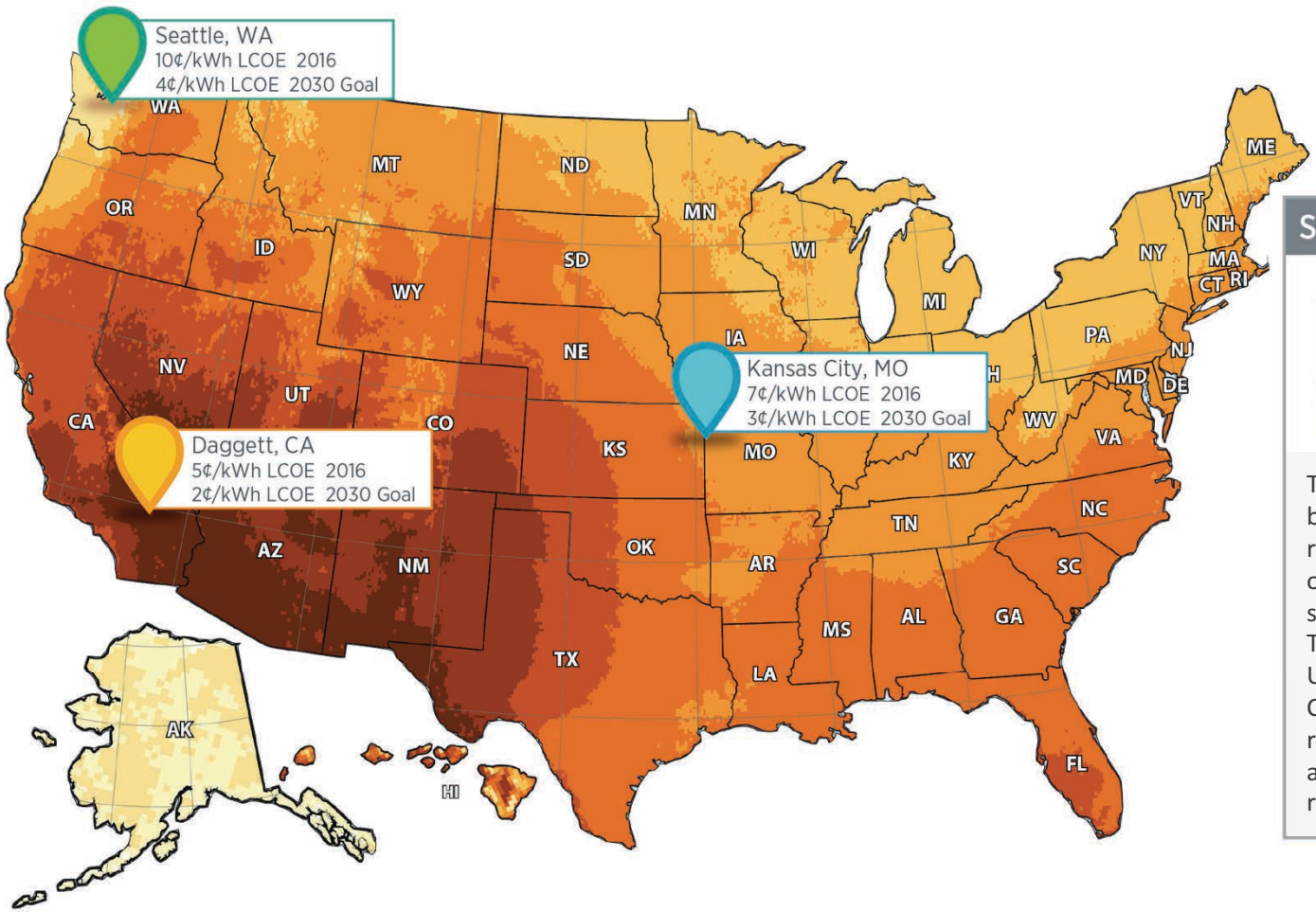
SunShot 2020 Targets in Reach — What's Next?



At 3¢/kWh solar would be among the lowest cost options for new generation— and *below* the variable costs of existing fuel plants.

* LCOE progress and targets for utility-scale PV are for average U.S. climate and without the ITC or state/local incentives. The 2016 number is for a system with one-axis tracking.

Average Solar Resource Calculation



Solar Resource Across America

kWh/m²/Day

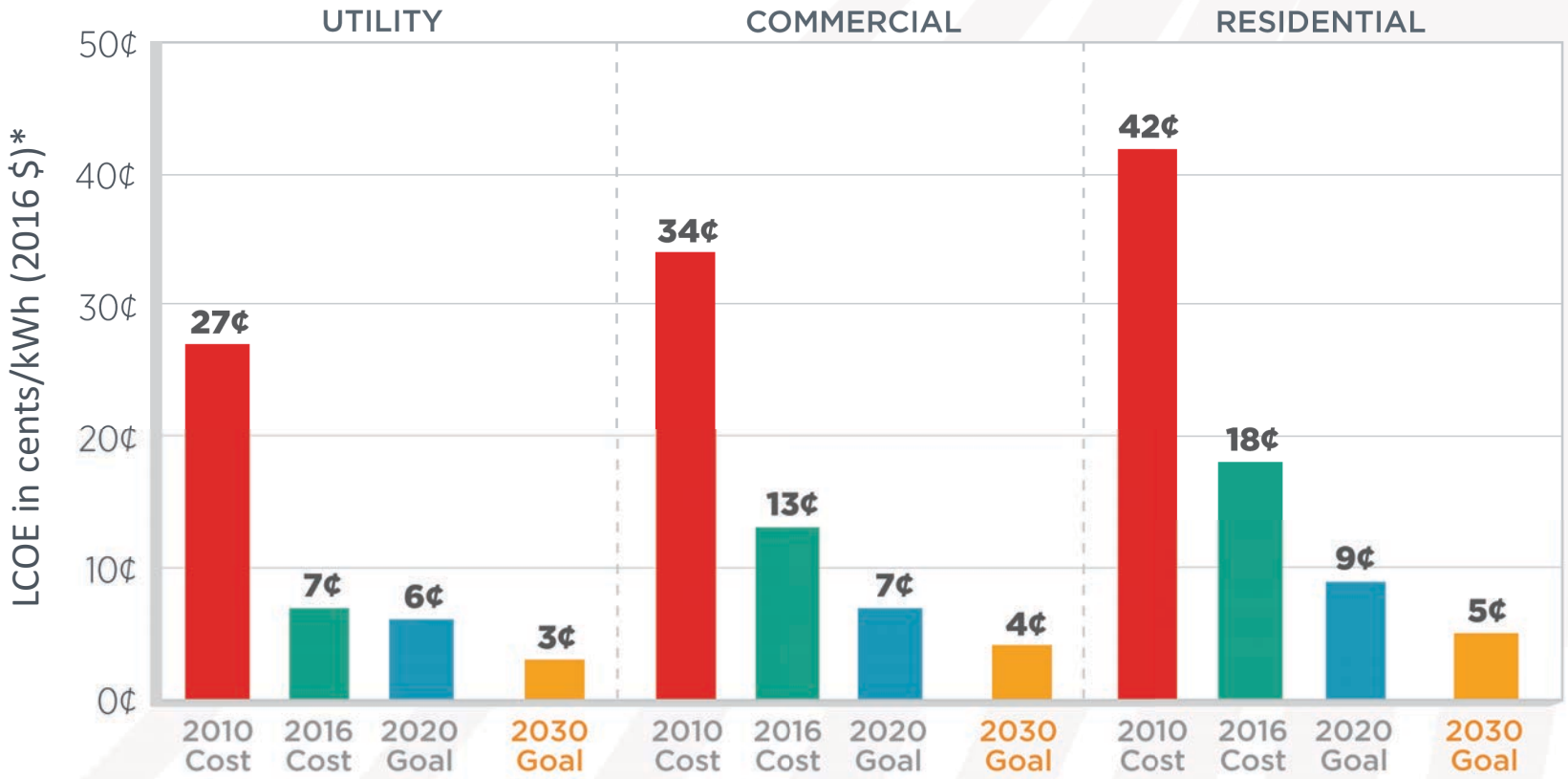
- > 6.5
- 6.0 to 6.5
- 5.5 to 6.0
- 5.0 to 5.5
- 4.5 to 5.0
- 4.0 to 4.5
- 3.5 to 4.0
- 3.0 to 3.5
- < 3.0

Daggett, CA - **High**
Kansas City, MO - **Average**
Seattle, WA - **Low**

The amount of power that is produced by a PV system depends upon the solar resource availability (in addition to other factors like temperature and snowfall), which is location dependent. The median solar resource for the United States is represented by Kansas City, MO, while the highest solar resource is represented by Daggett, CA, and the lowest solar resource is represented by Seattle, WA.

