Impacts of Solar-Export Credit Rates on Solar Deployment, Utilities, and Customers

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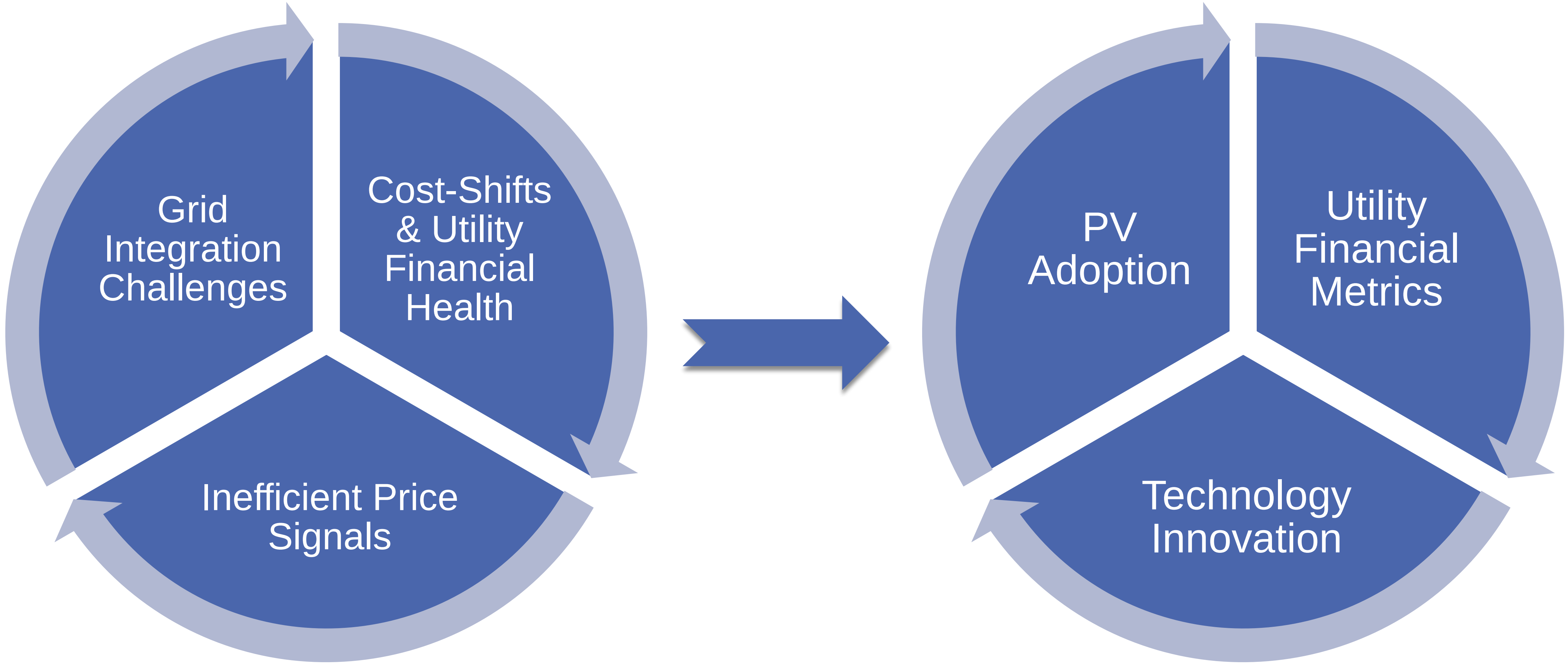
Outline

1. **General impacts of solar-export credit rates**
2. Grid exports and strategies for managing exports
3. Battery storage economics for managing grid exports

NEM Reforms: Motivations and Impacts

Motivations ***Impacts***



NEM reforms come in many shapes and sizes

Changes to underlying rate design

- Increased fixed charges
- Demand charges
- Time-varying pricing
- Minimum bills
- Locational pricing

Changes to/replacement of NEM

- **Export Credit Rates (Net Billing)**
- REC ownership rules
- Buy-all/sell-all
- Standby charges

Implications of NEM reforms differ for residential vs. non-residential customers

	Compensation under Standard NEM	PV Output Relative to Load	Coincidence between PV and Load
Residential	**Relatively high** *Reflects average cost of service*	**Relatively high** *PV often sized to meet 75-100% of annual energy consumption*	**Relatively low** *Class-level peak often occurs in early evening*
Non-Residential	**Relatively low** *Closer to utility's short-run marginal costs (because of 3-part rates)*	**Relatively low** *Often constrained by available roof-space*	**Relatively high** *Class-level peak often occurs in early afternoon*

Bottom line: *The transition from standard NEM to grid-export rates may be fairly inconsequential for many non-residential customers*

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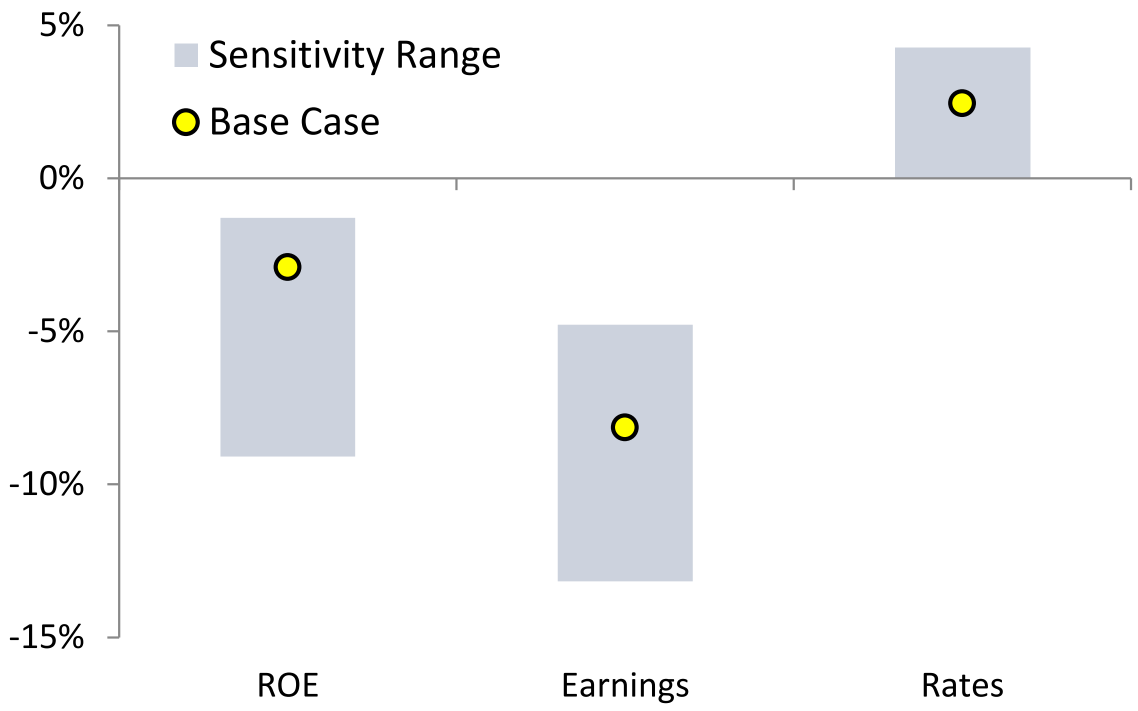
Utility Financial Impacts of Standard NEM
(which grid export rates might potentially mitigate)

- Earlier LBNL study that modeled the effects of net-metered PV on a Southwest IOU generally found that it:
  - Reduced shareholder ROE and earnings
  - Increased average retail rates
  - Depending significantly on specific conditions (e.g., deferral value, decoupling, etc.)
- Net billing will tend to reduce those effects, depending on:
  - Delta between grid export and retail rates
  - Level of grid exports
  - Impacts on PV deployment levels

Modeled Impacts of Full NEM for a SW Utility
Percentage change from no-PV to 10% PV

