
ECE 333
GREEN ELECTRIC ENERGY
15. *PV* ECONOMICS

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PV SYSTEM ECONOMICS



PV SYSTEM ECONOMICS

- Now that we know how to approximate the power and the energy delivered by a grid-connected *PV* system, the next step is to explore its economics
- The key inputs into to an economic analysis of a *PV* system are the investment costs and the expected annual energy production under a set of reasonable and justifiable assumptions

PV SYSTEM ECONOMICS

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

TOPICAL OUTLINE

- ❑ **Total *PV* system cost estimation**
- ❑ ***LCOE* determination of a *PV* system**
- ❑ **The *PV* system tax incentive impacts on the *LCOE***
- ❑ **The *PV* system tax benefits and rebate program
impacts**
- ❑ **Power purchase agreement issues**

EXAMPLE: BOULDER HOUSE *PV* SYSTEM

- The *PV* system for a Boulder house is designed to generate roughly 4,000 *kWh* annually
- The key cost components are

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

EXAMPLE: BOULDER HOUSE *PV* SYSTEM

- ❑ Assume the *PVs* have a 12 % efficiency and the inverter efficiency is 75 %
- ❑ We use the solar insolation tables in *Appendix G* to obtain the average daily insolation for a fixed array
- ❑ We compare the costs of a fixed array with a -15° tilt angle and those with a *single – axis* tracker

EXAMPLE: BOULDER HOUSE PV SYSTEM

- The solar insolation tables in *Appendix G* indicate the average daily insolation for a fixed array to be

$$5.4 \text{ kWh/m}^2\text{-d}$$

- We interpret the insolation as 5.4 h/d of 1 sun
- We compute

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

EXAMPLE: BOULDER HOUSE PV SYSTEM

- The costs of the *PVs* and the inverters are

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

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

- Given the 12 % efficiency of the *PVs*, the array area required is

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

EXAMPLE: BOULDER HOUSE PV SYSTEM

- We next consider the average daily insolation with a *single-axis* tracker of $7.2 \text{ kWh/m}^2 - d$ – i.e., 7.2 h/d of full sun – as given in *Appendix G*

- We compute

$$P_{DC, stc} = \frac{4,000}{(0.75)(7.2)(365)} = 2.03 \text{ kW}_p$$

- The costs of the PVs and the inverters are

EXAMPLE: BOULDER HOUSE PV SYSTEM

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

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

□ Thus the area for the system is

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

□ The tracker costs are

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

EXAMPLE: BOULDER HOUSE PV SYSTEM

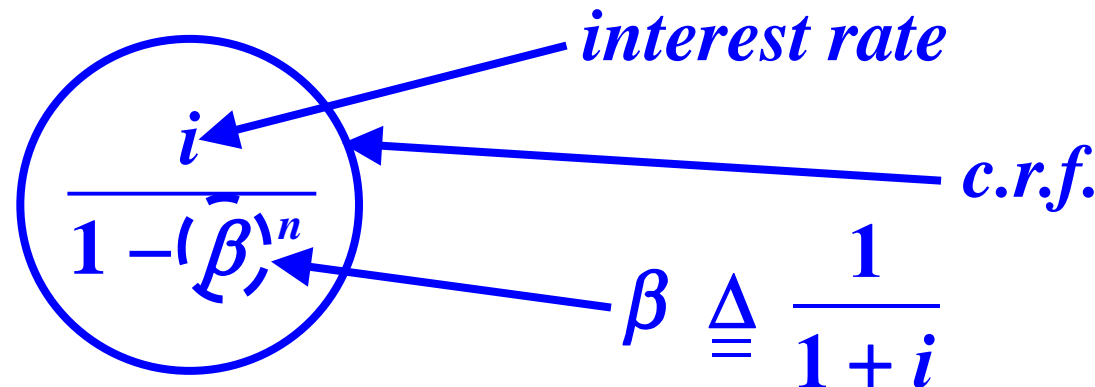
<i>element</i>	<i>fixed tilt array</i>	<i>single-axis tracker</i>
<i>PVs</i>	\$ 11,365	\$ 8,524
<i>inverter</i>	\$ 3,247	\$ 2,436
<i>tracker</i>	—	\$ 2,090
<i>installation</i>	\$ 3,800	\$ 3,800
<i>total</i>	\$ 18,412	\$ 16,850

EXAMPLE: BOULDER HOUSE *PV* SYSTEM

- The installation of the trackers increases the average daily insolation received at the *PV* panels and decreases the area required for the system
- While the trackers add \$ 2,090 to the fixed costs of the *PV* system, the *PV* system investment costs with the trackers are nevertheless markedly below those of the fixed panels

REVIEW OF THE *c.r.f.*

- The capital recovery factor is the principal mechanism we use 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