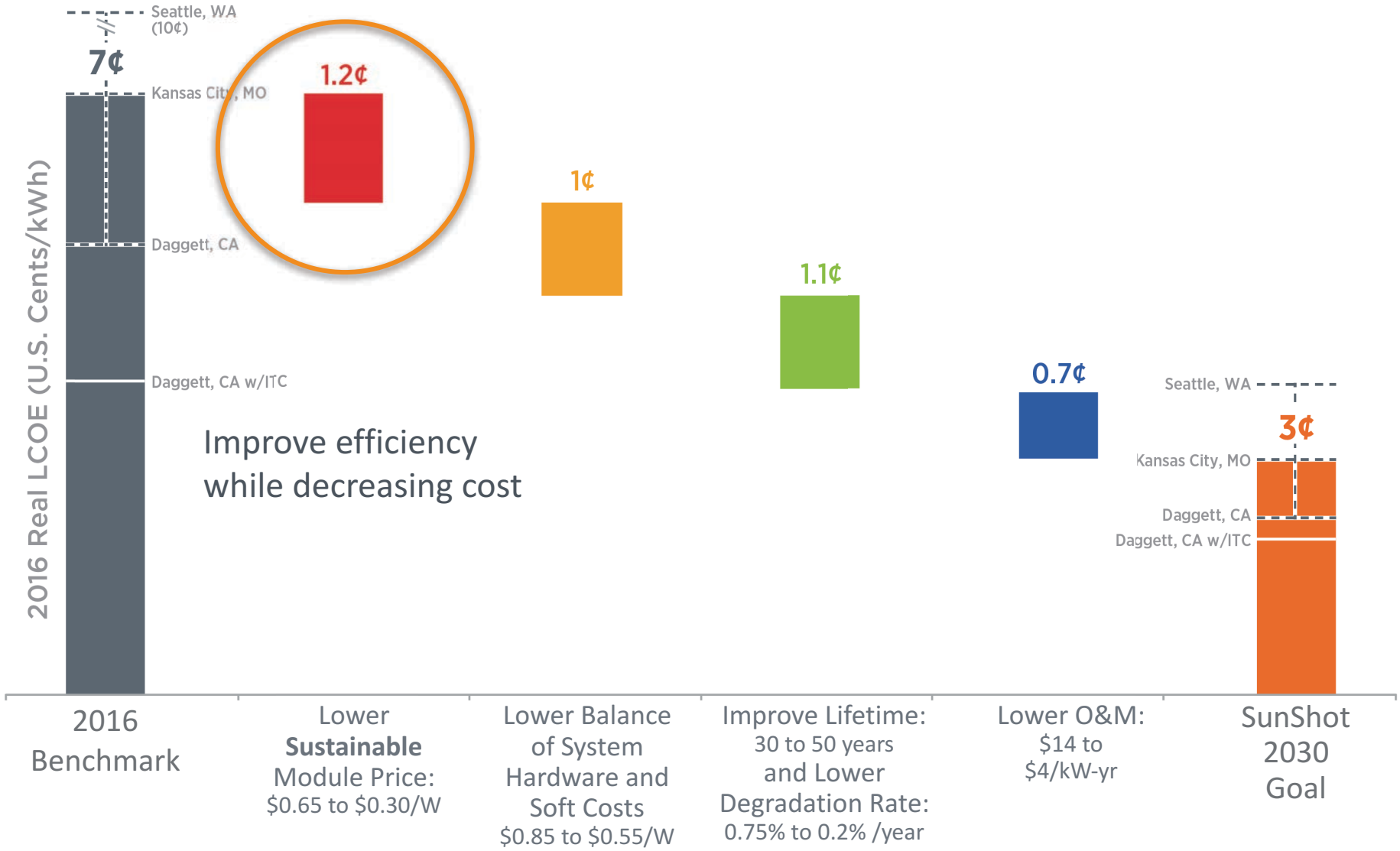
SunShot Progress and Goals

The solar industry is more than **90% of the way** to achieving SunShot's 2020 utility-scale cost target. SunShot's 2030 goal is to cut costs an additional **50% between 2020 and 2030**, to make solar the least expensive source of energy.



*Levelized cost of electricity (LCOE) progress and targets are calculated based on average U.S. climate and without the ITC or state/local incentives. Utility-scale PV uses one-axis tracking.

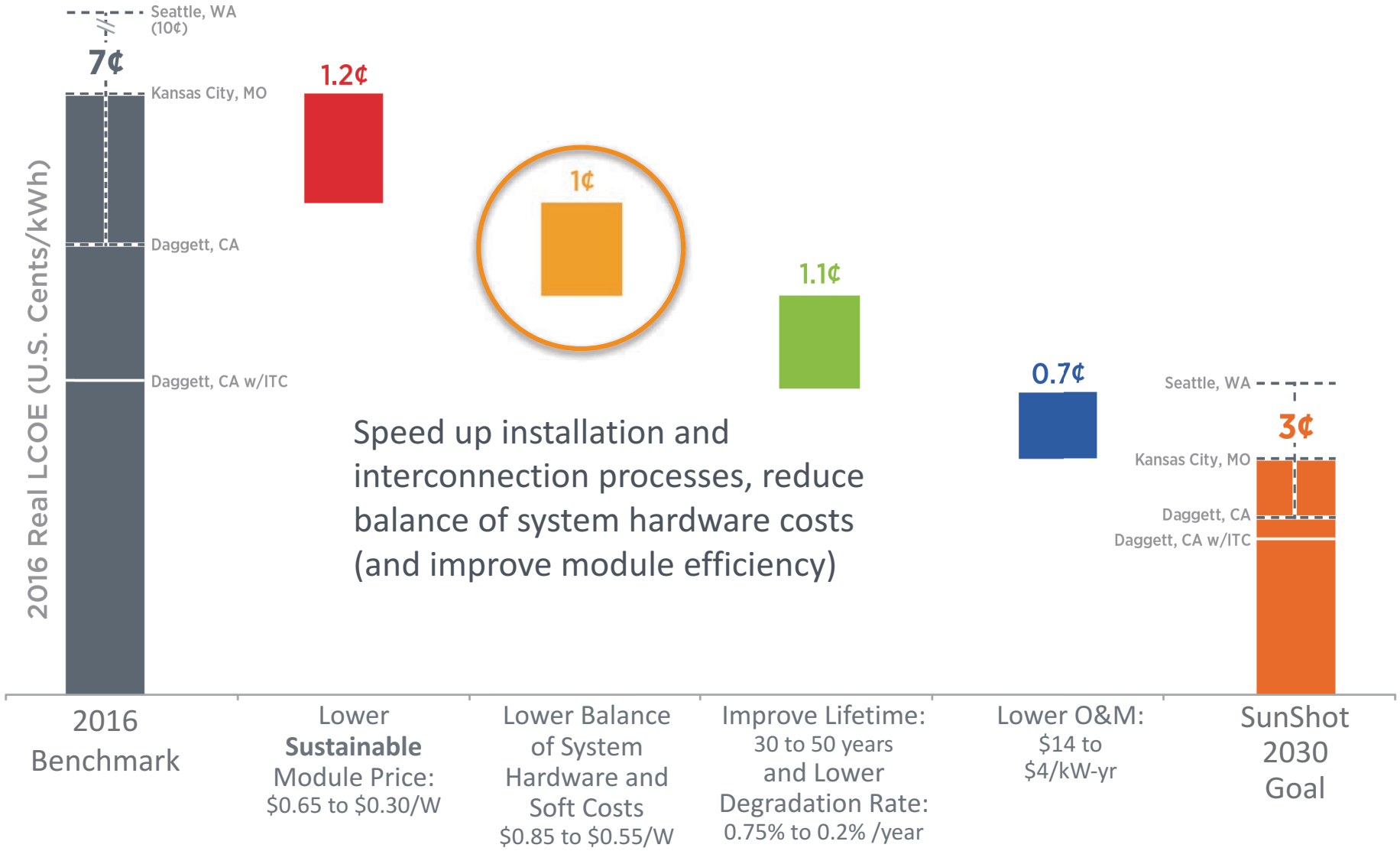
A Pathway To 3 Cents per kWh



100 $MW_{(DC)}$ One-Axis Tracking Systems With 1,860 $kWh_{(AC)}/kW_{(DC)}$ First-Year Performance. Includes 5 Year MACRS. Cost of capital is 7% and inflation is 2.5%.

SunShot U.S. Department of Energy

A Pathway To 3 Cents per kWh



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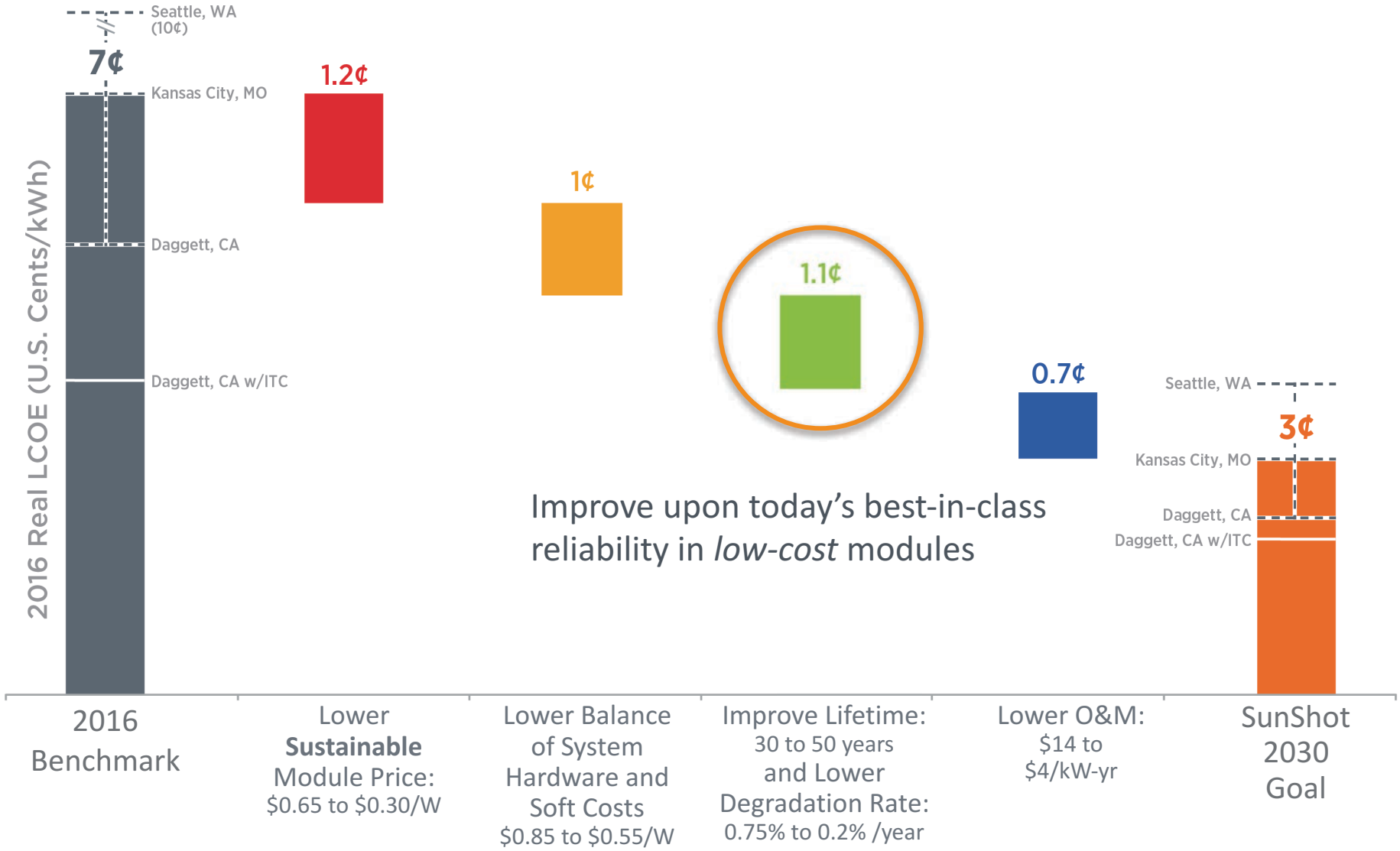

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SunShot U.S. Department of Energy

