ECE 333 – GREEN ELECTRIC ENERGY

15. *PV* ECONOMICS

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PV SYSTEM ECONOMICS

PV SYSTEM ECONOMICS

- **Now that we discussed the approximation of the power & energy delivered by a grid–connected *PV* system, we next explore its economics**
- **The key inputs into *PV system economic analysis* are the *investment costs* and the *expected annual energy production* under a set of reasonable and justifiable assumptions**

PV SYSTEM ECONOMICS

- **The key factors considered in the performance of a detailed economic analysis include:**
  - **debt terms and discount rates**
  - **the *O&M* costs**
  - **costs or residual values at system retirement**
  - **tax benefits**
  - **all incentives, such as *ITC* and rebates**
  - **electricity prices**

TOPICAL OUTLINE

- **Total *PV* system cost estimation**
- ***PV* system *LCOE* determination**
- **The *PV* system tax incentive impacts on the *LCOE***
- **The *PV* system rebate program benefits**
- ***Power purchase agreement – PPA* issues**
- **Numerical examples**

EXAMPLE: *BOULDER HOME PV SYSTEM*

- **The *PV* system for a Boulder house is designed to generate about 4,000 *kWh per year***
- **The key cost elements are**

component	*costs ($)*
PVs	$4.20/W\,(DC)$
inverter	$1.20/W\,(DC)$
tracker	$400 + 100/m^2$
installation	3,800

EXAMPLE: *BOULDER HOME PV SYSTEM*

- We use the solar insolation tables in *Appendix G* to obtain the average daily insolation in *Boulder* for a fixed array: 5.4 $kWh/m^2 - d$
- We interpret the insolation to be 5.4 *h/d* of 1 *sun*
- We assume a 0.75 *derate factor* and compute

$$P_{DC,stc} = \frac{4,000}{(0.75)(5.4)(365)} = 2.71\ kW_p$$

EXAMPLE: *BOULDER HOME PV SYSTEM*

- The costs of the *PV*s and the inverters are

$$costs\ of\ \ PVs\ =\ 4.20 \times 2{,}710\ =\ \$\ 11{,}365$$

$$costs\ of\ \ inverters\ =\ 1.20 \times 2{,}710\ =\ \$\ 3{,}247$$

- Given the 12 % efficiency of the *PV*s, the array area required for a 1–*sun* radiation is

$$area\ =\ \frac{P_{DC,stc}}{\left(1\ kW/m^2\right)\eta}\ =\ \frac{2.71}{1 \times 0.12}\ =\ 22.6\ m^2$$

EXAMPLE: *BOULDER HOME PV SYSTEM*

- **We next obtain the average daily insolation in *Boulder* with a *single–axis* tracker from *Appendix G*:**

  $7.2\ kWh/m^2 - d$, *i.e.*, $7.2\ h/d$ *of full sun*

- **We compute**

$$p_{DC,stc} = \frac{4,000}{(0.75)(7.2)(365)} = 2.03\, kW_p$$

- **The costs of the *PV*s and the inverters are**

EXAMPLE: *BOULDER HOME PV SYSTEM*

$$costs\ of\ \ PVs\ =\ 4.20\times 2,030\ =\ \$\,8,524$$

$$costs\ of\ \ inverters\ =\ 1.20\times 2,030\ =\ \$\,2,436$$

- Consequently, the area for the system becomes

$$area\ =\ \frac{P_{DC,stc}}{\left(1\ kW/m^{2}\right)\eta}\ =\ \frac{2.03}{1\times 0.12}\ =\ 16.9\,m^{2}$$

- The additional tracker costs are

$$costs\ of\ \ trackers\ =\ 400+16.9\times 100\ =\ \$\ 2,090$$

EXAMPLE: *BOULDER HOME PV SYSTEM*

element	*fixed tilt array*	*single–axis tracker*
PVs	**$ 11,365**	**$ 8,524**
inverter	**$ 3,247**	**$ 2,436**
tracker	–	**$ 2,090**
installation	**$ 3,800**	**$ 3,800**
total	**$ 18,412**	**$ 16,850**