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


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

EXAMPLE: *LCOE* FOR THE *PV* SYSTEMS

- We illustrate the determination of the *LCOE* with a *PV* system example with the following features:
 - installation costs: \$7 million
 - annual *O&M* costs: \$ 35,000
 - annual land lease fee: \$ 40,000
 - annual energy production: 4 *GWh*
 - 9 %, 20 – year loan
- The *c.r.f.* is computed to be

EXAMPLE: *LCOE* FOR THE PV SYSTEMS

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

- 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 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

Eligible Renewable/Other Technologies: Solar Water Heat, Solar Space Heat, Solar Thermal Electric, Solar Thermal Process Heat, Photovoltaics, Landfill Gas, Wind, Biomass, Hydroelectric, Geothermal Electric, Fuel Cells, Geothermal Heat Pumps, Municipal Solid Waste, CHP/Cogeneration, Solar Hybrid Lighting, Hydrokinetic Power (i.e., Flowing Water), Anaerobic Digestion, Small Hydroelectric, Tidal Energy, Wave Energy, Ocean Thermal, Fuel Cells using Renewable Fuels, Microturbines, Geothermal Direct-Use

Applicable Sectors: Commercial, Industrial, Utility, Agricultural

Amount: 30% for solar, fuel cells, small wind and PTC-eligible technologies;*
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://www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=US02F&re=1&ee=1

FEDERAL RENEWABLE ELECTRICITY PRODUCTION TAX CREDIT (*PTC*)

State: Federal

Incentive Type: Corporate Tax Credit

Eligible Renewable/Other Technologies: Landfill Gas, Wind, Biomass, Hydroelectric, Geothermal Electric, Municipal Solid Waste, Hydrokinetic Power (i.e., Flowing Water), Anaerobic Digestion, Small Hydroelectric, Tidal Energy, Wave Energy, Ocean Thermal

Applicable Sectors: Commercial, Industrial

Amount: 2.2¢/kWh for wind, geothermal, closed-loop biomass, solar ; 1.1¢/kWh for other eligible technologies. Generally applies to first 10 years of operation.

Eligible System Size: Marine and Hydrokinetic: Minimum capacity of 150 kW
Agricultural Livestock Waste: Minimum capacity of 150 kW

Carryover Provisions: Unused credits may be carried forward for up to 20 years following the year they were generated or carried back 1 year if the taxpayer files an amended return.

Expiration Date: Varies by technology

Web Site: <http://www.irs.gov/pub/irs-pdf/f8835.pdf>

Source: http://www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=US13F&re=1&ee=1

FEDERAL TAX FORM FOR *PTC*

Form **8835**

Department of the Treasury
Internal Revenue Service

Renewable Electricity, Refined Coal, and Indian Coal Production Credit

▶ Attach to your tax return.

▶ Information about Form 8835 and its separate instructions is at www.irs.gov/form8835.

OMB No. 1545-1362

2012

Attachment
Sequence No. **95**

Name(s) shown on return

Identifying number

Part I Electricity Produced at Qualified Facilities Placed in Service Before October 23, 2004

1	Kilowatt-hours produced and sold (see instructions)	x 0.022	1		
2	Phaseout adjustment (see instructions)	\$ x	2		
3	Credit before reduction. Subtract line 2 from line 1		3		
Reduction for government grants, subsidized financing, and other credits:					

11	Cooperative, estates, and trusts; subtract line 11 from line 10. Report this amount on Form 9800, line 11 if		12		
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Part II Electricity and Refined Coal Produced at Qualified Facilities Placed in Service After October 22, 2004 (After October 2, 2008, for Electricity Produced From Marine and Hydrokinetic Renewables), and Indian Coal Produced at Facilities Placed in Service After August 8, 2005

13	Electricity produced at qualified facilities using:	(a) Kilowatt-hours produced and sold (see instructions)	(b) Rate	(c) Column (a) x Column (b)		
a	Wind	13a	0.022			
b	Closed-loop biomass	13b	0.022			
c	Geothermal	13c	0.022			
d	Solar	13d	0.022			
e	Add column (c) of lines 13a through 13d and enter here (see instructions)				13e	

Source: <http://www.irs.gov/pub/irs-pdf/f8835.pdf>

TAX INCENTIVES FOR SOLAR

- ❑ The *PTC* originally enacted in the *Energy Policy Act* of 1992 for solar has been renewed numerous times and is currently set at 2.2 ¢/kWh
- ❑ The *PTC* supports electricity generated by utility–scale solar plants for the first *10-years* of operation.

link at <http://www.irs.gov/pub/irs-pdf/f8835.pdf>

EXAMPLE: TAX INCENTIVES FOR SOLAR

□ We illustrate the *PTC* impacts on the *LCOE* in the previous *PV* system example