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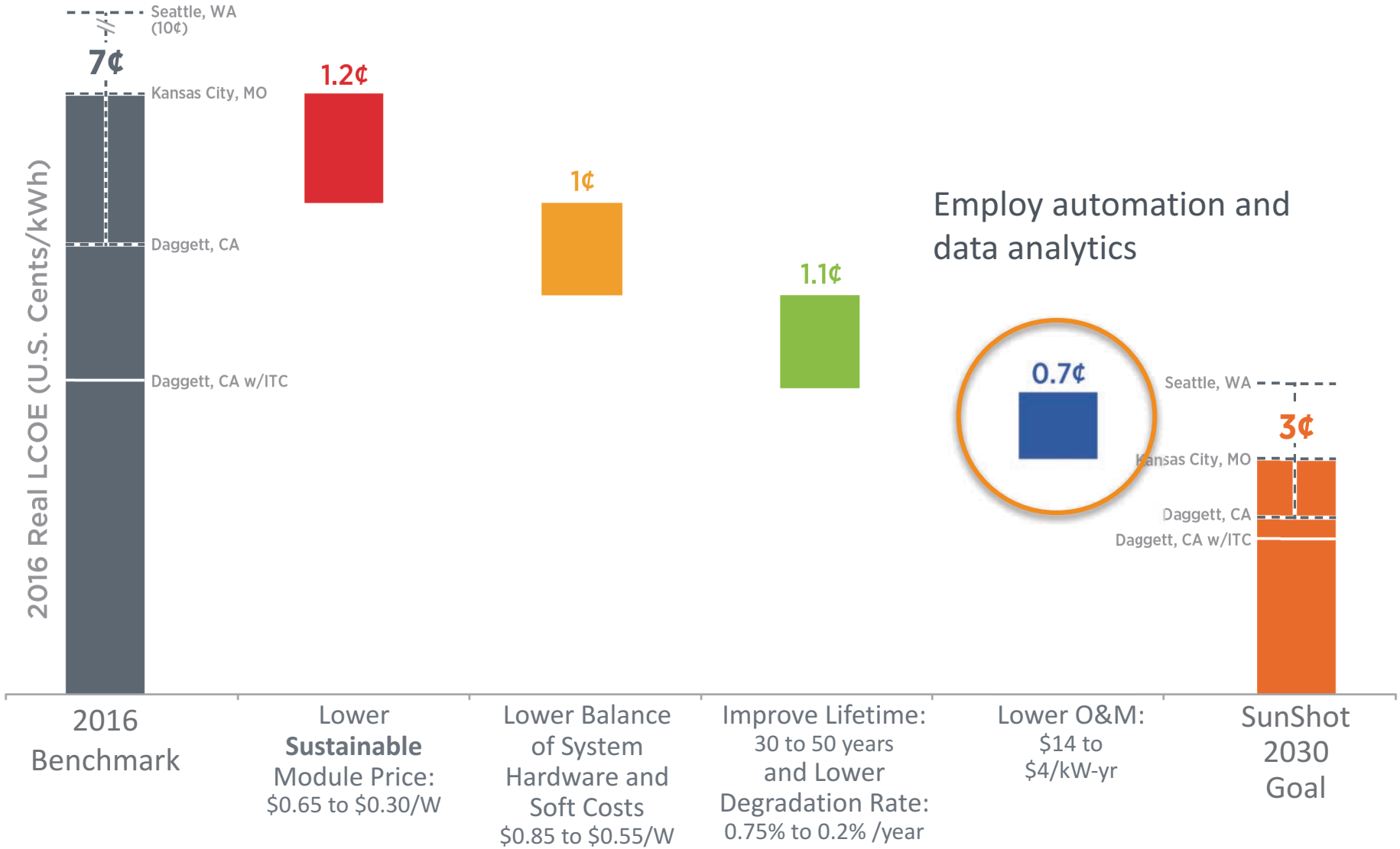

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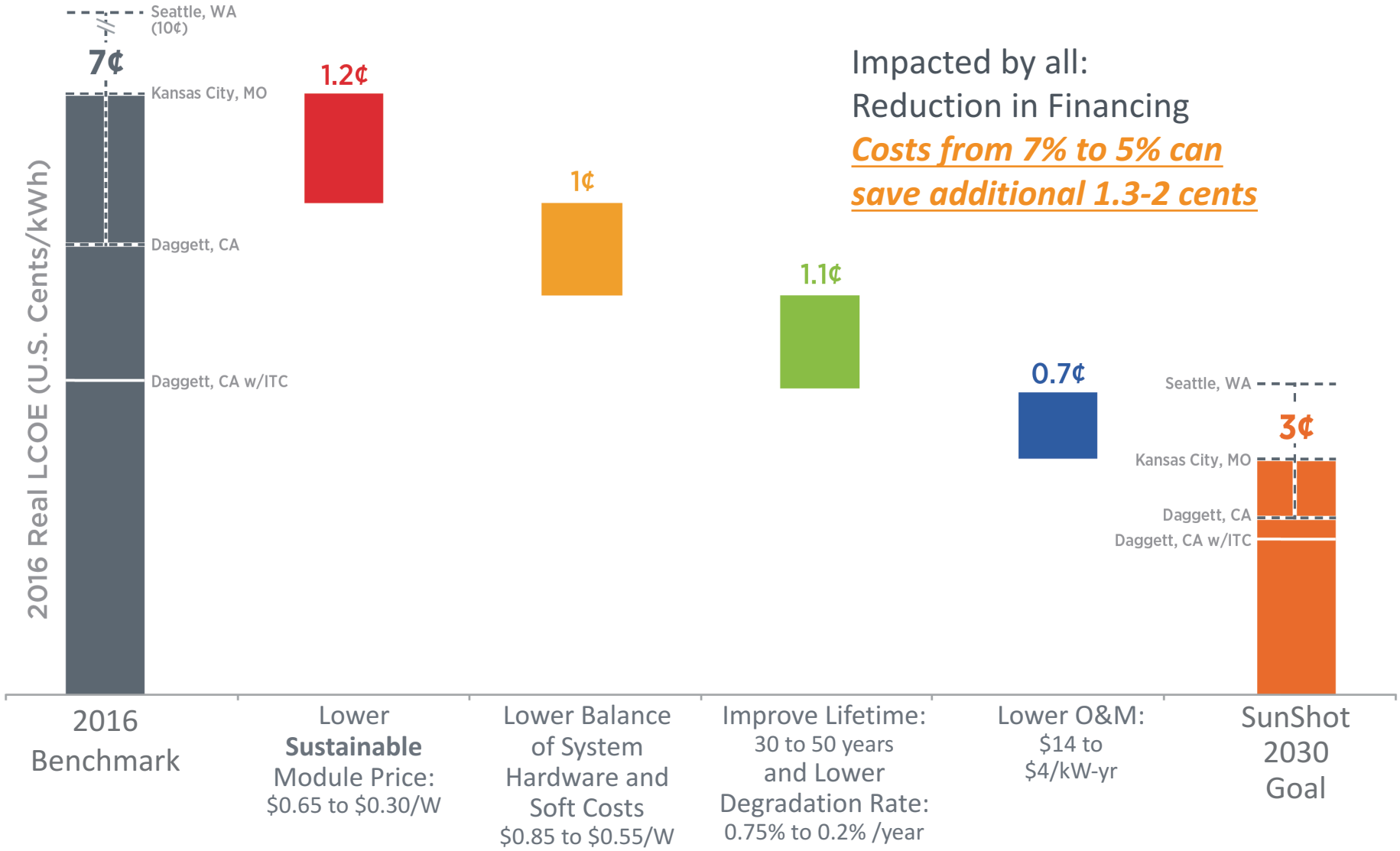

Impacted by all:
Reduction in Financing
Costs from 7% to 5% can save additional 1.3-2 cents

100 $MW_{(DC)}$ One-Axis Tracking Systems With 1,860 $kWh_{(AC)}/kW_{(DC)}$ First-Year Performance. Includes 5 Year MACRS. Cost of capital is 7% and inflation is 2.5%.

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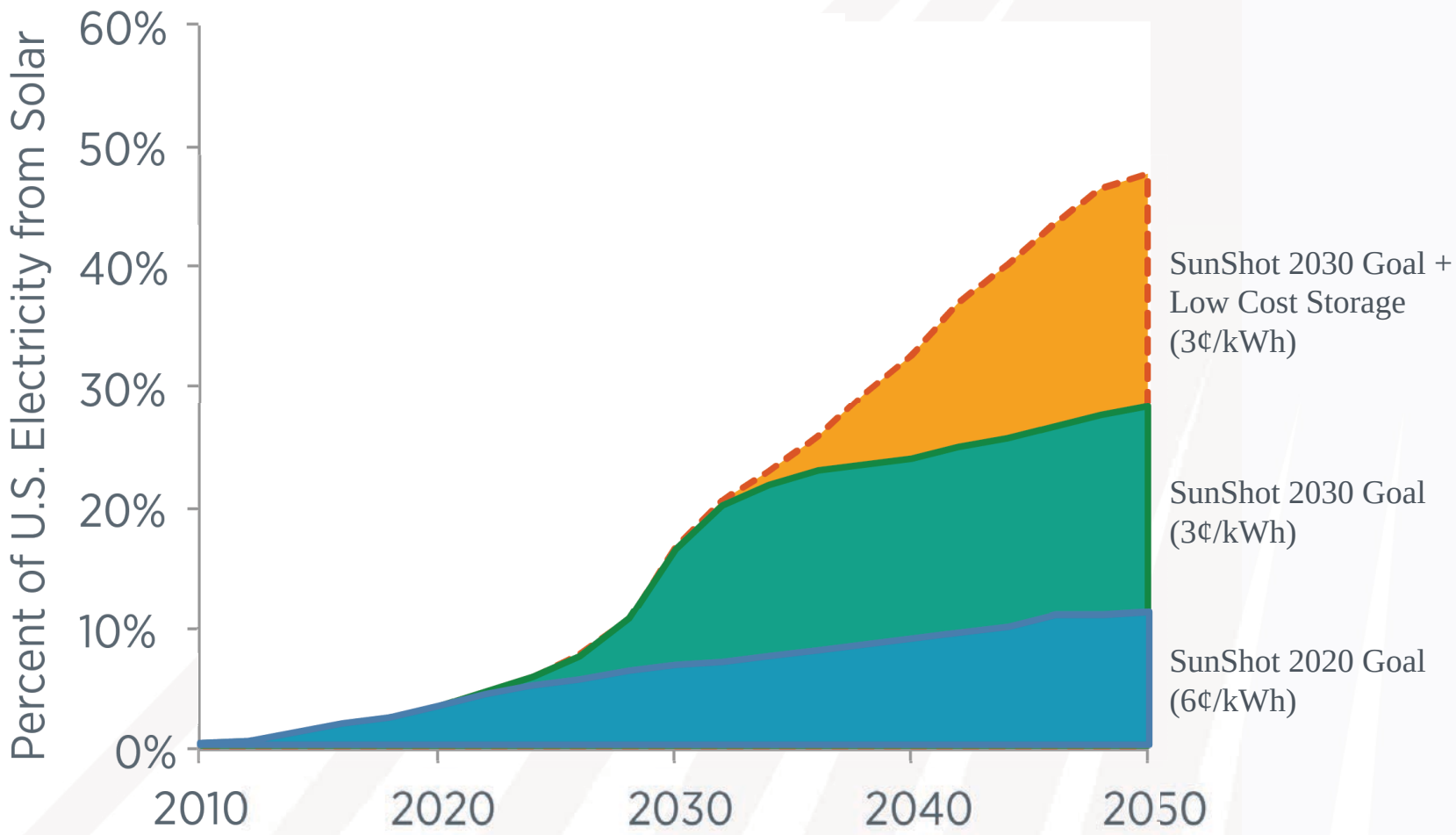
Half the Cost, More than Double the Solar



Quick Deployment Sidebar

How can and why should your school go solar?