EXAMPLE: *BOULDER HOME PV SYSTEM*

- The tracker installation raises the average daily insolation received at the *PV* panels and lowers the area required for the *PV* system
- While the trackers add *$* 2,090 to the fixed costs of the *PV* system, the overall *PV* system investment costs with the trackers *decrease*, nevertheless, markedly below those of the fixed panels

REVIEW OF THE *c.r.f.*

- **The *capital recovery factor* is *required* to determine the financing costs of a *PV* project**
- **A loan of *P* at interest rate *i* may be recovered over *n* years through *fixed* annual payments of**

interest rate

c.r.f.

$$A = P \frac{i}{1 - (\beta)^n}$$

$$\beta \triangleq \frac{1}{1+i}$$

EXAMPLE: *PV* SYSTEM *LCOE*

- We illustrate the determination of the *LCOE* with a *PV* system example with the following data:
  - installation costs: $\$ \, 7 \; million$
  - annual *O&M* costs: $\$ \; 35{,}000$
  - annual land lease fee: $\$ \; 40{,}000$
  - average annual energy production: $4 \; GWh$
  - $9 \; \%, \; 20 - year$ loan repaid annually
- We determine the *c.r.f.* to be

EXAMPLE: *LCOE* FOR THE *PV* SYSTEMS

$$c.r.f.\left(9\,\%,\ 20\,y\right) = \frac{\left(0.09\right)\left(1\ +\ 0.09\right)^{20}}{\left(1+0.09\right)^{20}\ -\ 1} = 0.1095\ y^{-1}$$

- The *c.r.f.* results in the annual amortized fixed costs of

$$7{,}000{,}000\ \times\ 0.1095 = \ \$\,766{,}500$$

- Then we can evaluate the *LCOE* using

$$\frac{766{,}500\ +\ 35{,}000\ +\ 40{,}000}{4{,}000{,}000} = \ 0.21\,\frac{\$}{kWh}$$

FINANCIAL INCENTIVES FOR SOLAR

- A significant factor that was ignored in the cost calculation in the previous example is the bene–ficial impacts of the *financial* and *tax incentives*
- Many solar installations are eligible for federal and state tax incentives for the purchase and implementation of *PV* systems

FEDERAL BUSINESS ENERGY INVESTMENT TAX CREDIT (*ITC*)

State:	Federal
Incentive Type:	Corporate Tax Credit
Administrator:	U.S. Internal Revenue Service
Expiration Date:	Varies by technology, see below
Eligible Renewable/Other Technologies:	Solar Water Heat, Solar Space Heat, Geothermal Electric, Solar Thermal Electric, Solar Thermal Process Heat, Solar Photovoltaics, Wind (All), Geothermal Heat Pumps, Municipal Solid Waste, Combined Heat & Power, Fuel Cells using Non-Renewable Fuels, Tidal, Wind (Small), Geothermal Direct-Use, Fuel Cells using Renewable Fuels, Microturbines
Applicable Sectors:	Commercial, Industrial, Investor-Owned Utility, Cooperative Utilities, Agricultural
Incentive Amount:	30% for solar, fuel cells, small wind* 10% for geothermal, microturbines and CHP
Maximum Incentive:	Fuel cells: $1,500 per 0.5 kW Microturbines: $200 per kW Small wind turbines placed in service 10/4/08 - 12/31/08: $4,000 Small wind turbines placed in service after 12/31/08: no limit All other eligible technologies: no limit

Source*: *http://programs.dsireusa.org/system/program/detail/658

TAX INCENTIVES FOR SOLAR

- **The *ITC,* enacted in the 2005 *Energy Policy Act* for solar, has been renewed numerous times**
- **The *ITC* supports electricity generated by solar *PV* systems of any size on residential/commercial properties and also includes batteries**
- **The *ITC* is 30 % of the *PV* system investment**

