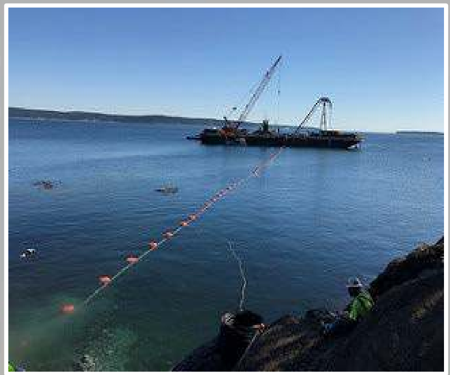

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Washington Clean Energy Fund (CEF) II – OPALCO Community Solar and Energy Storage on Decatur Island

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Chief Economist

Other team members: Vish Viswanathan, Jan Alam, Alasdair Crawford, Kendall Mongird, Yong Yuan, Di Wu, and Trevor Hardy of PNNL; Joel Mietzner, Travis Neal, Russell Guerry, and Jay Kimball of OPALCO.

January 19, 2018

DISCOVERY *in Action*

U.S. DEPARTMENT OF
ENERGY

Washington Clean Energy Fund (CEF) II OPALCO Analytics Program Synopsis

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Objective

- Provide a framework for evaluating the technical and financial benefits of energy storage, and exploring the value that energy storage can deliver to Washington utilities and the customers they serve.

Department of Commerce
Innovation is in our nature.

Phases

Phase 1:* Preliminary Economic Analysis** → ***Phase 2: Use Cases / Performance Monitoring → ***Phase 3:* Final Assessment**

1) Preliminary Economic Analysis
2) Install Energy Storage Systems (ESS), Run Use Cases, and Document Technical Performance
3) Final Evaluation

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Team

- **PNNL:** Brings expertise in energy/economics/environment system analysis and modeling
- **Orcas Power and Light Co-op (OPALCO):** Brings deep operational experience and required utility data / test sites
- **Washington Dept. of Commerce and U.S. Department of Energy**: Program management

Key Concepts in Energy Storage

- Energy storage provides services or functions or values; a use case is an application specific to an installation that provides defined value to the grid and community
- Energy assets come in many forms, and these technologies must be carefully characterized
  - Photovoltaics (PV)
  - UET vanadium flow battery
- Value comes in many forms
  - Bulk energy – arbitrage and capacity
  - Ancillary services – regulation, spin and non-spin reserve, load following, frequency response, flexible ramping, voltage support, black start
  - Transmission congestion relief and asset deferral
  - Distribution deferral, voltage support, conservation voltage regulation, and outage mitigation/resilience
  - Customer benefits – demand/energy charges, reliability, demand response, resilience
- Services/functions/values have to be stacked properly to avoid double counting, and a simulation/co-optimization process is needed
- Basis of this analysis establishes the entity to which benefits and costs accrue – this study evaluates impacts to OPALCO in the base case, including all costs and benefits of energy storage and PV

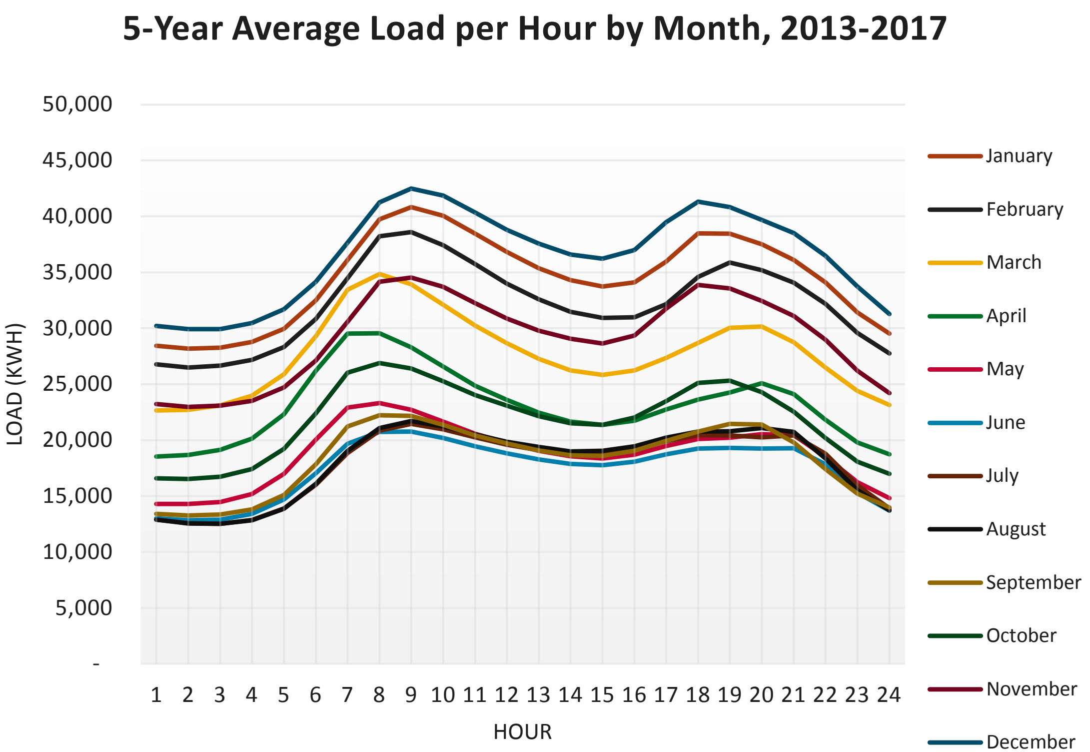
Decatur Island Substation Energy Storage & Community Solar

- $1 million grid modernization grant awarded to OPALCO as part of Washington Clean Energy Fund (CEF) II
- 0.5 MW / 2 MWh UniEnergy Technology Vanadium Redox Flow Battery
- 504 kW LG Community Solar Array from Puget Sound Solar
- Demonstrations of value
  - Integration of renewables onto the grid (reduce intermittency of community solar array)
  - Demonstration of islanding, Volt-VAR control, and other advanced control methods
- Potential PV and energy storage benefits:
  - Demand charge reduction
  - Load shaping charge reduction
  - Transmission charge reduction
  - Transmission submarine cable replacement deferral
  - Volt-VAR/CVR control
  - Outage mitigation

With DOE support, PNNL modeled battery operations to determine the long-term financial benefits and costs to OPALCO

OPALCO Load Analysis

- Average kWh load for the same hour across each day was calculated for every month of the year
- Each result was then ranked from highest to lowest, 1 through 24
- 4-hour time periods in both the morning and evening were then selected
- From these identified peaks, we can determine hours when discharging optimally reduces stress on the Fidalgo-Lopez transmission cable (used as constraint) – transmission deferral will be modeled as use case in final economic evaluation

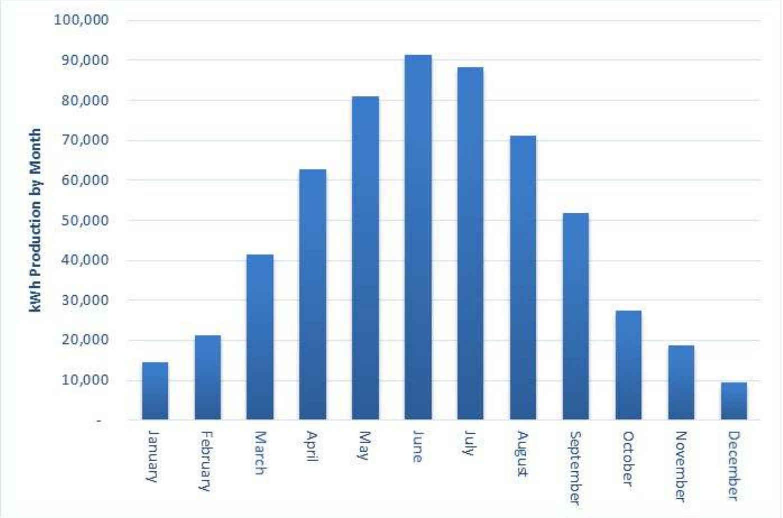


	January	February	March	April	May	June	July	August	September	October	November	December
Morning Peak	7-11am	7-11am	6-10am	6-10am	6-10am	6-10am	7-11am	7-11am	6-10am	6-10am	7-11am	7-11am
Evening Peak	5-9pm	5-9pm	5-9pm	5-9pm	5-9pm	5-9pm	5-9pm	5-9pm	4-8pm	4-8pm	4-8pm	4-8pm

