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Solar Plus: A Holistic Approach to Distributed Solar PV

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Solar Plus

Solar plus refers to an emerging approach to distributed solar photovoltaic (PV) deployment that uses energy storage and controllable devices to optimize customer economics.

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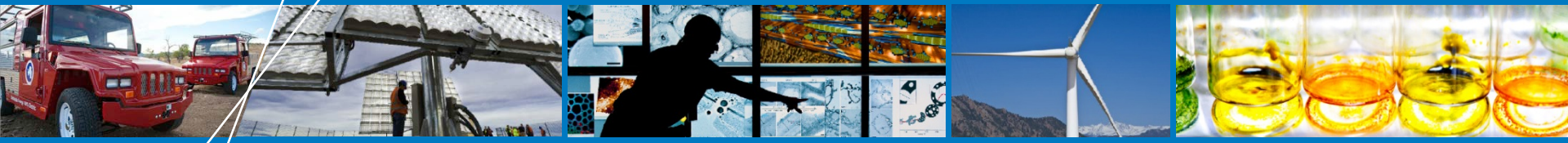
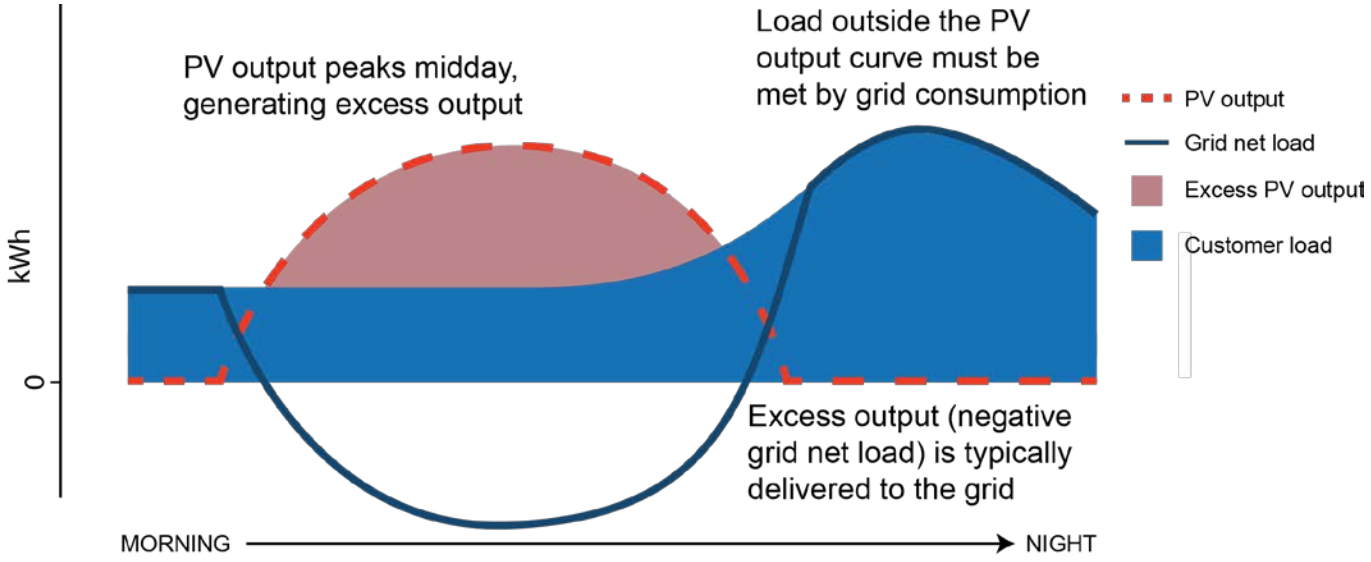


Introduction

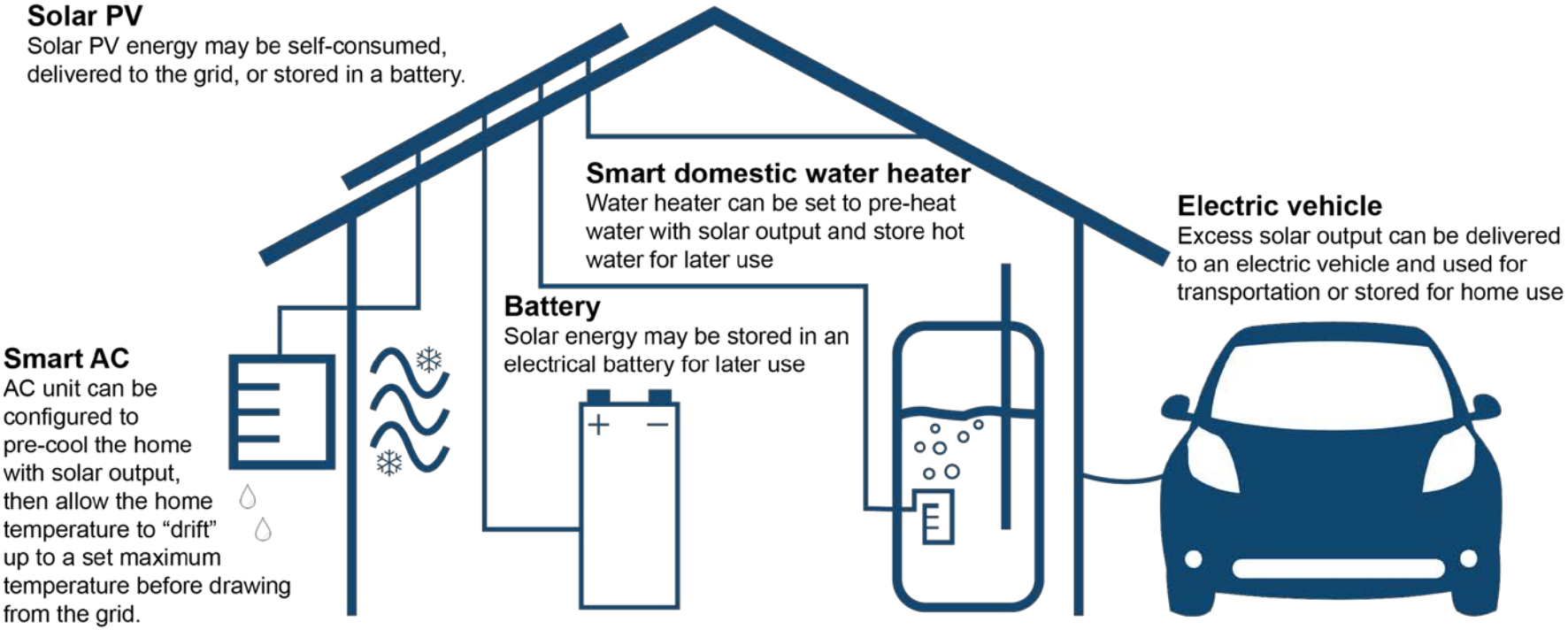
Maintaining PV Value as Rates Evolve



- Net metering addresses the temporal mismatch between PV output and customer load by compensating excess output
- But lower net metering rates and other rate reforms could reduce the value of PV under net metering programs
- **Solar plus could mitigate PV value loss by providing a technical solution to the mismatch between PV output and customer load**

Solar Plus Technologies

Solar plus increases customer system value through technologies such as electric batteries, smart domestic water heaters, smart air conditioner (AC) units, and electric vehicles (EVs).



How Does Solar Plus Work?

- Solar plus optimizes customer economics through load shifting.
- Solar plus technologies shift customer loads "under" the PV output curve, reducing grid electricity use.
- In time-of-use (TOU) rate structures, solar plus technologies can also shift grid electricity use from high-rate to low-rate periods.

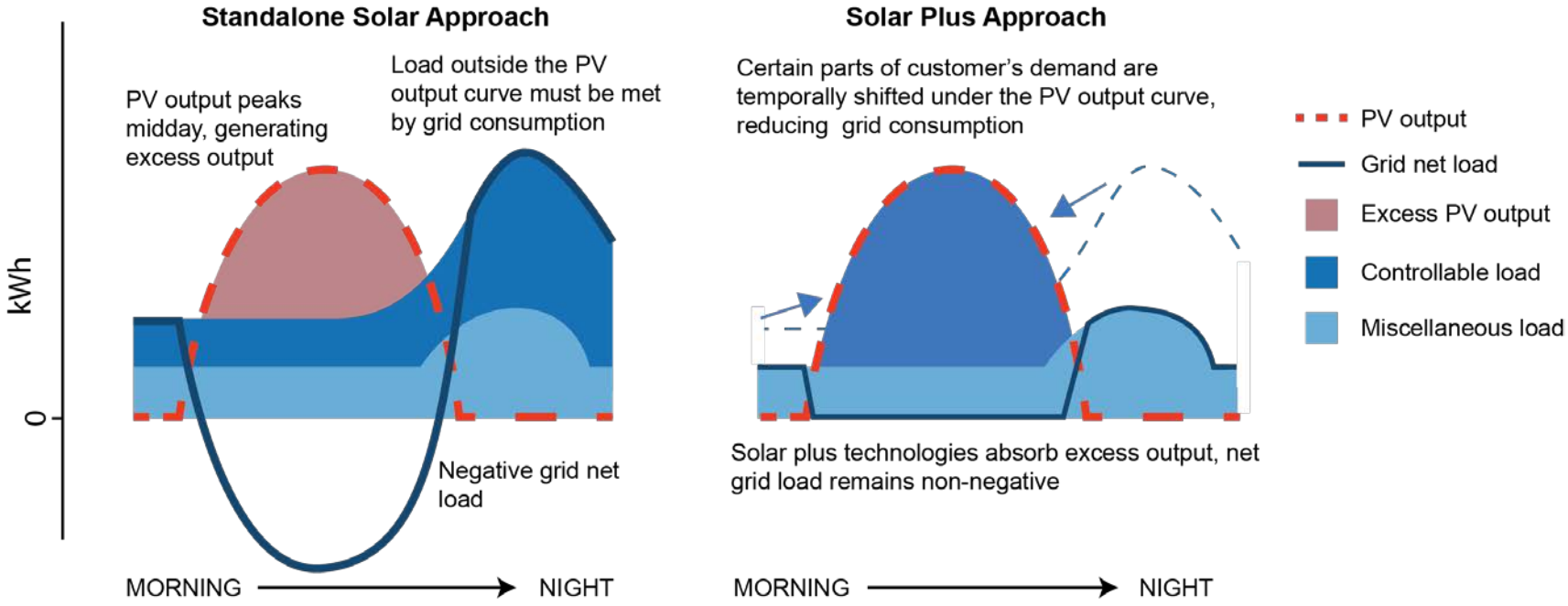
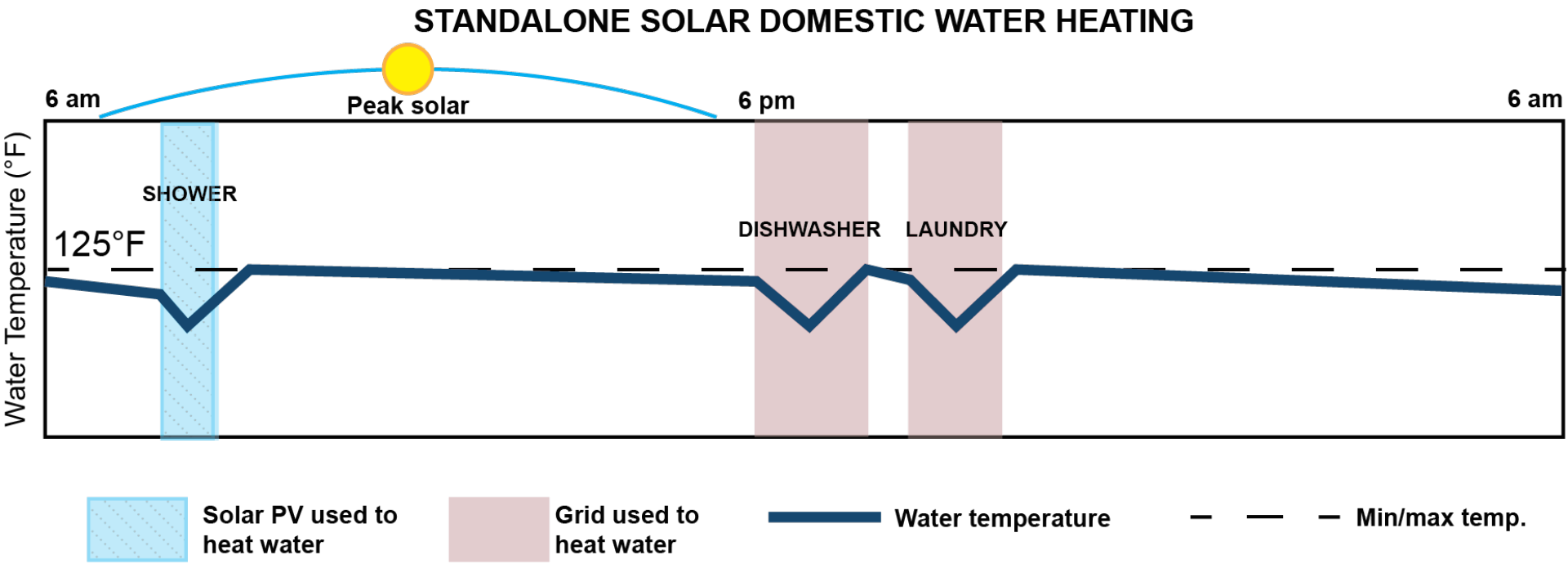