Recommend:

Expanding Midscale Solar: Examining the Economic Potential, Barriers, and Opportunities at Offices, Hotels, Warehouses, and Universities

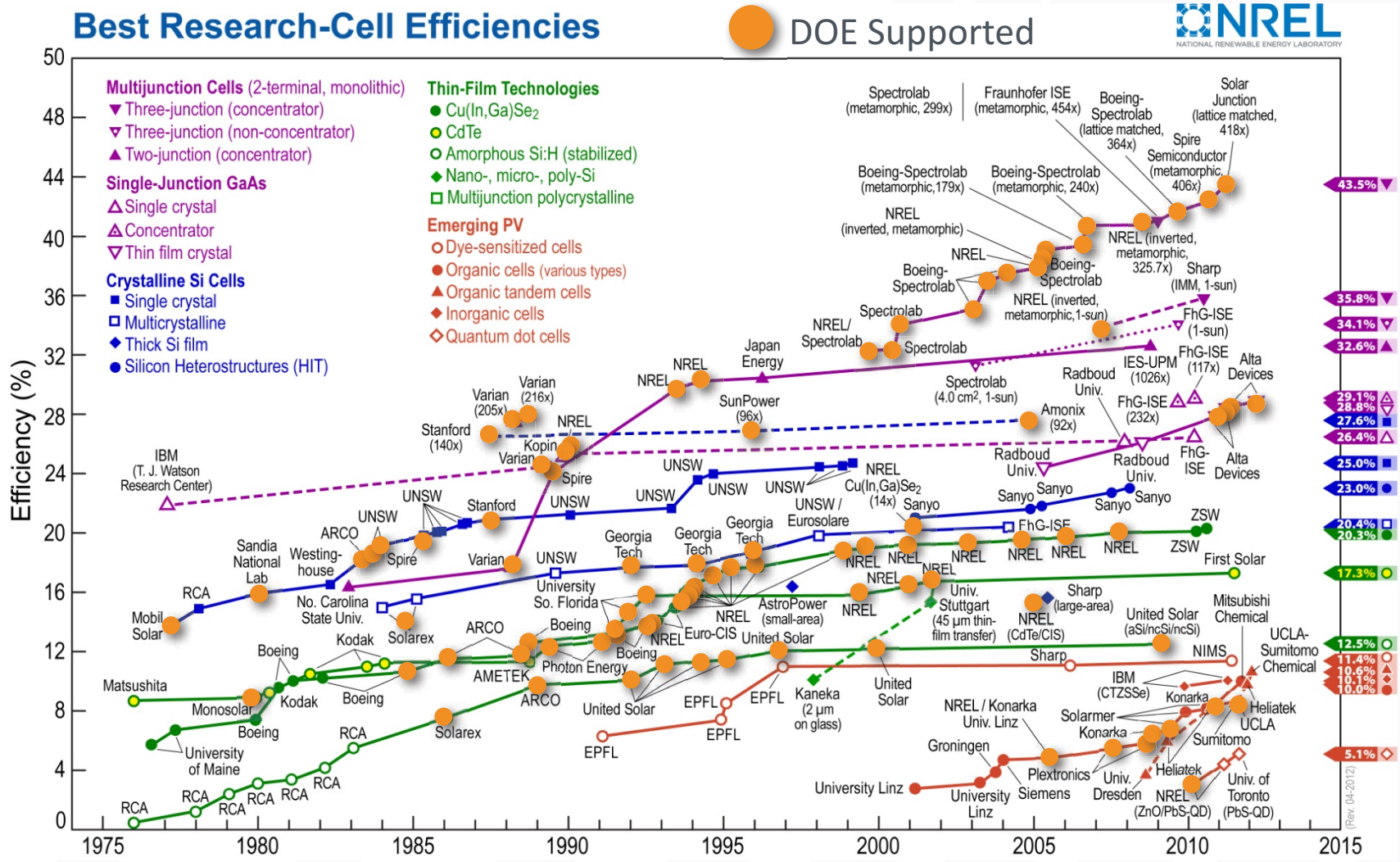
By Bird, Gagnon, Heeter from NREL

- If universities installed PV to cover 25% of load more than 16GW could be deployed!

http://www.nrel.gov/docs/fy16osti/65938.pdf

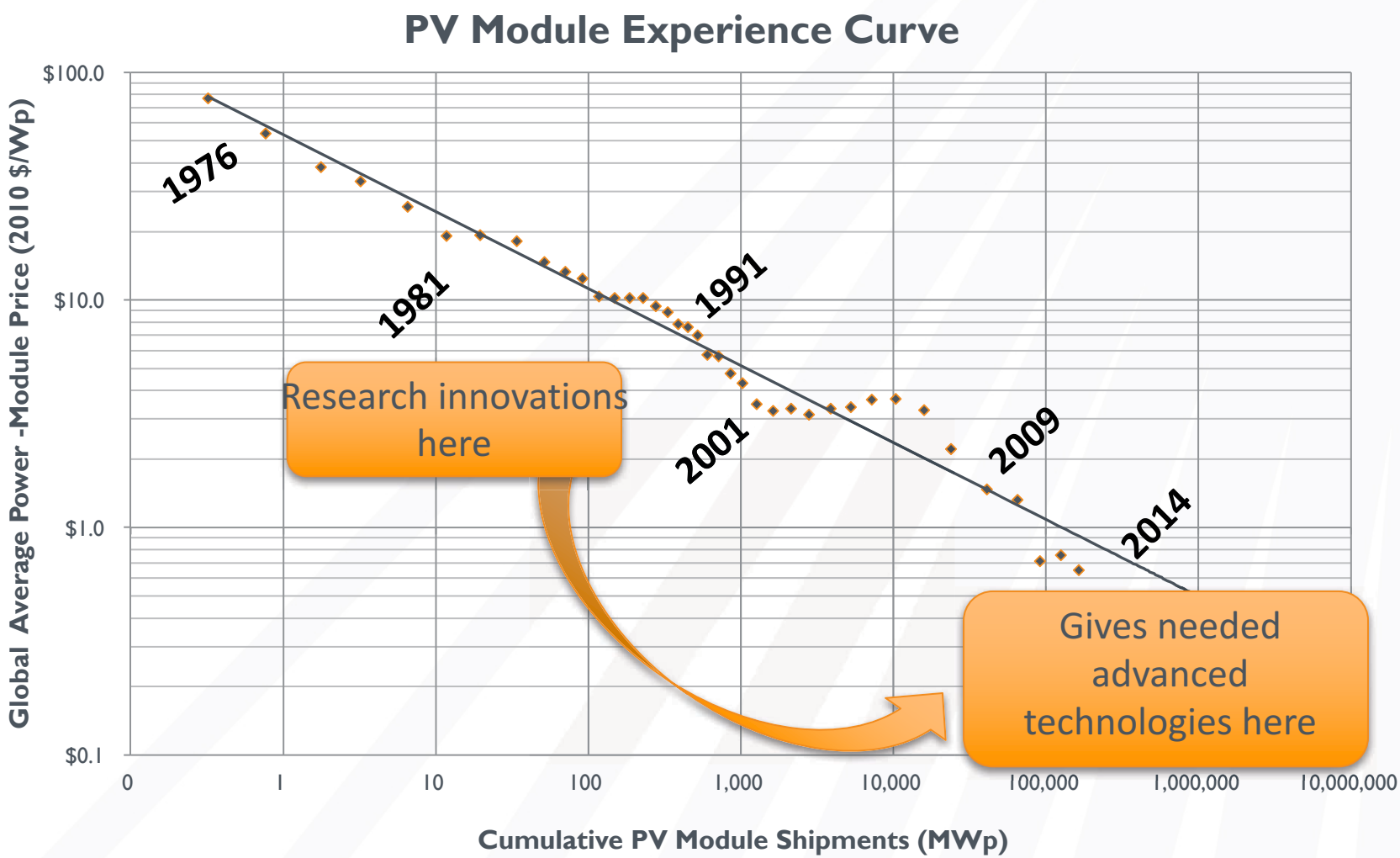
Photovoltaics

DOE has played a key role in driving up cell efficiencies (and tracking global progress)



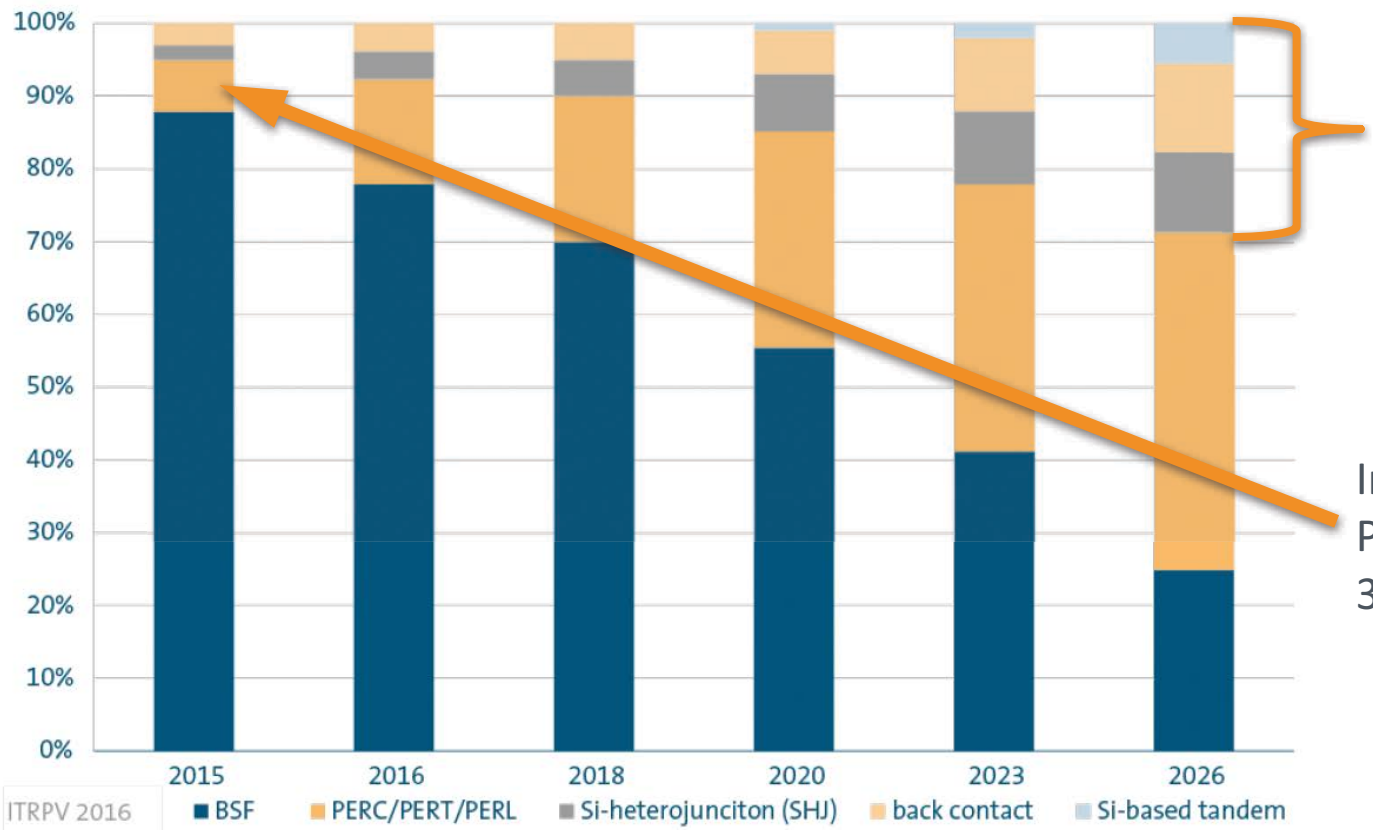
~50% of the world record cell efficiencies from 1975-2012 were made by researchers supported by the DOE