PV Production Estimation

- 504 kW community solar array installed on Decatur Island next to the Decatur Substation
- Puget Sound Solar estimated annual production at 582,674 kWh/year; our modeled estimates are very close at 579,545 kWh using 2015 weather data
- Solar analysis
  - 504 kW solar installed at latitude (degrees): 48.51 N, 122.81 W; tilt angle 20 degrees
  - Solar data gathered from National Solar Radiation Database (Physical Solar Model dataset was used)
  - Solar Position and Intensity (SOLPOS) calculator was used to calculate the position of the sun
  - Perez model used to calculate production; validated using National Renewable Energy Laboratory's System Advisor Model
  - Solar panels placed at latitude (degrees): 48.51 N, 122.81 W; tilt angle 20 degrees
  - Hourly PV production calculated over 18 years (1998-2015)

Shading Heatmap of PV Installation Source: Puget Sound Solar

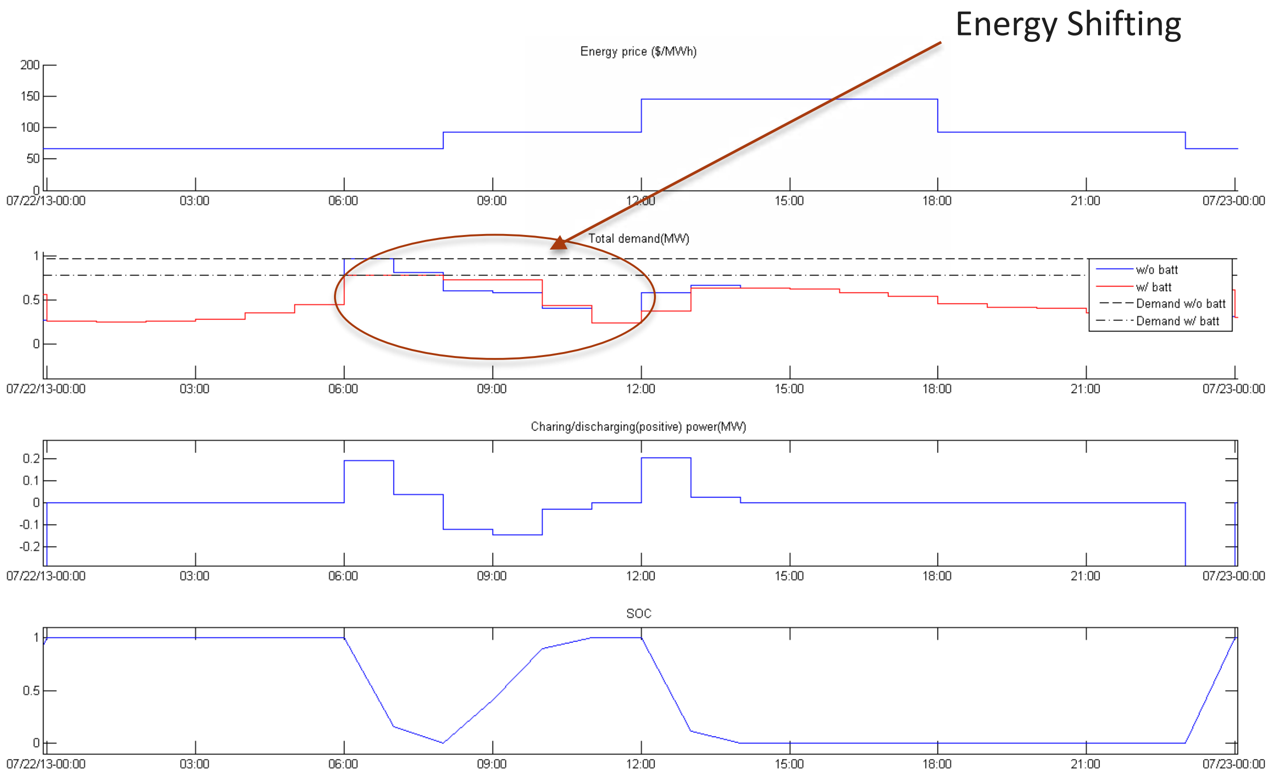


PV Production by Month

Use Case 1 – Demand Charge Reduction

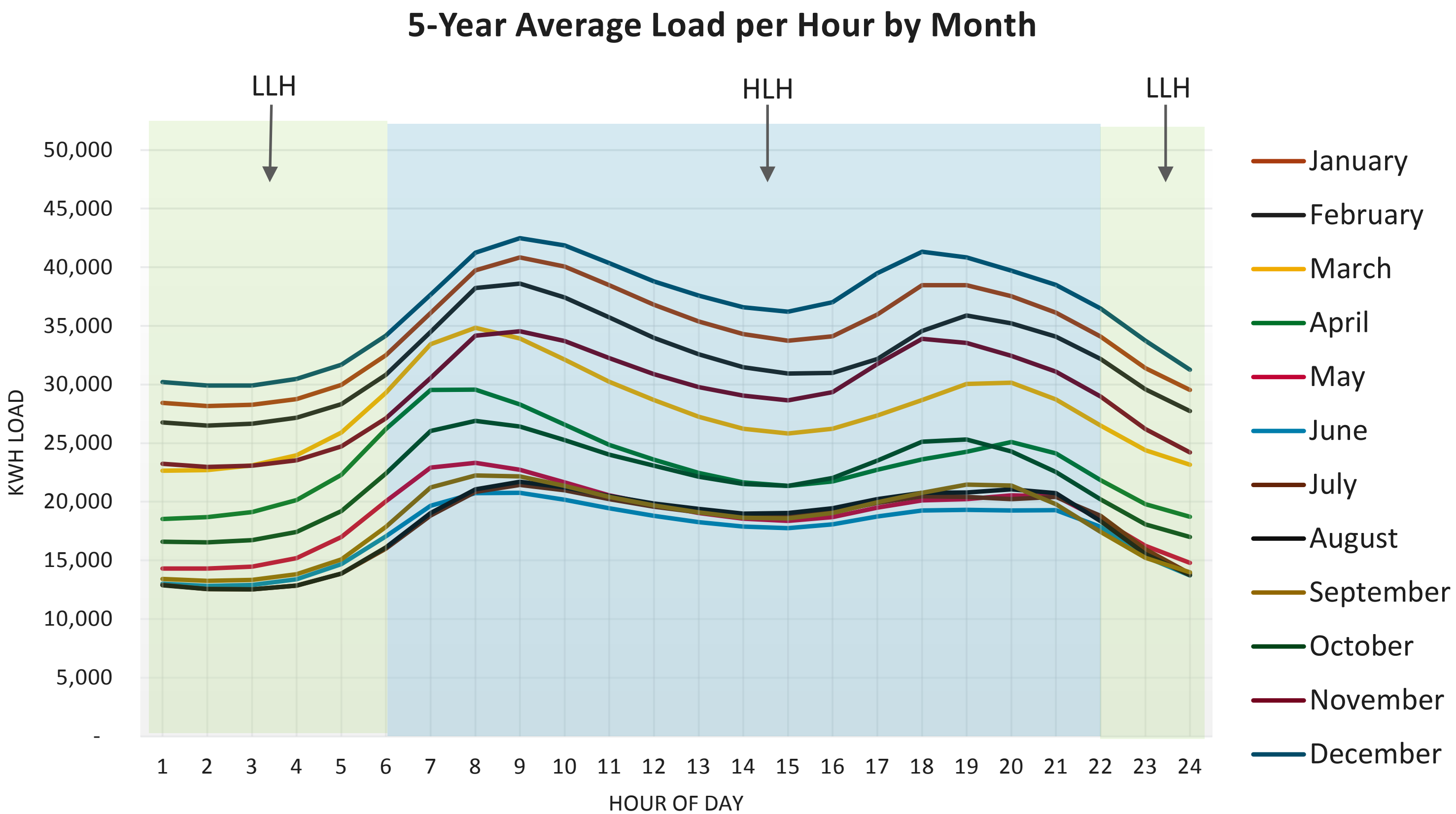
- Monthly charge determined by OPALCO's highest energy load (kWh) and average load during heavy load hours in a given month
- Value obtained by discharging energy to shave peak loads, reducing the basis of the charge