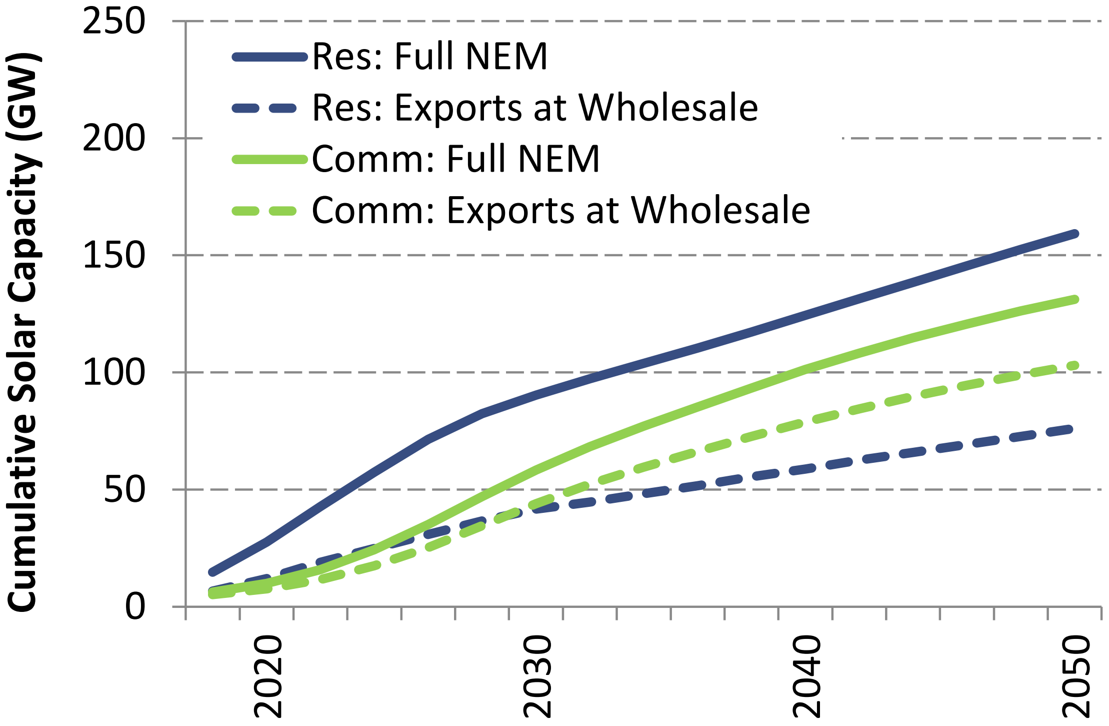


Source: Satchwell, A., A. Mills, G. Barbose, R. Wiser, P. Cappers, and N. Darghouth. 2014. *Financial Impacts of Net-Metered PV on Utilities and Ratepayers: A Scoping Study of Two Prototypical U.S. Utilities*. Berkeley, CA: Lawrence Berkeley National Laboratory.

PV Deployment Impacts from Moving to Grid Export Rates

- Used NREL's dSolar model to project aggregate U.S. distributed PV adoption under two alternate scenarios
  - Full NEM at retail rates
  - Grid exports compensated at regional wholesale prices
- Compared to full NEM, deployment is 55% lower for residential and 20% lower for non-residential customers
- Assumes static technology and system design

Projected Total U.S. Distributed PV Deployment
Full NEM vs. Grid Exports at Wholesale Prices



Source: Barbose, G., J. Miller, B. Sigrin, E. Reiter, K. Cory, J. McLaren, J. Seel, A. Mills, N. Darghouth, and A. Satchwell. 2016. *On the Path to SunShot: Utility Regulatory and Business Model Reforms for Addressing the Financial Impacts of Distributed Solar on Utilities*. Berkeley, CA: Lawrence Berkeley National Laboratory.

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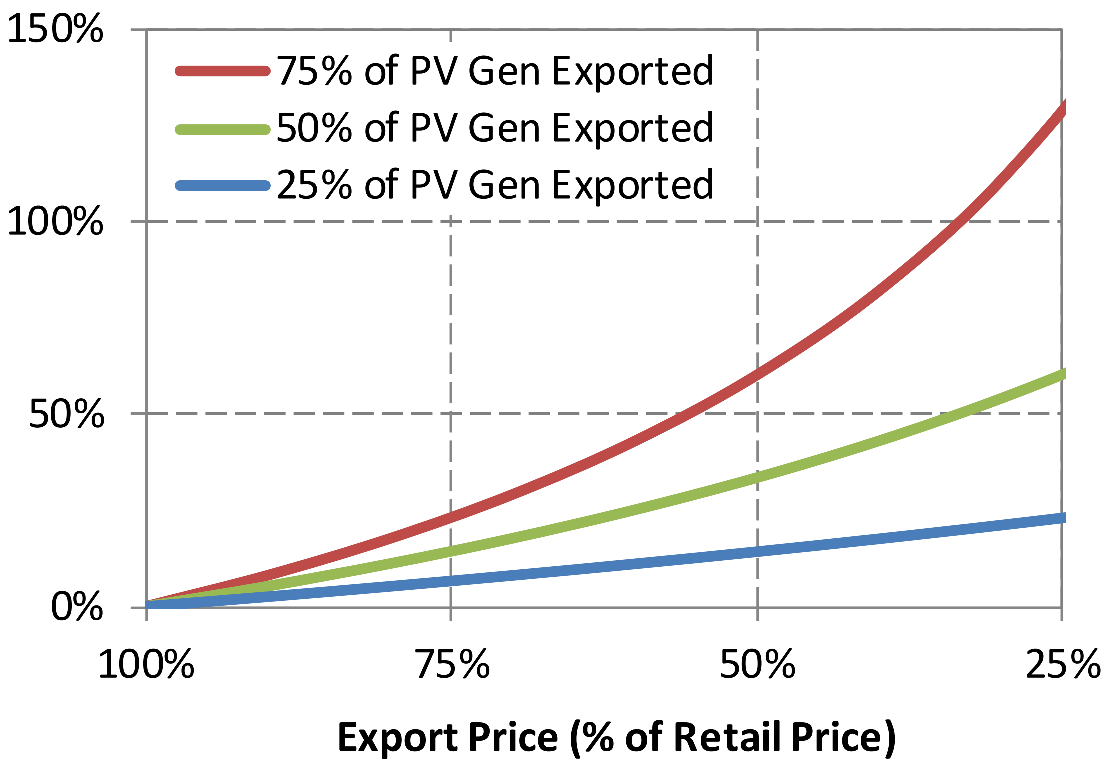
Outline

1. General impacts of solar-export credit rates
2. **Grid exports and strategies for managing exports**
3. Battery storage economics for managing grid exports

Interdependence of Export Price and Quantity

- Impacts of export credit rates depend on both export price and quantity
- Net billing structures incentivize reduced grid exports
  - West-facing roofs
  - Smaller system sizes
  - Load shifting
  - Storage
- The greater the price differential between retail and grid export rates, the greater that incentive

Increase in Payback Period Relative to NEM
as a Function of Grid Export Price and Quantity



Source: Barbose, G., J. Miller, B. Sigrin, E. Reiter, K. Cory, J. McLaren, J. Seel, A. Mills, N. Darghouth, and A. Satchwell. 2016. *On the Path to SunShot: Utility Regulatory and Business Model Reforms for Addressing the Financial Impacts of Distributed Solar on Utilities*. Berkeley, CA: Lawrence Berkeley National Laboratory.

LBNL Analysis of Grid Exports

Data and Analysis Overview

Hourly interval load data

- Random sample of 342 residential customers in Nevada without PV, under flat rates
- Data collected under DOE's Smart Grid Investment Grant) over 2012-2014

Modeled hourly solar PV production

- Developed with NREL's System Advisor Model
- Based on weather data for the same location and timeframe as the load data