Figure note: "Grid net load" refers to customer load at the meter, the net sum of customer load and PV output. Negative grid net load reflects PV exports to the grid.

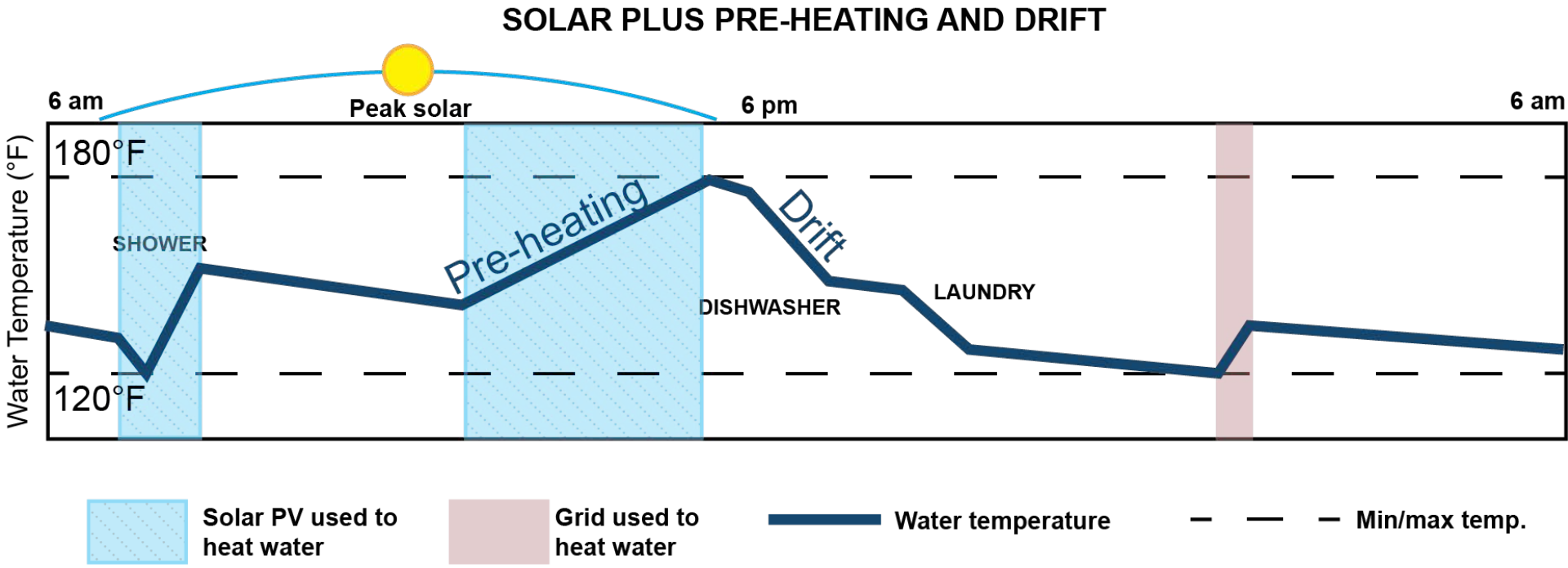
Traditional Water Heating

Typical electric water heaters heat water after each hot water draw to keep water around a target temperature (e.g., 125°F)



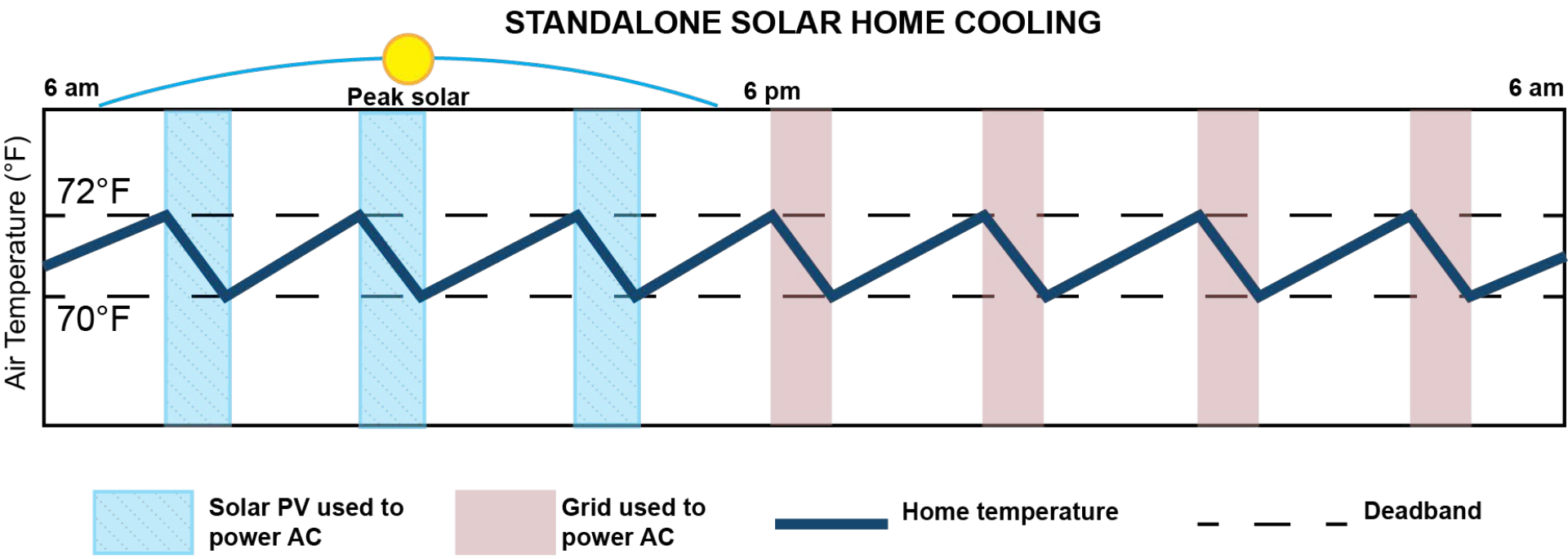
Smart Water Heating

The smart domestic water heat controls how and when the unit heats water. The unit uses PV output to pre-heat water to 180°F. After PV is no longer available, the unit allows water temperature to "drift" down to 120°F without using grid electricity to heat water.



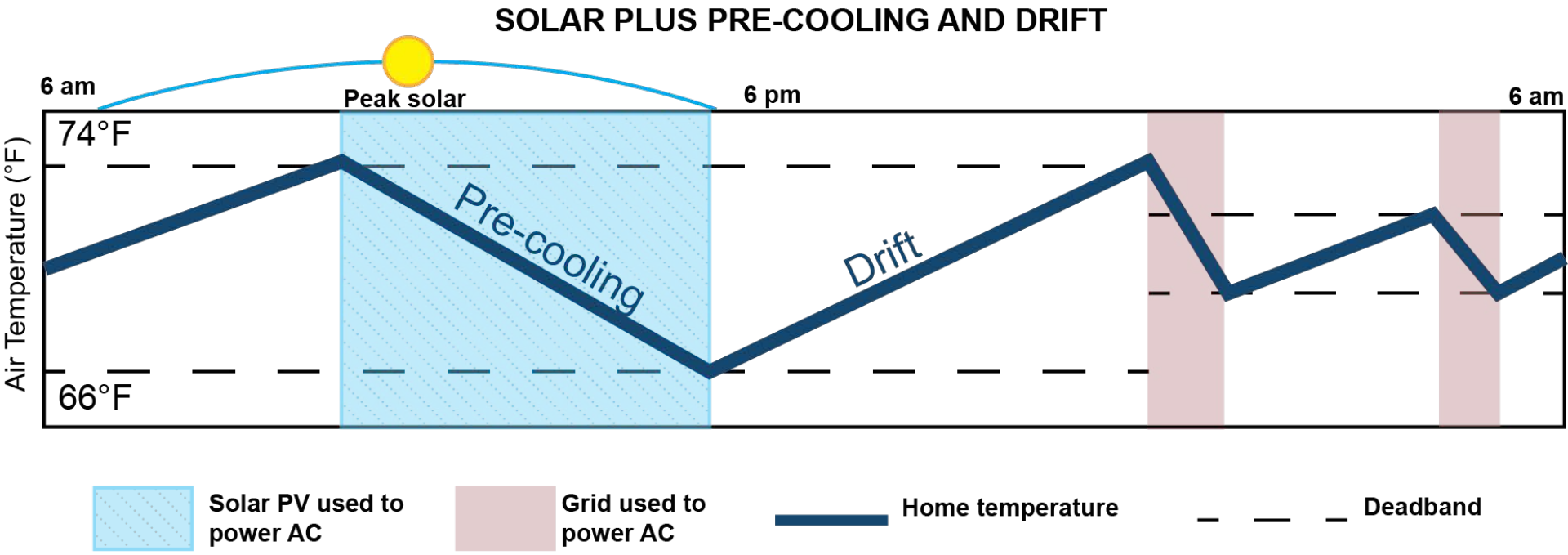
Traditional AC

A traditional AC unit maintains home temperature within some "deadband" (e.g., 70°F-72°F). The AC unit turns on each time the home's temperature reaches the upper end of the deadband.



Smart AC

The smart AC unit controls how and when the AC unit cools the home. The AC unit uses PV output to pre-cool the home to 66°F. The AC unit then allows the home's temperature to "drift" up to 74°F without using grid electricity.



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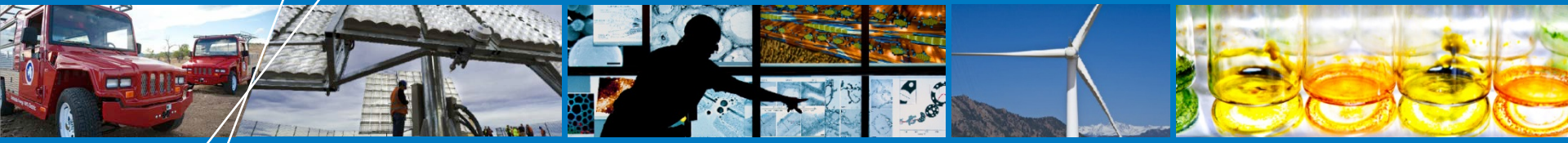


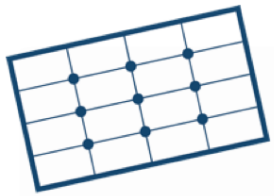
Methods

NREL REopt Model

- We use NREL's Renewable Energy Optimization (REopt) tool to model the economics of solar plus.
- For more information about REopt visit: http://www.nrel.gov/tech_deployment/tools_reopt.html.