EXAMPLE: TAX INCENTIVES FOR SOLAR

- We illustrate the *ITC* impacts on the *LCOE* in the previous *PV* system example
- With the *ITC* , the initial investment tax savings amount to $0.3 \times 7,000,000 = \$\, 2,100,000$
- The resulting *annual amortized fixed costs* become

$$(1-0.3) \times 7,000,000 \times 0.1095 = \$\, 536,550$$

EXAMPLE: TAX INCENTIVES FOR SOLAR

- Then we can evaluate the *LCOE* using

$$\frac{536,550 + 35,000 + 40,000}{4,000,000} = 0.15 \frac{\$}{kWh}$$

- We observe that the inclusion of the *ITC* results in a 6 ¢/*kWh* reduction in the *LCOE* – in effect, a *reduction of 27 % in the LCOE*

TAX BENEFITS FOR SOLAR

- **The use of a home loan to finance the installation of a *PV* system has an important impact on the *PV* electricity price in light of the income tax benefits, which depend explicitly on the homeowner's *marginal tax bracket* (*MTB*)**

TAX BENEFIT FOR SOLAR

- For a loan over several years, almost all of the first–year payments constitute the interest due, with a rather small contribution to the reduction of the loan principal, while the reverse allocation occurs towards the end of the loan life
- In the first year, interest is owed on the entire amount of the loan and the tax benefits are

$$i \times loan \times MTB$$

EXAMPLE: TAX BENEFIT FOR SOLAR

- Consider a $30\text{–}year$ $4.5\,\%$ loan to install a $3.36\text{–}kW_p$ residential *PV* system in Chicago, with an annual energy generation of $4{,}942\ kWh$

- The *c.r.f.* for the loan is

$$\frac{(0.045)(1 + 0.045)^{30}}{(1+0.045)^{30} - 1} = 0.06139\ y^{-1}$$

EXAMPLE: TAX BENEFIT FOR SOLAR

- The residential *PV* system costs $ 19,186 and the annual loan payment is

$$19,186 \times 0.06139 = \$1,178$$

- Then, the cost of *PV* electricity in the first year is

$$\frac{1,178}{4,942} = 0.238 \frac{\$}{kWh}$$

- During the first year, the owner pays the annual interest on the $ 19,186 loan in the amount of

EXAMPLE: TAX BENEFIT FOR SOLAR

$$\textit{first year interest} = 19{,}186 \times 0.045 = \$\,863$$

- We assume the homeowner is in the 25 % *MTB* and determine the first-year tax savings to be

$$863 \times 0.25 = \$\,216$$

which reduce the cost of *PV* electricity to

$$\frac{1{,}178 - 216}{4{,}942} = 0.192 \frac{\$}{kWh}$$

REBATES

- **Many states and certain jurisdictions have introduced rebate programs to promote investments in solar systems in all sectors**
- **A rebate reduces the total investment required by, in effect, returning some of the costs of the *PV* system installation to the investor:**

$$\textit{reduced costs} = \textit{original costs} - \textit{rebate}$$

ILLINOIS SOLAR AND WIND ENERGY REBATE PROGRAM

Budget:	$2.5 million
Start Date:	12/16/1997
Expiration Date:	10/10/2014 (current applications)
Eligible Renewable/Other Technologies:	Solar Water Heat, Solar Photovoltaics, Wind (All), Solar Pool Heating, Wind (Small)
Applicable Sectors:	Commercial, Industrial, Local Government, Nonprofit, Residential, Schools, State Government, Federal Government
Incentive Amount:	Residential PV: $1.50/watt or 25% of project costs Commercial PV: $1.25/watt or 25% of project costs Nonprofits and Public Sector PV: $2.50/watt or 40% of project costs Residential and Commercial Wind (SWCC certified): $1.75/watt or 30% of project costs Nonprofits and Public Sector Wind (SWCC certified): $2.60/watt or 40% of project costs Wind energy systems that are not SWCC certified: $1.00/watt Residential and Commercial Solar Thermal: 30% of eligible project costs Nonprofits and Public Sector Solar Thermal: 40% of eligible project costs
Maximum Incentive:	Residential: $10,000 Commercial: $20,000 Nonprofits and Public Sector: $30,000
Eligible System Size:	PV systems: Rated design capacity of at least 1 kW; Solar thermal systems: Designed to produce at least 0.5 therms or 50,000 Btus per day or contain at least 60 sq. ft. of collectors Wind: Name-plate capacity 1-100 kW

