

Economics of Solar PV and Stationary Storage for Electric Bus Charging in Missoula, Montana

Emma Elgqvist, NREL
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- This analysis relies on site information provided to NREL by Missoula that has not been independently validated by NREL.
- The analysis results are not intended to be the sole basis of investment, policy, or regulatory decisions.
- This analysis was conducted using the NREL REopt Model (<http://www.reopt.nrel.gov>). REopt is a techno-economic decision support model that identifies the cost-optimal set of energy technologies and dispatch strategy to meet site energy requirements at minimum lifecycle cost, based on physical characteristics of the site and assumptions about energy technology costs and electricity and fuel prices.
- The data, results, conclusions, and interpretations presented in this document have not been reviewed by technical experts outside of NREL or Missoula.
- This analysis was an initial screening and was conducted for limited use to inform further analyses.

Background

- This analysis was conducted under the first round of the [Solar Energy Innovation Network](#) (SEIN), a program led by the [National Renewable Energy Laboratory](#) (NREL) that assembles diverse teams of stakeholders to research solutions to real-world challenges associated with solar energy adoption.
- This analysis supported the efforts of the [Montana Solar Powered Community Transportation Initiative](#), a team consisting of the Montana Renewable Energy Association, Montana Energy Office at the Department of Environmental Quality, City of Missoula, City of Bozeman, City of Whitefish, Climate Smart Missoula, and Yellowstone-Teton Clean Cities.
- The team is investigating the synergies between solar generation and electric vehicle (EV) charging, including the potential opportunities and challenges related to co-locating solar energy and charging infrastructure to reduce costs and enhance co-benefits of the electrification of transportation.
- The City of Missoula's transit agency has purchased six electric buses. This analysis supports the team's efforts to understand the potential costs and specific options for using solar and storage to reduce EV bus charging costs.