Candidate Technologies

REopt deploys optimal combinations of PV, a battery, and smart load control to optimize customer economics based on customer bill savings.



PV

Electrical battery

Smart domestic water heater

Smart AC unit

Many other technologies, such as EVs, can serve as solar plus technologies. With EVs, customers could schedule vehicle charging to coincide with peak PV output. However, EV ownership is currently low in the United States, and EVs are not a solar plus option in our analysis.

Modeled Home

Customer loads are modeled using NREL's Building Energy Optimization model and typical meteorological year data. The modeled home is a 199-m^2 house with 3 bedrooms, 2 bathrooms, and 1.5 stories. More complete technical assumptions are available in the full report.

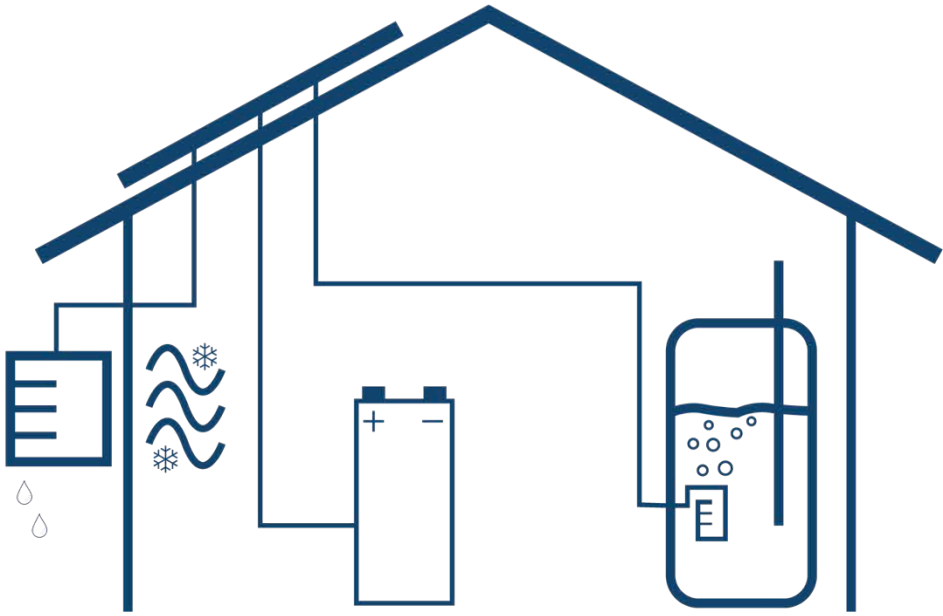
Scenarios

Standalone Solar

REopt is limited to deploying only a PV system and determines an optimal PV system size.

Solar Plus

REopt determines an optimal configuration of PV, battery, smart AC, and smart domestic water heater.



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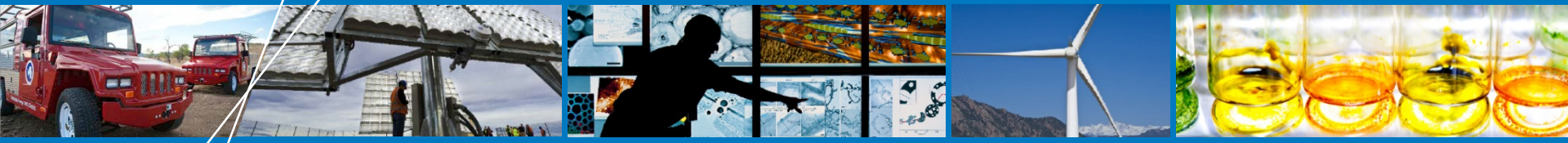


Sensitivity Analysis

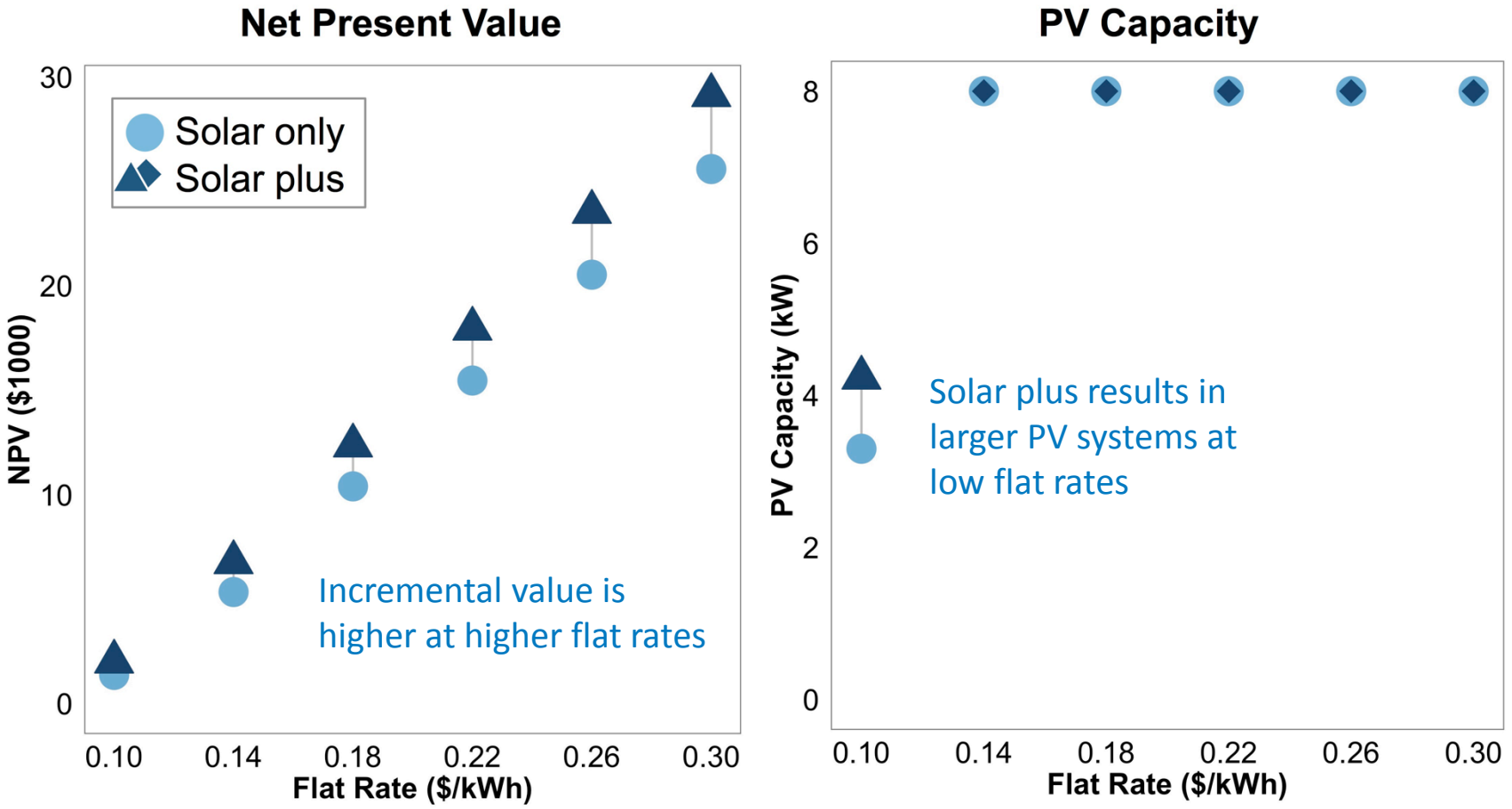
Sensitivity Analysis

- To model the economics of solar plus under different rate structures, we allow certain rate parameters to vary while holding all other factors constant.
- We use REopt to determine optimal combinations of solar plus technologies under different rate assumptions
- We estimate the system's net present value (NPV) of the system at each rate assumption
  - NPV is calculated relative to what the customer would pay without a PV system
- See technical report for all techno-economic assumptions.

Rate Parameters

- **Flat rates:** Customers pay a constant "flat" volumetric rate ($/kWh).
- **TOU rates:** Customers pay time-varying volumetric rates ($/kWh). The TOU "delta" refers to the difference between the peak and off-peak rates.
- **Net metering rates:** Customers are compensated ($/kWh) for excess PV output delivered to the grid.
- **Demand charges:** Fees are assessed based on peak demand ($/kW) during some period.
- See technical report for all assumptions.

Varying Flat Rates

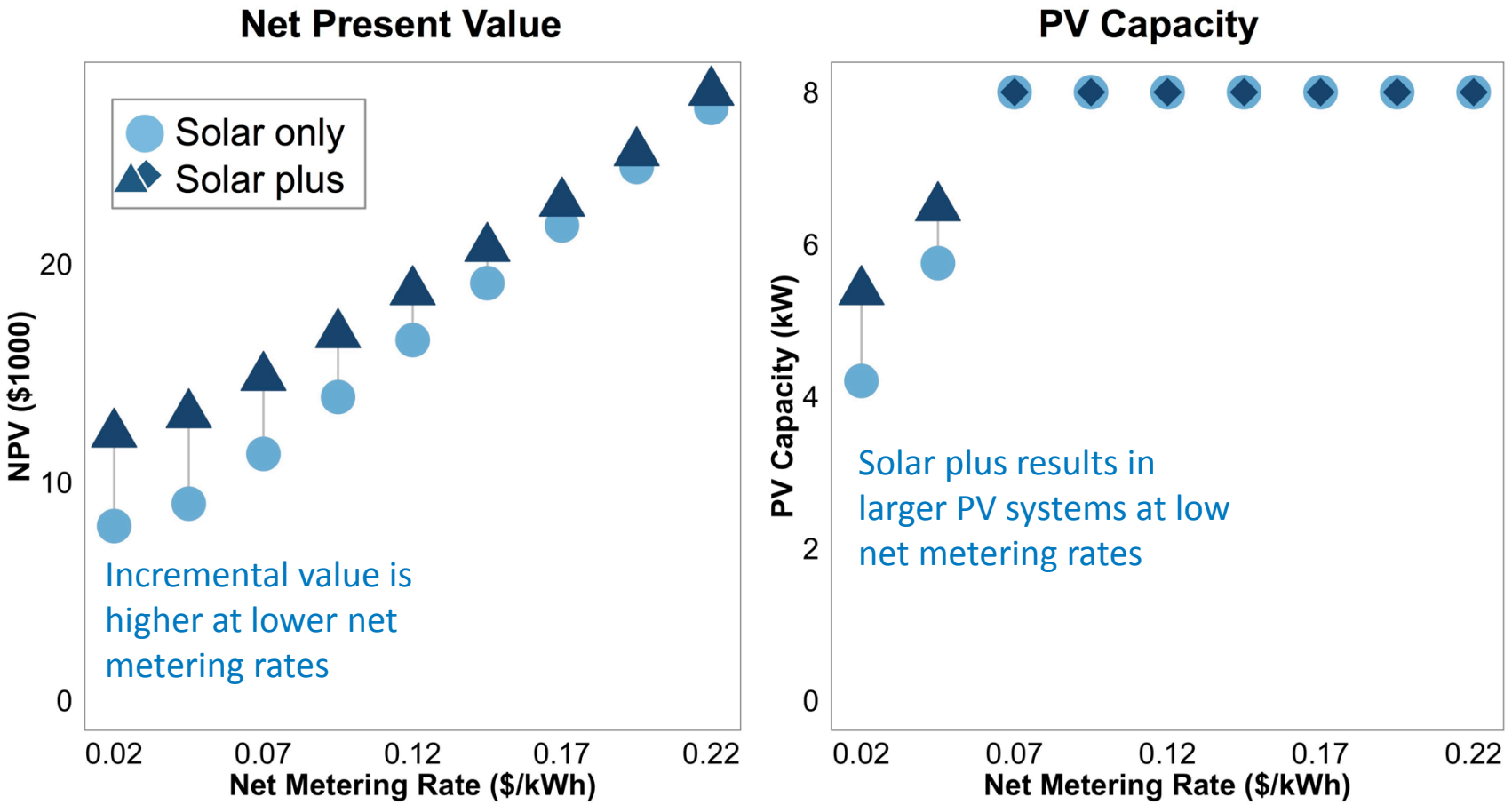


The Economics of Solar Plus Under Different Flat Rates

Assumptions: Net metering rate is half of flat rate at every step.