Grid exports calculated on hourly basis

- Would be greater if based on shorter intervals

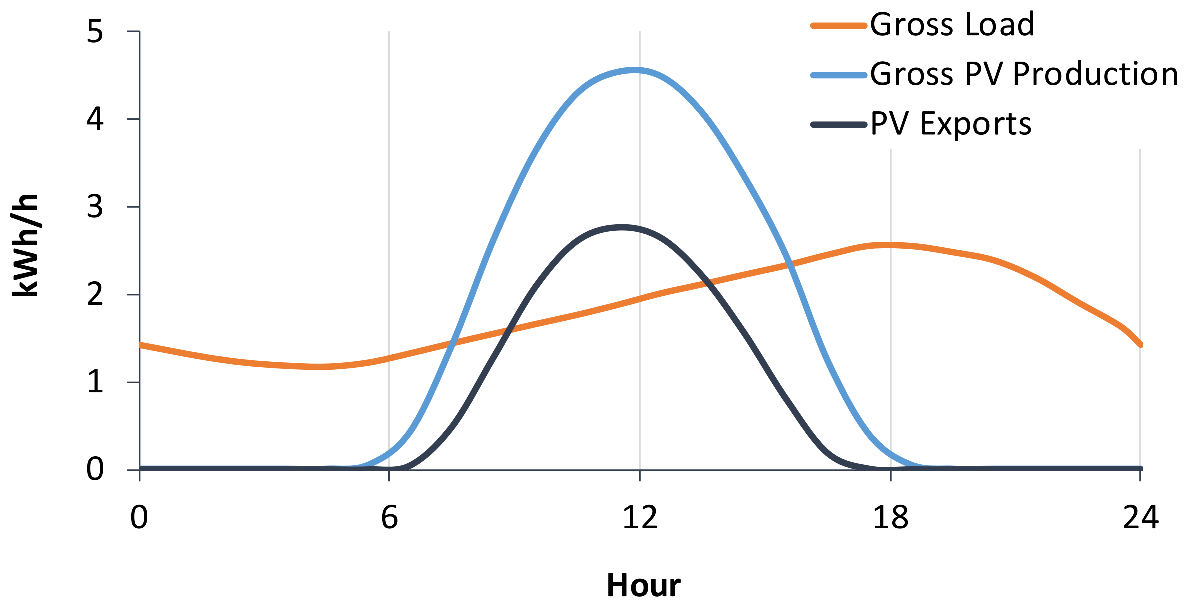
Intended to illustrate:

- Significance of grid exports
- Diversity across customers
- Impact of measures to reduce exports
- Temporal profile and implications for capacity value

Grid Exports Under a “Typical” System Design

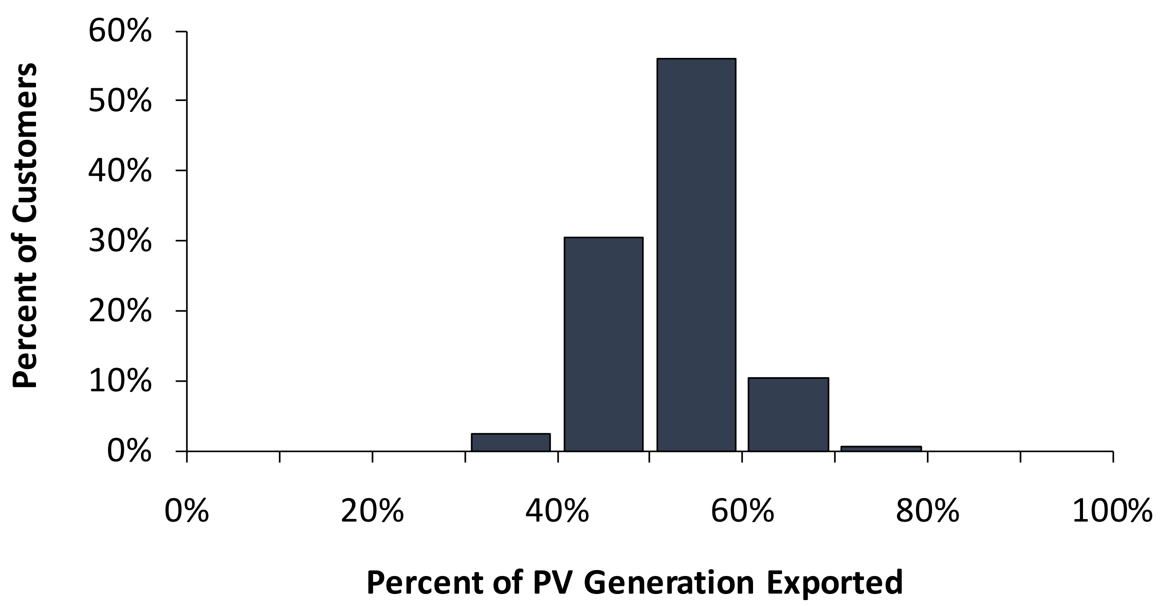
South-facing systems sized to generate 75% of each customer’s annual consumption

Average Hourly Profiles
Across all customers and days of the year



- Temporal profile of exports is similar to gross PV generation, though shifted slightly leftward
- ~50% of PV generation exported, on average

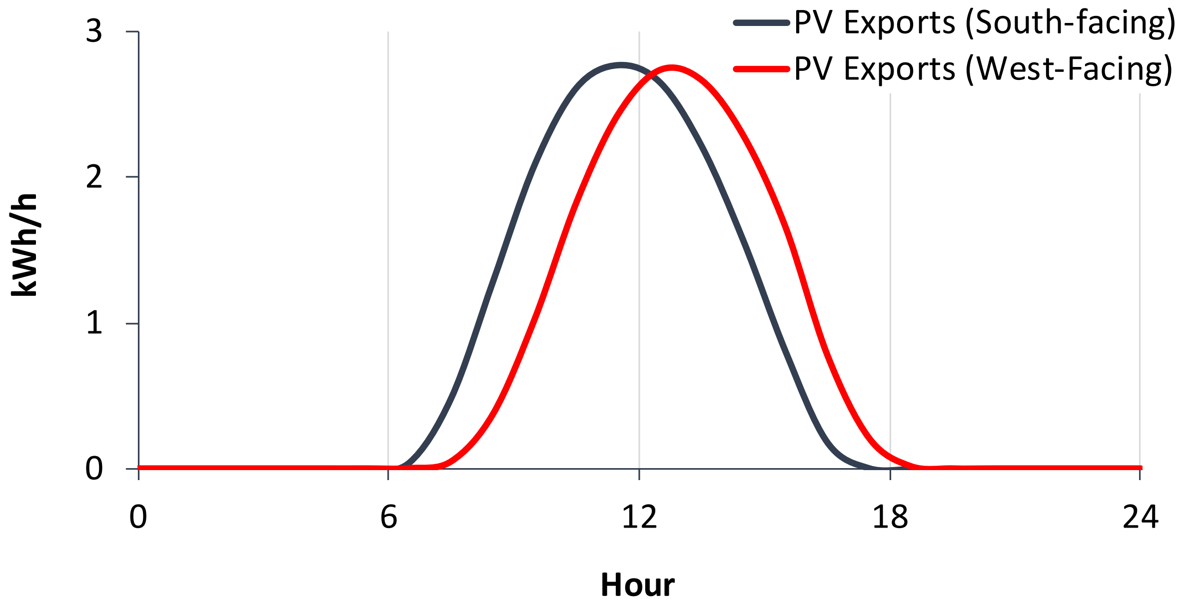
Distribution in Annual Grid Export Percentage
Across all customers



- Some diversity in export percentage across customers, but most are in the 40-60% range

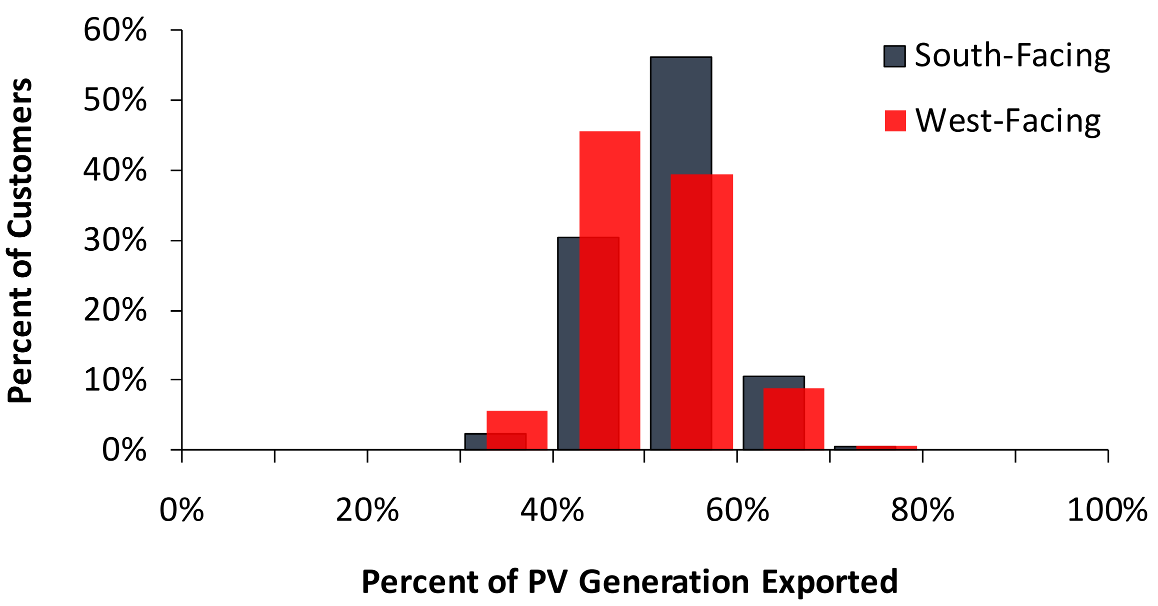
Targeting West-Facing Rooftops

Average Hourly PV Exports
Across all customers and days of the year



- Grid export profile shifted with peak in early afternoon
- Still, ~50% generation exported, on average