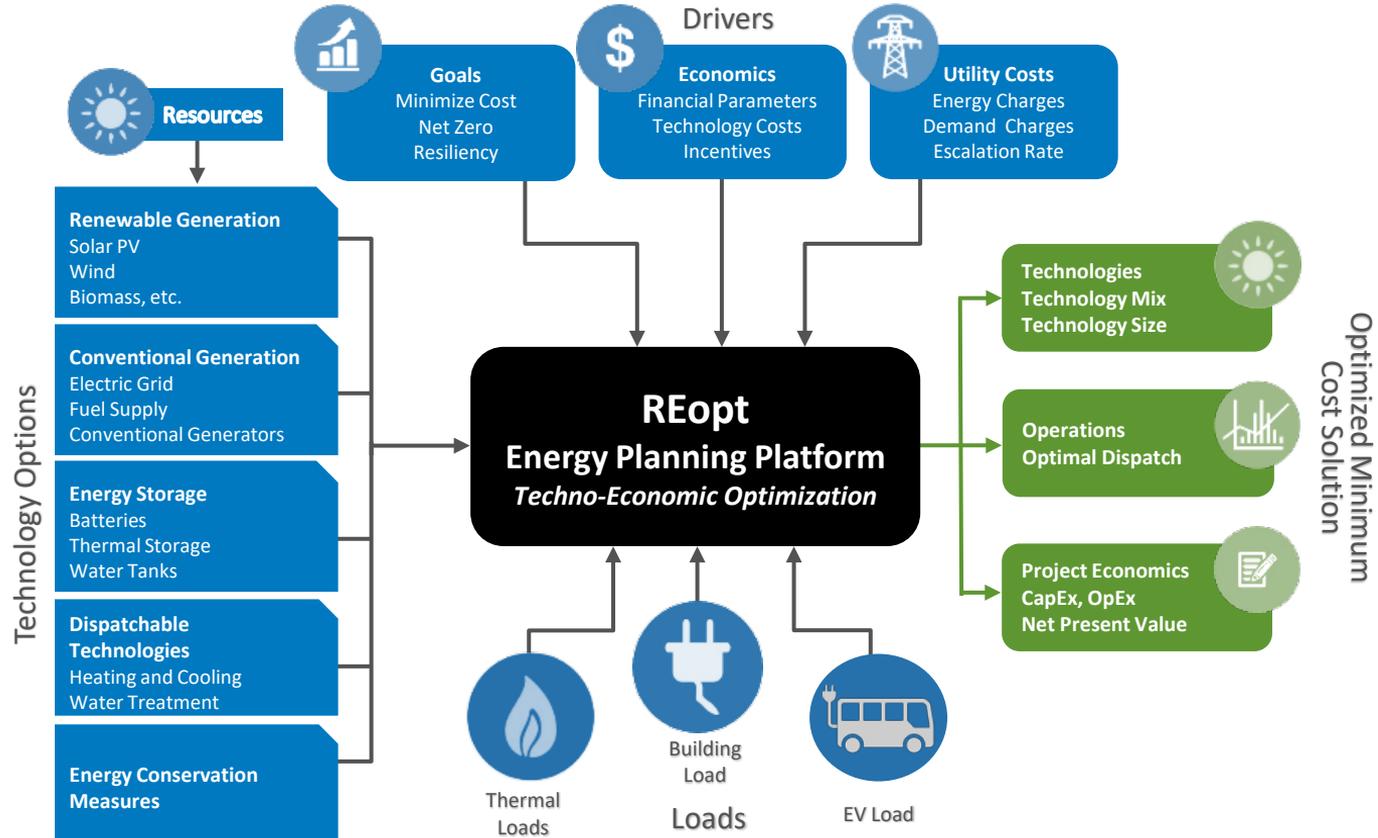
Analysis Overview

- In this analysis, NREL used the [REopt model](#) to evaluate the economics of charging six electric buses purchased by the City of Missoula, Montana
- Specifically, this analysis:
 - Compares the cost of charging the electric bus fleet at the bus depot with the cost of charging at the local university campus
 - Evaluates the techno-economic potential of adding solar photovoltaics (PV) and lithium-ion battery storage to mitigate the costs of charging the electric bus fleet.
- The analysis considers the:
 - Technical specifications of the buses being purchased
 - Hourly simulated electric load profile of the existing bus depot
 - Hourly electric load profile of the university campus
 - Existing electric rate structure of the bus depot
 - Existing electric rate structure of the university campus.

REopt Model Overview

Formulated as a mixed-integer linear program, the REopt model optimizes the integration and operation of behind-the-meter energy assets.

REopt solves a deterministic optimization problem to determine the optimal selection, sizing, and dispatch strategy of technologies chosen from a candidate pool such that loads are met at every time step at the minimum lifecycle cost.



Overview of inputs and outputs of the REopt model

Analysis of Bus Charging at Bus Depot

Bus Depot Current Electricity Rate

- The bus depot is billed under [NorthWestern Energy's General Service secondary demand rate](#).
- Demand charges are billed based on the highest monthly peak, regardless of time of day.
- This analysis assumes the bus depot would continue to be billed under this tariff after adding the load from bus charging.
- Note that fixed (\$/month) charges are not included in this analysis as these cannot be offset.

		\$/kWh	\$/kW	\$/month
Electric Delivery	CTC – QF	0.0032410		
	Distribution Delivery	0.0039240		
	Sec Tax Delivery	0.0015090		
	USBC	0.0011430		
	Sec Tax – Demand		2.4852570	
	Distribution Demand		4.9478300	
	Transmission Demand		2.4272180	
				7.35
Electric Supply	Deferred Supply	0.0018050		
	Sec Tax – Supply	0.0043050		
	Supply	0.0627340		
Total		0.078661	9.860305	7.35

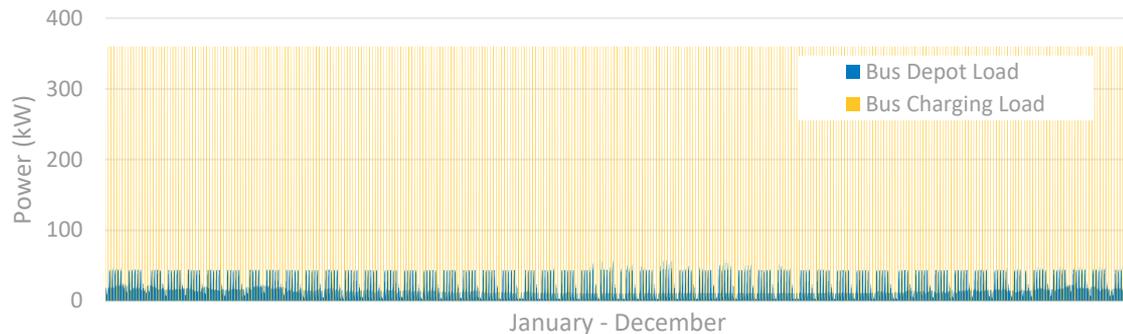
Summary of electricity bill components, based on data received from site.