Source: http://programs.dsireusa.org/system/program/detail/585

EXAMPLE: REBATES

- For instance, the total investment costs in the Chicago example are reduced by the 25 % rebate under the Illinois solar and wind energy program, and result in the reduced annual loan repayment

$$19{,}186 \;\times \left(1 \;-\; 0.25\right) \times\; 0.06139 \;=\; \$\,883$$

- After the rebate, the first-year interest becomes

EXAMPLE: REBATES

$$19{,}186 \times (1 - 0.25) \times 0.045 = \$648$$

- Therefore, the first-year tax savings are

$$648 \times 0.25 = \$162$$

- Consequently, the costs of *PV* electricity in the first year after the rebate reduce to

$$\frac{883 - 162}{4{,}942} = 0.146 \frac{\$}{kWh}$$

POWER PURCHASE AGREEMENTS

- In the broadest terms, a *power purchase agreement* (*PPA*) is a contract between two parties – a *seller* who generates electricity and a *buyer* who purchases the electricity
- The *PPA* defines all the terms for the purchase/sale of electricity between these parties, such as:
  - the start date of the project's commercial operation;
  - the delivery schedule for the electricity;

POWER PURCHASE AGREEMENT

- penalties for under delivery;
- payment terms; and
- termination

- The *PPA* defines the revenue and credit quality of a generation project and constitutes, as such, a key element of the *project finance side*
- There are many forms of *PPA* in use today and they vary according to the needs of the buyer, the seller, and the financing counterparties

POWER PURCHASE AGREEMENT

- **While the *PPA*s signed with utilities serve to finance utility–scale renewable energy resource installations under, typically, longer–term, fixed–price energy, the use of the *PPA* instrument to implement distributed generation projects to supply residential, commercial and municipal and state governments is a more recent application**
- **Under the *PPA* structure, project developers find a way to use federal tax credits to supply renewable**

POWER PURCHASE AGREEMENT

energy without any up–front investment on the part of the project buyer/eventual owner

- The **buyer** provides the area to the **developer** to install the system and purchases the energy at the ***negotiated price*** over the contract term
- Typically, the ownership of the project passes to the buyer once the tax credit payments end
- Recently, research centers and campuses started to use ***PPAs*** to install larger *PV* systems

EXAMPLE: ANNUAL ENERGY OF A SOLAR FARM AT CHAMPAIGN

- **A $82{,}961\text{–}m^2$ solar farm on the south campus is considered a key element of the University of Illinois' *Climate Change Program***
- **The average daily insolation received by the panels in the solar farm project is $5.1\ kWh/m^2-d$**