Progress along experience curve relies on decades of prior research



SunShot U.S. Department of Energy

Todays research is the pipeline to tomorrows mainstream technology



R&D needs to be conducted now to enable new technologies like these

Initial research on PERC was conducted 30 years ago

Source: *ITRPV Seventh Edition*, October 2016

NREL consortium will support and develop more durable module materials

Mission	Accelerate the RD&D of new durable module materials that significantly reduce the levelized cost of energy (LCOE) of photovoltaic (PV) systems: • Module materials account for ~40% of module costs • Design, develop, and de-risk new materials w/ industry • Capabilities informed by and provide value to industry
Key Players	NREL National Renewable Energy Laboratory; Sandia National Laboratories; SLAC National Accelerator Laboratory; Berkeley Lab Lawrence Berkeley National Laboratory
Website	www.duramat.org/

DuraMAT Durable Module Materials Consortium

Energy Materials Network U.S. Department of Energy

SunShot U.S. Department of Energy

NREL & Sandia materials and PV durability, coupled to SLAC characterization and LBNL materials and data science

- Leveraging National Lab capabilities that are difficult for industry to acquire such as accelerated testing at NREL and in-situ device characterization at SLAC
- Utilizes research awards to universities for in-depth studies

PV- Top challenges in next 5 years

- **Lowering capital expenditure (CapEx) requirements:** Research enabling new PV technologies and fabrication processes. Developing architectures that increase the efficiency of PV technologies while reducing the cost of manufacturing
- **Ensuring durability and reducing uncertainty**: Proving module and racking reliability beyond 25 years potentially using more durable materials than currently in the market. Publishing degradation pathways to reduce uncertainty and increase durability.
- **Increasing annual energy production:** Better scientific understanding and publication of soiling of PV technologies and translating standard conditions to real world performance
- **Reduce non-hardware barriers and strengthen the grid:** Developing module technologies that facilitate grid integration and rapid deployment
- **Maintain domestic PV talent pipeline:** Ensuring that basic science is effectively leveraged by domestic entities to develop competitive products; and providing tools, knowledge, and infrastructure to support a fully competitive US PV manufacturing sector

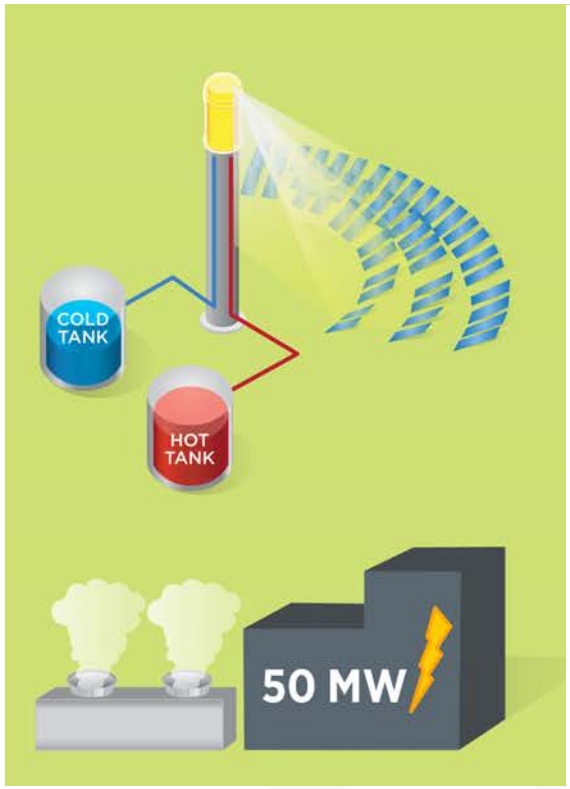
Concentrating Solar Power

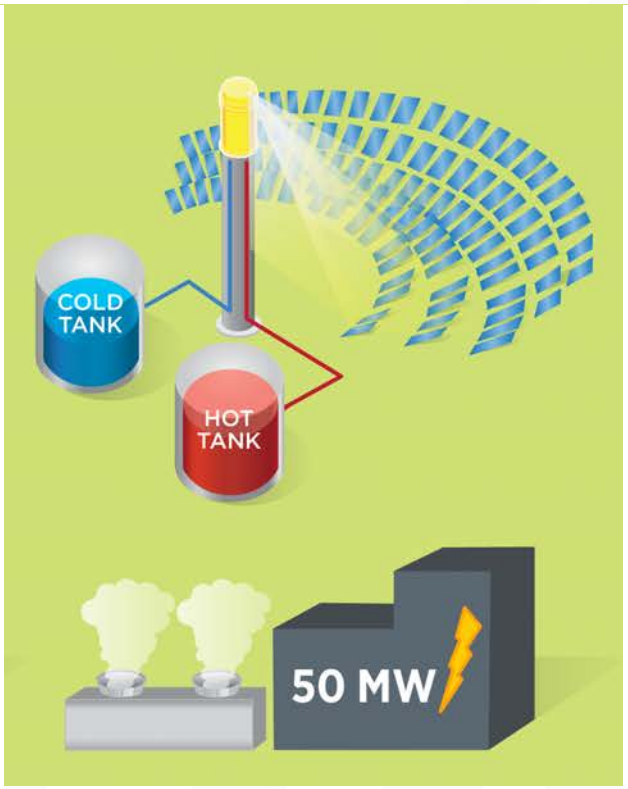
CSP: Flexible Designs for an Evolving Grid

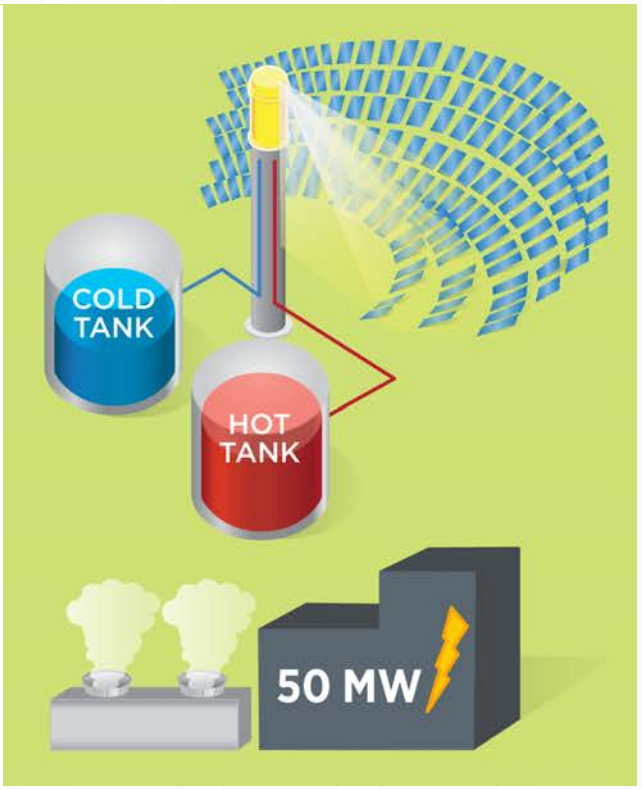
'Peaker'
(<6 hours of storage)

'Intermediate'
(9 hours of storage)

'Baseload'
(>12 hours of storage)

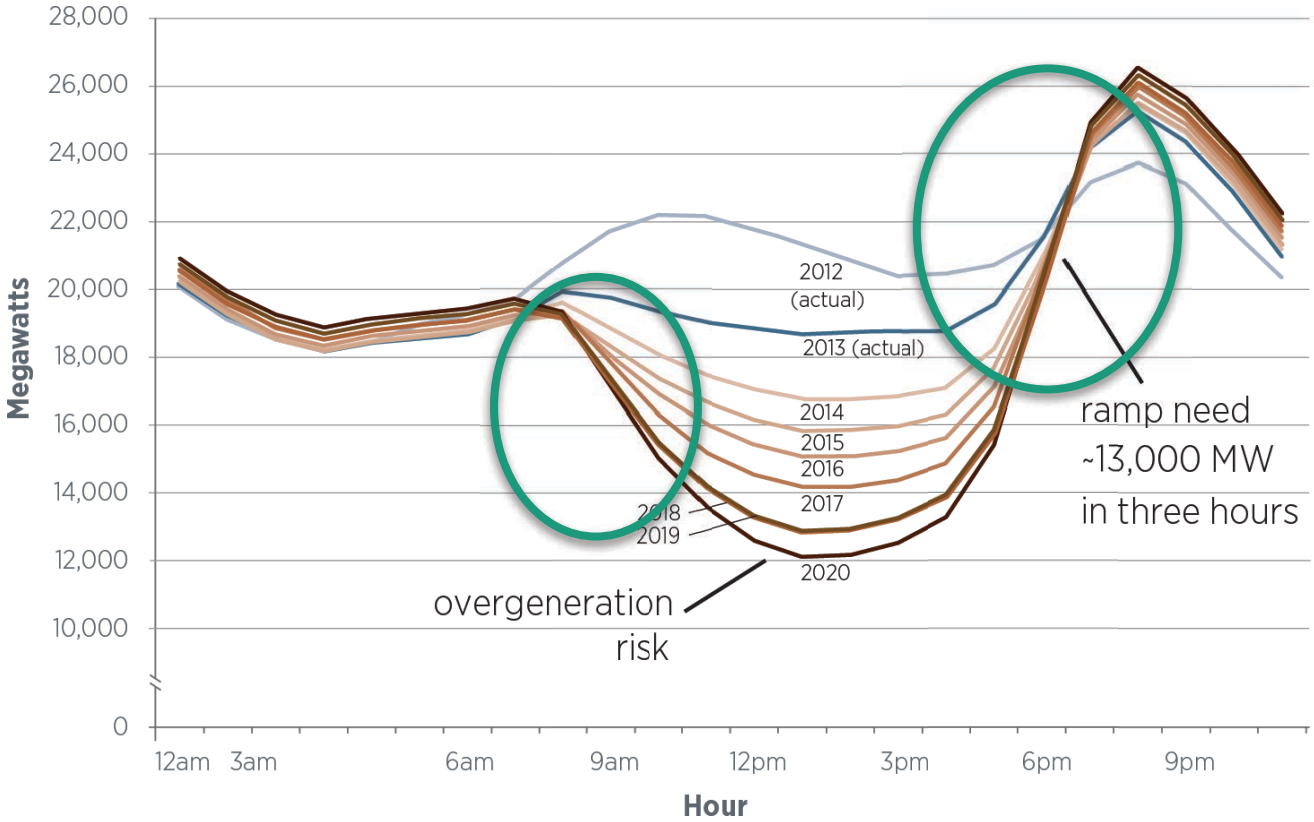






By choosing the size of the solar field and thermal energy storage, the same CSP technology can be configured to meet evolving demands of the future grid