Bus Depot & Electric Bus Fleet Charging Simulated Hourly Load Profiles

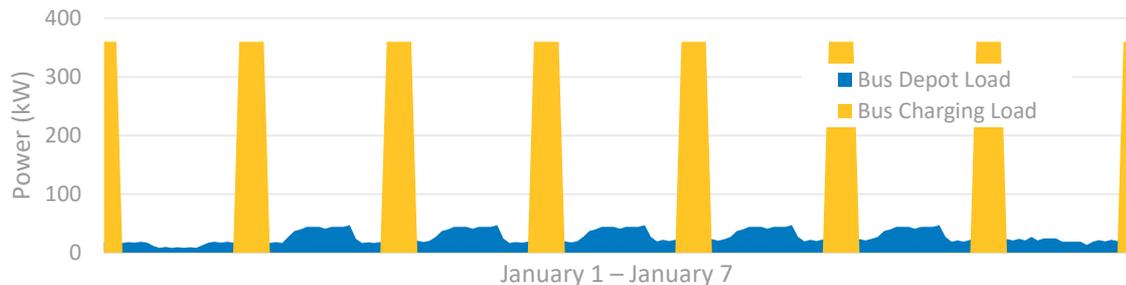
- The hourly load profile for the bus depot was simulated by scaling the [Department of Energy's Commercial Reference Building](#) load profile for a warehouse in climate zone 6B according to the site's actual annual energy consumption of 188,080 kWh (May 2017- April 2018).
- The hourly load profile for the bus charging was simulated assuming each of the 6 buses would charge at 60 kW for 5 hours (from 11 p.m. to 4 a.m.).

	Depot	Buses	Total
Max Peak (kW)	59	360	384
Annual Load (kWh)	188,080	657,000	845,080

Simulated Hourly Load Profiles - Full Year



Simulated Hourly Load Profiles - 1 Week



Cost of Charging at the Bus Depot

- The load at the bus depot is small compared to the bus charging load.
- As a result, the bus charging adds significant demand charges to the cost of electricity at the site, in addition to the energy charges.
- Based on this analysis, charging the six buses at the bus depot would cost approximately \$90,500/year, given the existing electricity rate structure and charging assumptions.

Scenario	Bus Depot	Bus Depot + Electric Buses	Incremental Cost of Buses
Purchased Utility Electricity (kWh/yr)	188,081	845,081	657,000
Year 1 Utility Electric Costs (Energy \$)	\$14,801	\$66,507	\$51,706
Year 1 Utility Electric Costs (Demand \$)	\$5,757	\$44,626	\$38,869
Year 1 Total Electricity Cost (\$)	\$20,558	\$111,133	\$90,575
Blended Rate of Electricity (\$/kWh)	\$0.109	\$0.132	\$0.138
Lifecycle Cost of Electricity (20 years)	\$394,822	\$2,134,217	\$1,739,395

Analysis of Bus Charging at the University Campus

University Current Electricity Rate

- The university campus is billed under [NorthWestern Energy's E191 General Service primary demand rate](#).
- Demand charges are billed based on the highest monthly peak, regardless of time of day.
- Compared to the electricity rate at the bus depot, the energy charges at the university are 3% lower and demand charges are 15% lower.
- Note that fixed (\$/month) charges are not included in this analysis as these cannot be offset.

