ECE 333 – GREEN ELECTRIC ENERGY

Lecture 16: PV Status and Issues

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PRIMARY SOURCE SHARES OF WORLD ELECTRICITY GENERATION: 1971–2021

Source: Global Energy Review; available at https://www.iea.org/reports/global-energy-review-2021/renewables

The chart illustrates the percentage distribution of primary source shares in world electricity generation from 1971 to 2021. Key categories include coal, nuclear, low-carbon, other renewables, solar, and wind. The data shows a shift towards low-carbon sources over time, with a notable increase in solar and wind energy generation in recent years.
RENEWABLE ELECTRICITY GENERATION BY NATION/REGION: 2020 – 2021

Source: Global Energy Review; available at https://www.iea.org/reports/global-energy-review-2021/renewables
OUTLINE

- PV solar system status: global and US
- PV system costs and prices
- Examples of large solar projects
- Major challenges in PV solar resource integration
- Key drivers of the PV system growth
- PV technology benefits
GLOBAL ANNUAL CUMULATIVE PV CAPACITY: 2010 – 2020

More than 138.2 GW of new capacity additions have increased the global cumulative PV capacity to over 773.2 GW.

The Asia-Pacific region with more than 368.3 GW is now the world’s leading region in terms of total installed capacity, with about a 58% share of the global PV capacity.
2020 INSTALLED PV SOLAR TOP 10 COUNTRIES

China; 35%

Rest of World; 19%

Brazil; 2%
Spain; 3%
India; 3%
South Korea; 3%
Germany; 4%
Australia; 4%
Japan; 6%
Vietnam; 8%
United States; 14%

2020 TOTAL INSTALLED PV SOLAR TOP 10 COUNTRIES

773.2 GW

- China: 33%
- United States: 12%
- Japan: 9%
- Germany: 7%
- India: 6%
- Italy: 3%
- Australia: 3%
- Vietnam: 2%
- South Korea: 2%
- Spain: 2%
- Rest of World: 21%

2019 PV SOLAR STATUS

- The global PV cumulative capacity reached 773.2 GW with the 138.2 GW added in 2020 – a 22% increase over the 2019 installed capacity.

- China, US and Vietnam were the top three nations in PV capacity additions in 2020.

- In 2020, 18 nations installed more than 1 GW of PV capacity.
China installed 48.2 GW – a 60% growth from the 30.1 GW installed in 2019 – to continue as the largest solar capacity nation in the world.

The US solar power capacity additions increased from 13.3 GW in 2019 to 19.2 GW in 2020.

India, with its 41 GW of PV capacity, became the 5th largest solar capacity nation in the world.
The **Asian-Pacific** region is the largest solar capacity region in the world with its circa 60% share of the global \( PV \) capacity.

Europe’s cumulative total of 173.9 GW represents a 22.4% of the global \( PV \) capacity with the addition of only 23.7 GW of \( PV \) capacity; nevertheless, the *European* region maintains its position as the 2\(^{nd}\) largest solar capacity region in the world.
GLOBAL PV CAPACITY ADDITIONS BY REGION: 2000 – 2020

ANNUAL SOLAR PV ADDED CAPACITY SHARES BY REGION: 2012 – 2020

GLOBAL CUMULATIVE PV SOLAR CAPACITY BY REGION: 2000 – 2020

CUMULATIVE SOLAR PV INSTALLED CAPACITY SHARES: 2012 – 2020

TOP 10 SOLAR PV NATIONS IN 2020 AND COMPARISON TO 2019

TOP 10 COUNTRIES SOLAR CAPACITY PER CAPITA 2020

2009 – 2020: GLOBAL PV ELECTRICITY GENERATION


increase above previous year’s generation

TWh


8.3 12.2 30.5 33.3 38.1 40.7 48.2 62.3 75.2 125.3 131.1 139.5 131.9

Global PV electricity generation increase above previous year’s generation.

