Cost Benefit Analysis Panel

Lessons from the Earlier Study: Comparative Generation Costs of Utility-Scale and Residential-Scale PV in Xcel Energy Colorado's Service Area

PRESENTED BY

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NREL Grid Integration Workshop

September 19, 2017

THE Brattle GROUP

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Overview of the Study – 1/2

Study compares the per MWh customer energy supply costs of adding 300 MW_{-DC} of PV panels.

Generation cost savings scale with installation size

Most studies compare the cost of solar to the cost of other resources, but a "solar to solar" comparison demonstrates that utility-scale deployment of solar PV achieves many of the same benefits at about half the cost of residential-scale PV.

UTILITY-SCALE	RESIDENTIAL-SCALE
6.6¢/kWh – 11.7¢/kWh**	12.3¢/kWh – 19.3¢/kWh**

* Source: "Comparative Generation Costs of Utility-Scale and Residential-Scale PV in Xcel Energy Colorado's Service Area" report* July 2015, The Brattle Group.

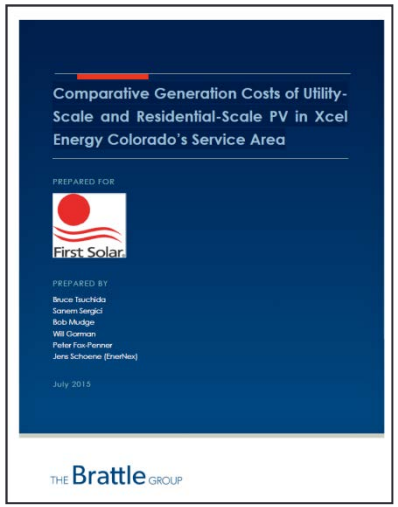
** Refers solely to generation costs projected in 2019 based on the study. Prices noted are based on historic data and not necessarily reflective of current pricing.

WHY THE GAP?

The large gap in per-MWh costs between utility- and residential-scale systems results principally from: (a) lower total plant costs per installed kilowatt for larger facilities; and (b) greater solar electric output from the same PV capacity due to optimized panel orientation, tracking; and (c) other economies of scale and efficiencies associated with utility-scale installations. Based on a review of literature, avoided transmission and distribution costs by residential-scale systems are not large enough to close this gap in generation costs.

300 MW utility-scale solar PV plant = 60,000 residential installations

Study released July 2015


Comparative Generation Costs of Utility-Scale and Residential-Scale PV in Xcel Energy Colorado's Service Area

PREPARED FOR

First Solar

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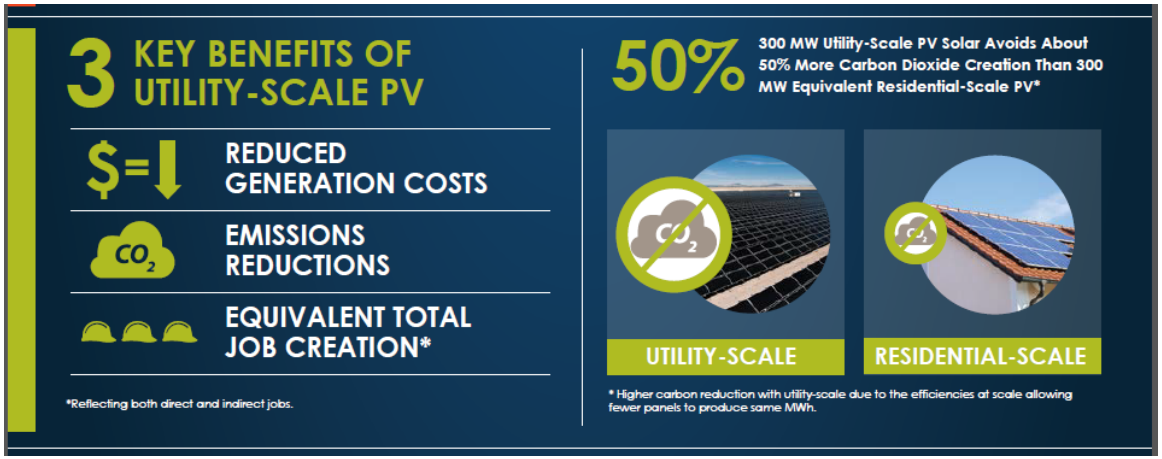
Peter Fox-Penner
Jens Schoene (EnerNex)

July 2015

THE Brattle GROUP

Study finds that customer generation costs per solar MWh are generally ***approximately twice as high*** for residential-scale systems than the equivalent amount of utility-scale PV systems.