Distribution in Annual Grid Export Percentage
Across all customers

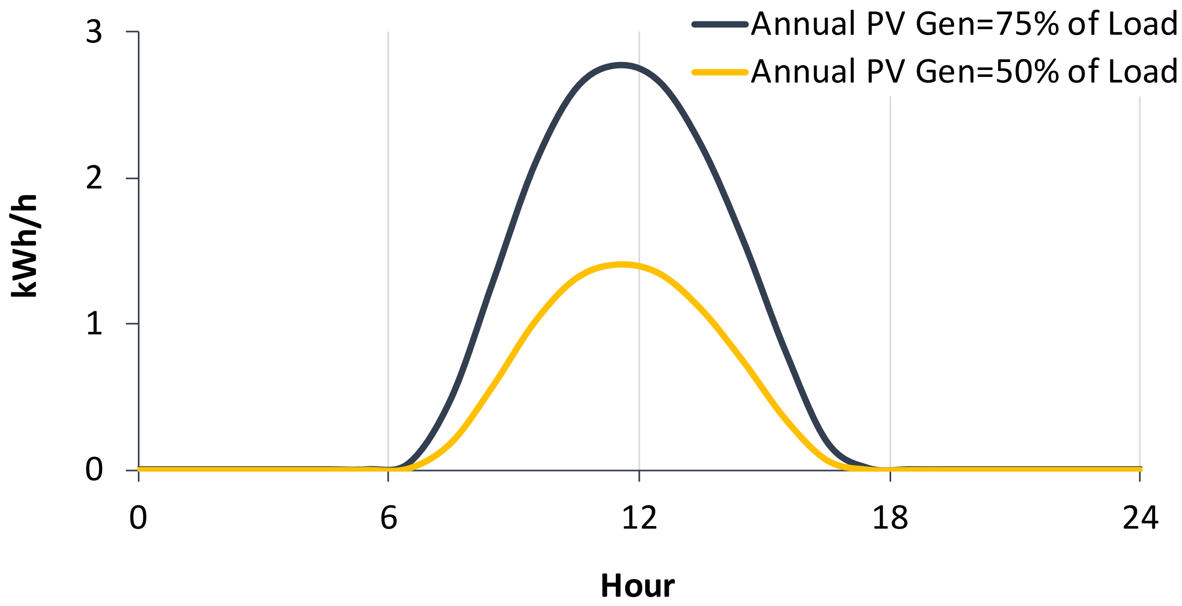


- Grid export quantity reduced slightly for some customers, but most are still in the range of 40-60% of total PV generation

Installing Smaller Systems

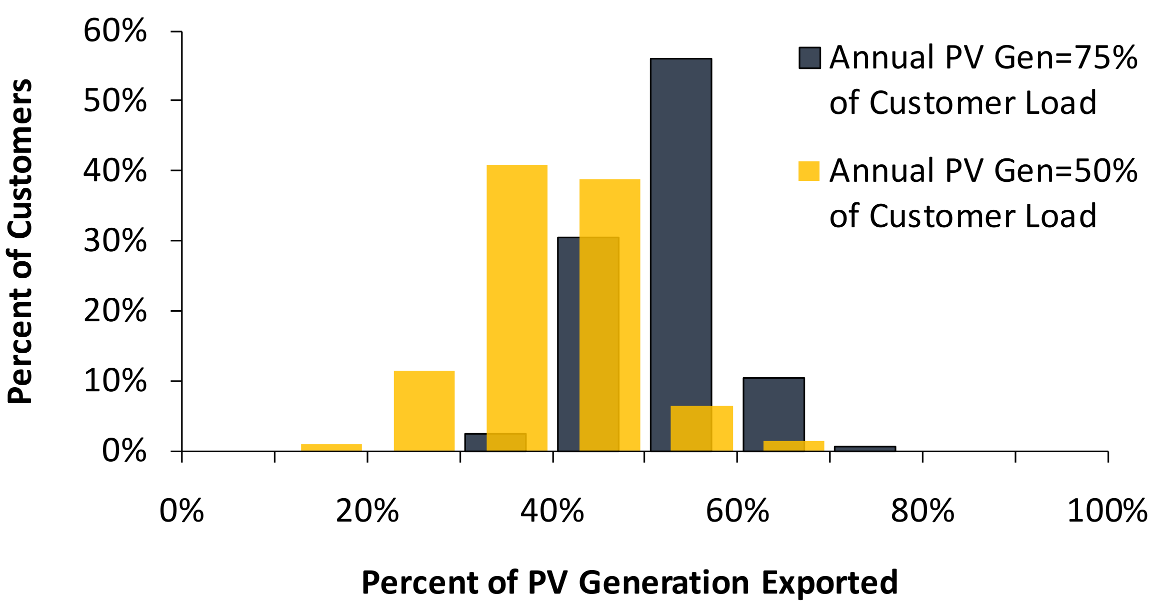
Systems sized to generate 50% of annual customer load

Average Hourly PV Exports
Across all customers and days of the year



- Lower peak but similar temporal profile as larger systems

Distribution in Annual Grid Export Percentage
Across all customers



- On average, 40% of PV generation exported; most customers in the range of 30-50%

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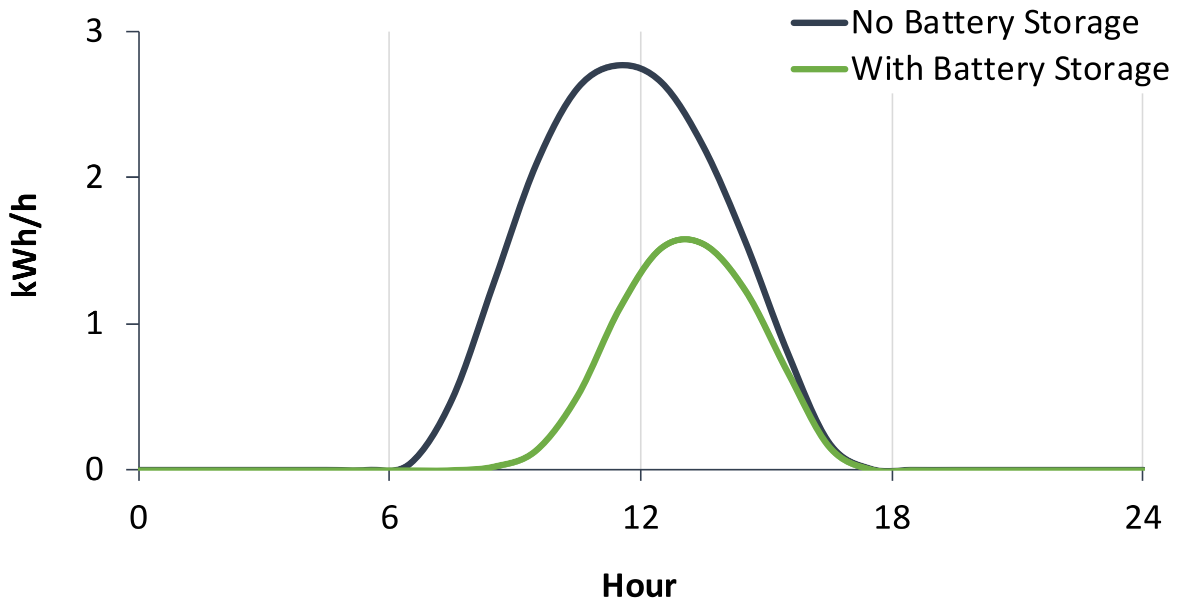
Adding Storage to PV