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SOLAR AND RENEWABLE SHARE OF GLOBAL CAPACITY: 2015 – 2020


renewable capacity change as a % of global capacity additions

capacity of non-renewable resources as a share of global capacity

solar capacity change as a % of global capacity additions

other renewable energy source share of global capacity

solar capacity as a % of global capacity

2008 – 2020 EUROPEAN PV ANNUAL CAPACITY ADDITIONS

cumulative capacity previous year

annual capacity added

EUROPEAN ANNUAL WIND AND PV GENERATED ELECTRICITY: 2007 – 2020

PV

wind

TWh


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2009 – 2019: PV SOLAR ELECTRICITY GENERATION BY LEADING NATIONS

ANNUAL US SOLAR PV ADDITIONS
BY CONSUMER SECTOR: 2010 – 2020

2002 – 2020 US ANNUAL PV CAPACITY ADDITIONS


MW

0 5,000 10,000 15,000 20,000


924 1,925 3,378 5,053 6,922 7,873 15,110 11,013 10,740 13,372 19,200

5,000 10,000 15,000 20,000

MW


924 1,925 3,378 5,053 6,922 7,873 15,110 11,013 10,740 13,372 19,200
US CUMULATIVE SOLAR CAPACITY: 2010 – 2020

GW

4.4   7.1   12.1  20.7  32.0  44.4  63.2  85.0  103.7  123.1  151.1

Source: https://www.eia.gov/outlooks/aeo/electricity/sub-topic-02.php
THE TOP 10 US STATES WITH THE LARGEST 2021 PV CAPACITY

Source: https://www.seia.org/solar-industry-research-data

<table>
<thead>
<tr>
<th>State</th>
<th>MWp</th>
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<tbody>
<tr>
<td>CA</td>
<td>24,463</td>
</tr>
<tr>
<td>NC</td>
<td>5,260</td>
</tr>
<tr>
<td>AZ</td>
<td>3,738</td>
</tr>
<tr>
<td>NV</td>
<td>3,145</td>
</tr>
<tr>
<td>TX</td>
<td>2,924</td>
</tr>
<tr>
<td>NJ</td>
<td>2,732</td>
</tr>
<tr>
<td>MA</td>
<td>2,465</td>
</tr>
<tr>
<td>FL</td>
<td>2,289</td>
</tr>
<tr>
<td>UT</td>
<td>1,650</td>
</tr>
<tr>
<td>GA</td>
<td>1,570</td>
</tr>
</tbody>
</table>

MWp: Gigawatts
US NET SOLAR GENERATION 2010 – 2020

US SOLAR UTILITY – SCALE
GENERATION: 2009 – 2020

FRACTION OF DISTRIBUTED SOLAR SYSTEMS WITH ENERGY STORAGE

**Source:** Solar Energy Industries Association, available online at https://www.seia.org/solar-industry-research-data

**Notes:**
- **2019:**
  - Solar only:
  - Storage:

**2022E:**
- Solar only:
- Storage:

**2025E:**
- Solar only:
- Storage:
A COMMUNITY SOLAR PROJECT:
CORTLAND SOLAR 2 IN CORTLAND, IL

CUMULATIVE US COMMUNITY SOLAR INSTALLATIONS


Installed capacity in MWdc


NY  CO  IL  MD  MA  MN
2020 US STATUS OF PV SYSTEMS BY STATES

- CA, TX and NC account for over a third of the US cumulative PV capacity.

- The solar industry in NC is growing rapidly due to the state’s Renewable Energy and Energy Efficiency Portfolio Standard (REPS) that allowed clean energy entities to compete with utilities to offer customers choice in their energy supply and the 2017 NC law that authorized solar leasing.
THE 2020 STATUS OF \textit{US} \textit{PV} SYSTEMS

- \textit{US} is a major player in the global \textit{PV} solar capacity and energy arena

- The 2020 \textit{US} cumulative utility-scale \textit{PV} capacity increased to roughly 99.3 GW, due to the numerous utility-scale projects in the added 19.2 GW of new \textit{PV} capacity in 2020

- The community solar grew 35\% from 1,523 MW in 2018 to 2,056 MW in 2019 and to 3,000 MW in 2020
US SOLAR ENERGY IS BOOMING

- PV solar installation costs fell more than 70% since 2010
- Conformance with state RPS requirements is no longer as key a driver as earlier; many new corporate procurements of off-site solar projects, typically, use various PPA mechanisms
- Since 2018, US had over 2 million solar installations
2019 US UTILITY – SCALE SOLAR PROJECTS