REopt deploys the smart AC unit and smart domestic water heater at all flat rates, but it does not deploy a battery under our assumptions

Flat Rates: Varying Net Metering Rates

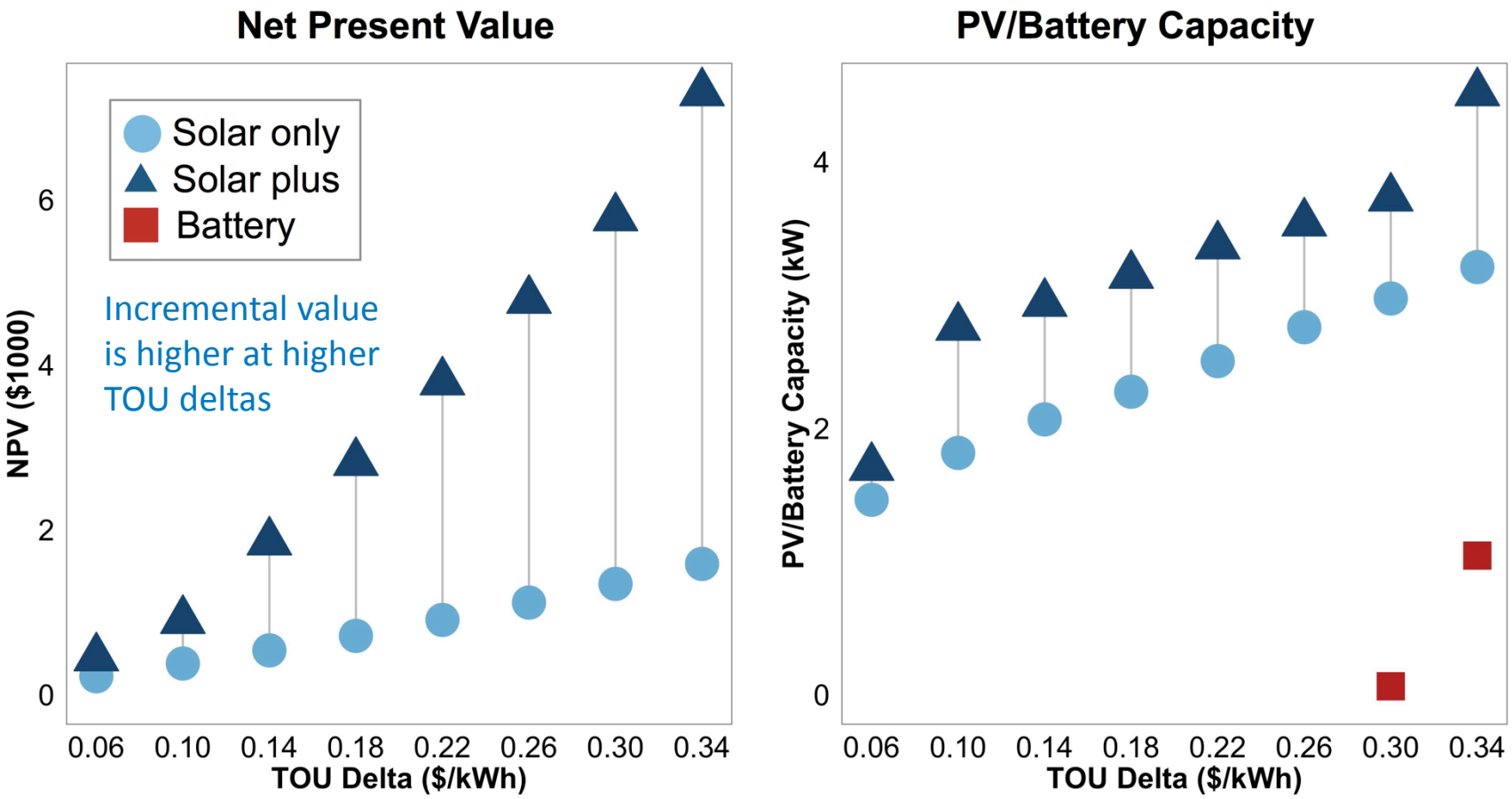


The Economics of Solar Plus Under Different Net Metering Rates

Assumptions: Flat rate of $0.22/kWh.

REopt deploys the smart AC unit and smart domestic water heater at all net metering rates, but it does not deploy a battery.

TOU Rates: Varying TOU Deltas

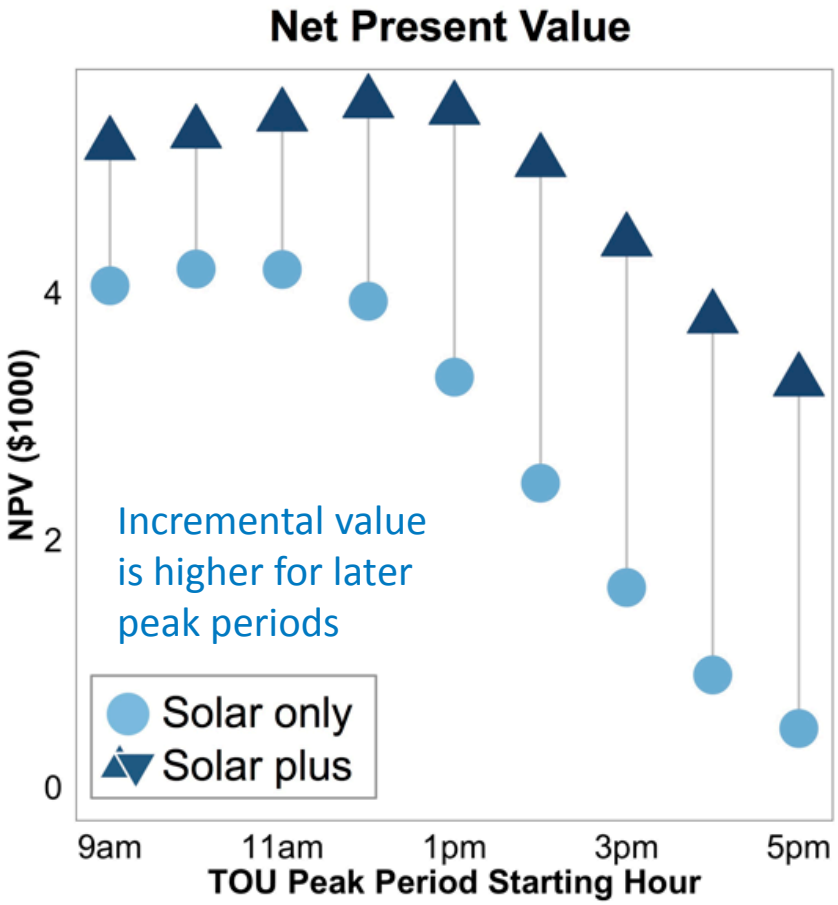


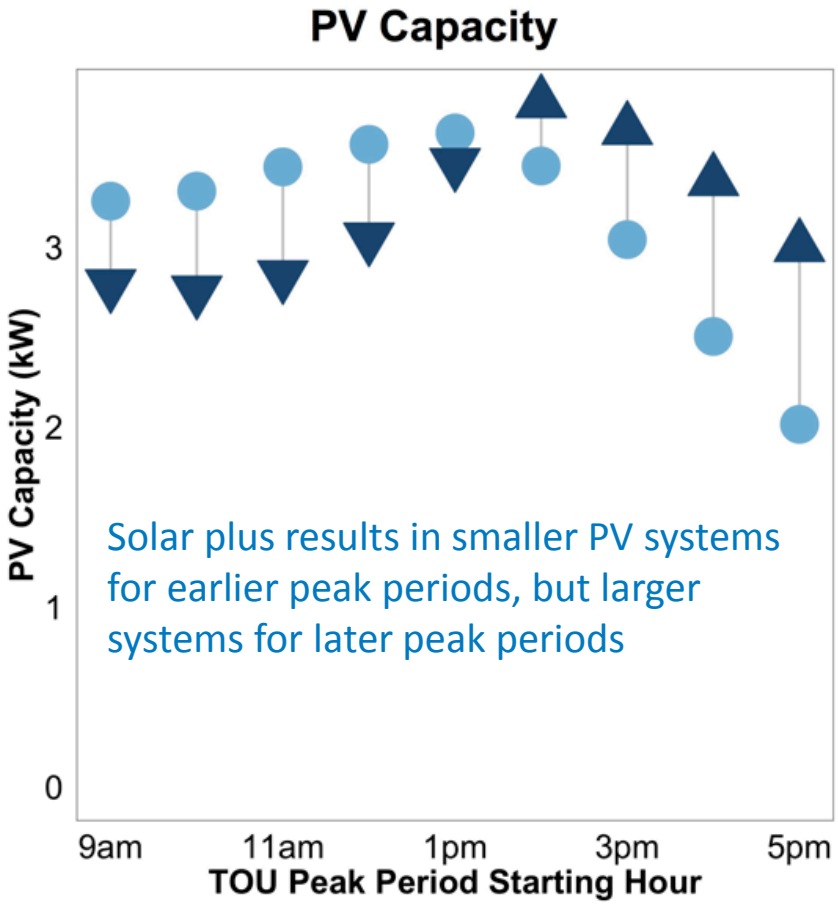
The Economics of Solar Plus Under Different TOU Deltas

Assumptions: Off-peak rate is $0.08/kWh, net metering rate is $0.03/kWh, peak period is 4pm-9pm.