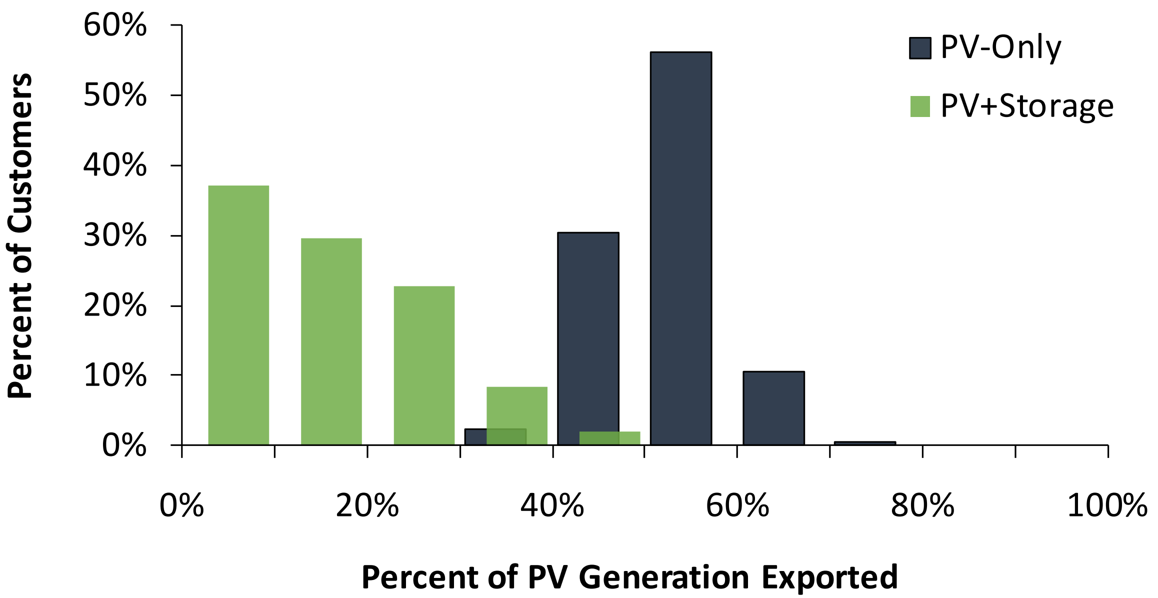
13-kWh / 5-kW battery storage, with flat retail rates and grid export rates

Average Hourly PV Exports
Across all customers and days of the year



- PV exports reduced to ~20% of total PV generation, on average
- Temporal profile shifted rightward, based on storage charging protocol under flat rates

Distribution in Annual Grid Export Percentage
Across all customers



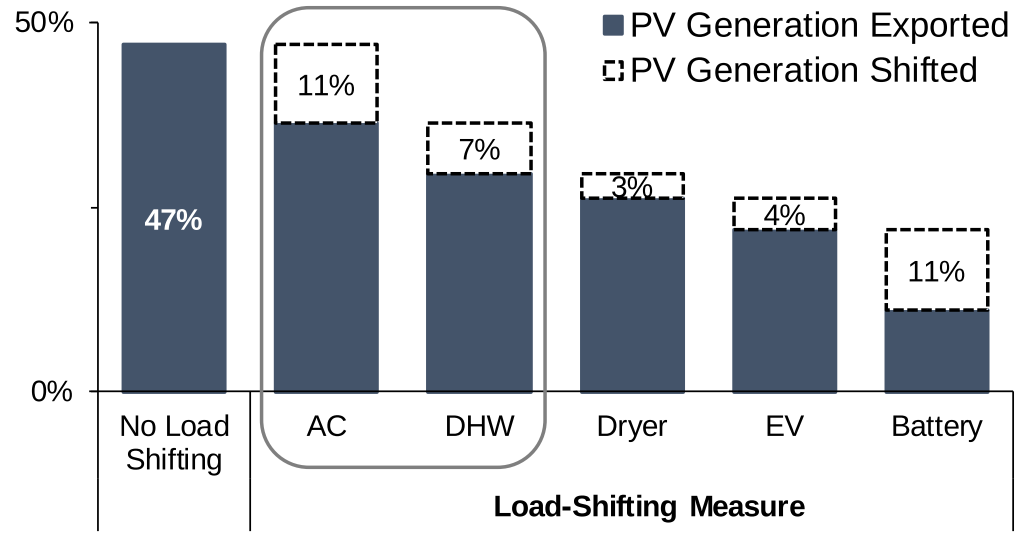
- Exports range from 0-30% most customers (storage size is fixed, but PV size varies with load)
- Customers could install larger batteries and further reduce/eliminate exports, albeit with diminishing economic returns

Load Shifting to Reduce Grid Exports

Literature review

- Controllable loads for reducing PV grid exports: A/C, DHW (resistance or heat pump), appliances (e.g., dryers), pool pumps, EVs, etc.
- RMI case study of Hawaii "zero-export" tariff:
  - Low-cost A/C and DHW load-shifting measures reduce grid exports from 47% to 29% of annual PV generation
  - Additional cost-effective load shifting via controllable electric dryer (more expensive), EV, and batteries
- NREL "Solar Plus" study: A/C and DHW load-shifting almost always cost effective for managing exports
- Numerous academic studies on optimized building control with PV, mostly in European context
  - A number of such studies estimated 2-15% of PV generation could be shifted from export to self-consumption (Luthander et al. 2015), though larger shifts possible with TES (e.g., Salpakari & Lund 2016)

Based on RMI analysis of demand flexibility potential for Hawaii PV customer with 10 kW PV system (generation = 80% of annual load)



Adapted from Dyson, M., J. Mandel, et al. 2015. *The Economics of Demand Flexibility: How "flexiwatts" create quantifiable value for customers and the grid*. Rocky Mountain Institute.

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Managing Grid Exports: Summary Points

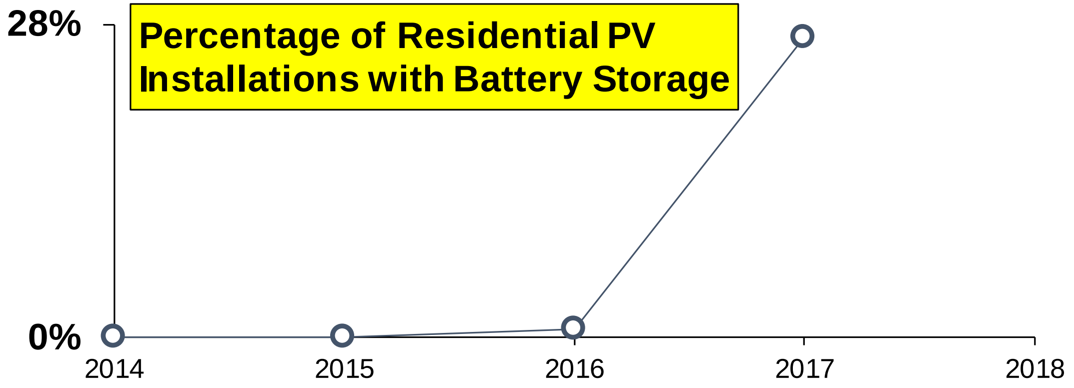
- A typical residential PV system exports ~40-60% of annual generation
  - Based on hourly netting; higher export percentage if instantaneous or 15-min netting
  - Grid export tariffs only address issues associated with this portion of PV generation
- PV exports have a similar temporal profile to gross PV generation
  - By extension, unmanaged grid exports have similar per-kWh value as gross PV generation
- Options for meaningfully managing grid exports are limited
  - Orienting panels westward has a modest impact on temporal profile; likely provides only marginal value to the customer and utility
  - Reducing system size reduces exports, but not proportionally; systems would need to be extremely small to substantially reduce annual exports
  - Load shifting options for many customers may be limited to A/C; more-significant shifting likely requires electrified water/space heating or EVs
  - Battery storage will generally be the only feasible option for most customers to significantly reduce exports

Outline

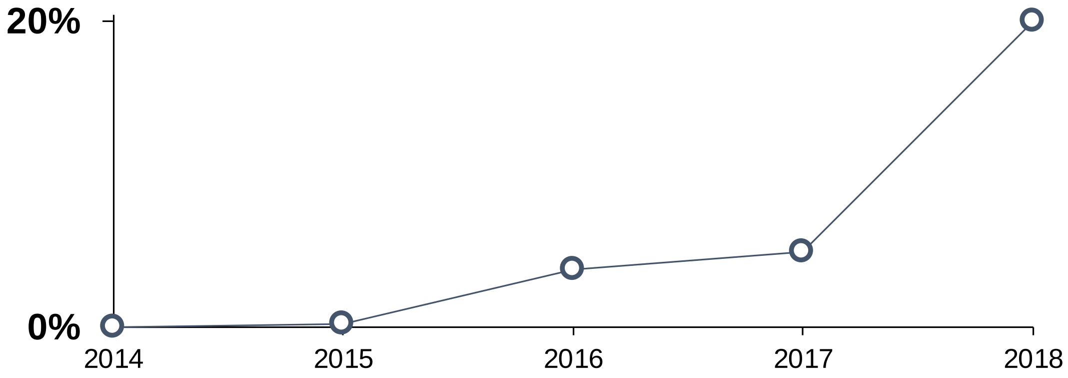
1. General impacts of solar-export credit rates
2. Grid exports and strategies for managing exports
3. **Battery storage economics for managing grid exports**