<u>Note: Results by use case are provided later in this presentation.</u>



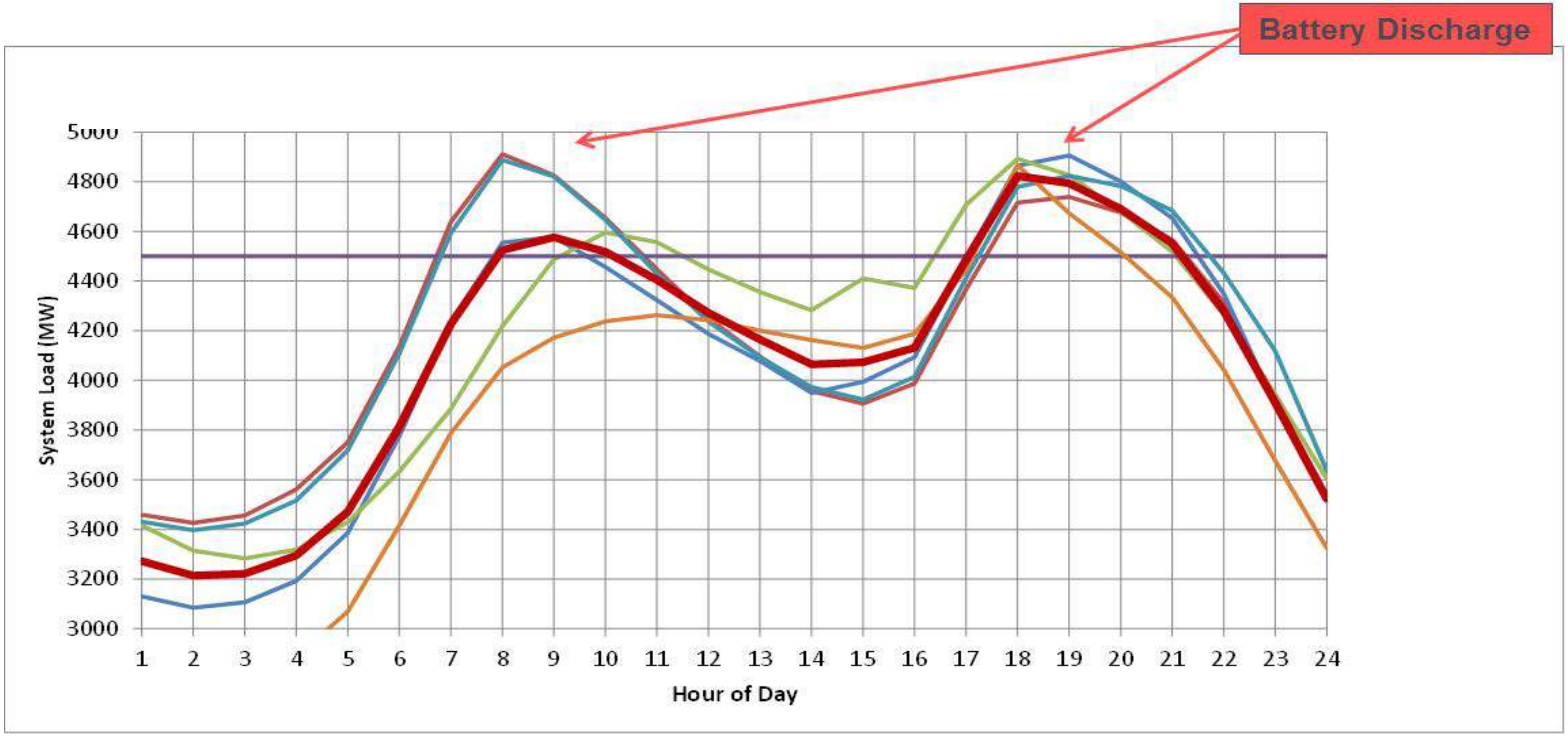
Use Case 2 – Load Shaping Charge Reduction

- Monthly charge/credit determined by taking deviation between expected load (kWh) for both Heavy Load Hours (HLH) and Light Load Hours (HLH)
- Value obtained by charging battery during lower-rate LLHs and discharging during higher-rate HLHs, also through PV production during HLHs



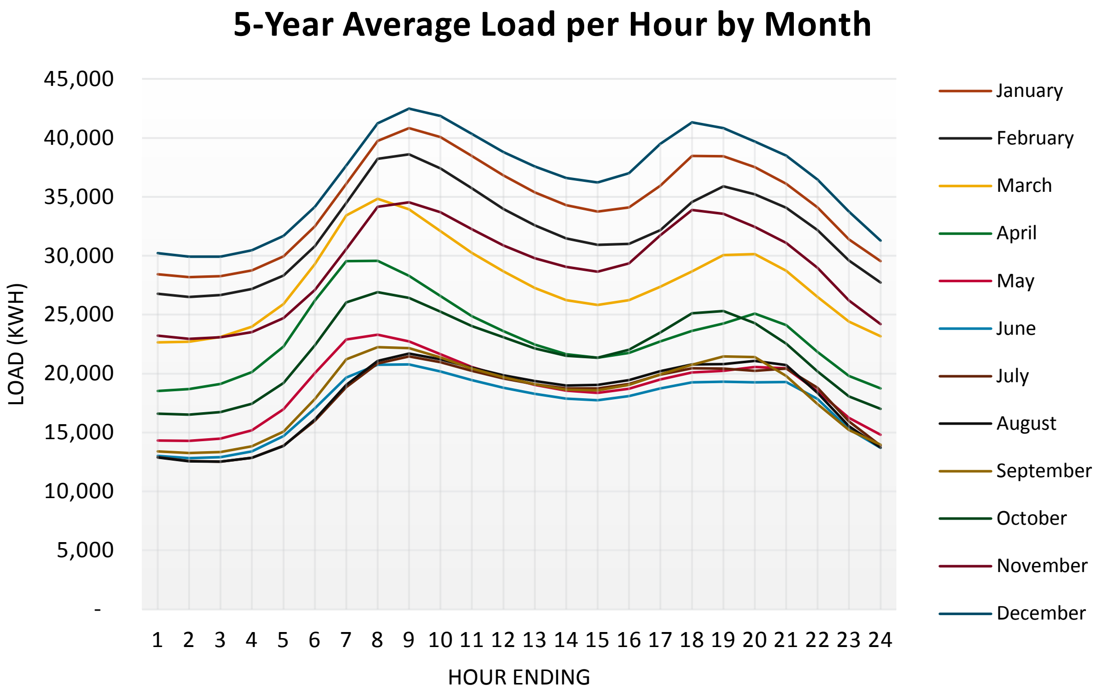
Use Case 3 – Transmission Charge Reduction

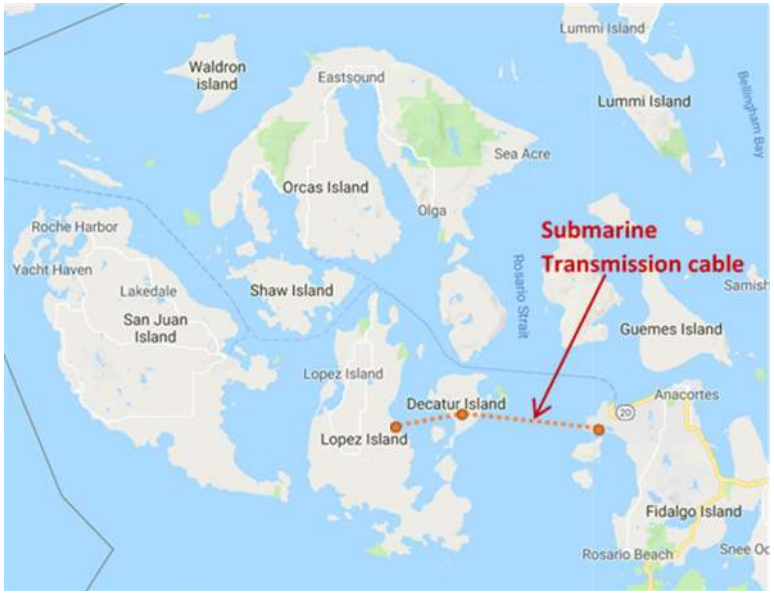
- Monthly charge determined by OPALCO's total energy purchases (kWh) during Bonneville Power Administration's (BPA) peak transmission load hour – transmission charge is $2.10 per kW-month
- Value obtained through PV generation or ESS discharging during estimated BPA peak transmission load hours, reducing the basis of the charge



Use Case 4 – Transmission Submarine Cable Replacement Deferral

- BPA-owned submarine transmission cable from Anacortes to Decatur & Lopez Islands, energized in 2002 with an approximate 40-year lifespan
- Value obtained by reducing heating on the cable and acting as a reactor that compensates for the submarine cable's large capacitance, extending the length of its usable life and deferring costly new cable investment by approximately 3.3 years. All future cable expenditures deferred but only two rounds included in assessment due to risk/uncertainty
- Deferral value calculated to be $2.0 million in present value (PV) terms





Detail on Transmission Submarine Cable Deferral Estimate – OPALCO, Cable 5, and ESS