Overview of the Study – 2/2



Important to note that costs discussed are *generation costs only*. However, adding other costs mainly strengthens the conclusion.

- A review of literature suggests that total cost of PV power within a more optimized power system will be substantially less expensive for equal amounts of utility-scale compared to residential-scale.
- A majority of non-monetized benefits are positively correlated with MWh output; therefore, one would expect greater value to be ascribed to utility-scale systems because of the significantly higher relative output of those systems.

Other Cost & Benefits Considered Qualitatively – 1/2

Monetized Non-Generation Cost & Benefits: these costs (or benefits if avoided) and their respective effect on the relative cost of utility- and residential-scale systems are presented below:

Cost Category	Content	Estimated Impact
1 - Changes in the Bulk Power System Operating Costs	Integrating Capacity and Ancillary Services	• Costs likely to be slightly higher for residential-scale PV
	Rest-of-System Fuel Cost* Differences and Transmission Losses	• Fuel costs significantly lower for utility-scale PV due to higher capacity factor • Transmission losses lower for residential-scale PV
2 - Changes in Non-Solar Generation Capacity	Avoided Generation Capacity	• Slightly lower costs for utility-scale PV
3 - Changes in Transmission System Capital Costs	Avoided Transmission Capital Costs	• Slightly to moderately lower costs for residential-scale PV
4 - Changes in Distribution System Capital and Operating Costs	Avoided or Increased Distribution System Capital Costs	• Highly variable and case-specific, but generally unlikely to be large positive or negative at the levels considered in this study
	Avoided or Increased Distribution System Operating Costs and Losses	• Slightly to moderately higher costs for residential-scale PV • Slightly to moderately lower losses for residential-scale PV at the levels considered in this study

Overall, we believe that accounting for these costs and benefits are not likely to change our conclusion, as in most cases we expect these costs and benefits to be one or two orders of magnitude smaller than generation costs for the PV levels considered in this study.

Other Cost & Benefits Considered Qualitatively – 2/2

Non-Monetized Benefits (Externalities)

- Water Savings.
- Fuel Price Hedge.
- Energy Security and Resilience.
- Greenhouse Gas and Criteria Air Pollutant Reductions.
- Job Creation.

For all of the above excluding energy resilience and job creation, utility-scale PV provides greater benefits consistent with the roughly 50% more solar energy it produces.

- Residential-scale PVs have the potential to provide greater resilience but it is exceedingly difficult to put a monetary value on the difference.
- Comparative total (direct and indirect) job impacts of utility- vs. residential-scale cannot be determined without a much more complete analysis, but we believe there is likely no significant difference.

Overall, we do not expect that accounting for externalities is likely to change our conclusion.

Where We Are Today

Recent NREL study "The U.S. Solar Photovoltaic System Cost Benchmark: Q1 2017"

- Levelized cost of electricity (LCOE) benchmarks without subsidies:
  - 12.9 - 16.7 cents/kWh for residential systems
  - 9.2 - 12.0 cents/kWh for commercial systems
  - 5.0 - 6.6 cents/kWh for utility-scale fixed-tilt systems
  - 4.4 - 6.1 cents/kWh for utility-scale one-axis tracking

  About one-third?

  By comparison, the Study assumed the generation cost in 2019 to be:
    - 12.3 - 19.3 cents/kWh for residential systems
    - 6.6 - 11.7 cents/kWh for single-axis tracking utility-scale systems
- Total installed system cost (W_{-DC}) – one of the primary inputs used to compute LCOE – has declined:
  - \$2.80 W_{-DC} for residential systems
  - \$1.85 W_{-DC} for commercial systems
  - \$1.03 W_{-DC} for fixed-tilt utility-scale systems
  - \$1.11 W_{-DC} for one-axis tracking utility-scale systems