Value of CSP – Flexible, Reliable, Dispatchable Generation



4.8 GW CSP deployed globally; **1.9 GW** in the US

BrightSource

ABENGOA

SOLARRESERVE

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nrg

NEXTera ENERGY RESOURCES

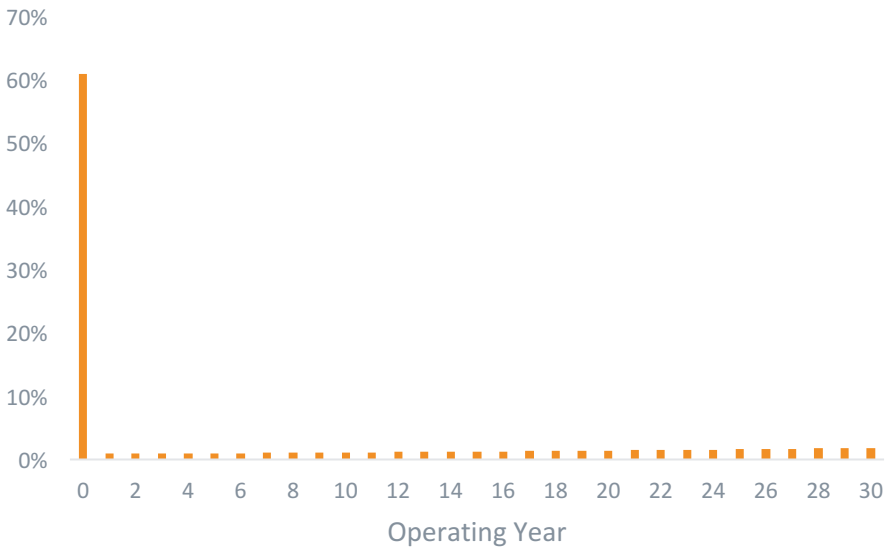
CSP can provide dispatchable electricity, without fuel and the associated operating cost uncertainty of conventional plants

Dispatchable Power with No Fuel Cost Uncertainty

U.S. Natural Gas Electric Power Price
Dollars per Thousand Cubic Feet

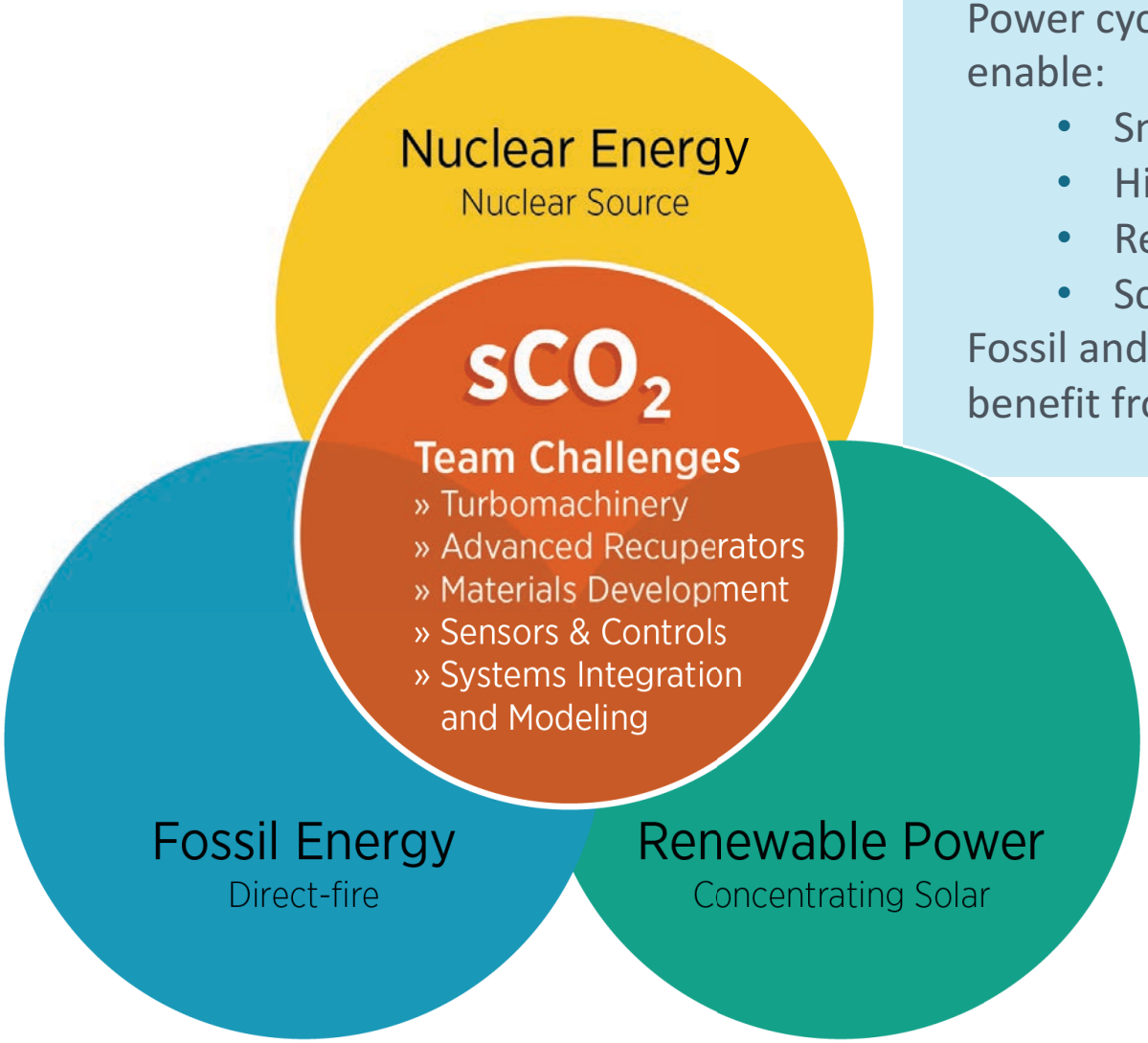
Source: EIA

Sunshot CSP: Projected Annual Expenses
as Percentage of Total Lifetime Costs



CSP provides long-term predictable power costs with little variable costs.
CSP is a complementary component of a diversified generation portfolio.

Next Generation CSP: Reaching High Efficiencies with Advanced Supercritical CO_2 Power Cycles



Power cycles using supercritical CO_2 enable:

- Smaller Footprint
- Higher Efficiency
- Reduced Water Use
- Scalability

Fossil and nuclear technologies also benefit from integration with sCO_2 cycles

Next Generation CSP: High Temperature, High Efficiency Leveraging Cross-Cutting STEP Initiative

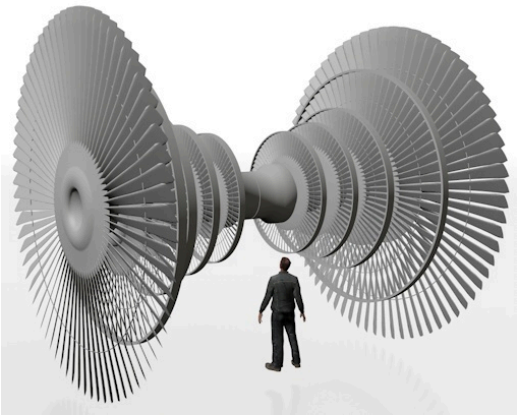
Supercritical CO_2 Power Cycles

- Smaller Footprint
- Higher Efficiency
- Reduced Water Use
- Scalability

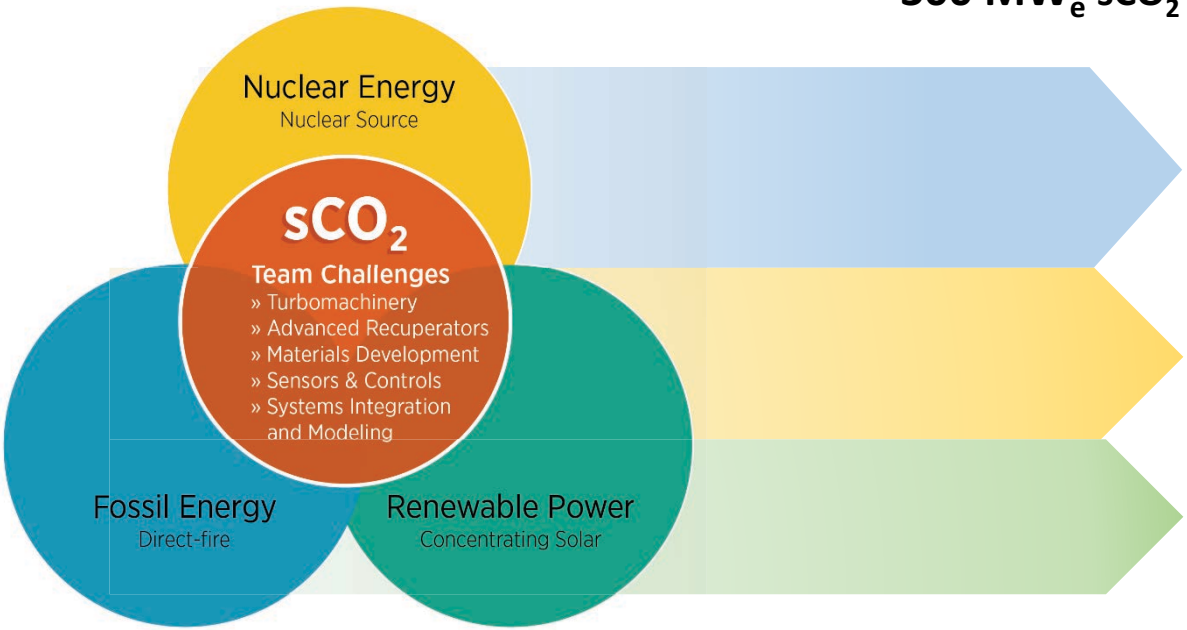
National benefits:

- Enhance U.S. energy independence and energy security
- Boost U.S. leadership in energy technology
- Lower cost of electricity generation
- Create jobs

300 MW_e sCO_2



300 MW_e Steam Turbine



Crosscut Team Goals

- Coordinate technology scale up and integration
- Launch facilities to test and validate the technology

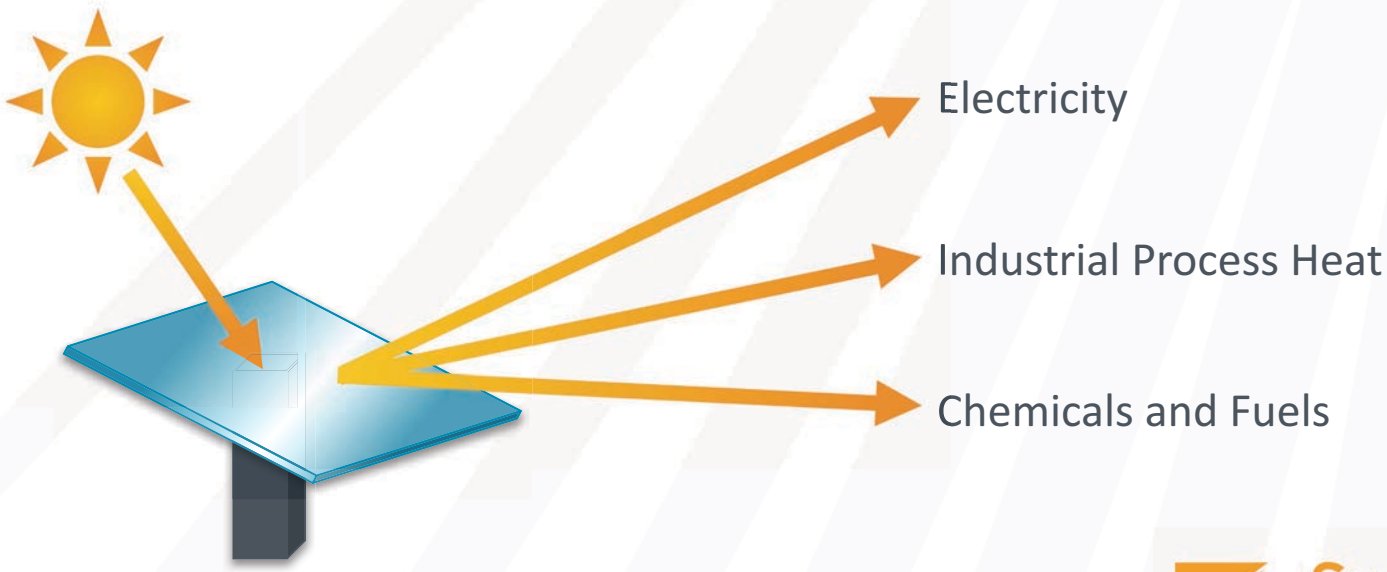
  2020 Operation
  Indirect-fired 10 MWe pilot facility

  2026 Operation
  Commercial-scale demonstration plant

- Demonstrate thermal cycle efficiency of $\geq$ 50%
- Optimize performance and lower capital costs

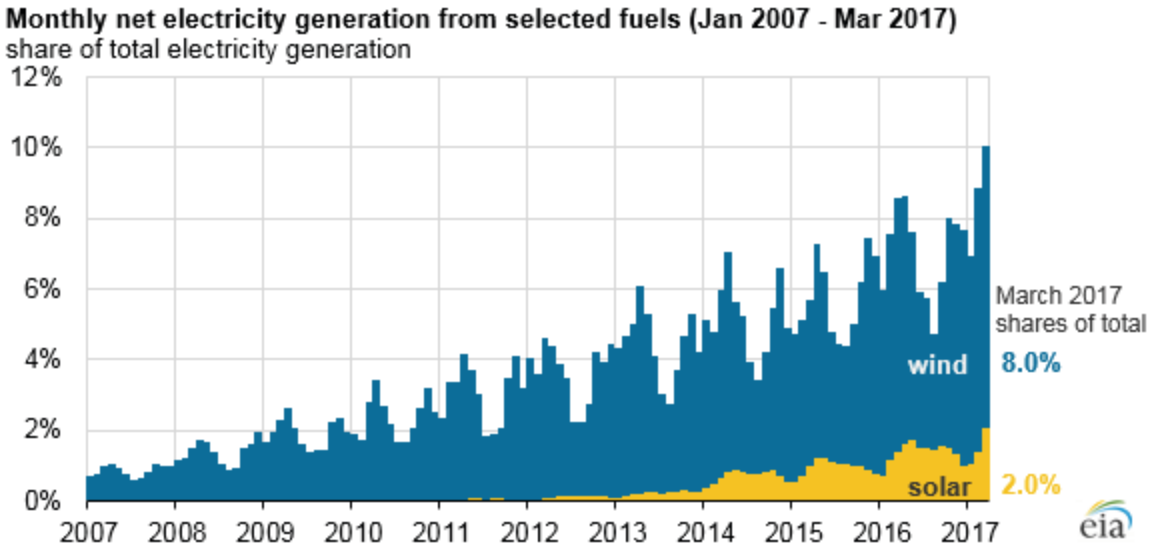
CSP- Five opportunities for next five years

- Continue to lower the cost of **solar thermal collectors** (durable, high performance mirrors and support structure)
- Develop **low-cost, high-performance heat exchangers** that leverage US-specific manufacturing expertise
- Develop Gen3 CSP systems capable of **integration** with **high efficiency supercritical CO_2 power cycles**
- Pursue early-stage research using solar thermal energy for the **production of chemicals and fuels**
- Develop technologies for **solar thermal industrial heat**



Systems Integration

Wind and solar in March accounted for 10% of U.S. electricity generation for first time

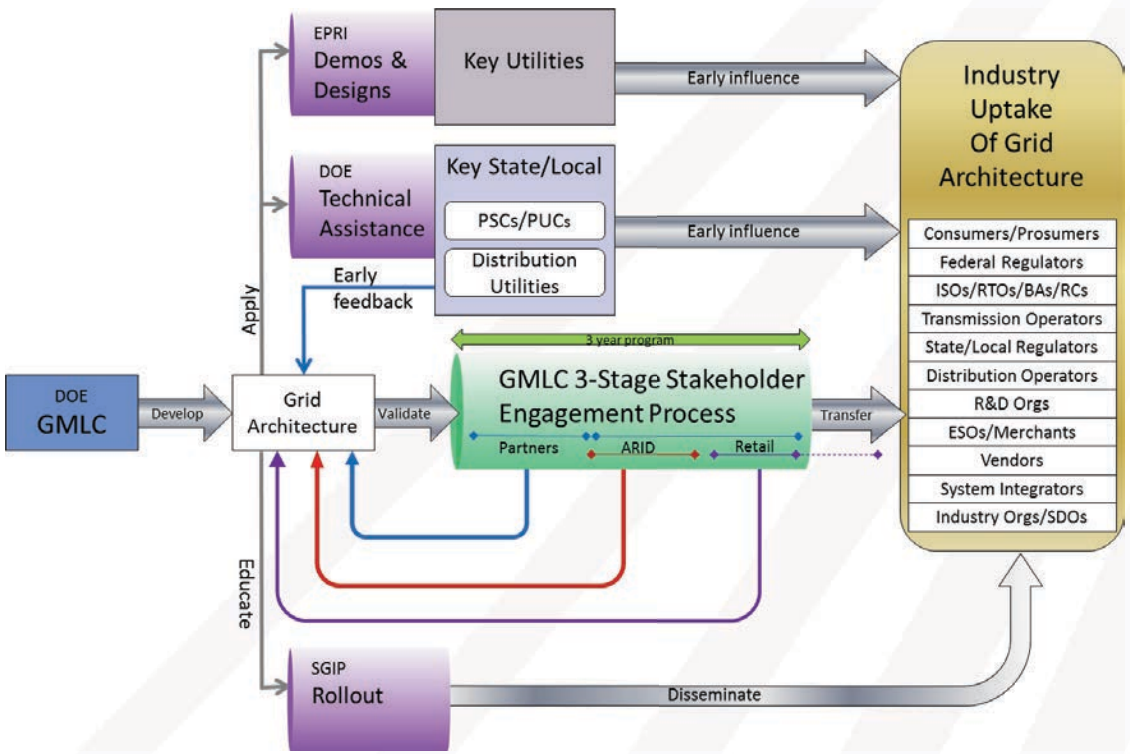


For the first time, monthly electricity generation from wind and solar (including utility-scale plants and small-scale systems) exceeded 10% of total electricity generation in the United States, based on March data in EIA's *Electric Power Monthly*. Electricity generation from both of these energy sources has grown with increases in wind and solar generating capacity. On an annual basis, wind and solar made up 7% of total U.S. electric generation in 2016.