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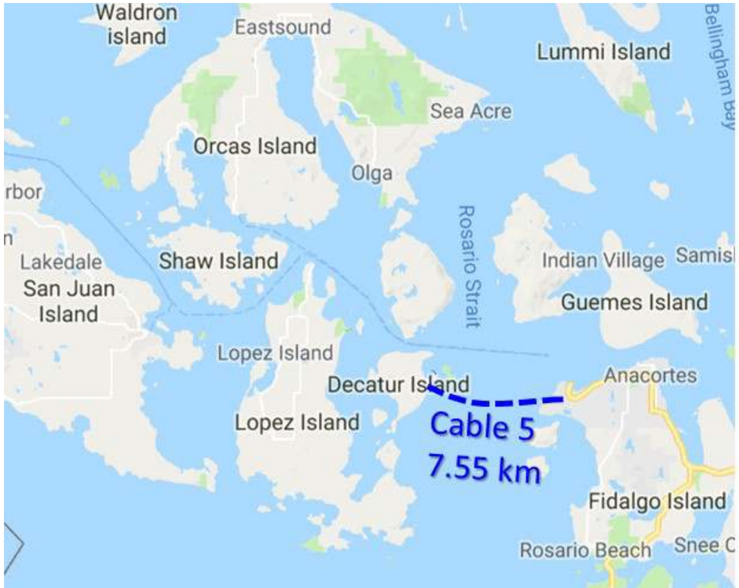
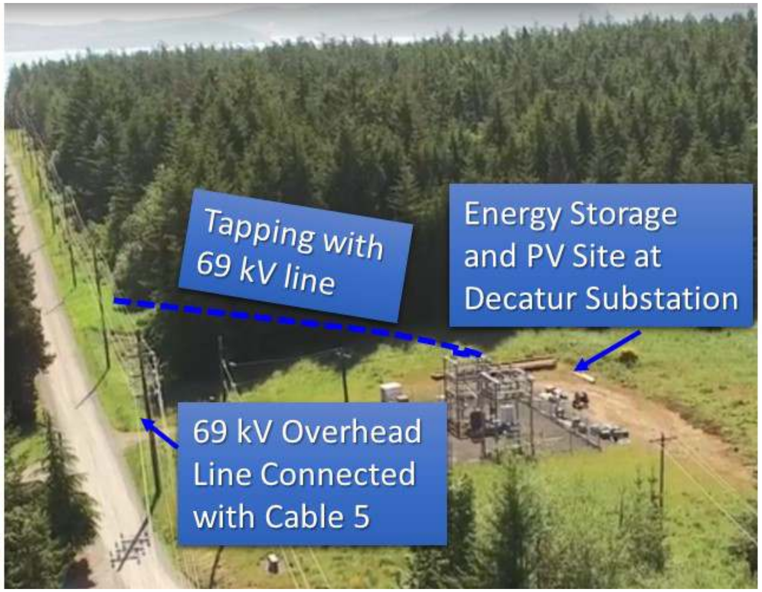
- OPALCO imports power through a 69 kV XLPE insulated cable from BPA, with the cable tied in on Fidalgo Island
- Currently the power routes through the Lopez Substation, but OPALCO is planning a tap from the 69 kV cable overhead at Decatur Substation, which will also be the site for a 0.5 MW, 2 MWh ESS and community solar
- PV and ESS operation could reduce loading stress on the cable and have a potential life extension benefit
- Potential life extension is assessed using “Electrothermal Life Model”





Life Estimation Approach

$$t_P = \left[-\log(1-P_T)\right]^{\frac{1}{\beta}} \alpha_0 \left(\frac{E}{E_0}\right)^{-(n_0-bcT)} \exp(-BcT)$$

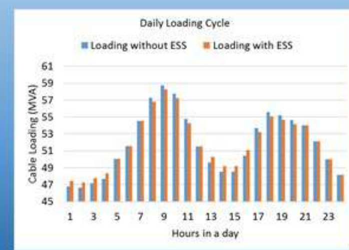
Mini-cable Sample Life Model

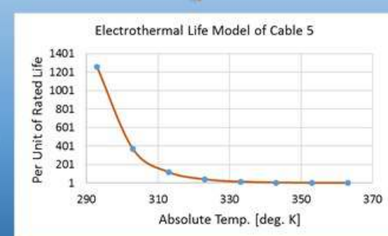
+

$$L_D = t_P\left[\frac{-\log(1-P_D)}{-D\log(1-P_T)}\right]^{\frac{1}{\beta}}$$

Actual Cable Life Model

Loading Cycle





Fitted Life Estimation Curve

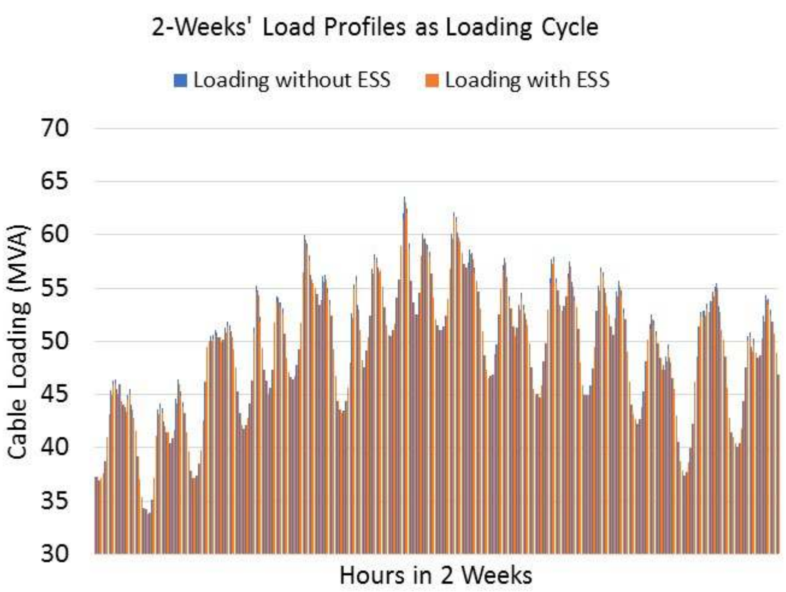
"X" Years

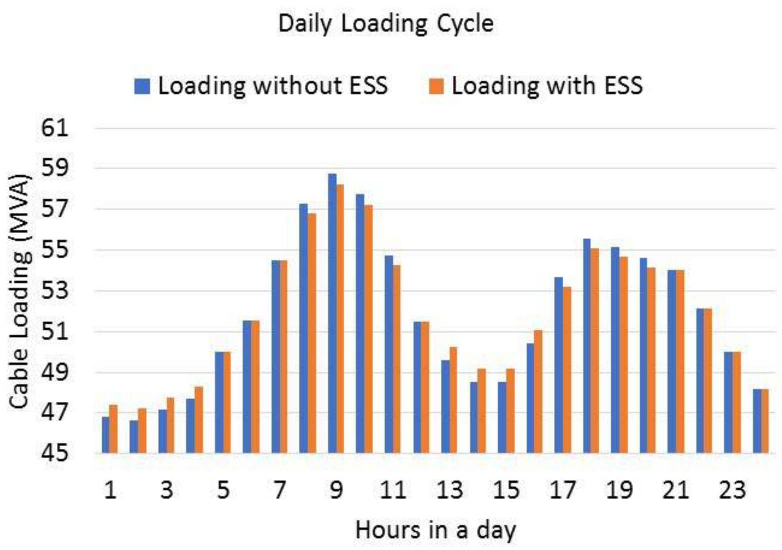
Estimated Life/ Extension

- Multistress Probabilistic Life Estimation Model
- Fitted using accelerated aging test data
- Estimates life at a given loading cycle exposing the cable to electrical and thermal stress

Potential Life Extension Benefit of ESS and Solar PV

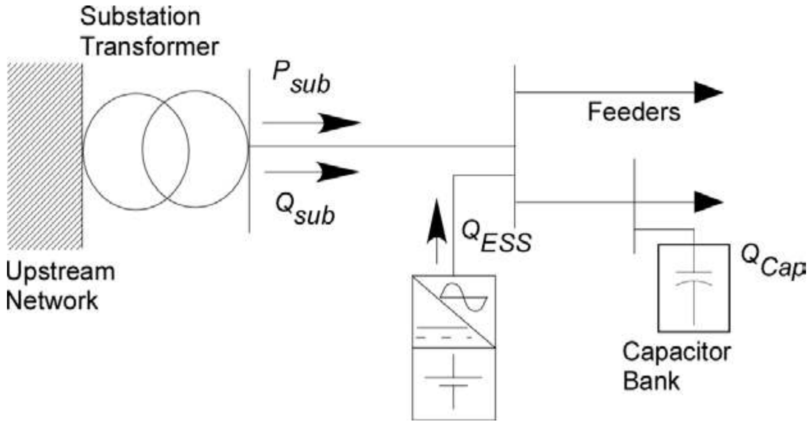
- Two weeks of data used to construct cable loading cycle
- ESS discharges at 0.488 MW for 4 hours during morning and evening peaks; charging rates target lowest load hours
- Using the fitted model and the selected load cycle, potential life extension is estimated to be 3.3 years
- Investigation using more complete sets of data on cable specification and operation, with readings on Fidalgo Island, will be performed in the future