□ With the *PTC* , the annual tax savings amount to

$$0.022 \times 4,000,000 = \$ 88,000$$

□ The present value of the 10-*year PTC* savings are

given by

EXAMPLE: TAX INCENTIVES FOR SOLAR

$$\frac{88,000}{\frac{(0.09)(1 + 0.09)^{10}}{(1 + 0.09)^{10} - 1}} = \$ 574,753$$

- The total fixed costs are then reduced to

$$7,000,000 - 574,753 = \$ 6,435,246$$

- The annual amortized fixed costs become

$$6,435,246 \times 0.1095 = \$ 704,659$$

EXAMPLE: TAX INCENTIVES FOR SOLAR

- Therefore, the *LCOE* with *PTC* reduces to

$$\frac{704,659 + 35,000 + 40,000}{4,000,000} = 0.195 \frac{\$}{kWh}$$

- We observe that the introduction of the *PTC*

results in a 1.6 ¢/kWh reduction 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 on the homeowner

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 very small contribution to the reduction of the loan principal, while the opposite 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 – *year* 4.5 % loan to install a residential 3.36 – kW_p PV system in Chicago, with the annual energy of 4,942 kWh

□ The *c.r.f.* for the loan is

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

EXAMPLE: TAX BENEFIT FOR SOLAR

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

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

- Thus the cost of *PV* electricity in the first year is

$$\frac{1,178}{4,932} = 0.239 \frac{\$}{kWh}$$

- 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

$$\frac{1,178 - 216}{4,932} = 0.192 \frac{\$}{kWh}$$

REBATES

- ❑ Many states and certain jurisdictions have introduced rebate programs to promote investments in solar systems
- ❑ 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

State: Illinois

Incentive Type: State Rebate Program

Eligible Renewable/Other Technologies: Solar Water Heat, Photovoltaics, Wind, Solar Pool Heating

Applicable Sectors: Commercial, Industrial, Residential, Nonprofit, Schools, Local Government, State Government, Fed. Government, Associations

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

Program Budget: \$1.5 million

Start Date: 12/16/1997

Expiration Date: 10/31/2013 (current applications)

Source: http://www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=IL05F

EXAMPLE: REBATES

- For instance, if the total investment costs in the previous example are reduced by the 25 % rebate under the Illinois solar and wind energy program, we can determine the reduced annual payment

$$19,186 \times (1 - 0.25) \times 0.06139 = \$ 883$$

- Then the first year interest reduces to

EXAMPLE: REBATES

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

- Therefore the first year tax savings are given by

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

- Consequently the cost of *PV* electricity in the first year reduces to

$$\frac{648 - 162}{4,932} = 0.146 \frac{\$}{kWh}$$

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 commercial operation;
 - the schedule for delivery of electricity;

POWER PURCHASE AGREEMENT

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

- A *PPA* defines the revenue and credit quality of a generation project and constitutes thus a key instrument of project finance
- 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