Source: 2019 data; https://www.seia.org/research-resources/major-solar-projects-list
CLEAN POWER CAPACITY GROWTH BY STATE

operational clean energy capacity by state

Source: American clean power 2021, q1; available at https://cleanpower.org/wp-content/uploads/2021/05/CPQ-2021Q1_public.pdf; p. 6
# The 2021 Five Largest US PV Installations

<table>
<thead>
<tr>
<th>Plant</th>
<th>Location</th>
<th>Capacity (MW)</th>
<th>Year Built</th>
<th>Owner</th>
<th>Electricity Purchaser</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar Star</td>
<td>Rosamond, CA</td>
<td>579</td>
<td>2015</td>
<td>BHE Renewables</td>
<td>SCE</td>
</tr>
<tr>
<td>Copper Mountain Solar Facility</td>
<td>Boulder City, NV</td>
<td>552</td>
<td>2016</td>
<td>Sempra Generation</td>
<td>PG&amp;E &amp; SC Public Power Authority</td>
</tr>
<tr>
<td>Desert Sunlight Solar Farm</td>
<td>Riverside County, CA</td>
<td>550</td>
<td>2015</td>
<td>NextEra, Sumitomo</td>
<td>PG&amp;E &amp; SCE</td>
</tr>
<tr>
<td>Topaz Solar Farm</td>
<td>San Luis Obispo, CA</td>
<td>550</td>
<td>2014</td>
<td>Berkshire Hathaway Energy</td>
<td>PG&amp;E</td>
</tr>
<tr>
<td>Mount Signal Solar</td>
<td>Calexico, CA</td>
<td>460</td>
<td>2018</td>
<td>8minutenergy Renewables</td>
<td>SCE &amp; SDG&amp;E</td>
</tr>
</tbody>
</table>

SOLAR STAR FARM

- The *Solar Star Farm* is a 579–MW PV power station located in *Antelope Valley* near Rosamond, CA.

- Completed in June 2015 by *SunPower*, *Solar Star* became the world's largest solar farm in terms of capacity from the 1.7 million solar panels installed on a 13 km² (3,200 acres) area.
**SOLAR STAR FARM**

- Compared to other large plants, *Solar Star* uses a fewer arrays, with each array mounted on a single-axis tracker.

- Generation of clean electricity form the farm is expected to power about 255,000 homes and avoid the annual emission of 570,000 tons of CO$_2$.
LONGYANGXIA DAM SOLAR PARK
LONGYANGXIA DAM SOLAR PARK

- The world’s largest PV plant is the 850-MW Longyangxia Dam Solar Park, which is located in Qinghai Province, China.
- Construction began in March 2013 and the first phase of the project (530 MW) was commissioned on December 4, 2013.
- The second phase of the project was completed in 2015.
- The expected annual generation is 824 GWh.
CESTAS SOLAR FARM

With a total capacity of 300 MW, Cestas Solar Farm is the largest PV plant in Europe.

This solar park is located at Cestas, in Southwest France, and is expected to supply electricity to meet the needs of 250,000 people.

Electricity is sold under a 20–year PPA with the French utility EDF at a price of 105 €/MWh.
ROOFTOP PV SOLAR
Rooftop solar electricity still represents a small portion of US electricity generation.

Residential solar continues to grow from quarter to quarter even since the onset of the COVID-19 pandemic in total installed residential capacity.

State government incentives to promote solar energy have led to widespread rooftop solar in the Western states – CA, AZ, CO and NV – and in NC due to the law that authorized solar leasing.
Location–dependent incentives for utility customers to install rooftop solar panels vary from state to state and include tax credits, installation cost rebates and *net metering*.

At present 40 states, the *District of Columbia* and 3 territories offer net metering.