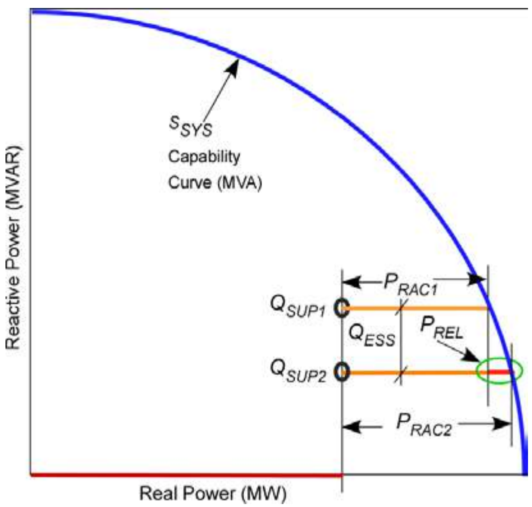


Use Case 5– Volt-VAR Support and CVR

- ESS used to provide reactive power locally, thus reducing energy losses and releasing upstream network capacity
- Benefit limited by available capacity of the ESS inverter to sink/source VAR; handled in post processing after needs of other use cases are met
- CVR factor (% reduction in demand / % reduction in voltage) estimated based on voltage/power data from BPA & OPALCO
- Benefit is negligible based on local loads and because release of upstream capacity benefits BPA, not OPALCO



ESS Meeting Local VAR Demand



Release of Upstream Network Capacity

Use Case 6 – Outage Mitigation

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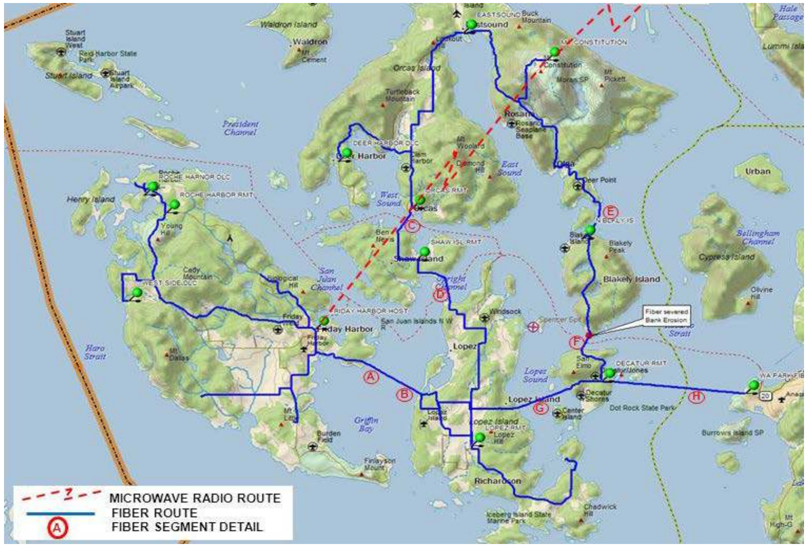
- Outage Data
  - Outage data obtained for Decatur and Center Islands for 8 years (8 outages)
  - All outages modeled and all could have been entirely mitigated – average of 1 per year / 152 minute duration
- Customer information
  - Number of customers affected by each outage obtained from OPALCO
  - Type of customers affected also determined
  - Annual benefit of roughly $21k annually
- Communication System
  - Federal Communications Commission requires 24 hours of backup generation
  - 48 kWh of energy held in reserve
  - ESS provides $8,500 cost savings to OPALCO by providing this backup; annual O&M at $750

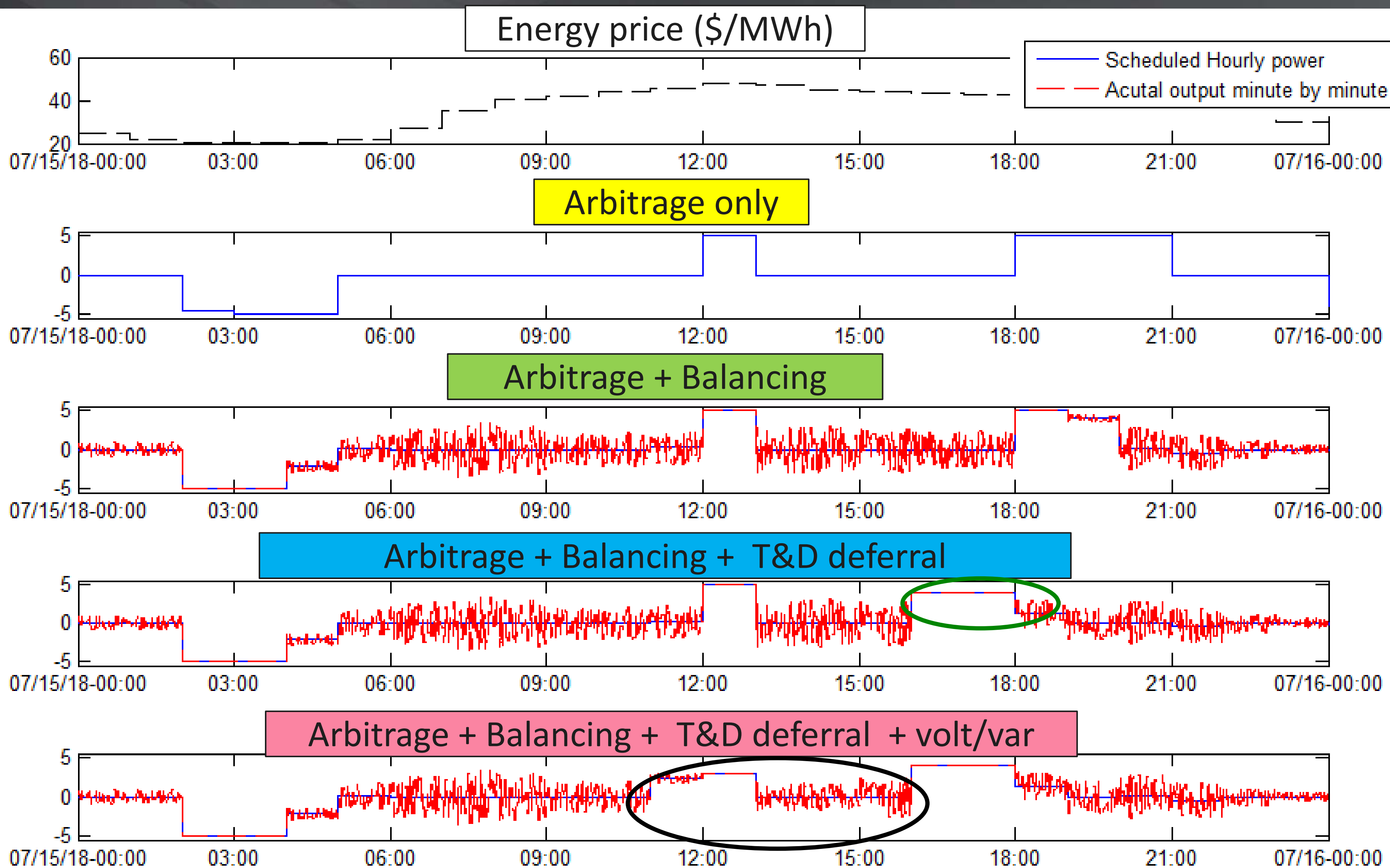
Interruption Cost	Interruption Duration					
	Momentary	30 Minutes	1 Hour	4 Hours	8 Hours	16 Hours
Medium and Large C&I (Over 50,000 Annual kWh)						
Cost per Event	$12,952	$15,241	$17,804	$39,458	$84,083	$165,482
Cost per Average kW	$15.9	$18.7	$21.8	$48.4	$103.2	$203.0
Cost per Unserved kWh	$190.7	$37.4	$21.8	$12.1	$12.9	$12.7
Small C&I (Under 50,000 Annual kWh)						
Cost per Event	$412	$520	$647	$1,880	$4,690	$9,055
Cost per Average kW	$187.9	$237.0	$295.0	$857.1	$2,138.1	$4,128.3
Cost per Unserved kWh	$2,254.6	$474.1	$295.0	$214.3	$267.3	$258.0
Residential						
Cost per Event	$3.9	$4.5	$5.1	$9.5	$17.2	$32.4
Cost per Average kW	$2.6	$2.9	$3.3	$6.2	$11.3	$21.2
Cost per Unserved kWh	$30.9	$5.9	$3.3	$1.6	$1.4	$1.3

Source: Sullivan, M., J. Schellenberg., M. Blundell. 2015. "Updated Value of Service Reliability Estimates for Electric Utility Customers in the United States." Prepared for U.S. Department of Energy by Lawrence Berkeley National Laboratory. San Francisco, CA.