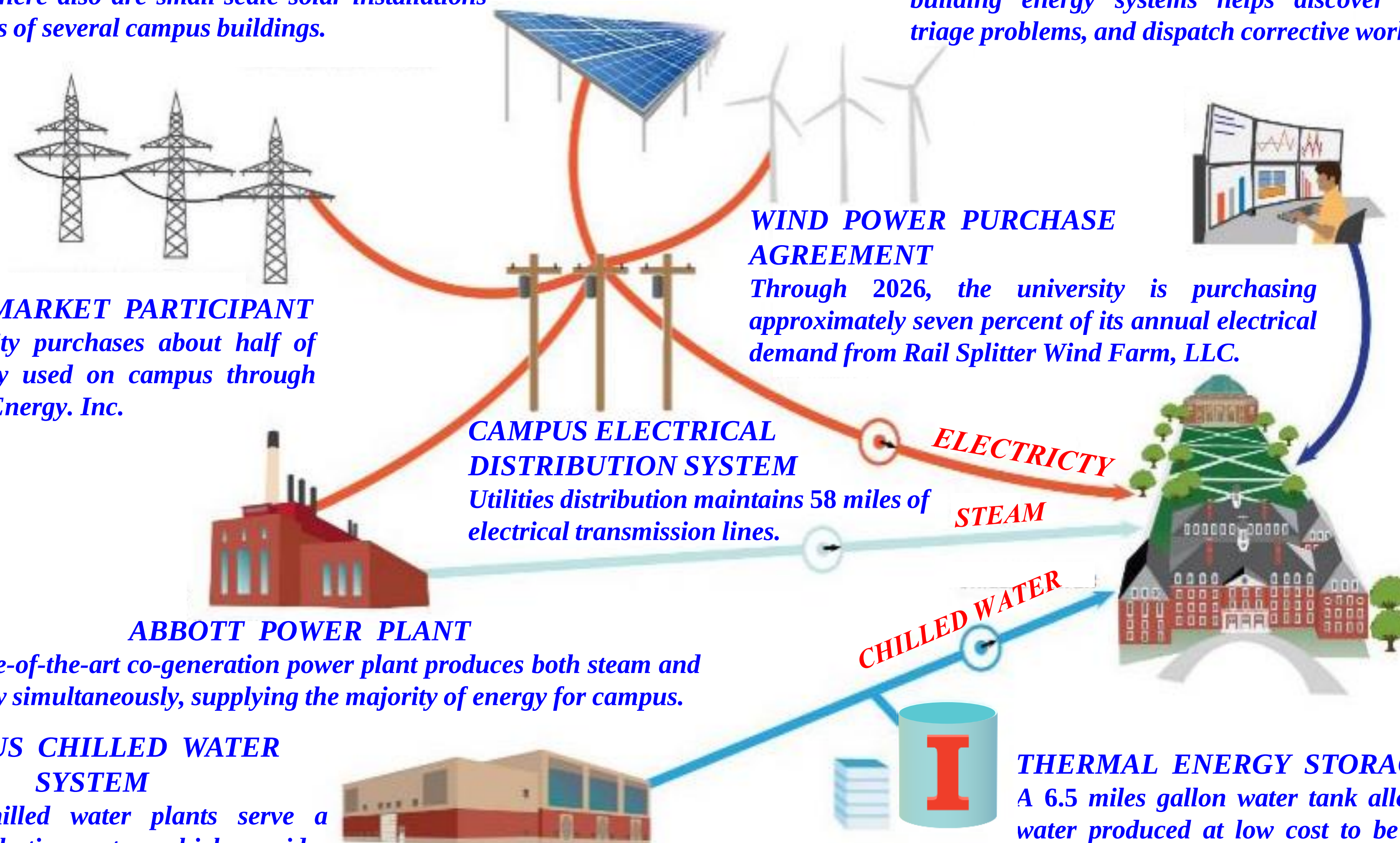
UIUC CAMPUS ENERGY SYSTEM

SOLAR INSTALLATIONS

The Solar Farm produces about two percent of the annual electrical demand of the Urbana-Champaign campus. There also are small-scale solar installations on rooftops of several campus buildings.

ENERGY MANAGEMENT CONTROL CENTER

Integrated data and control systems deliver improved demand and consumption forecasting. The display of building energy systems helps discover inefficiencies, triage problems, and dispatch corrective work effectively.



WIND POWER PURCHASE AGREEMENT

Through 2026, the university is purchasing approximately seven percent of its annual electrical demand from Rail Splitter Wind Farm, LLC.

ENERGY MARKET PARTICIPANT

The university purchases about half of the electricity used on campus through Prairieland Energy. Inc.

CAMPUS ELECTRICAL DISTRIBUTION SYSTEM

Utilities distribution maintains 58 miles of electrical transmission lines.

ABBOTT POWER PLANT

This state-of-the-art co-generation power plant produces both steam and electricity simultaneously, supplying the majority of energy for campus.

CAMPUS CHILLED WATER SYSTEM

Regional chilled water plants serve a central distribution system which provides cooling for the majority of buildings on the central campus.

THERMAL ENERGY STORAGE TANK

A 6.5 miles gallon water tank allows cooling water produced at low cost to be stored and used to serve air-conditioning loads during peak periods.