  By comparison, the Study assumed installed cost in 2019:
    - \$2.25/W_{-DC} for residential systems
    - \$1.43/W_{-DC} for single-axis tracking utility-scale systems

Open Discussion

Appendix

Study release presentation from July 2015 NARUC Summer Meeting, New York City, NY

Comparative Costs of Utility-Scale and Residential-Scale PV in Xcel Energy Colorado's Service Area

PRESENTED AT
NARUC Summer Meeting
New York City, New York

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July 13, 2015

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Agenda

Introduction and Purpose

Key Study Findings

Overview of Study Methodology

- Projecting Installed Cost of PV Plants
- Projecting Power Output from Colorado PV Plants
- Modeling Customer Costs

Study Results

Costs and Benefits Considered Qualitatively

Conclusions

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Introduction and Purpose

Solar Photovoltaics (PVs) are deployed in various configurations ranging from a few kilowatts (residential-scale) to hundreds of megawatts (utility-scale), with distinct implications for the system they are deployed in. Existing solar studies have tended to focus on two policy concerns:

- Overall costs and benefits of PVs compared to *non-solar resources.*
- Impacts of Net Energy Metering (NEM) and other tariff options for small-scale PV.

This report fills a void in literature by comparing the costs and other impacts of large- and small-scale PVs. More specifically, this report looks at the Xcel Energy Colorado system in 2019 and compares the per MWh customer energy supply costs of adding 300 MW of PV panels (W_{-DC}) either in the form of:

- 60,000 distributed 5-kilowatt residential-scale (rooftop) systems owned or leased by retail customers; or
- 300 MW of utility-scale solar power plants that sell their entire output to Xcel Energy Colorado under long-term purchase power agreements (PPA).

Important to note that our costs are <u>generation costs only</u>. However, we conclude that adding other costs mainly strengthens our conclusion, rather than changes it.

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Key Study Finding

Our study finds that customer generation costs per solar MWh are generally approximately twice as high for residential-scale systems than the equivalent amount of utility-scale PV systems.

- Reference Case costs are $83/MWh for utility-scale and $167/MWh for residential-scale PV systems.

We believe that inclusion of monetized non-generation costs and benefits and non-monetized benefits (externalities) are not likely to change our conclusion as:

- A review of literature suggests that total cost of PV power within a more optimized power system will be substantially less expensive for equal amounts of utility-scale compared to residential-scale.
- A majority of non-monetized benefits are positively correlated with MWh output; therefore, one would expect greater value to be ascribed to utility-scale systems because of the significantly higher relative output of those systems.

See complete study at www.Brattle.com

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Xcel Energy Colorado as the Test Case

Xcel Energy Colorado was chosen as the test case for this study because:

- It is reasonably representative of a midsize utility system in the Western U.S. based on the size of system, load profile, and the current level of penetration of residential-scale systems in its service territory.
- It is also reasonably representative of investor-owned utilities in the West in terms of the mix of urban and rural load and distribution feeders.

While the results of our analysis solely apply to Xcel Energy Colorado system and should not be transferred to other regions without proper calibrations, the general relationship we find between costs is likely to hold true for many U.S. utilities with significant solar potential.

The report was prepared by consultants at The Brattle Group for First Solar, with support from the Edison Electric Institute. Xcel Energy Colorado provided data and technical support.“