Recent rate reforms for NEM customers have prompted rapid growth of solar + storage in several states

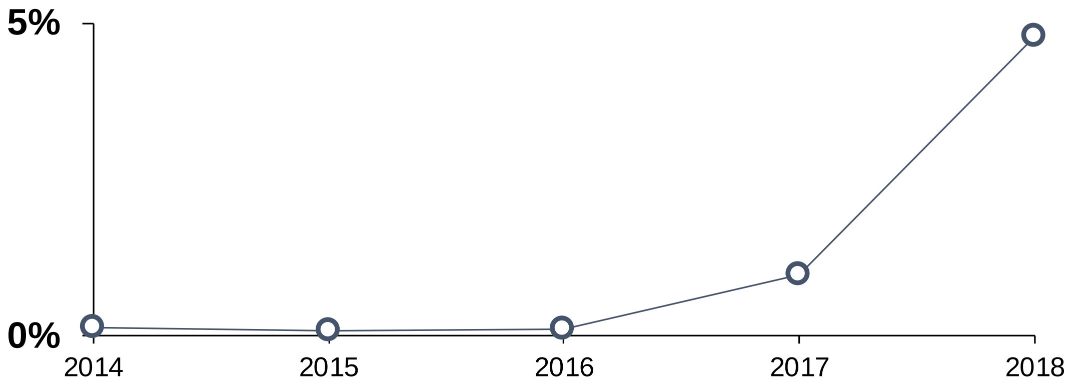
Hawaii (*grid export credit rates or prohibition on exports)*



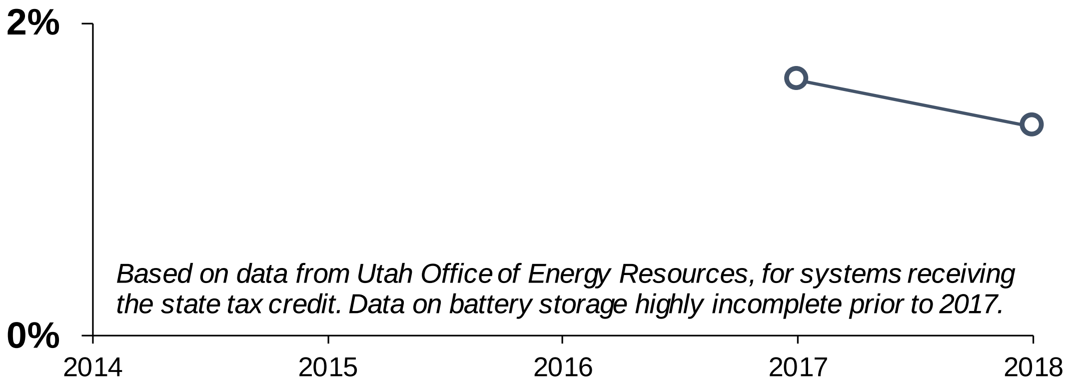
Salt River Project *(demand charges for PV customers)*



California *(TOU rates required for solar PV customers)*



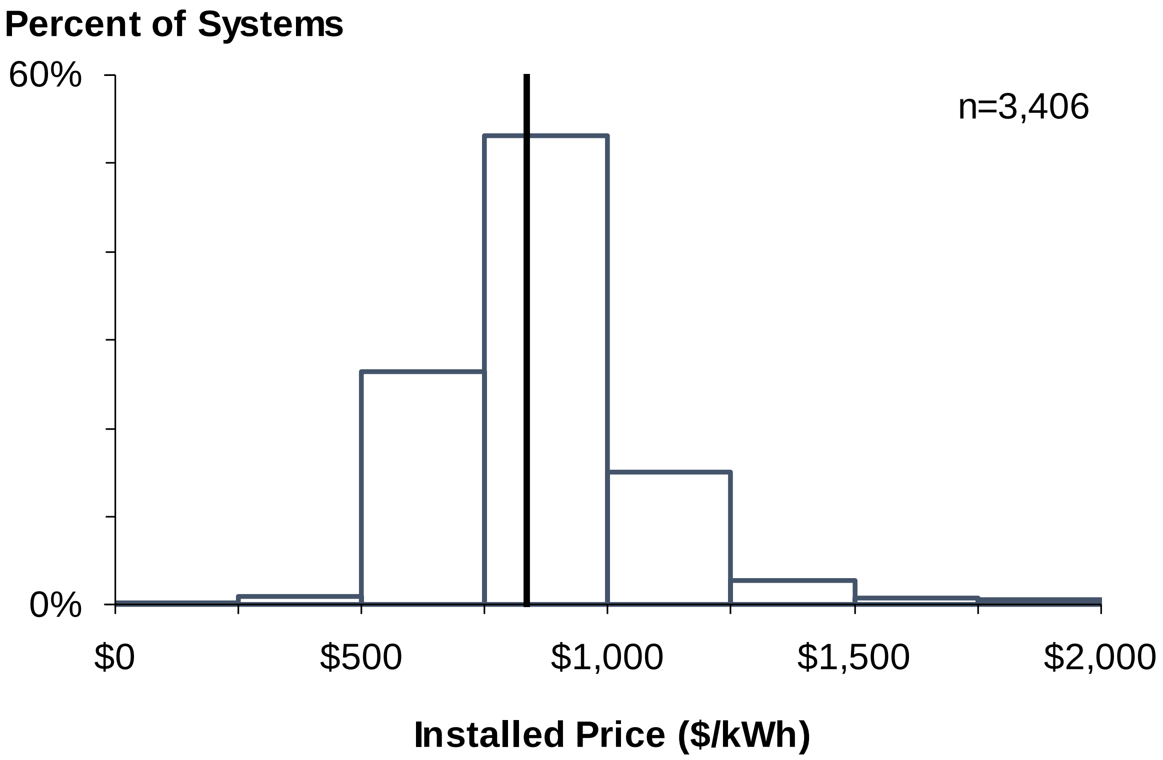
Utah *(for comparison)*



Installed Prices for Residential Battery Storage Systems

- Among systems installed through CA's SGIP in 2018:
  - Median reported price of $833/kWh
  - But fairly wide spread, with most systems ranging from $500-1,250/kWh
  - Lower end of that spread likely represents under-reporting of total costs
- Residential battery storage market is still in early stages of development and prices projected to decline rapidly
  - E.g., WoodMac and Lazard both project 8% per year decline, for Li-ion battery packs