*EIA* in 2019 noted that rooftop electricity is less than 0.25% of the *US electricity generation*. 
NOVEMBER 2019: US ROOFTOP SOLAR CAPACITY PER CAPITA


US total rooftop capacity (< 1 MW) = 22,705 MW

HI: highest per capita capacity = 0.50 kW

US per capita capacity = 0.07 kW

top 10 states

1 HI  6 NJ
2 MA  7 CT
3 CA  8 NV
4 AZ  9 RI
5 VT  10 MD

kW Per Capita
- 0.20 - 0.50
- 0.15 - 0.20
- 0.10 - 0.15
- 0.05 - 0.10
- 0.00 - 0.05
NOVEMBER 2019: US AVERAGE RETAIL ELECTRICITY PRICES BY STATES


- high prices drive rooftop solar implementation
- so do state incentives for rooftop solar or the lack thereof
NET METERING

- Under net metering – a billing mechanism that credits solar energy system owners for the energy injected into the grid – customers pay only for the electricity consumed that exceeds the amount fed into the grid, the so-called net energy.
NET METERING

US NET METERING STATUS


40 States + DC, AS, GU, PR, & USVI currently have mandatory Net Metering rules
5 of these states are in transition to policies other than net metering

KEY
- State-developed mandatory rules for certain utilities (35 states + DC + 4 territories)
- In transition to statewide distributed generation compensation rules other than net metering (5 states)
- Statewide distributed generation compensation rules other than net metering (5 states)
- No statewide mandatory rules, but some utilities allow net metering (2 states)

U.S. Territories:
- AS
- PR
- VI
- GU
Net energy consumption = $\mathcal{E}_2 + \mathcal{E}_3 - \mathcal{E}_1$

- PV power output
- Energy bought from the grid
- Excess energy sold to the grid
- Load

$\mathcal{E}_1$ represents the energy sold to the grid.

$\mathcal{E}_2$ and $\mathcal{E}_3$ represent the energy bought from the grid.

Midnight

Energy bought from the grid

Energy sold to the grid
NET METERING

- The implementation of net metering varies from one jurisdiction to another.

- In CA, solar owners have received federal tax credits, rebates under the so-called CA Solar Initiative, which has been phased out, and net metering; CA has the nation’s largest quantity of installed solar PV capacity.
The payments foregone by the net metered solar owners are pushing the distribution utilities to shift the collection of the electricity infrastructure to the non-solar-owner customers; many utilities have viewed this development as the so-called "death spiral"; but, the various changes in net metering have lessened such concerns.
RENEWABLE ENERGY CERTIFICATE (RECs)

- The RECs, known as the *renewable energy credits* or *green tags*, are tradable and non-tangible energy commodities that provide proof of the production of 1 MWh of electricity by a renewable resource.

- Every renewable energy resource gets paid for its production from two sources: the energy is compensated through sales into the electricity markets or via PPA's; in addition, the sale by the solar/wind resource of RECs, which represent its energy generation, is a separate revenue stream.
Since the energy and the **RECs** are sold separately and possibly to different buyers, the **green energy consumption** and the proof of the production may be in different jurisdictions.

The prices of **RECs** vary from one jurisdiction to another and their use across different states are subject to the **non-uniform rules** across the states.

**RECs** provide buyers and sellers flexibility in trading renewable energy across state borders.
REC's

- The *REC*s convey the environmental benefits of the renewable resource electricity and, under a tracking mechanism, provide direct accounting to meet the *RPS* goals in each jurisdiction.

- The *REC*s provide auditable proof of the amount of renewable energy production injected into the grid by solar/wind resources.
THE WAY SOLAR BECAME SO CHEAP

Source: Gregory F. Nemet, “How Solar Energy Became Cheap,” Routledge, 2018
PV SOLAR CAPACITY PRICE DECLINE

ANNUAL US SOLAR CAPACITY ADDITIONS AND PRICES

Source: Wood Mackenzie and SEIA Q1 2020; available online at https://www.seia.org/solar-industry-research-data

installed capacity (MWdc)

blended average PV system price ($/W)