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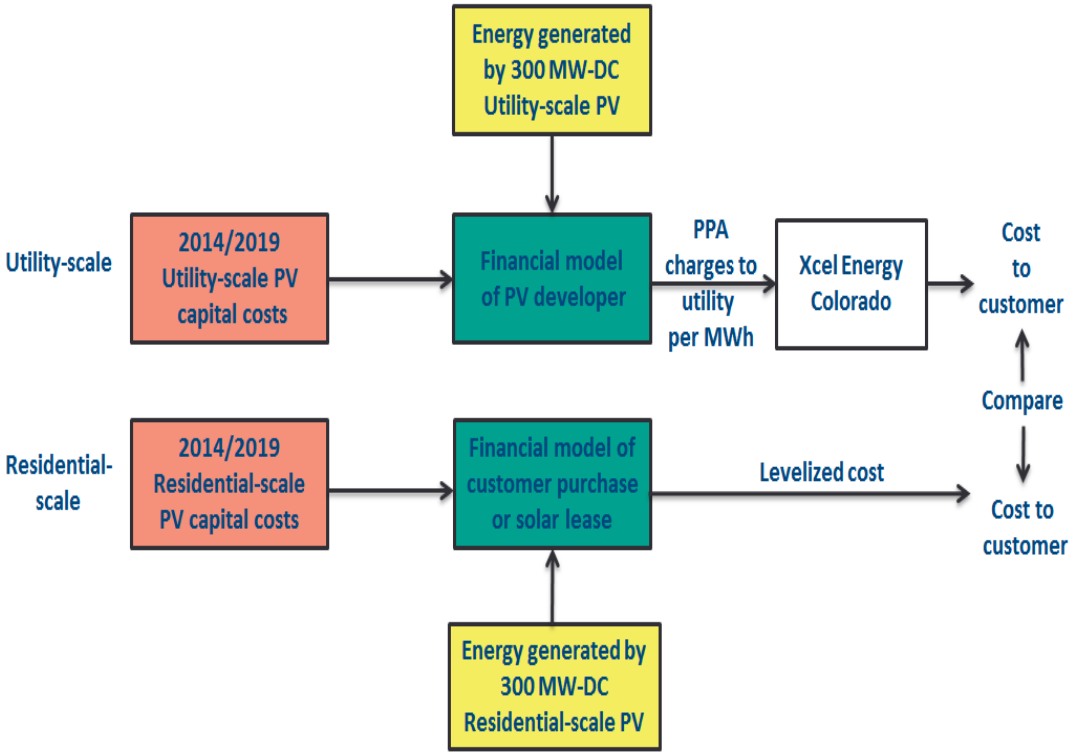
4 Steps of this Study

Step 1 (red shading): analysis of national data on PV installations by size, type, and project capital costs.

Step 2 (yellow shading): analysis of insolation and other engineering data to estimate energy produced by 300 MW utility- and residential-scale systems.

Step 3 (green shading): developer financial model to estimate annual stream of customer payments for utility- and residential-scale.

Step 4 (not shown in figure): qualitatively consider transmission and distribution costs and non-monetized social costs.



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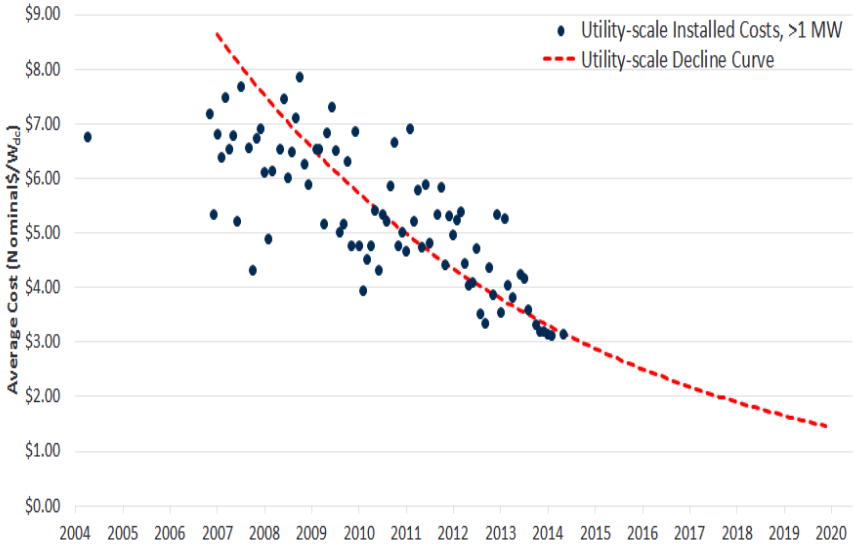
Step 1: Forecasting Utility- & Residential-scale PV Costs

NREL OPEN PV data used to forecast utility- and residential-scale PV costs.