2015, CenturyLink fiber cable network that provides voice, E911, and data services to the San Juan Islands (Source: CenturyLink)

Bundling Services: How To Do It Optimally



Decatur Island PV and ESS Cost and Allocations of Cost

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Cost by Item		Cost Allocation		
Cost Item	**Cost**	**OPALCO**	**WA CEF**	**Community Solar Participants**
PV System	$828,146			$828,146
UET Vanadium Flow Battery	$1,500,000	$595,000	$905,000	
Installation costs	$300,000	$300,000		
Electrical	$90,000	$90,000		
Site/Civil	$110,000	$110,000		
Overheads	$70,000	$70,000		
WA Sales Tax	$160,000	$160,000		
Contingency	$100,000	$100,000		
Total	***$3,158,146***	***$1,425,000***	***$905,000***	***$828,146***

Decatur Island PV and ESS Cost and Allocations of Cost

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Cost Basis of Study

Cost by Item		Cost Allocation		
Cost Item	**Cost**	**OPALCO**	**WA CEF**	**Community Solar Participants**
PV System	$828,146			$828,146
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Overheads	$70,000	$70,000		
WA Sales Tax	$160,000	$160,000		
Contingency	$100,000	$100,000		
Total	***$3,158,146***	***$1,425,000***	***$905,000***	***$828,146***

Rate Impacts and Other Assumptions

- OPALCO costs are converted to rate impacts
  - Construction costs
  - Operations and maintenance (O&M costs)
  - Insurance costs
  - Borrowing costs
  - Property tax costs
  - Utility sale tax costs
- Full rate impacts estimated at $2.7 million over 20 years or $1.63 million in present value terms
- Other costs
  - Energy losses resulting from energy storage system cycling – roughly $19k annually
  - Lost revenue due to credits to customers – roughly $62k annually

Assumption	Value	Source
Energy storage book life	20 years	UET Proposal
Annual battery O&M	$30,000	UET Proposal
Insurance rate	.271%	OPALCO
Borrowing rate	3%	OPALCO
Cost of capital	5.47%	OPALCO
Property tax	.345%	OPALCO
Utility sales tax	3.8734%	OPALCO
Inflation rate	3.25% next 5 years followed by 4% in all subsequent years	OPALCO

Results – OPALCO Benefits and Costs (20-Year Present Value Terms)

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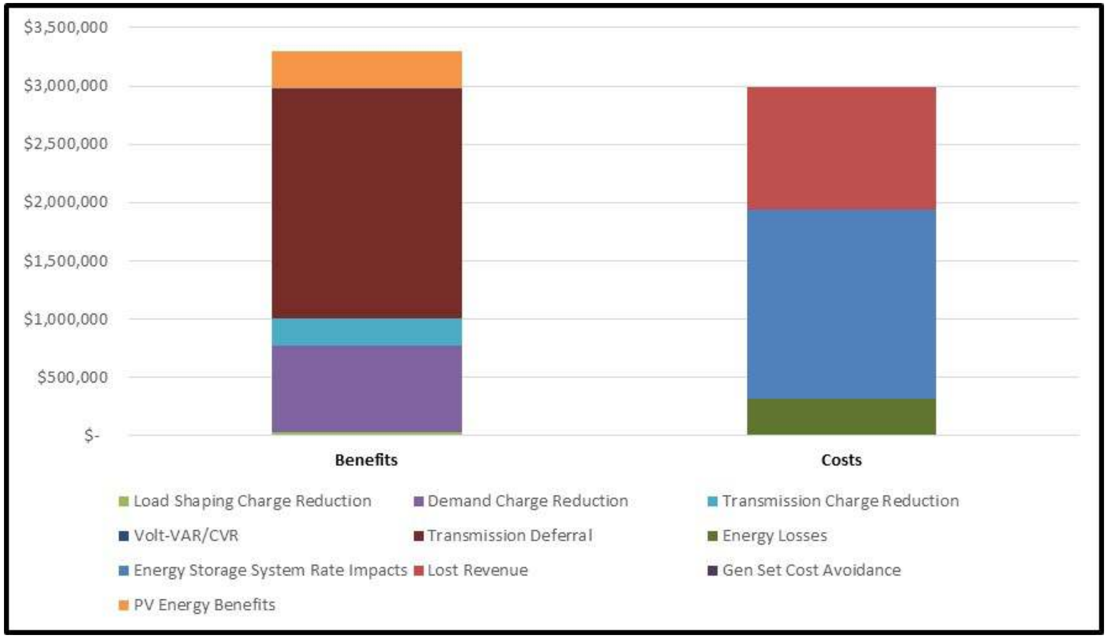
- Total 20-year value of PV and ESS operations at $3.3 million in present value terms, while costs are $3.0 million for a benefit-cost ratio of 1.10
- Benefits largely driven by transmission deferral benefit at $2.0 million in present value terms and ability of storage to reduce transmission and demand charges
- Total system costs
  - Energy storage costs estimated at $1.6 million in present value terms
  - $1.0 million (present value terms) in lost revenue resulting from community solar production
  - $0.3 million in energy costs associated with round trip efficiency (RTE) losses, RTE at 70% for peak shaving



Element	Benefits	Costs
Load Shaping Charge Reduction	$ 36,404	
Demand Charge Reduction	$ 739,802	
Transmission Charge Reduction	$ 227,331	
PV Energy Benefits	$ 313,434	
Volt-VAR/CVR	$ 3,380	
Transmission Deferral	$ 1,957,878	
Gen Set Cost Avoidance	$ 19,706	
Lost Revenue		$ 1,048,046
Energy Losses		$ 315,457
Energy Storage System Rate Impacts		$ 1,630,291
	$ 3,297,936	**$ 2,993,795**

Results – Monthly Impact of PV and ESS on OPALCO Bill in 2017

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- Annual bill reduced by $59,375; monthly reductions highest in summer months
- PV actually increases demand charges by reducing loads during high load hours
- Energy storage is effective at reducing transmission and demand charges
- Battery responsible for 82% of the estimated benefits

	Impacts of Battery and PV on Monthly OPALCO Bill				
	Demand Charge	Load Shaping Charge	DC+LSC	Transmission Charge	Total
January	$ (4,234)	$ 617	$ (3,617)	$ (1,026)	$ (4,643)
February	$ (4,042)	$ 355	$ (3,687)	$ (1,026)	$ (4,713)
March	$ (3,204)	$ 10	$ (3,194)	$ (1,026)	$ (4,220)
April	$ (2,311)	$ (374)	$ (2,685)	$ (1,041)	$ (3,726)
May	$ (2,046)	$ (824)	$ (2,870)	$ (1,440)	$ (4,310)
June	$ (2,385)	$ (1,200)	$ (3,584)	$ (1,295)	$ (4,879)
July	$ (4,737)	$ (1,248)	$ (5,985)	$ (1,155)	$ (7,140)
August	$ (5,360)	$ (914)	$ (6,273)	$ (1,178)	$ (7,451)
Septembe	$ (3,386)	$ (441)	$ (3,827)	$ (1,183)	$ (5,010)
October	$ (3,667)	$ 303	$ (3,364)	$ (1,026)	$ (4,390)
Novembe	$ (3,855)	$ 619	$ (3,235)	$ (1,026)	$ (4,261)
December	$ (4,547)	$ 942	$ (3,605)	$ (1,026)	$ (4,631)
Total	**$ (43,773)**	**$ (2,154)**	**$ (45,928)**	**$ (13,448)**	**$ (59,375)**

Results – OPALCO Benefits and Costs (20-Year Present Value Terms)

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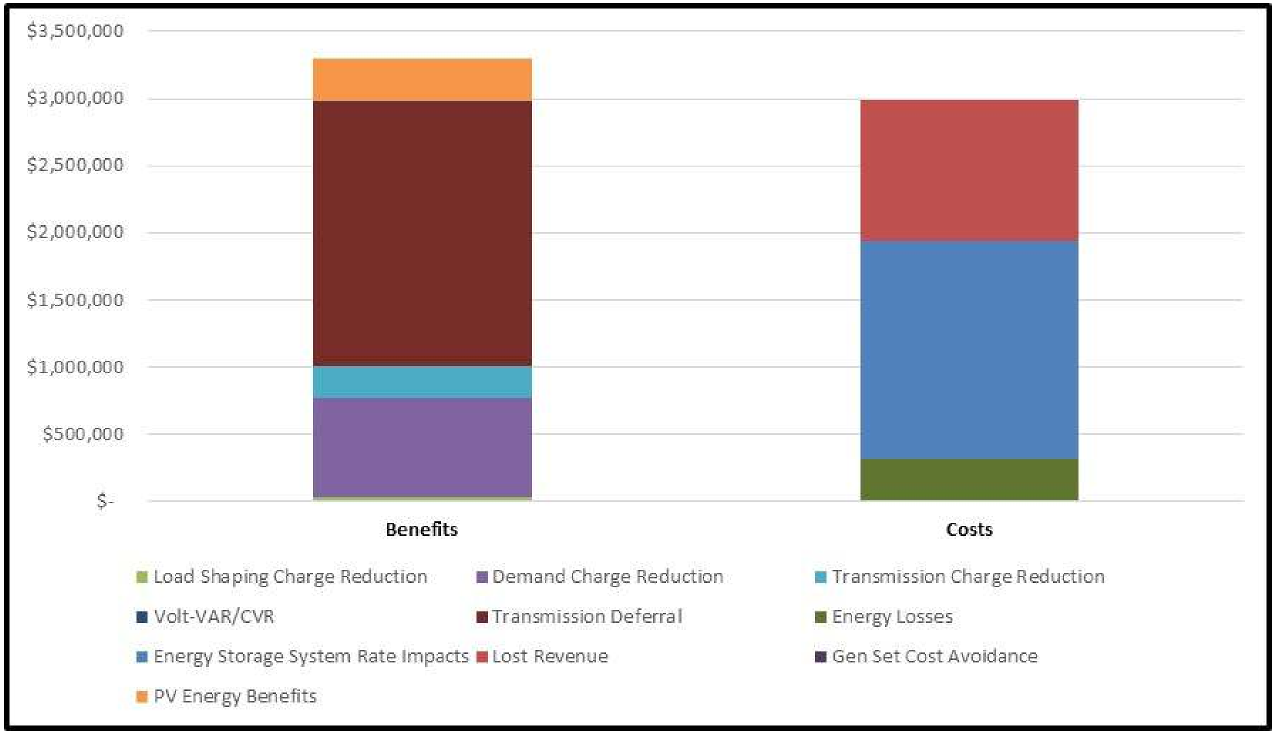