0.00 1.00 2.00 3.00 4.00 5.00 6.00

2,000 4,000 6,000 8,000 10,000 12,000 14,000 16,000 18,000 20,000

SOME LOW SOLAR PRICES IN THE 2019 AUCTIONS


* : PPA with PTC
** : average winning bid
*** : with 2.5% annual escalation

<table>
<thead>
<tr>
<th>Country</th>
<th>PPA / WSB / ESC</th>
<th>2019 Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>PT</td>
<td>PPA</td>
<td>1.65 $/KWh</td>
</tr>
<tr>
<td>UAE</td>
<td>WSB</td>
<td>1.70 $/KWh</td>
</tr>
<tr>
<td>BR</td>
<td>PPA</td>
<td>1.73 $/KWh</td>
</tr>
<tr>
<td>US-CA</td>
<td>WSB</td>
<td>1.90 $/KWh</td>
</tr>
<tr>
<td>US-ID</td>
<td>WSB</td>
<td>2.18 $/KWh</td>
</tr>
<tr>
<td>TN</td>
<td>WSB</td>
<td>2.44 $/KWh</td>
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<tr>
<td>ET</td>
<td>WSB</td>
<td>2.53 $/KWh</td>
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<tr>
<td>UZ</td>
<td>WSB</td>
<td>2.68 $/KWh</td>
</tr>
<tr>
<td>CO ***</td>
<td>PPA</td>
<td>2.70 $/KWh</td>
</tr>
<tr>
<td>KZ</td>
<td>WSB</td>
<td>3.20 $/KWh</td>
</tr>
</tbody>
</table>
SOME LOW SOLAR PRICES IN THE 2020 AUCTIONS

COMPETITIVE PRICES OF RENEWABLE ENERGY

- Average solar PV price in the **Brazilian A–6 Auction** in October 2019 reaches **2.052 ¢/kWh**.

- The average price for solar PV in **US** in 2020 was **2.9193 ¢/kWh**.

- *Portugal’s latest solar energy auction* in August 2020 had a bid for a solar price at **1.316 ¢/kWh**.
COMPETITIVE PRICES OF RENEWABLE ENERGY

- In the July 2020 Abu Dhabi’s 2 GW solar tender, solar sold at about $0.0135 /kWh.

- Los Angeles Department of Water and Power set a new solar + battery record in US at the price of 2.376 ¢/kWh.
EVOLUTION OF SOLAR PV AVERAGE AUCTION PRICES: 2013 – 2020

LCOE COMPARISON: 2020

LCOE OF UTILITY–SCALE RENEWABLE GENERATION: 2010 & 2020

Source: IRENA Renewable Power Generation Costs in 2020 p. 15;
GLOBAL WEIGHTED AVERAGE TOTAL INSTALLED COSTS SINCE 2010

Source: IRENA Renewable Power Generation Costs in 2020 p. 17;
UTILITY–SCALE SOLAR PV TOTAL INSTALLED COSTS: 2010 – 2020

Source: IRENA Renewable Power Generation Costs in 2020 p. 73;
UTILITY–SCALE SOLAR PV
WEIGHTED–AVERAGE LCOE TRENDS


Data starts in 2006


<table>
<thead>
<tr>
<th>State</th>
<th>Solar PV Capacity Factor in %</th>
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<tr>
<td>CA</td>
<td>28.4</td>
</tr>
<tr>
<td>NC</td>
<td>21.0</td>
</tr>
<tr>
<td>AZ</td>
<td>29.1</td>
</tr>
<tr>
<td>NV</td>
<td>27.8</td>
</tr>
<tr>
<td>TX</td>
<td>24.6</td>
</tr>
<tr>
<td>GA</td>
<td>23.2</td>
</tr>
<tr>
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<tr>
<td>NJ</td>
<td>16.8</td>
</tr>
<tr>
<td>MA</td>
<td>16.5</td>
</tr>
<tr>
<td>U.S. average</td>
<td>24.7</td>
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Chart Title
Series 3
Series 2
Series 1
US FIXED – TILT UTILITY – SCALE PV SYSTEMS

Source: EIA, Today in Energy, October 26, 2018; available online at https://www.eia.gov/todayinenergy/detail.php?id=37372
RESIDENTIAL PV LCOE BY LOCATION

SOLAR PANEL INSTALLED CAPACITY vs. MANUFACTURING IN 4 NATIONS

Source: Gregory F. Nemet, “How Solar Energy Became Cheap,” Routledge, 2018
PV INSTALLATION COSTS BY SECTORS: Q1 2010 – 2020