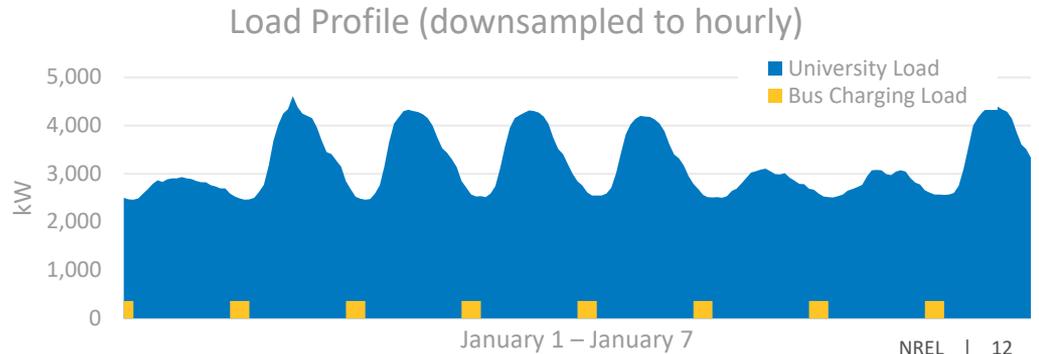
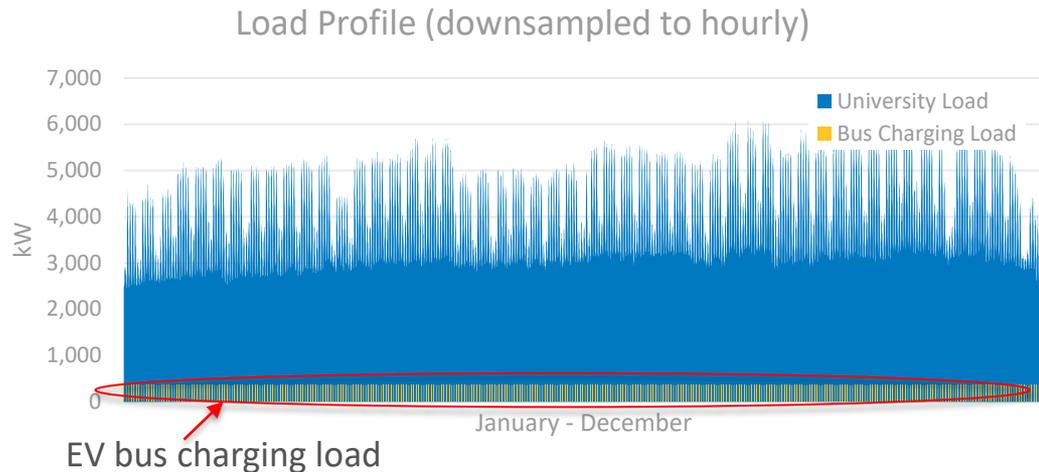
		\$/kWh	\$/kW	\$/month
Electric Delivery	CTC – QF	0.0031520		
	Distribution Delivery	0.0056750		
	Sec Tax Delivery	0.0020470		
	USBC	0.0009000		
	Pri Tax - Demand		2.2097500	
	Distribution Demand		3.2394250	
	Transmission Demand		2.9501400	
				19.85
Electric Supply	Deferred Supply	0.0017560		
	Pri Tax – Supply	0.0037620		
	Supply	0.0587210		
Total (\$)		0.076013	8.399315	19.85

Summary of electricity bill components, based on data received from site.

University Load Data

- The University of Montana provided 15-minute interval data (which was down sampled to hourly for this analysis).
- The additional load from charging the EV buses is very small relative to the load of the university.
- The peaks of the bus charging load are out of alignment with the peaks of the university load, so no additional demand charges are incurred.

	University	Buses	Total
Max Peak (kW)	6,078	360	6,078
Annual Load (kWh)	34,541,951	657,000	35,198,951



Cost of Charging at the University

- The load at the university is large compared to the bus charging load.
- In addition, the bus charging load is out of alignment with the peak load at the university.
- As a result, charging the buses at the site does not result in additional demand charges.
- Based on this analysis, charging the six buses at the university would cost approximately \$50,000/year.