- While not resulting in an economic windfall, the project does “pencil out”
- Additional “difficult to quantify” value in
  - Knowledge transfer
  - Institutional know-how
  - Public awareness
  - Resilience
  - Energy security
  - Emissions reductions

Results – OPALCO Benefits and Costs + Outage Mitigation Benefits

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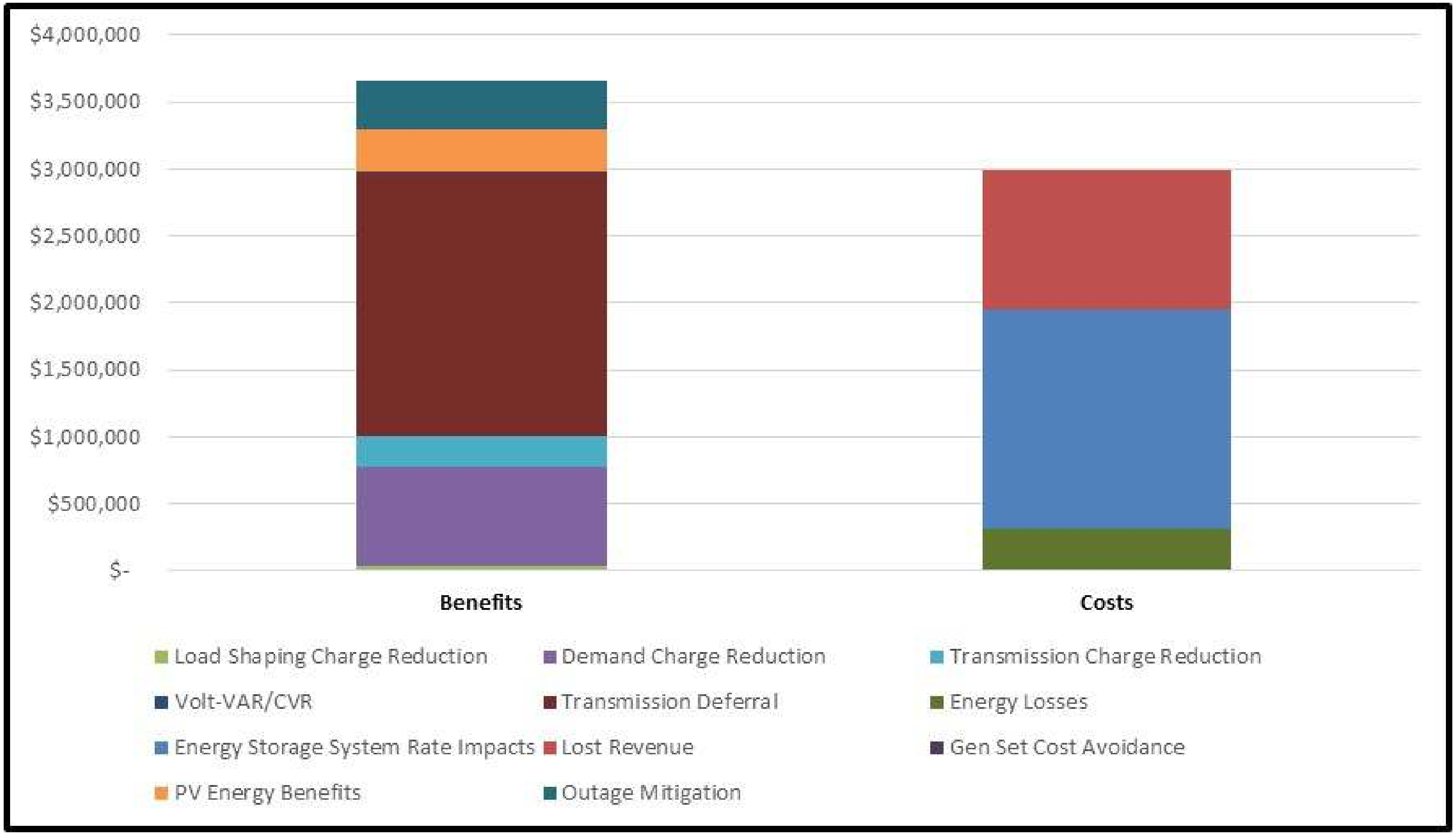
- Total 20-year value of outage mitigation benefits are estimated at $356,490 in present value terms; including outage mitigation improves the benefit-cost ratio to 1.22.



Energy Storage System Benefits and Costs in Isolation (20-year Present Value Terms)

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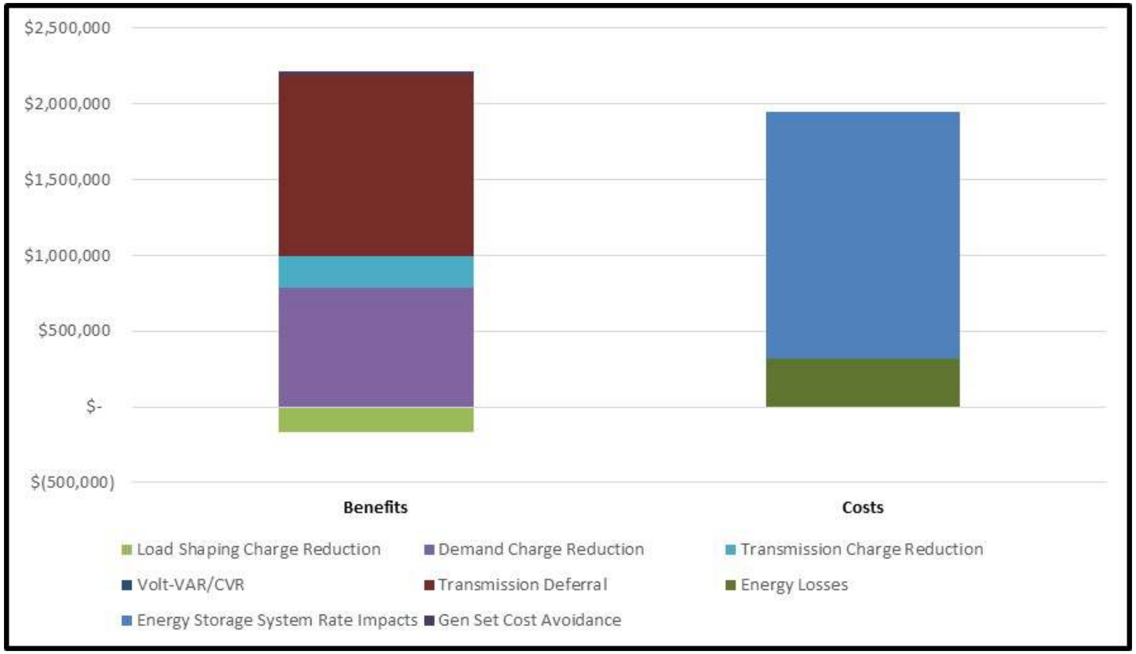
- Impact of isolating energy storage
  - Reduces load shaping benefits
  - Reduces transmission deferral benefits
  - Has little effect on demand and transmission charges
  - Eliminates PV energy benefits and associated lost revenue
- Net benefits of energy storage in isolation estimated at roughly $42,000; benefit-cost ratio of 1.05
- With outage mitigation benefits included, net benefits total $453,000; benefit-cost ratio of 1.23



Element	Benefits	Costs
Load Shaping Charge Reduction	$ (170,057)	
Demand Charge Reduction	$ 783,998	
Transmission Charge Reduction	$ 208,084	
Volt-VAR/CVR	$ 3,380	
Transmission Deferral	$ 1,197,400	
Gen Set Cost Avoidance	$ 19,706	
Energy Losses		$ 315,457
Energy Storage System Rate Impacts		$ 1,630,291
	$ 2,042,510	**$ 1,945,748**

What is the ESS Doing on a Typical Day?