Source: Clean Technica; available at https://cleantechnica.com/2021/02/13/charts-a-decade-of-cost-declines-for-pv-systems/
PV INSTALLATION COSTS BY SECTORS: Q1 2010 – 2020

Source: Clean Technica; available at https://cleantechnica.com/2021/02/13/charts-a-decade-of-cost-declines-for-pv-systems/

utility-scale
one-axis tracker

fixed tilt

$ / W_p


4.75 4.08 2.77 2.13 1.97 1.93 1.53 1.08 1.08 0.95 0.94 5.66 4.79 3.29 2.50 2.25 2.08 1.63 1.16 1.16 1.02 1.01

other labor BOS inverter module
<table>
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<th>company</th>
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<tr>
<td>LG energy</td>
<td>South Korea</td>
</tr>
<tr>
<td>SunPower</td>
<td>US</td>
</tr>
<tr>
<td>REC</td>
<td>South Korea</td>
</tr>
<tr>
<td>Q cells</td>
<td>China</td>
</tr>
<tr>
<td>Seraphim</td>
<td>US</td>
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<td>Trina Solar</td>
<td>China</td>
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<td>Jinko Solar</td>
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<td>Canadian Solar</td>
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<td>SunTech</td>
<td>China</td>
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<tr>
<td>JA Solar</td>
<td>China</td>
</tr>
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</table>

DOE SOLAR PROGRAM GOALS

- The US Department of Energy Sunshot Initiative is a national collaborative effort to make PV energy cost-competitive with fossil-fired generation has been met or, in some cases, surpassed.

- The goals for PV by 2020 were set at 4 – 5 ¢/kWh in the residential sector, 5 – 6 ¢/kWh in the commercial sector, and 4 – 6 ¢/kWh in the utility sector.
PV DEVELOPMENT CHALLENGES

- The efficiency of typical PV modules used in energy production is still rather low.

- Solar energy is highly uncertain, variable and intermittent renewable resource and the PV system electricity production has limited controllability and dispatchability.
PV EFFICIENCY BY MATERIAL

- c-Si
- mc-Si
- CIGS
- CdTe
- a-Si

Production module max
Laboratory cell max
Theoretical max

η (%)
CHRONOLOGICAL PV OUTPUT AND ERCOT LOAD PATTERNS

source: http://www.ercot.com/gridinfo/
THE KEY DRIVERS OF US PV GROWTH

- A most important driver is the declining costs of installed PV; in addition, the legislative and regulatory initiatives at the federal, state and local levels helped the growth of US PV.

- The federal drivers include:
  - tax incentives that were established to accelerate investment into PV installations;
  - loan guarantees provided by the 2009 American Recovery and Reinvestment Act (ARRA) allowed the US Department of Energy to provide...
THE KEY DRIVERS OF US PV GROWTH

preferential financing support to qualifying renewable energy projects;

- cash grants that provide direct cash infusion into commercial projects as an alternative to the tax credits

- At the state level, the drivers included
  - RPS requirements that stimulate investments in solar plants to meet the specified goal of renewable resource electricity generation
THE KEY DRIVERS OF *US PV* GROWTH

- *rebate programs* enacted to reduce the total investment costs of *PV* systems, especially for residential/commercial *PV* installations

- *net metering and TOU rates* that allow customers to offset their monthly electricity bills by the production of their own energy from their own *PV* outputs and the sale of the excess energy to the local distribution utility
GERMANY PV INSTALLATION COSTS AND SUBSIDIES

installed costs

subsidies

year

source: http://www.economist.com/
KEY $PV$ BENEFITS

- Residential/commercial $PV$ system installations reduce the amount of electricity these customers purchase from the local utility.

- As $PV$ systems produce the most power when the insolation is highest around solar noon, the generation by solar reduces the need for and use of the expensive and polluting fossil generation units.
KEY PV BENEFITS

- PV systems are important supply resources that lessen the nation’s dependence on fossil fuels
- The clean PV–generated electricity helps reduce the amount of GHG – a major contributor to global climate change
- The growing PV industry provides local jobs and economic development opportunities to states and regions to create sustainable paths to meet the nation’s energy needs