REopt deploys the smart AC unit and smart domestic water heater at all TOU deltas (differences between peak and off-peak rates), and it deploys a battery at TOU deltas above $0.26/kWh

TOU Rates: Varying Peak Period Timing





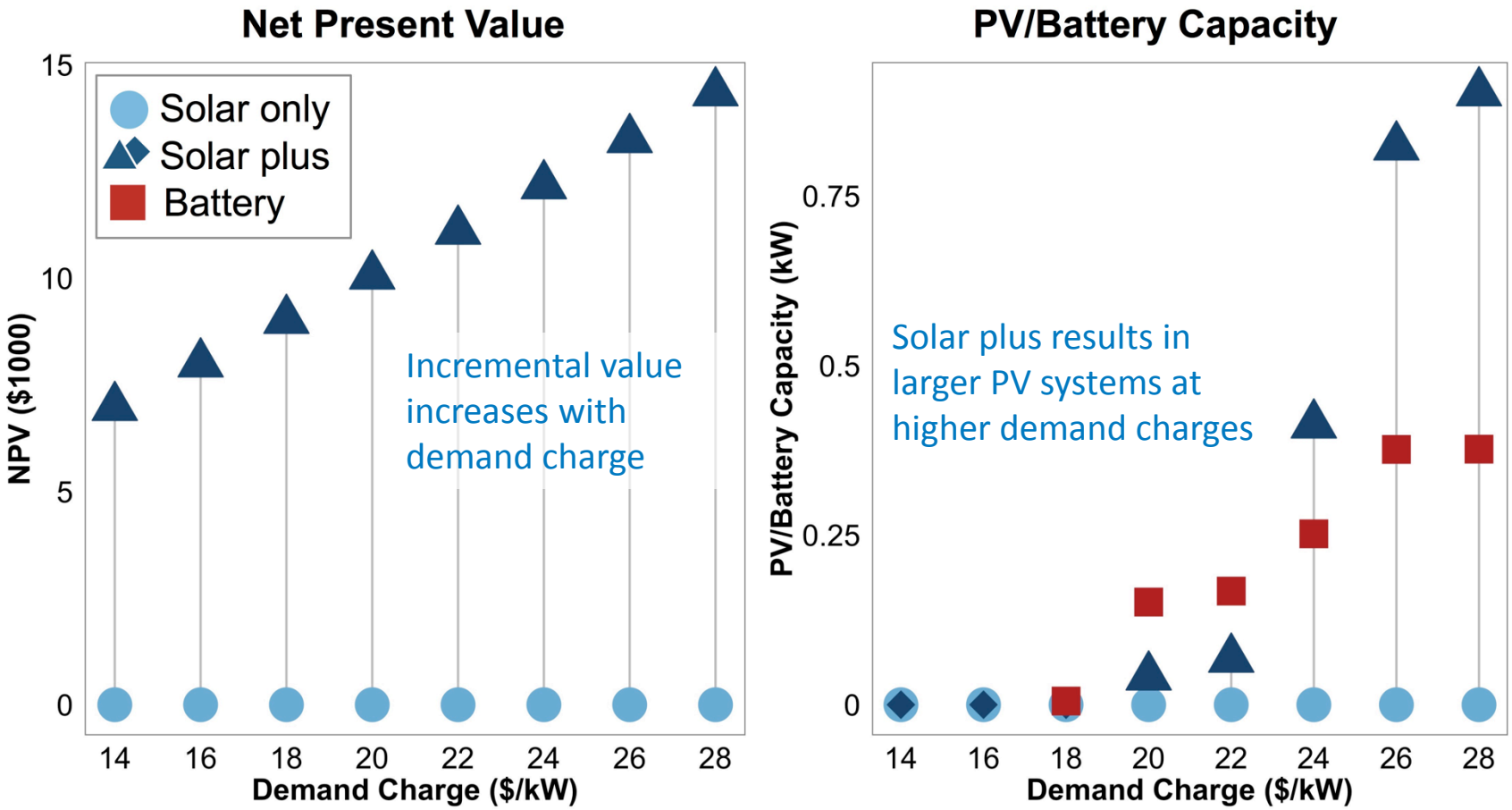
The Economics of Solar Plus with TOU Rates and Different Peak Rate Periods

Each point on x-axis represents beginning of a 5-hour peak rate period.

Assumptions: Off-peak rate of $0.08/kWh, on-peak rate of $0.22/kWh, net metering rate of $0.03/kWh.

REopt deploys the smart AC unit and smart domestic water heater, but no battery, under all peak rate periods.

Flat Rates: Varying Demand Charges



The Economics of Solar Plus Under Different Demand Charges

Assumptions: Flat rate of $0.06/kWh, net metering rate $0.03/kWh.

REopt deploys a smart AC unit and smart domestic water heater at all demand charges, and it deploys a battery for demand charges above $16/kW

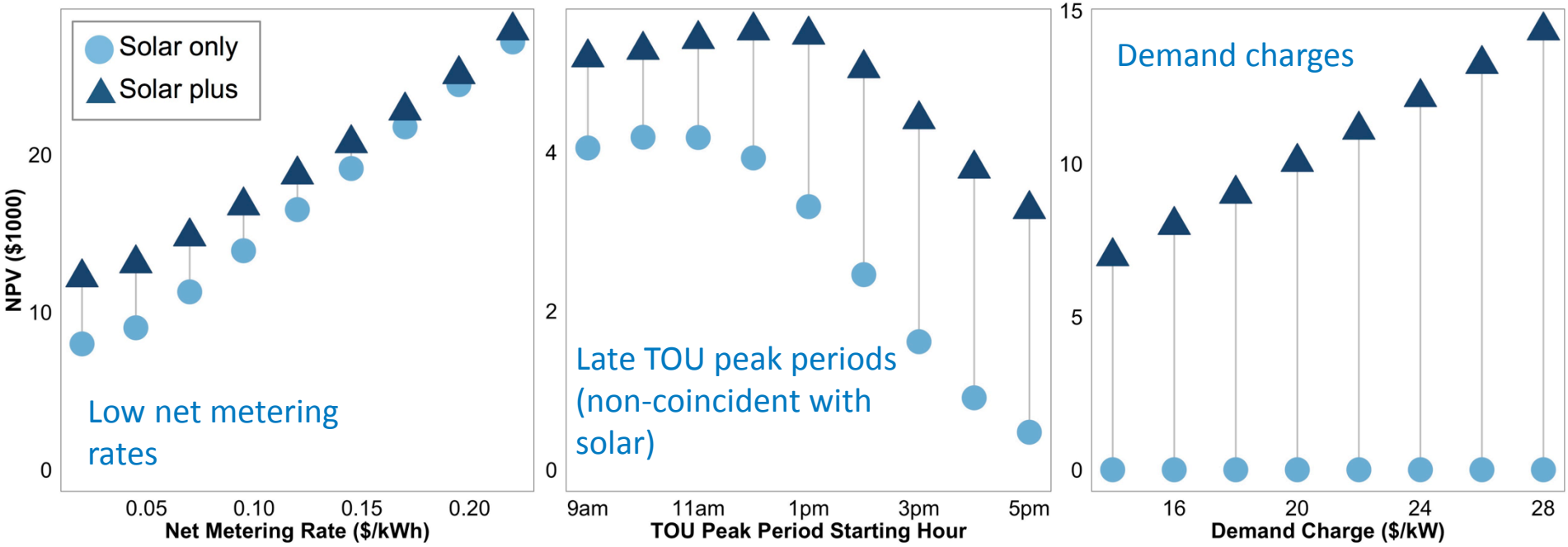
Sensitivity Analysis Summary

- Solar plus improves system value under all rate structures with less-than-retail rate net metering.*
- The incremental value of solar plus is greater for customers with:
  - High flat rates
  - Low net metering rates
  - High TOU peak rates
  - Peak rate periods that do not coincide with PV output
  - High demand charges

* Solar plus also improves system value with full retail rate net metering for customers with TOU rate structures or demand charges.

Sensitivity Analysis Summary

The incremental benefits of solar plus are higher for rate designs that are generally less favorable for PV economics:



The results suggest that solar plus may mitigate some of the negative impacts of certain rate designs on PV economics.

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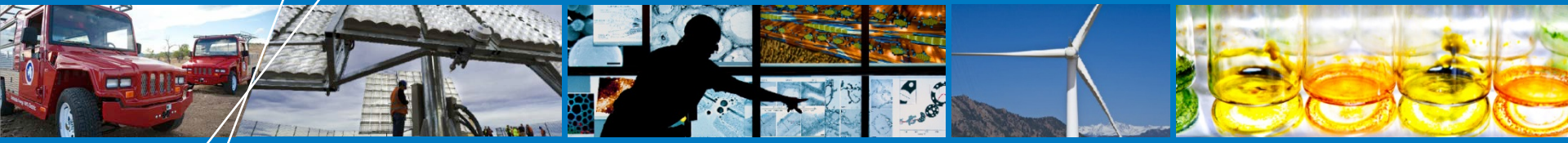


Case Studies

Hawaii Self-Supply Rate

- In late 2015, the Hawaii PUC effectively ended net metering with the approval of a "self-supply" rate.
- Case study based on a home in Honolulu.

RATES ($/kWh)	TOU PERIODS	NET METERING
Peak: $0.35	Peak: 5pm-10pm	None
Off-peak: $0.22	Off-peak: 10pm-9am	
Midday $0.13	Midday: 9am-5pm	

Abbreviations used in the following figures: AC = air-conditioner load, BESS = battery energy storage load (system charging), DHW = domestic hot water load, Misc = miscellaneous customer load (other than AC and DHW).