Utility-Scale Installed Costs with Decline Curve

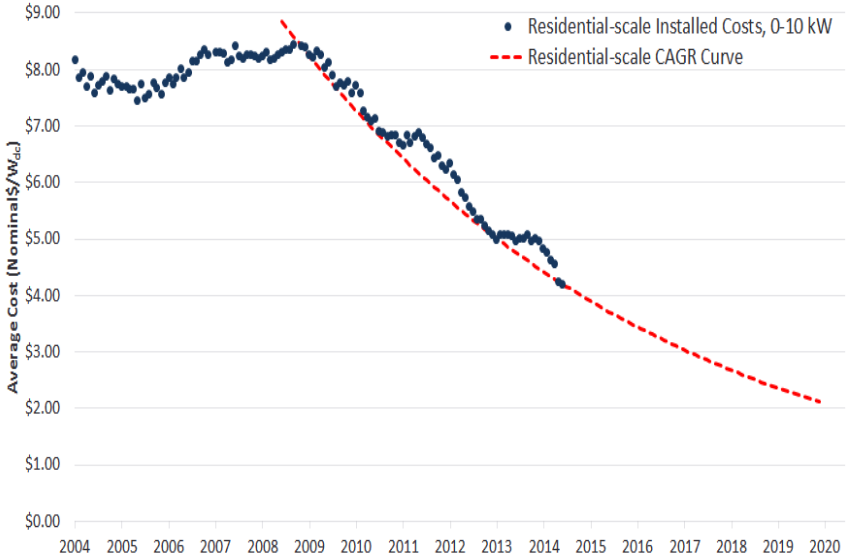


Source: NREL Open PV Project; Analysis by The Brattle Group

Installed cost in 2014: $2.88/$W_{DC}$

Installed cost in 2019: $1.43/$W_{DC}$

Residential-Scale Installed Costs with Decline Curve



Source: NREL Open PV Project; Analysis by The Brattle Group

Installed cost in 2014: $4.25/$W_{DC}$

Installed cost in 2019: $2.25/$W_{DC}$

Note: Prices noted are based on historical data and not necessarily reflective of current pricing.

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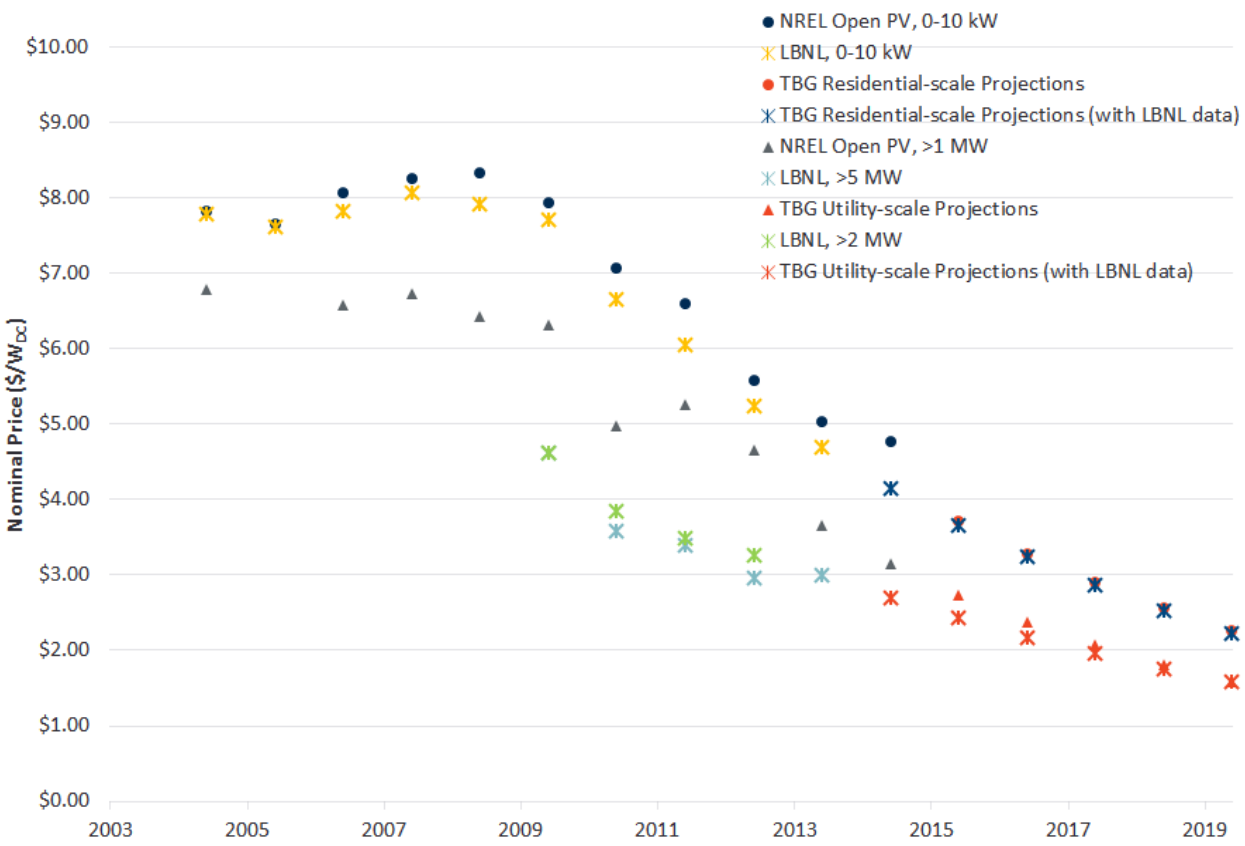
Comparing PV Cost Projections with Other Sources