THE UNIVERSITY OF ILLINOIS *PV* PROJECT

http://www.fs.illinois.edu/services/utilities-energy/production/solar-farm

THE UNIVERSITY OF ILLINOIS *PV* PROJECT

- The University of Illinois set a goal in its 2015 *Climate Action Plan* that specified that 12.5 *GWh* of electricity is provided by solar installations on campus property by 2020

- To meet this goal, University of Illinois has dedi– cated 20.5 acres (82,961 m^2) of campus land in the South Farms area to install a solar farm

THE UNIVERSITY OF ILLINOIS *PV* PROJECT

- **In order to take advantage of the tax incentives, University of Illinois signed a 10–*year PPA* with the developer *Phoenix Solar Inc.* to design, build, operate and maintain the solar farm for the first 10 *years* of its life, at which point the solar farm will become the property of the University**

THE UNIVERSITY OF ILLINOIS *PV* PROJECT

- The solar farm is directly connected to the campus's electrical distribution system
- The annual energy production from the solar farm is estimated at 7.86 *GWh*, roughly 2 % of the campus 432.45 *GWh* of electricity used in 2012
- University of Illinois has agreed to buy all the energy produced by the solar farm during its first 10 *years* of its life at the fixed price negotiated

EXAMPLE: THE UNIVERSITY ILLINOIS *PV* PROJECT

- **We provide an approximation of the production and cost aspects of this solar farm based on the data that is representative for *PV* systems**
- **We do not have information on the company's tax situation and therefore we use a reasonable debt financing situation of a 5–%, 10–*year* loan for the solar farm**

EXAMPLE: THE UNIVERSITY ILLINOIS *PV* PROJECT

- *Phoenix Solar Inc.* design is for the *PV* system to generate roughly $7.86\ GWh$ annually
- The average daily Champaign insolation received by a fixed panel is $5.2\ kWh/m^2\text{–}d = 5.2\ h/d$ of $1\text{–}sun$
- We assume a value of $\chi' = 0.8$, so that

$$p_{DC,stc} = \frac{7,860,000}{(0.8)(5.2)(365)} = 5,180\, kW_p$$

EXAMPLE: THE UNIVERSITY OF ILLINOIS *PV* PROJECT

- The key cost components are

component	*costs ($)*
PV module	1.20/*W* (*DC*)
PCU	0.30/*W* (*DC*)
other equipment	0.60/*W* (*DC*)

- The total fixed costs of the solar farm are

$$\left(1.20 + 0.30 + 0.60\right)\left(5{,}180{,}000\right) = \$\,10.8\ million$$

EXAMPLE: THE UNIVERSITY OF ILLINOIS *PV* PROJECT

- *Phoenix Solar Inc.* leases the land at 1 $\$/m^2$ with annual costs of

$$costs_{land} = 1 \times 82,961 = \$\ 82,961$$

- We assume the annual solar farm *O&M* costs are 10 $\$/MWh$ so the total annual *O&M* costs are

$$costs_{O\&M} = 0.01\ \$/kWh \times 7,860,000\, kWh = \$\ 78,600$$

EXAMPLE: THE UNIVERSITY OF ILLINOIS *PV* PROJECT

- If the developer of the solar project uses a debt instrument with a 5–*%* interest 10–*year* term

$$c.r.f.\left(5\%,\ 10y\right) = \frac{\left(0.05\right)\left(1\ +\ 0.05\right)^{10}}{\left(1+0.05\right)^{10} - 1} = 0.129\ y^{-1}$$

- Under the 2015 *ITC*, the initial tax savings to the developer were

$$10,800,000 \times 0.3 = \$\,3,240,000$$

EXAMPLE: THE UNIVERSITY OF ILLINOIS *PV* PROJECT

- The annual amortized fixed costs are then

$$10{,}800{,}000 \times (1 - 0.3) \times 0.129 \;=\; \$\,975{,}240$$

- Consequently, the *LCOE* is determined to be

$$\frac{975{,}240 \;+\; 82{,}961 \;+\; 78{,}600}{7{,}860{,}000} \;=\; 0.145\,\frac{\$}{kWh}$$