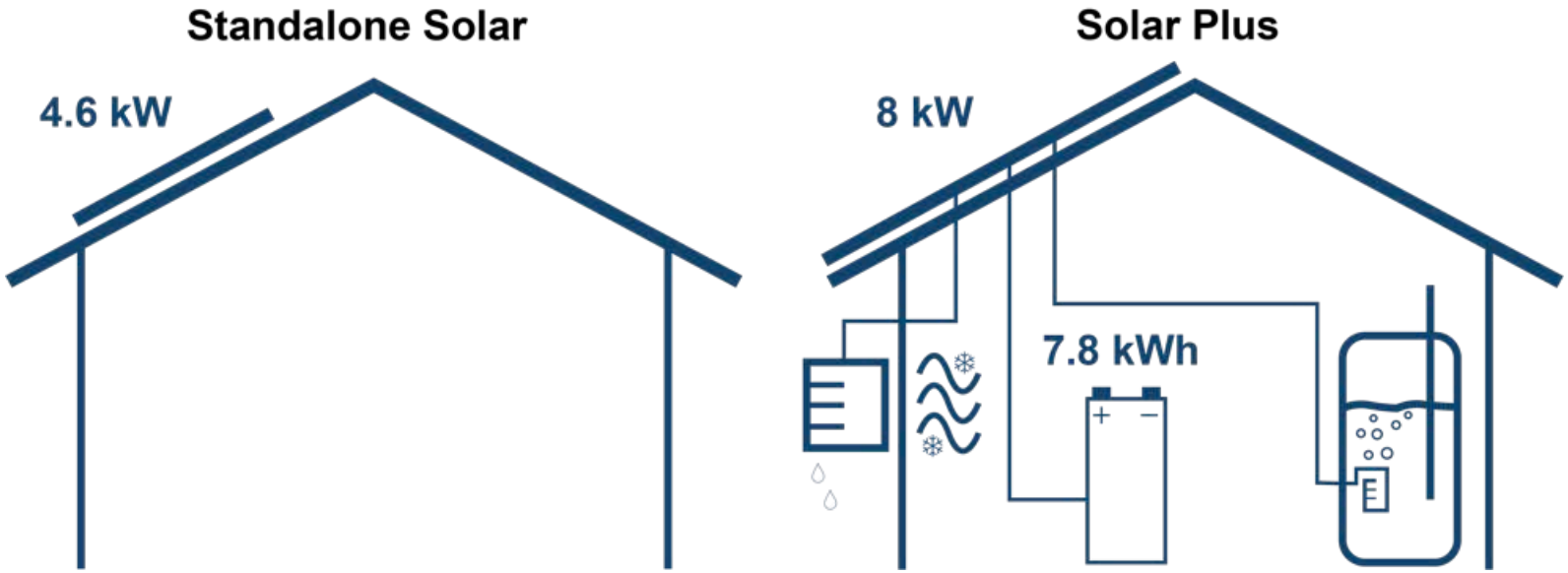
Results: Hawaii

System Deployments

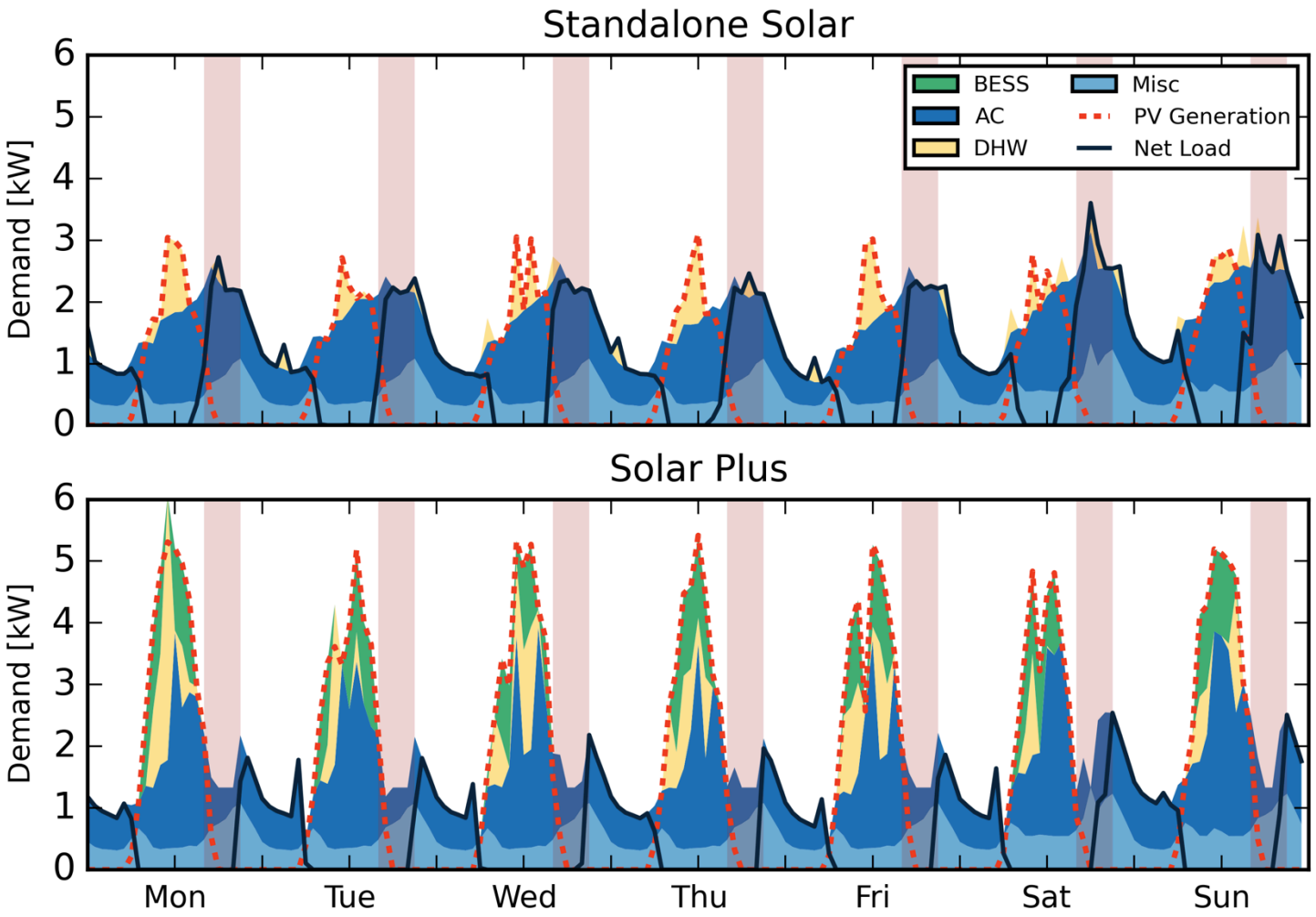
Standalone Solar	Solar Plus			
PV	**PV**	**Smart DHW**	**Smart AC**	**Battery**
4.6 kW	8 kW	Deployed	Deployed	7.8 kWh

System NPVs

Standalone Solar	Solar Plus
$5,684	$16,851



Results: Hawaii



Hawaii PV and Customer Load Profiles under Standalone Solar and Solar Plus Approaches (based on week in August)

TOU peak periods depicted by shaded columns

Nevada Declining Net Metering

- Following a 2015 ruling, net metering is scheduled to decline from $0.092/kWh in 2016 to $0.026/kWh in 2028.
- Case study based on a home in Las Vegas.

RATES	TOU PERIODS	NET METERING
Volumetric: $0.106/kWh Service charge: $29.23/mo	None (flat rate)	$0.055/kWh

Results: Nevada

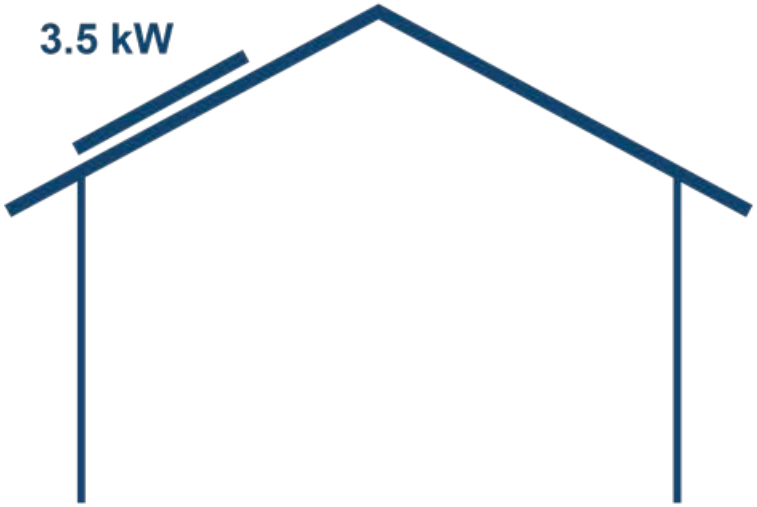
System Deployments

Standalone Solar	Solar Plus			
PV	**PV**	**Smart DHW**	**Smart AC**	**Battery**
3.5 kW	4.3 kW	Deployed	Deployed	-

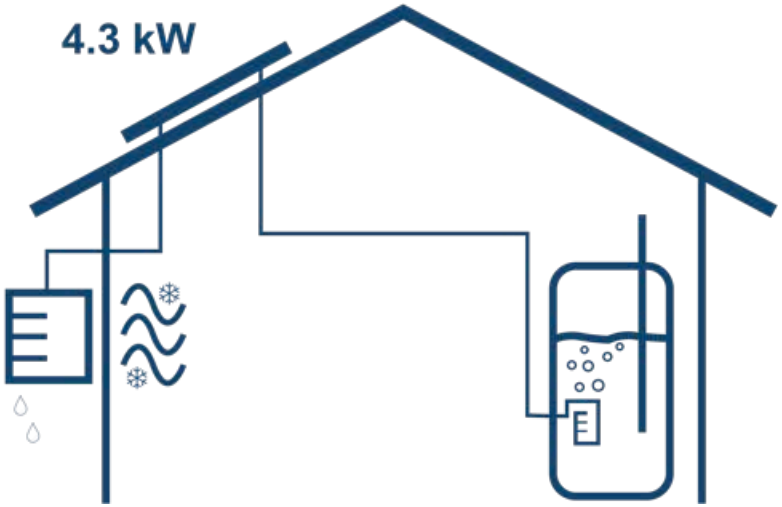
System NPVs

Standalone Solar	Solar Plus
$1,117	$1,984

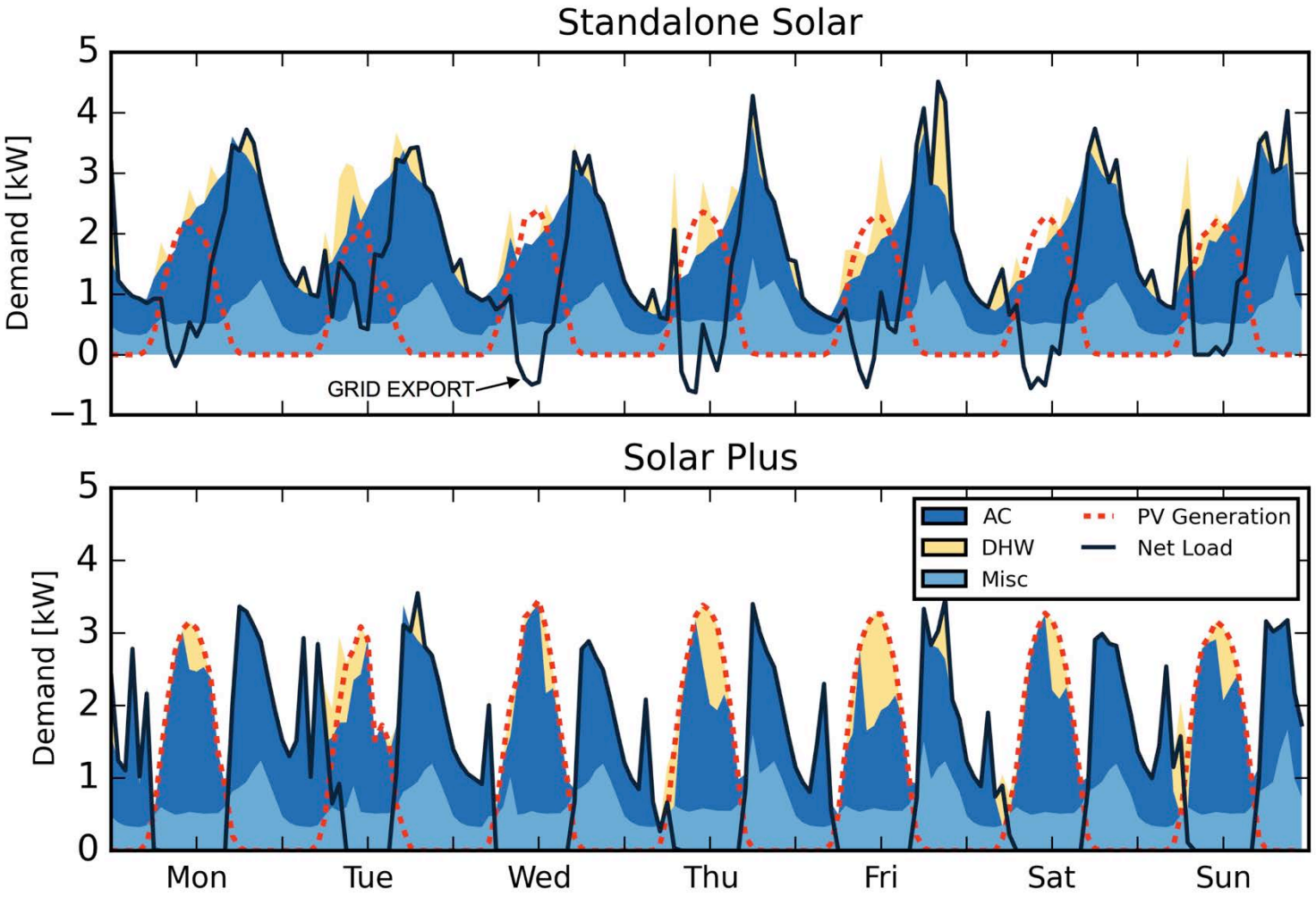
Standalone Solar



Solar Plus



Results: Nevada



Nevada PV and Customer Load Profiles under Standalone Solar and Solar Plus Approaches (based on week in July)

California TOU Rates

- In 2016, California amended its net metering rules to require PV customers to participate in TOU rates.
- Case study based on a home in San Francisco.