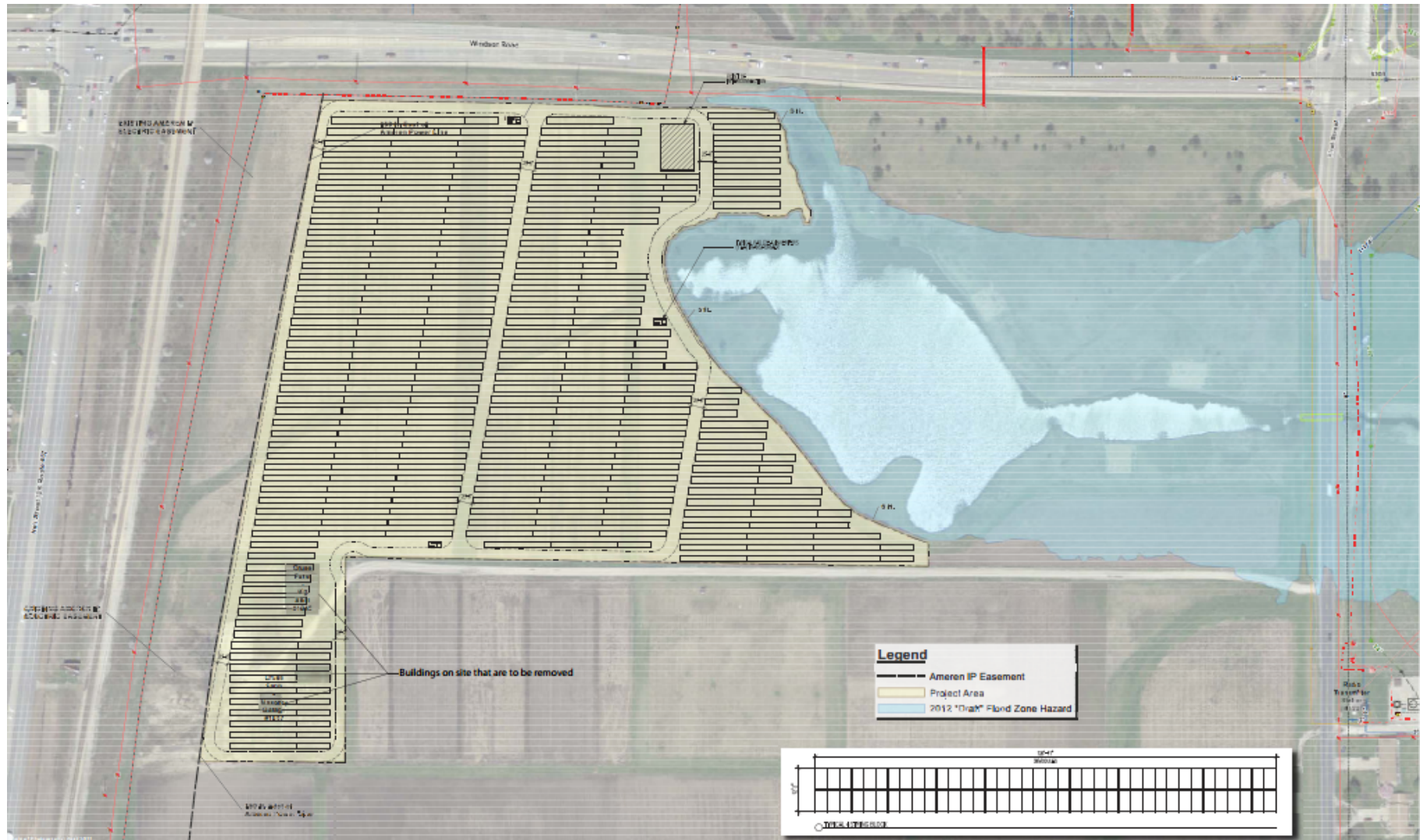
- ❑ While the *PPAs* signed with utilities serve to finance utility-scale renewable energy resource installations under, typically, long-term, fixed-price energy, the use of the *PPA* vehicle to implement **distributed generation projects** to supply residential, commercial and municipal and state governments 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 involving any up-front investment on the part of the buyer

- ❑ The **owner** provides the space to the **seller** to install the system and purchases energy from the system at a negotiated price for the contract term
- ❑ Typically, the ownership of the project passes to the customer at the end of the tax credit payments
- ❑ More recently, research centers and campuses make use **PPAs** to install larger **PV** systems

THE UNIVERSITY OF ILLINOIS PV PROJECT



THE UNIVERSITY OF ILLINOIS *PV* PROJECT

- ❑ **The University of Illinois set a goal in the 2010 *Climate Action Plan* that specifies that 5 % of the campus electricity to be supplied from renewable energy resources by 2015**
- ❑ **To meet this goal, University of Illinois is dedicating 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

becomes the property of the University

THE UNIVERSITY OF ILLINOIS *PV* PROJECT

- ❑ The solar farm is connected directly to the University's electrical distribution system
- ❑ The annual energy production from the solar farm is estimated at *7.86 GWh*, roughly 2% of the 2012 electricity usage of *432.45 GWh* for the campus
- ❑ University of Illinois has agreed to buy all the energy from the solar farm during the first 10 *years*

EXAMPLE: THE UNIVERSITY ILLINOIS *PV* PROJECT

- ❑ We provide an approximation of this solar farm based on the data that is representative for today's *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 insolation receive by a fixed panel is *5.2 kWh/m² - d* – i.e., *5.2 h/d* of *1-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

<i>component</i>	<i>costs (\$)</i>
<i>PV module</i>	1.20/W (DC)
<i>PCU</i>	0.30/W (DC)
<i>other equipment</i>	0.60/W (DC)

- The total fixed costs of the solar farm are

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

EXAMPLE: THE UNIVERSITY OF ILLINOIS *PV* PROJECT

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

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

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

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

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

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

- Under the *PTC* , the annual savings obtained are

$$7,860,000 \times 0.022 = \$ 172,920$$

EXAMPLE: THE UNIVERSITY OF ILLINOIS *PV* PROJECT

- Thus the present value of the 10-year *PTC* is

$$\frac{172,920}{0.129} = \$ 1,340,465$$

- The annual amortized fixed costs are then

$$(10,800,000 - 1,340,465)(0.129) = \$ 1,220,292$$

- Consequently, the *LCOE* is determined to be

$$\frac{1,220,292 + 82,961 + 78,600}{7,860,000} = 0.17 \frac{\$}{kWh}$$

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 and takes over ownership thereafter
- ❑ Once the University of Illinois becomes the owner and operator of the solar farm, all the fixed and variable costs are born by the University