Source: EIA Today in Energy

Part of the DOE Grid Modernization Initiative

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy



GMLC 1.2.1 Grid Architecture

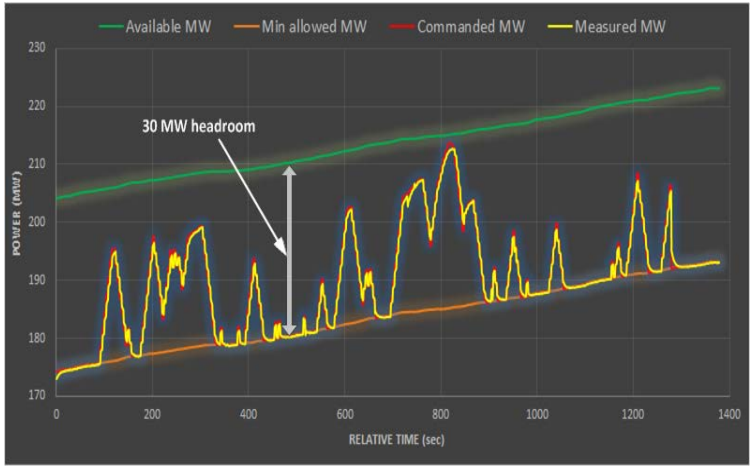
Source: Jeffery Taft, PNNL

Cross-Cutting R&D

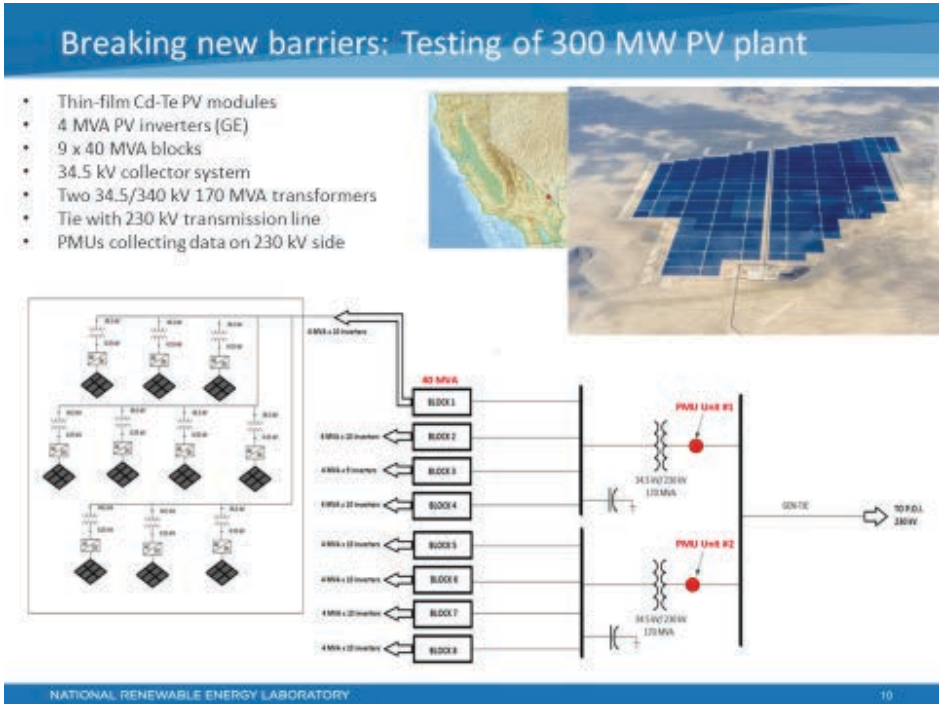
- Design and Planning Tools
- System Operations, Power Flow, and Control
- Sensing and Measurements
- Devices and Integrated System Testing
- Security and Resilience
- Institutional Support

SunShot U.S. Department of Energy

CAISO/First Solar Inverter Testing



- 4-sec AGC signal provided to PPC
- 30 MW headroom
- Tests were conducted for 30 minutes at:
  - Sunrise
  - Middle of the day
  - Sunset
- 1-sec data collected by plant PPC

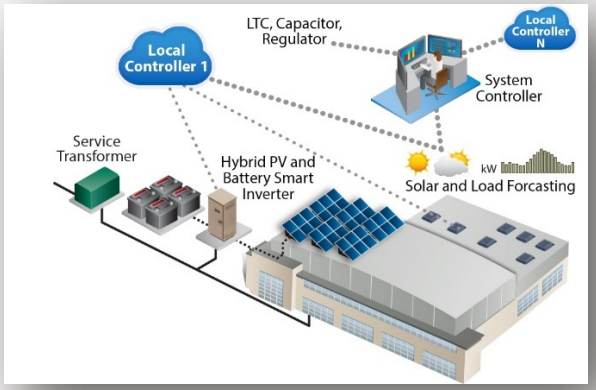


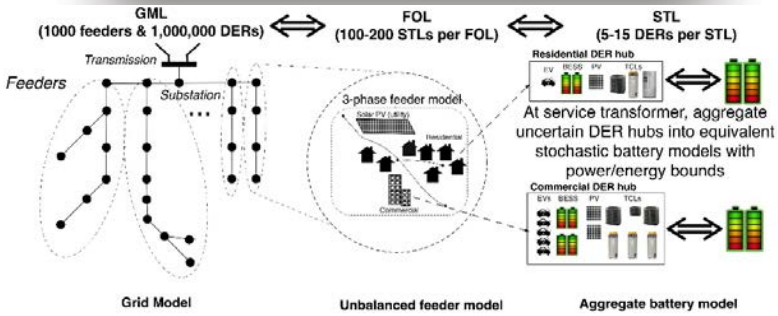
Courtesy: NREL, Vahan Gevorgian

http://www.nrel.gov/docs/fy17osti/67799.pdf

System Integration Opportunities

- Forecasting Integration
  - Utility operations and individual buildings
- Grid controls, sensors and communications
- Power Electronics
- Human/Technology/System Nexus
  - How do unpredictable actors impact energy operations?
- The Internet of Everything!

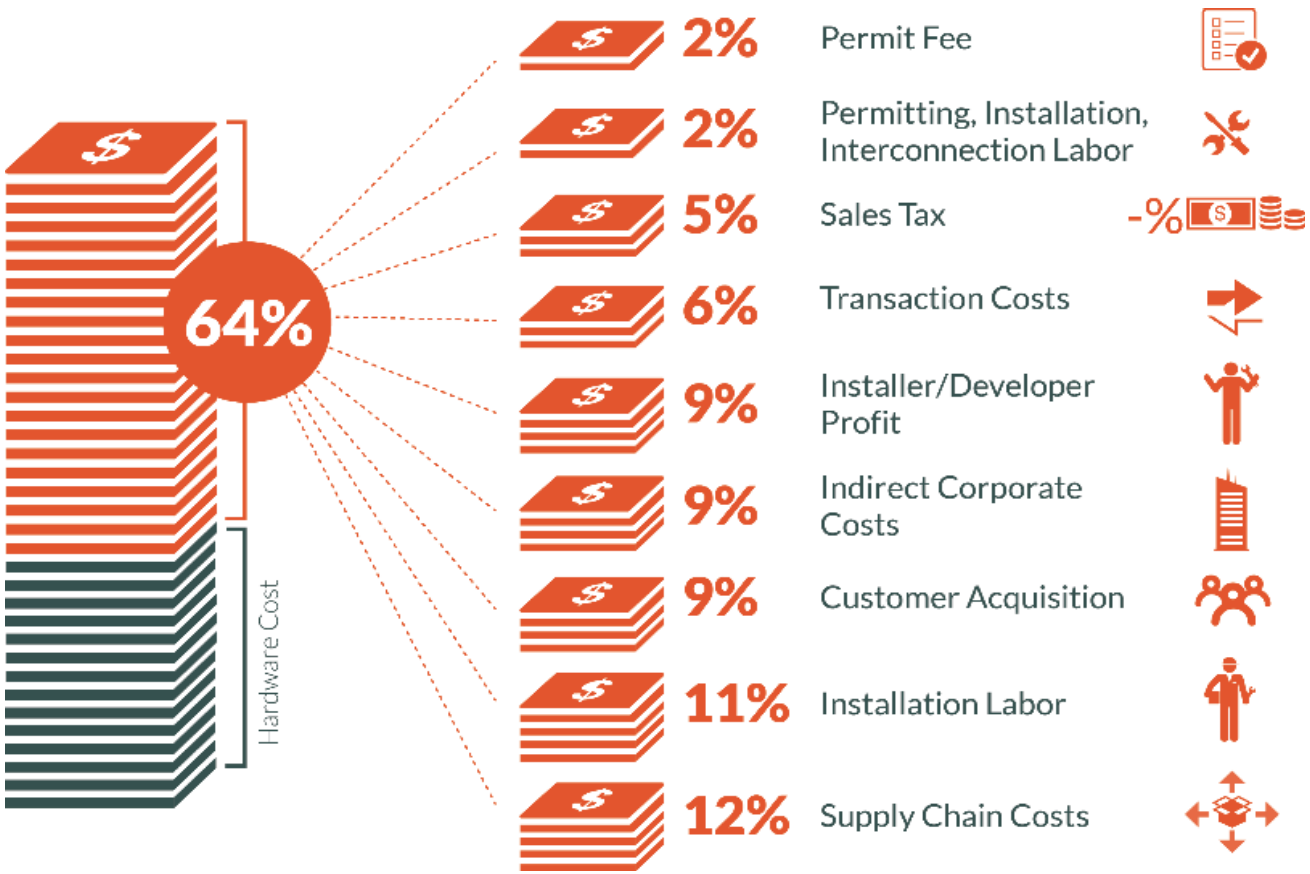




Solar Soft Costs

It's not all about the hardware….

For residential PV systems:

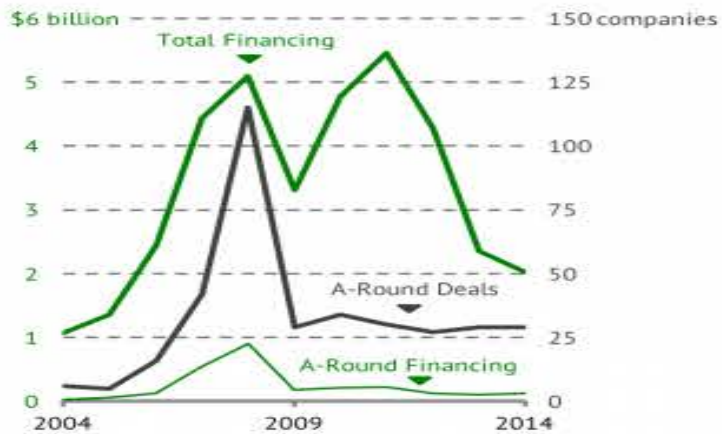


Getting To Market

The Entrepreneurial Landscape

Energy Investment Hurdles:
-Highly regulated
-Capital Intensive
-Slow Evolving Market

- PLENTY of business opportunity remains!
- No such thing as easy money



- Remember new technology takes time to get to market!

Image from: *Venture Capital and Cleantech: The Wrong Model for Clean Energy Innovation*
Gaddy et al, MIT Energy Initiative, July 2016

Characteristics of Successful Entrepreneurs

- Be in constant feedback mode
  - This might be hard but…..
    - No ones baby is as beautiful as they think it is!
- Be flexible with regard to applications
  - Don’t focus on a single market at the detriment of other money making/scaling opportunities
- Diverse advisor set, include the customer voice
- Patience and Persistence!

Science & Technology Policy Fellowships at SunShot

Play an integral role in establishing and implementing new initiatives in energy efficiency and renewable energy at DOE.

Drive innovations to make solar the most cost-effective source of electricity.

Design national R&D strategies for:

- Concentrating Solar Power
- Systems Integration
- Photovoltaics
- Technology to Market
- Soft Costs

Next Round of Applications Due January 2018

For additional information or to apply:

VISIT: eere.energy.gov/education/stp_fellowships.html

EMAIL: STPfellowships@orise.orau.gov

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Thank you!

Questions?