RATES ($/kWh)	TOU PERIODS	NET METERING
Summer (Jun-Sep) Peak: $0.36 Off-peak: $0.26 Winter (Oct-May) Peak: $0.22 Off-peak: $0.20	Peak: 4pm-9pm	Follows TOU structure

Results: California

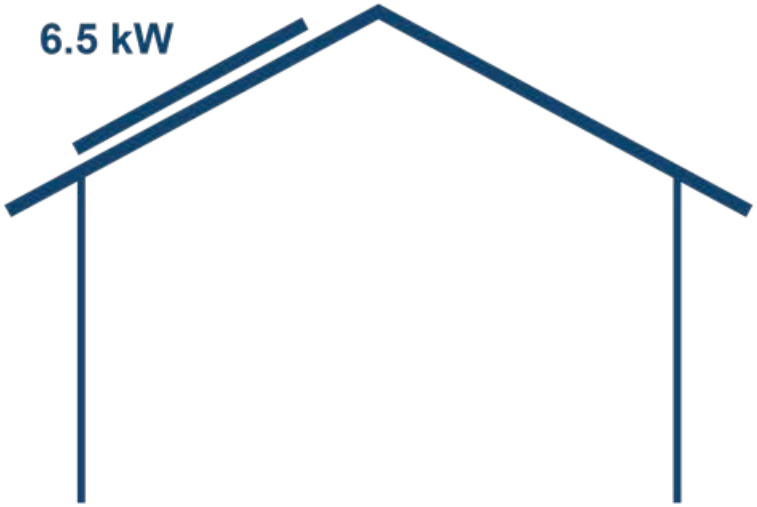
System Deployments

Standalone Solar	Solar Plus			
PV	**PV**	**Smart DHW**	**Smart AC**	**Battery**
6.5 kW	6.5 kW	Deployed	-	-

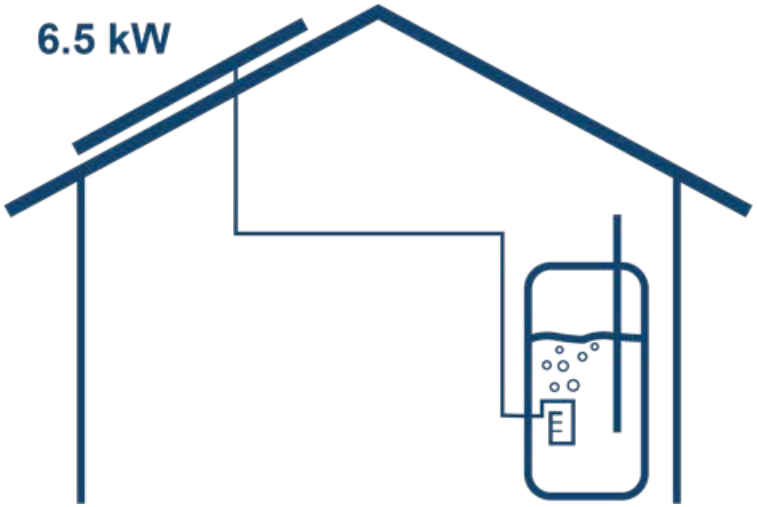
System NPVs

Standalone Solar	Solar Plus
$19,386	$20,637

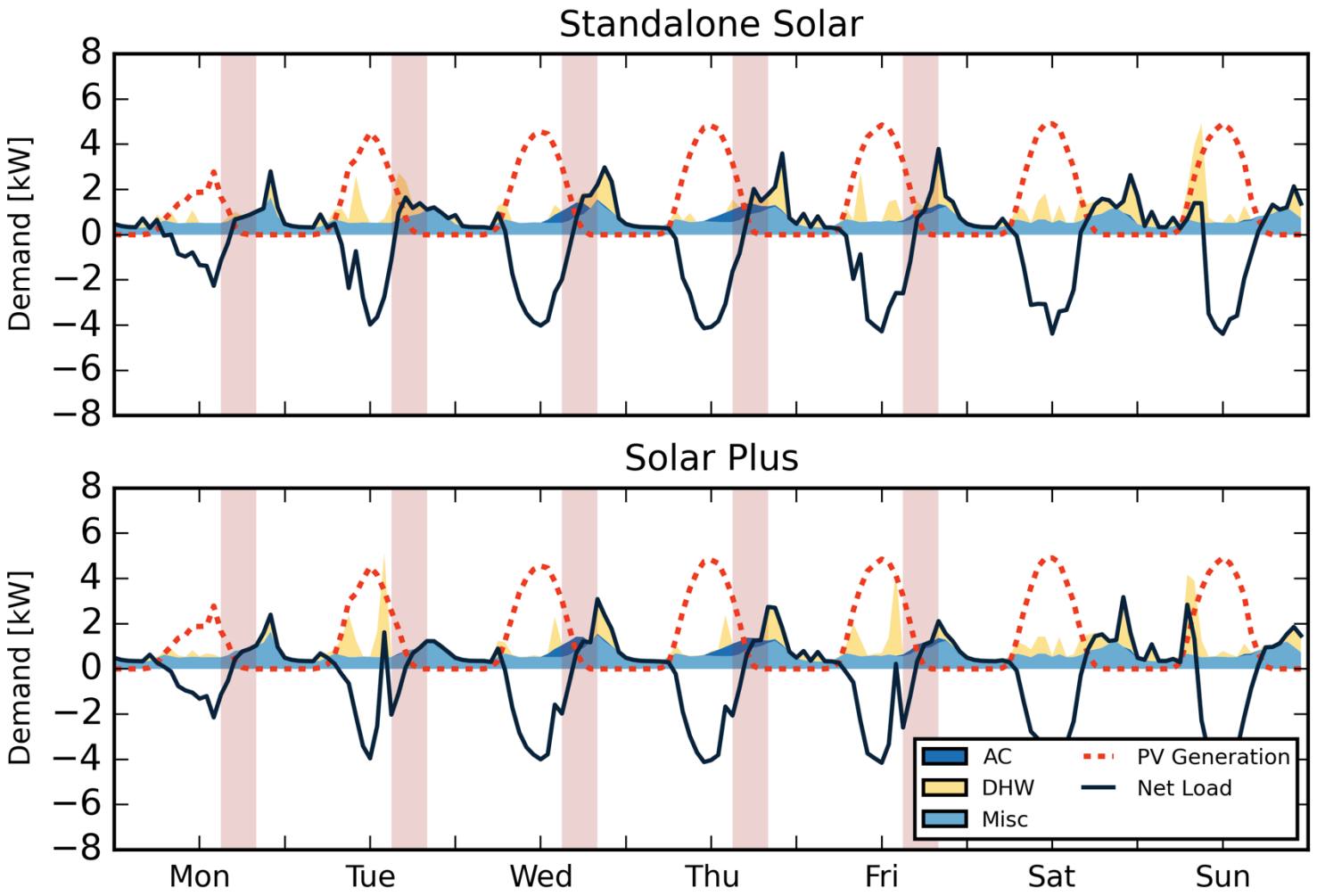
Standalone Solar



Solar Plus



Results: California



California PV and Customer Load Profiles under Standalone Solar and Solar Plus Approaches (based on week in July–August)

TOU peak periods depicted by shaded columns

Arizona Super Peak

- The “super peak” is designed to incentivize customers to reduce electricity use during the peak hours of the summer months.
- Case study based on a home in Phoenix.

RATES ($/kWh)	TOU PERIODS	NET METERING
Off-peak: $0.06 Nov-Apr Peak: $0.20 May-Oct Peak: $0.24 Super peak: $0.47* * Applies Jun-Aug	Peak: 12pm-7pm Super peak: 3pm-6pm	$0.03/kWh

Results: Arizona Super Peak

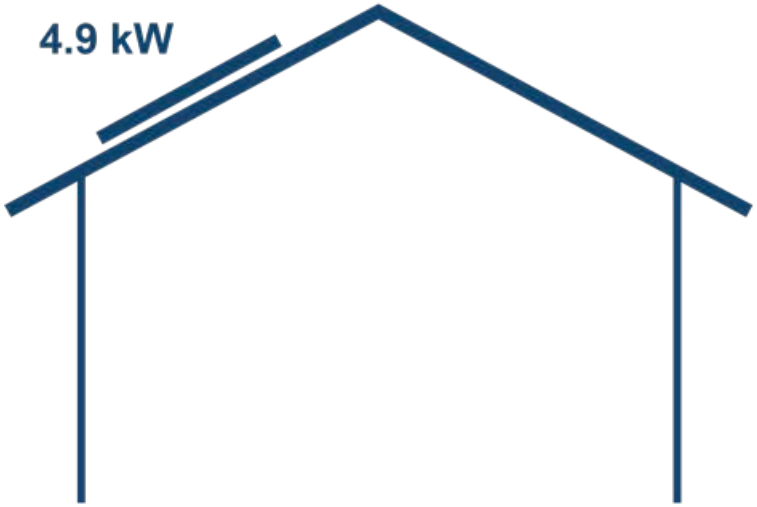
System Deployments

Standalone Solar	Solar Plus			
PV	**PV**	**Smart DHW**	**Smart AC**	**Battery**
4.9 kW	4.2 kW	Deployed	Deployed	-