Scenario	University	University + Electric Buses	Incremental Cost of Elec Buses
Purchased Utility Electricity (kWh/yr)	34,541,951	35,200,036	657,000
Year 1 Utility Electric Costs (Energy \$)	\$2,625,187	\$2,675,203	\$50,016
Year 1 Utility Electric Costs (Demand \$)	\$569,120	\$569,120	\$0
Year 1 Total Utility Cost (\$)	\$3,194,307	\$3,244,323	\$50,016
Blended Rate of Electricity (\$/kWh)	\$0.0925	\$0.0922	\$0.0762
Lifecycle Cost of Electricity (20 Year)	\$75,948,156	\$77,137,710	\$1,189,554

Analysis of Adding Photovoltaics and Battery Storage for Bus Charging

PV + Storage for Electric Bus Charging: Scenarios Evaluated

NREL evaluated the potential to add PV and lithium-ion battery storage to the bus depot to help offset the added cost of charging the electric buses. The results of the following two scenarios were compared:

- Base Case: All electricity is purchased from the utility at the time of demand. Total electricity costs include the load of the bus depot plus the load of charging the electric buses (under one meter). This is the analysis presented in the prior section.
- PV + Storage: The cost-optimal size and dispatch of PV and stationary battery storage, as defined by the minimum lifecycle cost of electricity to serve the load of the bus depot and bus charging. This analysis assumes electricity can be purchased from the utility, the PV system can be net-metered (up to 50 kW), and that stationary storage can be optimally dispatched to mitigate electricity costs.

PV + Storage Analysis Assumptions

Input	Assumption
Technologies	Solar PV, stationary lithium-ion battery storage
Ownership model	3 rd party financed
Analysis period	20 years
Discount rate	3% for site/8.1% for developer
Escalation rate	2.60% per EIA utility cost escalation rates
Inflation rate	2.1% per EIA
Incentives	30% Investment Tax Credit; 5 year MACRS for PV
Net metering limit	50 kW
Electricity sellback rate	\$0/kWh
Interconnection limit	None
PV costs	\$2.00/W ground mount installed; \$15.50/kW/yr. operations and maintenance
Storage costs	\$500/kWh and \$1000/kW; replacement costs in year 10: \$230/kWh and \$460/kW
Solar resource	TMY2 Weather File Missoula, MT (1991–2005 National Solar Radiation Data Base)
Area for PV	Unlimited
Module Type	Standard
Array Type	Fixed (open rack)
Array Tilt / Array Azimuth	46.91° / 180°
PV System Losses	14.08%
PV Capacity Factor	14.20%
Solar Radiation (kWh/m ² /day)	4.28

PV + Storage at Bus Depot Analysis Results

- When net metered, a 50 kW PV system appears marginally cost effective.
- Storage is not found to be cost effective.
- 7% of the load from the depot and bus charging would be generated by the PV system.
- The PV system would produce electricity during the day, and offset energy costs. It would not offset demand costs as the peak demand occurs at night.
- The PV system would save the depot \$2,000 over the 20-year analysis period.

Scenario	Base Case	Optimal Size of PV + Storage
Storage Size (kW)	-	0
Storage Size (kWh)	-	0
Storage Cost (\$)	-	0
PV Size (kW DC)	-	50
PV Cost (\$)	-	\$100,000
PV Electricity Produced (kWh)	-	59,356
Percent RE (%)	0%	7%
Purchased Utility Electricity (kWh/yr)	845,065	796,079
Year 1 Utility Electric Costs (Energy \$)	\$66,507	\$61,835
Year 1 Utility Electric Costs (Demand \$)	\$44,626	\$44,626
Year 1 Total Utility Cost (\$)	\$111,133	\$106,461
Lifecycle Cost of Electricity	\$2,134,217	\$2,131,778
Net Present Value	N/A	\$2,466

Summary and Conclusions

- In this analysis, NREL compared the economics of charging six electric buses at the bus depot and the university campus in Missoula, Montana.
- Since the load at the bus depot is small compared to the simulated load from charging the buses, charging the buses at the depot adds significant demand charge costs to the electricity bill, in addition to energy charges.
- The load at the university campus is large compared to the simulated load from bus charging and the peak load of the university is not coincident with the peak demand load of the electric buses, so charging the buses at the university does not result in additional demand charges.
- The size and shape/timing of the building or campus load makes a significant difference in the incremental economics of electric charging costs because of the cost of the demand charges.
- Considering the load and electricity rate at the bus depot in Missoula, MT, adding photovoltaics may result in cost savings, especially when net-metering is available.
- Storage could potentially be charged with PV and discharged to serve load during peak demand times, thus reducing demand charges. However, storage was not found to be cost-effective under the assumptions of the analysis.

Thank you

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Contact: Emma Elgqvist emma.elgqvist@nrel.gov

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