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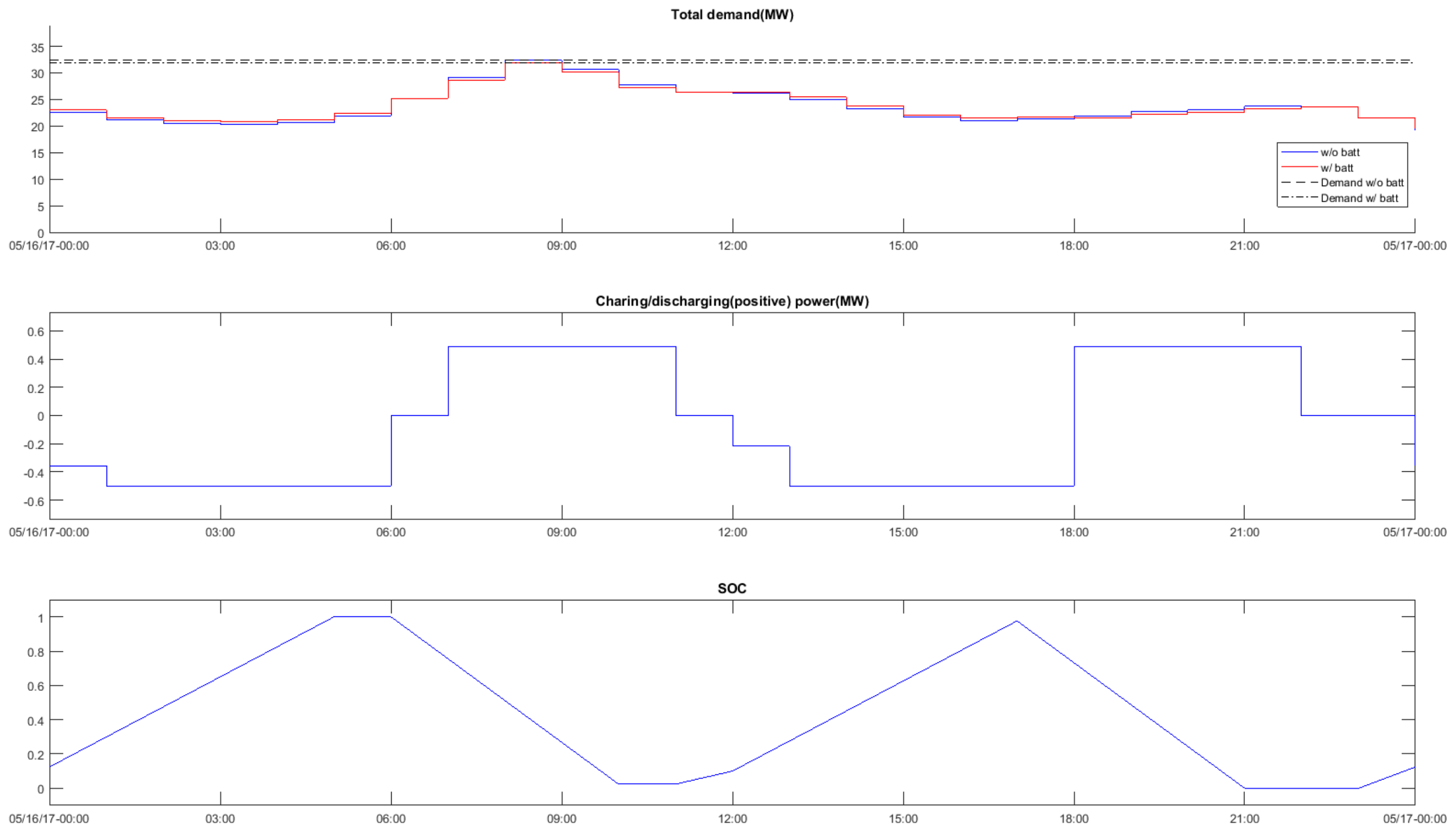
- Plot shows the load with and without the battery system, energy output, and state of charge for a typical day; PNNL modeled one-year of operations



Zeroing In on Load Impacts

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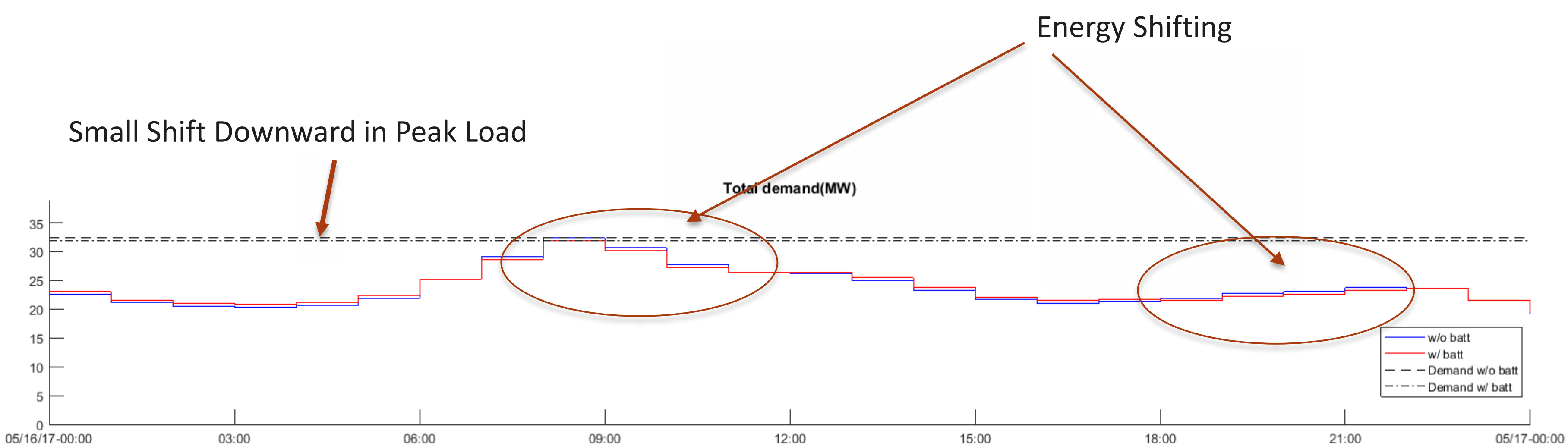

Benefits of shaving peaks includes transmission charge reductions, demand charge reductions, and transmission deferral benefits associated with reducing stress on the Fidalgo-Lopez Island Cable No. 5

Conclusions

- The energy storage and community solar systems on Decatur Island generate seven discreet benefits to OPALCO: demand charge reduction, load shaping charge reduction, transmission charge reduction, transmission deferral, energy cost reduction, Volt-VAR/CVR, and outage mitigation
- The capital cost of the UET vanadium flow battery system totals $1.5 million or $750/kWh; full deployed cost of $2.33 million ($1,165/kWh)
- Total 20-year value of PV and ESS operations totals $3.3 million in present value terms, while costs are $3.0 million for a benefit-cost ratio of 1.10
  - Benefits largely driven by transmission deferral benefit ($2.0 million) and reductions in demand charges ($0.7 million)
  - Costs driven by ESS costs minus Washington CEF grant and lost revenue tied to compensation of owners of PV
- Net benefits of energy storage in isolation estimated at roughly $42,000; benefit-cost ratio of 1.05
- Modeling of outages indicates that PV and ESS could have mitigated all outages on Decatur and Center Islands occurring in past 8 years at an average annual benefit of approximately $21,000

Next Steps

Task	Participant(s)
1) Receive comments from OPALCO and revise preliminary economic assessment	Pacific Northwest National Laboratory; Orcas Power & Light Co-op
2) Refine transmission deferral analysis using data collected over longer period of time on Decatur and Fidalgo Islands	Pacific Northwest National Laboratory; Orcas Power & Light Co-op
3) Build transmission deferral into economic optimization formulation	Pacific Northwest National Laboratory
4) Execute contract between OPALCO and PNNL to perform ESS testing	Pacific Northwest National Laboratory; Orcas Power & Light Co-op
5) Prepare ESS test plan	Pacific Northwest National Laboratory
6) Perform energy storage testing and present findings	Pacific Northwest National Laboratory; Orcas Power & Light Co-op
7) Revise and finalize economic assessment	Pacific Northwest National Laboratory
8) Issue final report	Pacific Northwest National Laboratory

Acknowledgments

- **Dr. Imre Gyuk** - Energy Storage Program Manager, Office of Electricity Delivery and Energy Reliability, U.S. Department of Energy
- **Bob Kirchmeier** - Senior Energy Policy Specialist, Clean Energy Fund Grid Modernization Program, Washington State Energy Office