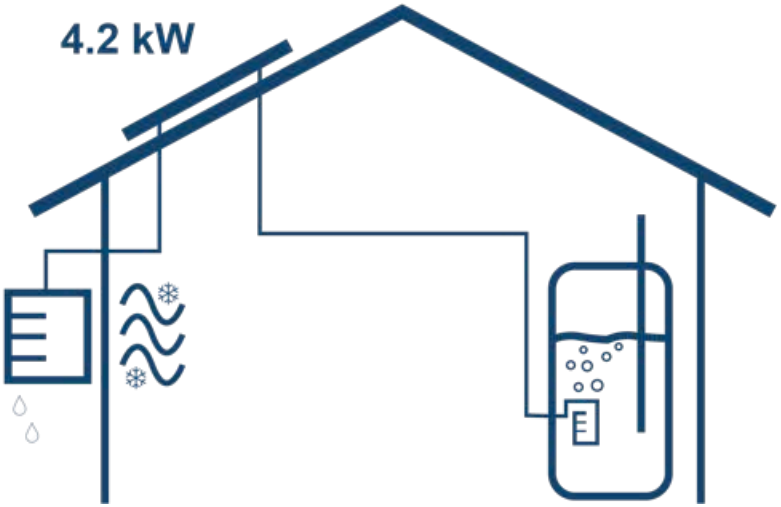
System NPVs

Standalone Solar	Solar Plus
$5,968	$9,565

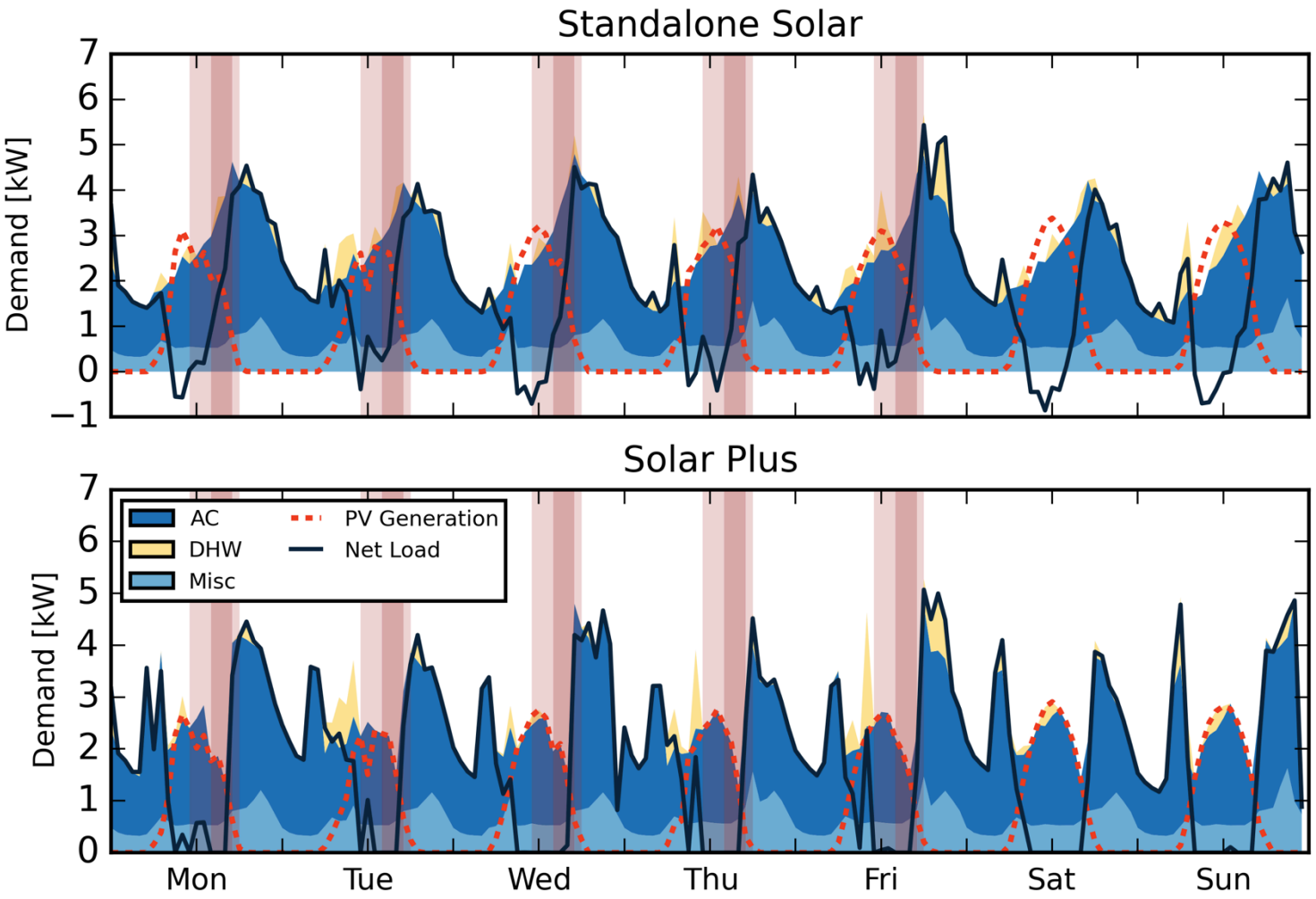
Standalone Solar



Solar Plus



Results: Arizona Super Peak



Arizona Super Peak PV and Customer Load Profiles under Standalone Solar and Solar Plus Approaches (based on week in July)

TOU peak period depicted by light shaded columns, super peak by dark column

Arizona Demand Tariff

- Assesses a demand charge based on maximum demand during peak hours (12pm-7pm).
- Case study based on a home in Phoenix.

RATES	TOU PERIODS	NET METERING
Off-peak: $0.04/kWh	Peak: 12pm-7pm	$0.03/kWh
Nov-Apr Peak: $0.06/kWh Demand: $9.30/kW		
May-Oct Peak: $0.09/kWh Demand: $13.50/kW		

Results: Arizona Demand Tariff

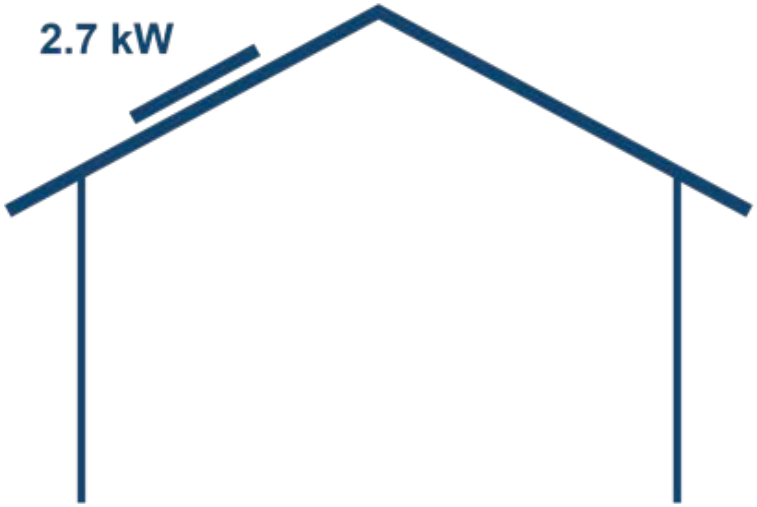
System Deployments

Standalone Solar	Solar Plus			
PV	**PV**	**Smart DHW**	**Smart AC**	**Battery**
2.7 kW	2.6 kW	Deployed	Deployed	0.3 kWh

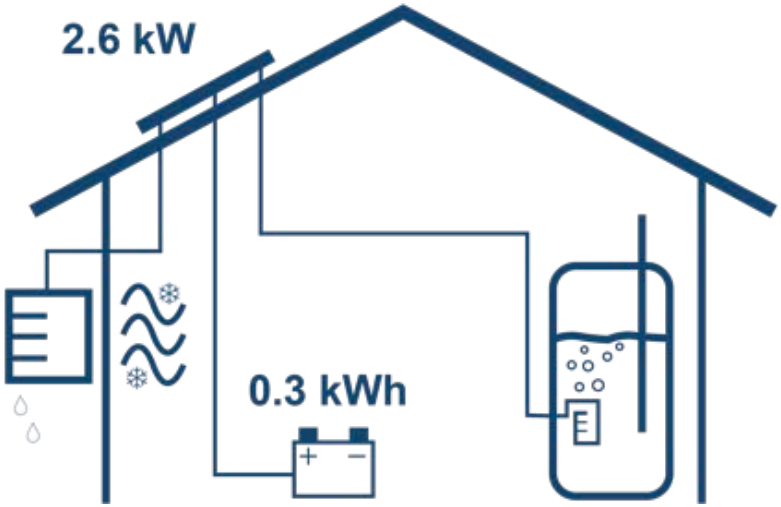
System NPVs

Standalone Solar	Solar Plus
$750	$6,651

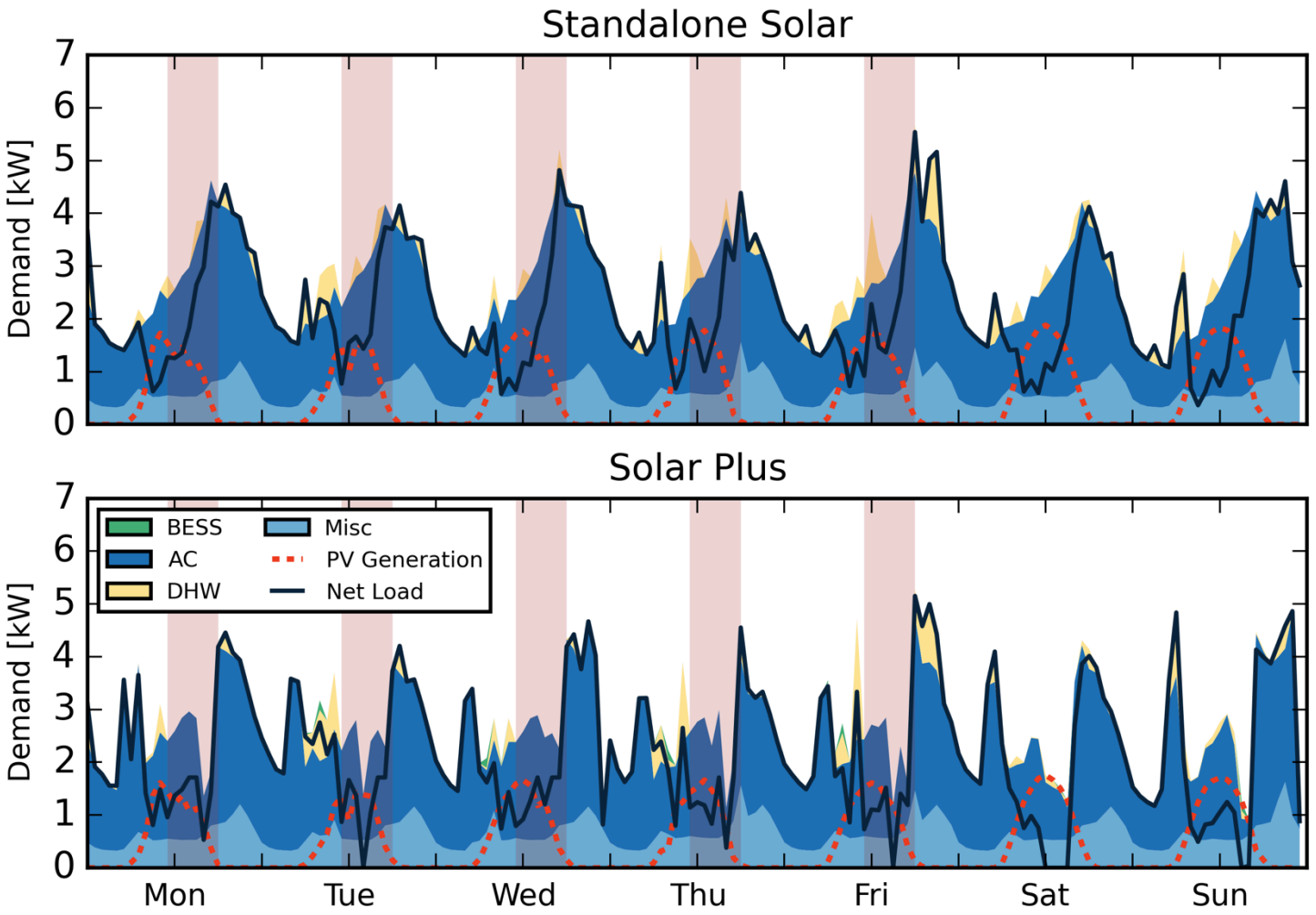
Standalone Solar



Solar Plus



Results: Arizona Demand Tariff



Arizona Demand Tariff PV and Customer Load Profiles under Standalone Solar and Solar Plus Approaches (based on week in July)

TOU peak periods depicted by shaded columns

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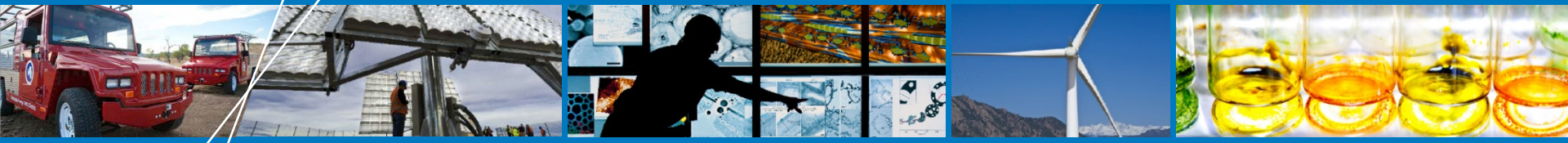

Summary

Summary

- Solar plus increases PV system value through increased solar self-use and grid arbitrage (in TOU rate structures).
- Solar plus may mitigate some of the negative economic impacts of certain rate structures such as low net metering rates, TOU rates where the peak period is non-coincident with PV output, and demand charges.

Future work

- Incorporate other technologies: EVs, controllable refrigeration, other controllable appliances, controllable heating.
- Model solar plus under new rate structures.
- Incorporate additional value streams such as grid-outage resiliency and grid-level ancillary services.

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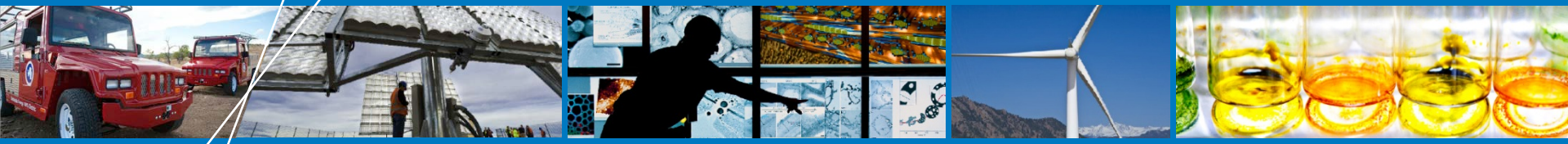

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