Installed Price of Residential Battery Storage Systems Interconnected in 2018

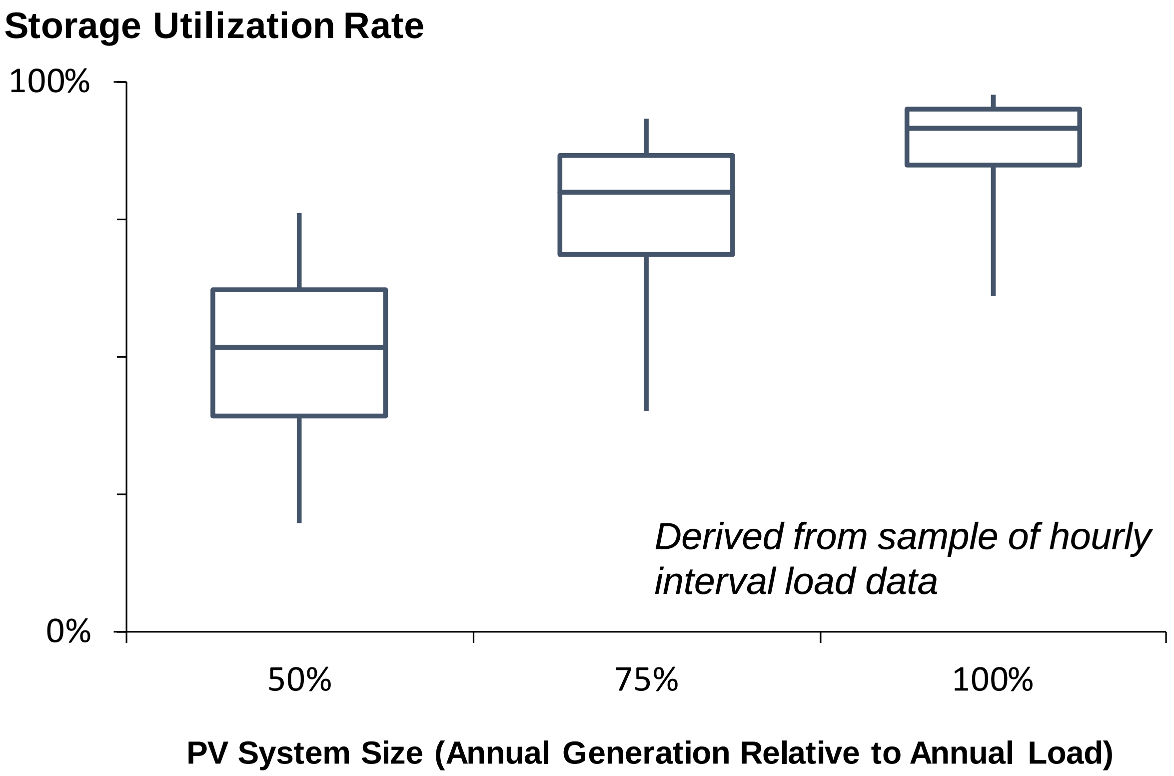


Source: California's Self-Generation Incentive Program (SGIP)

Storage Utilization Rates for Managing Grid Exports

- Storage utilization rate (aka duty cycle) refers to the average depth of daily discharge
- A key driver for storage economics when used to arbitrage between grid export rates and retail rates
- Under grid export rates, constrained by the amount of exports
  - In turn, a function of PV system size and coincidence with customer load (see figure)
  - For typical PV system sizing, storage utilization rates might be expected to range from 50-90%

Example: Utilization rates for a 13-kWh/5-kW battery storage system under a grid export tariff



Customer Economics of Storage for Managing Exports

Would it be economic for a customer to install storage, solely to manage grid exports?

	Bookend 1	Bookend 2
Delta between average retail and grid export rates	$0.05/kWh	$0.15/kWh
Battery storage up-front cost (pre-ITC)	$1250/kWh	$500/kWh
Storage utilization rate	50%	90%
Payback period (with ITC)	***137 years***	***9 years***

Bottom line: *Under highly favorable conditions, battery storage could be a (marginally) economical customer investment, just on the basis of managing grid exports.*
But how well do these customer-economics align with the value to the utility system?

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Rate design dictates how customers operate storage

Comparison of storage control strategies

	Grid Export Tariffs with Flat Rates	Hourly Time-Varying Rates
Charging strategy	Charge as soon as possible each day, once PV begins exporting	Concentrate charging during low-cost periods
Discharging strategy	Delay as long as possible, to preserve charge in case of outage	Concentrate discharge during system or local peak demand hours

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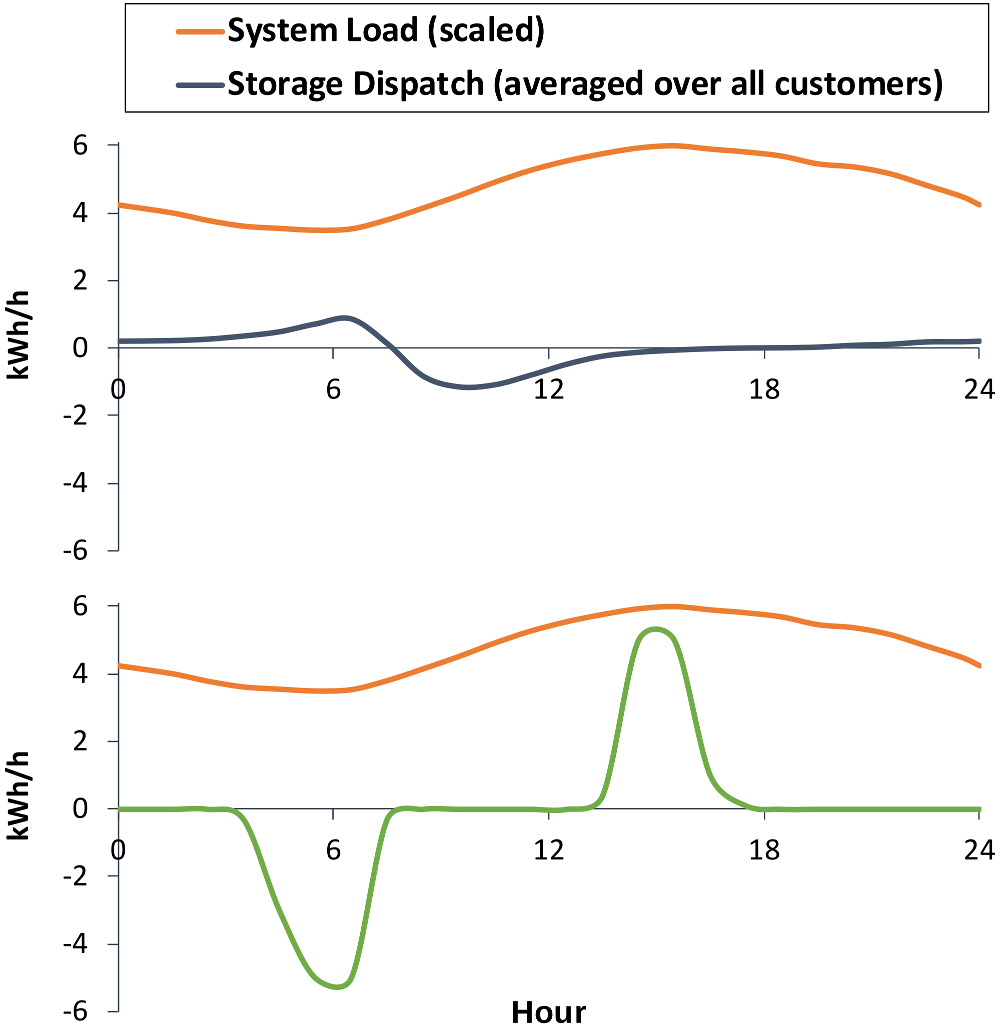
…which in turn determines its value to the utility system

Storage Dispatch on the System Peak Day

Grid Export Tariffs with Flat Rates

Hourly Time-Varying Rates



Capacity credit ≈ 0%

- Relatively little PV exports on peak load days
- No price signal for when to discharge

Capacity credit = 20-100%

- Range reflects different calculation methods
- Constrained by energy-limited nature of battery storage

The value of energy storage under a grid export tariff with flat rates vs. an idealized time-varying rate

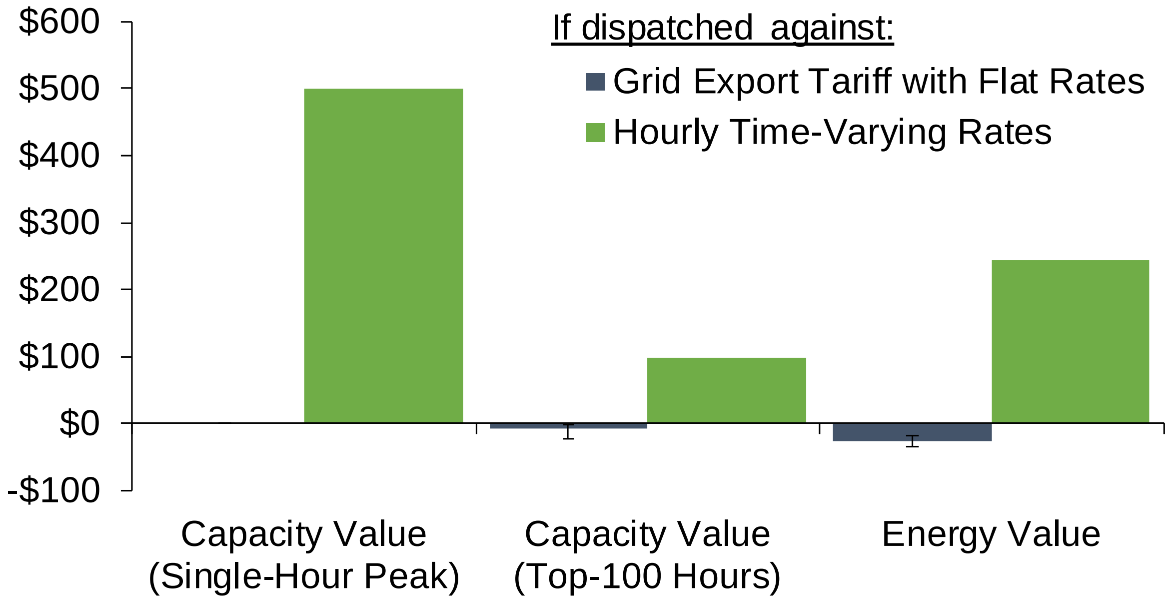
Considering just capacity and energy value to the bulk power system…