For the historic period, compared to the NREL data, LBNL values are slightly lower for residential-scale, and significantly lower for utility-scale.

2013 and onwards, the gap narrows and by 2019, prices calculated using LBNL data match those using NREL data.

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Generation from Equal-size 300 MW PV Systems

Power produced by residential- vs. utility-scale PV systems of equal total size (panel capacity in W_{-DC}) is a key driver of our results.

Power produced is a function of:

- Insolation (direct and diffuse) over time.
- Precise location of panels on ground.
- Orientation of panels and tracking capability.
- Shading.
- Maintenance/operations of panels.

Due to the complexity and importance of estimating unbiased generation (and capacity factor) differences, we engaged EnerNex and two independent peer reviewers:

- Steven Hegedus, University of Delaware.
- Jan Kleissl, University of California, San Diego.

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Step 2: Estimate Power Output from PV Plants

Size and location

- 60,000 residential-systems are distributed using the same geographical pattern that current residential systems are now installed within Xcel Colorado (mostly around Greater Denver area).
- 300 MW utility scale in the form of two plants (while utility-scale plants are likely to be located in the Pueblo area with strong transmission backbone and favorable insolation, insolation levels were assumed be equal between residential- and utility-scale systems).

Insolation data

- Utilized actual insolation data measured at one-minute intervals, compiled through a survey of all actual measured insolation levels in and around Xcel Energy Colorado service area.

Solar Electric Production

- Solar electric production calculated through a 3-step process:
  - Spatial smoothing of solar irradiance
  - Panel tilt and tracking
  - Conversion losses of power production (including AC/DC conversion, panel and inverter efficiencies, soiling, shading, etc.)
- EnerNex and Reviewers agreed that expected utility-scale generation exceeded residential-scale generation by approximately 50%.

Typical Year Solar Generation for 300MW$_{-DC}$ Panels located Denver, CO		
PV Type	**Utility-scale**	**Residential-scale**
Generation (MWh)	596,655 MWh	400,125 MWh
Capacity Factor (%)	24.2%*	16.2%

* Assumes 250MW$_{-AC}$ inverters and 300MW$_{-DC}$ panels

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Step 3: Modeling Customer Costs

We estimate per-MWh customer cost of utility- and residential-scale PVs using a financial model originally developed for Connecticut's Clean Energy Finance and Investment Authority (CEFIA), commonly referred to as Connecticut's "Green Bank."

- The model calculates revenue requirements driven by assumptions for technical parameters, capital and operating costs, economic assumptions such as inflation, capital sourcing (debt, equity and tax equity), and associated costs, as well as other incentives, as applicable.
- The model assumes a 25 year contract life for the utility-scale PVs and a 25 year asset life for the residential-scale PVs (all NPVs are also calculated over 25 years.)
  - Output after 25 years, premature retirement, and disposal costs are not included.

Next slide provides a snapshot of the assumptions that go into modeling of the customer costs for the Reference Case.

- Residential-scale systems are analyzed for systems owned by the customer (with lower overall customer costs) and systems leased to the customer (with higher overall customer costs). The comparison of this study is mostly between customer owned residential-scale systems and utility-scale systems.