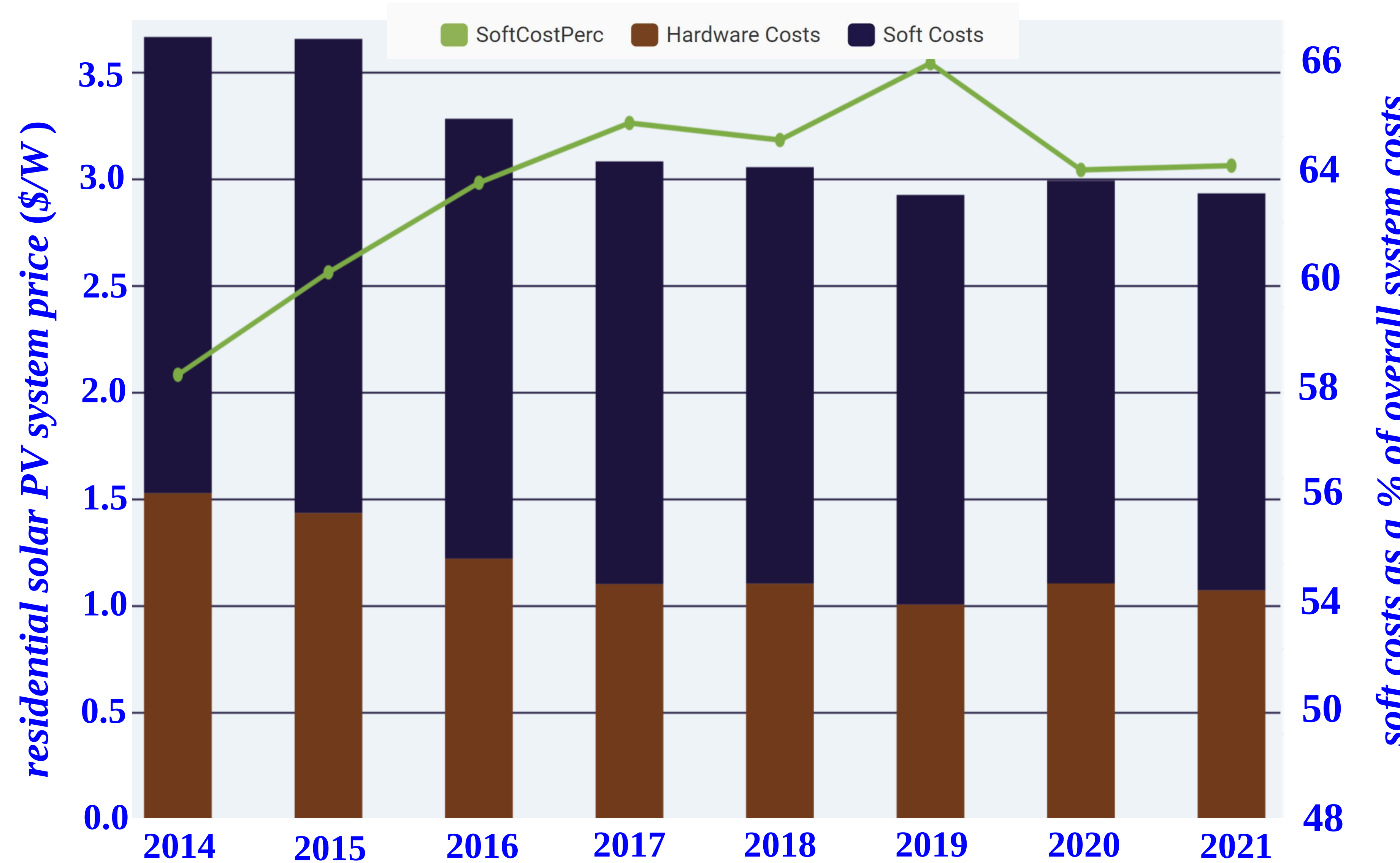
THE UNIVERSITY OF ILLINOIS *PV* PROJECT

- **Indeed, the University of Illinois pays about *$* 15 *million* to *Phoenix Solar Inc.* for the first 10 *years* of operation before it assumes asset ownership**
- **Once the University of Illinois becomes the owner and operator of the solar farm, all the variable costs are born by the University**

IMPLICATIONS OF THE *ITC*

- **The residential and commercial solar *ITC* has been instrumental in the huge growth of annual solar installations in the *US***
- **In 2015 the *ITC* was extended for another eight years, providing market certainty for the solar industry**

ANNUAL RESIDENTIAL SOLAR *PV* SYSTEM COSTS: 2014 - 2021



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