- Battery storage dispatch against grid export tariffs with a flat rate provides effectively **no value** (or slightly negative value) to the utility system
- In contrast, dispatch against hourly time-varying rates would yield energy and capacity savings of **$350-750/year** for a 5-kW/13-kWh battery storage system, depending on how capacity credit is determined

Battery Storage Capacity & Energy Value

Illustrative comparison under two dispatch strategies

Annual utility-system value of 5-kW/13-kWh battery storage unit



Notes: Capacity credit under each dispatch scenario based on NV Energy system hourly loads for 2013. Capacity value then estimated based on an assumed long-run marginal cost of capacity equal to $100 per kW of utility peak demand. Energy value calculated using 2013 CAISO real-time hourly market prices for the SUMMIT_ASR-APND hub, located in Southern Nevada. For the grid export tariff, the bars represent median values, and the error bands represent the 20th and 80th percentile values, across the 342 residential customer load profiles in our sample.

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Customer Economics of Storage if Compensated Directly for Capacity and Energy Value

Capacity value ($/kW-storage)	$20-100/kW-yr
Energy value ($/kWh-storage)	$19/kWh-yr
Storage system up-front cost ($/kWh-storage)	$500-1250/kWh
Customer payback period (with ITC)	***6-33 years***

Per the methods, data sources, and assumptions described on the previous slide

- Could be an economic customer investment, under favorable conditions
- Other potential sources of system value (e.g., local voltage regulation and ancillary services) could further bolster these returns if communicated via rates or otherwise
- Ability to ride through customer outages may provide some additional private value

Battery Storage for Managing Grid Exports: Summary

- Grid export tariffs can incentivize customers to install storage as a means of managing grid exports (if the price delta is high enough)
  - As evident in several jurisdictions that have already adopted grid export tariffs
- But using storage to arbitrage between retail rates and grid export rates does not necessarily provide commensurate value to the utility or ratepayers
  - Charging and discharging will often occur at times that provides only limited value to the utility system
  - Moving PV exports back behind-the-meter may re-ignite issues related to embedded-cost recovery (defeating one purpose of grid export tariffs)
- BTM storage can provide significant value to the utility system
  - But requires price signals that are more closely coupled to utility cost structure

Contacts

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Background: *Impacts of roof-space constraints on non-residential PV system sizing*

Table 3. Characteristics of DOE Commercial Reference Buildings

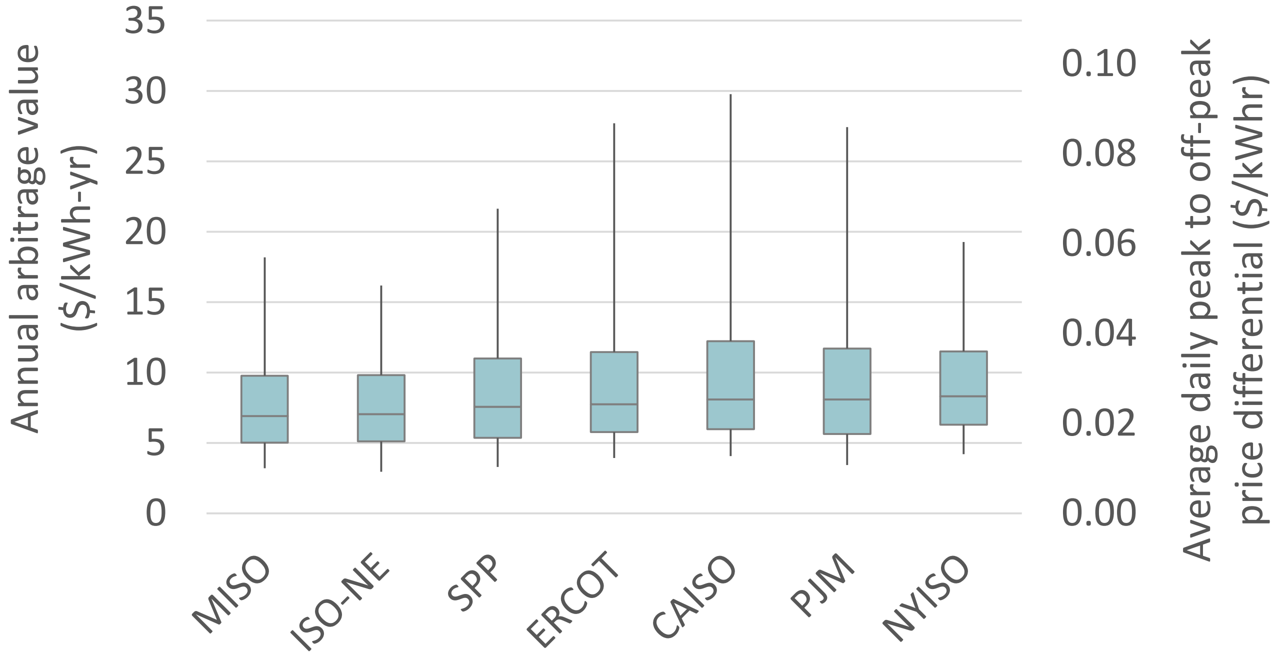
All Locations					Example location[9] (Phoenix, AZ)		
Building Type	Floor Area (ft²)	Number of Floors	Estimated Roof Area (ft²)	Maximum System Capacity[10] (kW)	Annual Building Load (MWh)	Peak Building Demand (kW)	Annual Energy Offset with PV
Full-Service Restaurant	5,500	1	5,500	26	322	68	11.5%
Hospital	241,351	5	48,270	296	9,287	1,510	4.7%
Large Hotel	122,120	6	20,353	96	2,842	553	5.7%
Large Office	498,588	12	41,549	255	6,244	1,580	5.4%
Medium Office	53,628	3	17,876	84	742	318	16.9%
Outpatient	40,946	3	13,649	64	1,388	321	6.7%
Primary School	73,960	1	73,960	454	888	328	67.4%
Quick-Service Restaurant	2,500	1	2,500	12	194	39	9.0%
Secondary School	210,887	2	105,444	647	3,193	1,178	20.8%
Small Hotel	43,200	4	10,800	51	600	133	12.0%
Small Office	5,500	1	5,500	26	66	19	51.1%
Standalone Retail	24,962	1	24,962	118	327	104	46.8%
Strip Mall	22,500	1	22,500	106	297	93	48.7%
Supermarket	45,000	1	45,000	276	1,687	367	24.5%
Warehouse[11]	52,045	1	52,045	188	269	96	100%

Source: Davidson, C., P. Gagnon, P. Denholm, and R. Margolis. 2015. *Nationwide Analysis of U.S. Commercial Building Solar Photovoltaic (PV) Breakeven Conditions*. Golden, CO: National Renewable Energy Laboratory.

- Roof-space constraints often limit roof-mounted PV to <25% of non-residential annual energy needs
- Grid exports may therefore be negligible for many non-residential systems
- Some important exceptions
  - Warehouses
  - Schools (seasonally)
  - Ground-mounted and shade structures

Storage arbitrage value in wholesale energy markets

Annual value of bill savings from RTP arbitrage
Based on historical day-head hourly prices



Notes: Based on prices from 100 randomly selected price nodes for each ISO from 2009 or latest market redesign (whichever is later) through August 2018. Storage assumed to be able to charge and discharge fully in the two lowest and highest priced hours of each day, respectively. Box plots represent 5th, 25th, 50th, 75th, and 95th percentiles.

- RTP most common among industrial customers though overall number of customers small compared to TOU (Nezamoddini and Wang 2017)
- RTP arbitrage value has relatively low range and variability across years and markets
  - Typically $6-$14 per kWh of storage per year, though some nodes experience higher price volatility
- Reflects fairly limited differential between average peak and off-peak prices
- Greater hourly variability and arbitrage value possible if:
  - Retail RTP also reflects temporal variability in marginal transmission and distribution costs
  - Growing PV penetration leads to greater price volatility