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Reference Case Assumptions

		Utility	Residential	
No ITC Extension		ITC Monetized by Tax Equity	Lease (ITC Monetized by Tax Equity)	Customer Purchase
Assumptions				
Installed Cost (DC)	$/ kW	1,430	2,250	2,250
DC Overbuild	%	20%	0%	0%
DC to AC Conversion	%	96%	94%	94%
Inflation	%	2%	2%	2%
FOM	$/ kW-Year	26	26	26
Contract/ Asset Life**	Years	25	25	25
Debt Life***	Years	15	15	15
Capacity Factor (AC)	%	29.06%	16.24%	16.24%
Annual Derate Factor	%	0.50%	0.50%	0.50%
SREC Price (10 Years)	$/kWh	-	0.001	0.001
Tax Rate	%	40%	40%	40%
Investment Tax Credit	%	10%	10%	0%
Accelerated Depreciation	MACRS	5	5	-
Cost of Debt	%	8.0%	8.0%	3.8%
Cost of Tax Equity	%	8.0%	8.0%	0.0%
Cost of Developer Equity	%	12.0%	12.0%	0.0%
Capital Structure - Gross				
Debt***	%	47%	47%	100%
Tax Equity****	%	35%	35%	0%
Developer Equity****	%	18%	18%	0%
Total	%	100%	100%	100%
Average DSCR***	EBITDA/ DS	1.5	1.5	1.0
Revenue Requirement				
Levelized Nominal	$/kWh	0.083	0.182	0.167
Discount Rate	%	7.6%	7.6%	7.6%
PVRR	$M	556	812	752

** Assumes asset reverts to customer at zero cost at contract end

*** Assumed to be backlevered if tax equity in capital structure

**** Monetizes ITC, as relevant. Tax equity modeled as partnership flip @ 10 years.

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Reference Case and Scenarios

We establish a Reference Case and five scenarios to account for possible variations in tax treatment for solar installations and other factors

No	Name	Installed PV Costs	ITC	ITC monetized by	Inflation
Reference Case	No ITC Extension*	Projected costs in 2019	10%	Tax-equity partner	2%
Scenario 1	2019 ITC @ 30%	Projected costs in 2019	30%	Tax-equity partner	2%
Scenario 2	2019 Developer Absorbing ITC	Projected costs in 2019	10%	Developer	2%
Scenario 3	2019 Higher Inflation	Projected costs in 2019	10%	Tax-equity partner	4%
Scenario 4	2019 Lower PV Cost	Projected costs in 2019 discounted by 20%	10%	Tax-equity partner	2%
Scenario 5	2014 Actual PV Cost	Actual costs in 2014	30%	Tax-equity partner	2%

Note: Residential-scale purchased systems are not eligible for ITC effective January 1st, 2017. Our Reference Case and Scenarios (with the exception of Scenario 1) are consistent with this current tax code that assumes 10% ITC for utility-scale, residential-scale lease systems, and 0% ITC for residential-scale purchased/owned systems.

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Levelized Cost Comparison ($ per MWh)

Our study finds that customer generation costs per solar MWh are estimated to be more than twice as high for residential-scale systems ($167/MWh) than the equivalent amount of utility-scale PV systems ($83/MWh) under the Reference Case assumptions.

The generation cost difference between the utility- and residential-scale systems owned by customers ranges from 6.7¢/kWh to 9.2¢/kWh solar across the scenarios. To put this in perspective, national average all-in retail residential electric rates in 2014 were 12.5¢/kWh.

Levelized Price Comparison Across Scenarios ($/MWh)					
No	Scenario	Utility-scale	Residential-scale Purchase	Cost Difference (Res-Utility)	Residential-scale Lease
Reference	**No ITC Extension***	**83**	**167**	**83**	**182**
Scenario 1	2019 ITC @ 30%	66	123	**57**	140
Scenario 2	2019 Developer absorbs ITC	66	N/A	**N/A**	140
Scenario 3	2019 Higher Inflation	95	187	**92**	206
Scenario 4	2019 Lower PV Cost	69	137	**67**	149
Scenario 5	2014 Actual PV Cost	117	193	**76**	237

* 10% ITC for utility-scale and residential-scale lease systems and 0% ITC for residential-scale purchase systems

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NPV Comparison of Generation Costs ($ million)

Our study finds residential-scale PV costs $87 million to $195 million more than the utility-scale on an NPV basis over 25 years for the Reference Case and remaining five Scenarios.

In 2014, 1,200 MW of residential-scale PV systems were installed in the U.S. If the same amount of residential-scale PV systems (1,200 MW) were installed in 2019, these PV systems would cost customers roughly $800 million more in NPV than a comparable purchase of utility-scale systems, under conditions assumed for the Reference Case.

2014 Net Present Value of Costs with 7.6% Discount Rate ($ millions)					
No	Scenario	Utility-scale	Residential-scale Purchase	Cost Difference (Res-Utility)	Residential-scale Lease
Reference	**No ITC Extension***	**556**	**752**	**195**	**812**
Scenario 1	2019 ITC @ 30%	438	554	116	625
Scenario 2	2019 Developer absorbs ITC	438	N/A	N/A	625
Scenario 3	2019 Higher Inflation	538	716	178	785
Scenario 4	2019 Lower PV Cost	463	617	153	668
Scenario 5	2014 Actual PV Cost	781	869	87	1061

* 10% ITC for utility-scale and residential-scale lease systems and 0% ITC for residential-scale purchase systems

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Step 4: Cost & Benefits Considered Qualitatively

1- Monetized Non-Generation Cost & Benefits: these costs (or benefits if avoided) and their respective effect on the relative cost of utility- and residential-scale systems are presented below:

Cost Category	Content	Estimated Impact
1 - Changes in the Bulk Power System Operating Costs	Integrating Capacity and Ancillary Services	• Costs likely to be slightly higher for residential-scale PV
	Rest-of-System Fuel Cost* Differences and Transmission Losses	• Fuel costs significantly lower for utility-scale PV due to higher capacity factor • Transmission losses lower for residential-scale PV
2 - Changes in Non-Solar Generation Capacity	Avoided Generation Capacity	• Slightly lower costs for utility-scale PV
3 - Changes in Transmission System Capital Costs	Avoided Transmission Capital Costs	• Slightly to moderately lower costs for residential-scale PV
4 - Changes in Distribution System Capital and Operating Costs	Avoided or Increased Distribution System Capital Costs	• Highly variable and case-specific, but generally unlikely to be large positive or negative at the levels considered in this study
	Avoided or Increased Distribution System Operating Costs and Losses	• Slightly to moderately higher costs for residential-scale PV • Slightly to moderately lower losses for residential-scale PV at the levels considered in this study

Overall, we believe that accounting for these costs and benefits are not likely to change our conclusion, as in most cases we expect these costs and benefits to be one or two orders of magnitude smaller than generation costs for the PV levels considered in this study.

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Step 4: Cost & Benefits Considered Qualitatively (cont'd)

2- Non-Monetized Benefits (Externalities)

- Water Savings.
- Fuel Price Hedge.
- Energy Security and Resilience.
- Greenhouse Gas and Criteria Air Pollutant Reductions.
- Job Creation.

For all of the above excluding energy resilience and job creation, utility-scale PV provides greater benefits consistent with the roughly 50% more solar energy it produces.

- Residential-scale PVs have the potential to provide greater resilience but it is exceedingly difficult to put a monetary value on the difference.
- Comparative total (direct and indirect) job impacts of utility- vs. residential-scale cannot be determined without a much more complete analysis, but we believe there is likely no significant difference.

Overall, we do not expect that accounting for externalities is likely to change our conclusion.

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Conclusion

We find that utility-scale PV system is significantly more cost-effective than residential-scale PV systems when considered as a vehicle for achieving the economic and policy benefits commonly associated with PV solar.

- Customer generation costs per solar MWh are estimated to be more than twice as high for residential-scale systems ($167/MWh) than the equivalent amount of utility-scale PV systems ($83/MWh) for the Reference Case.

It is important to recognize cost differentials between residential- and utility-scale systems, particularly if utilities and their regulators are looking to maximize the benefits of procuring solar capacity at the lowest overall system costs.

Moreover, most of the environmental and social benefits provided by PV systems can be achieved at a much lower total cost at utility-scale than at residential-scale.

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