Presentation to the Clean Cities and Communities Coalition Network
April 3, 2024

HEVISAM

Heavy-duty battery **E**lectric **V**ehicle **I**nfrastructure **S**cenario **A**nalysis **M**odel

Overview & Case Studies for Port and School Bus Electrification

Amgad Elgowainy, Krishna Reddi, Sajag Poudel
Systems Assessment Center
Energy Systems & Infrastructure Analysis Division
Argonne National Laboratory

HEVISAM: A Technoeconomic Analysis (TEA) Tool

HEVISAM is an Excel-based platform for comparing the cost of recharging options for medium- and heavy-duty battery electric vehicles (BEVs).

HEVISAM helps users identify cost drivers of current recharging technologies for various station configurations and vehicle charging demand profiles.

Levelized Cost of Charging (LCOC)

LCOC is the average net present cost of electricity delivered by the charging station over a defined analysis period.

LCOC calculations include:

- The capital cost, including uninstalled equipment and installation cost
- The operations and maintenance (O&M) cost
- The energy cost of the charging station
- Annual cash flows of the charging station
- Levelized charging cost in $/kWh

HEVISAM allows users to modify charging scenarios, capital cost, electricity rates, etc., to evaluate scenarios of interest.

HEVISAM evaluates levelized cost ($/kWh) of fast charging scenarios of BEVs

Inputs

Station Configurations
- w/ or w/o battery storage
- - Equip. type
  - # of charging ports

Fleet Parameters
- Fleet type and size
- Vehicle charging schedule
- Battery charging profile

Cost Data
- Equipment cost
- Electricity rates

Economic and financial inputs

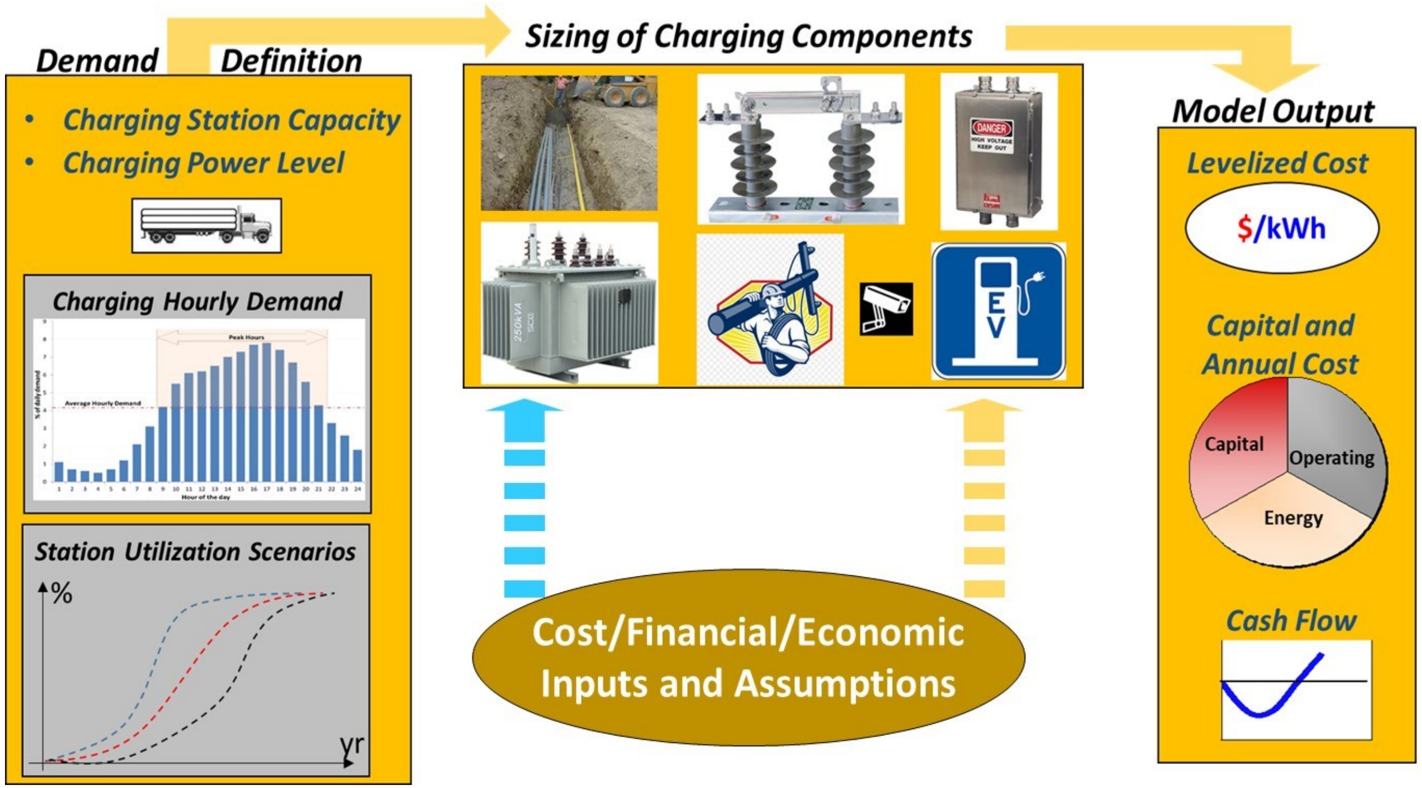
Outputs

Station Capital and O&M Costs
- Direct capital investment
- Other capital investment
- O&M and energy

Output Cost Information
- Levelized cost ($/kWh)
- Cash flows

https://hdsam.es.anl.gov/index.php?content=hevisam

HEVISAM tool leveraged HDRSAM for FCEVs



- ✓ Provides a framework with transparent assumptions and methodology
  - consistent with other DOE tools
- ✓ Systematically examines impact of various scenarios and parameters
- ✓ Informs TCO, market segmentation, ISATT, 21CTP, etc.

https://hdsam.es.anl.gov/index.php?content=hevisam

Argonne NATIONAL LABORATORY

HEVISAM Data Sources

	Vehicle and Fleet parameters	Capital Costs	Energy Costs	Operating Costs	Station Configurations
Expert* interviews	√	√	√	√	√
Vendor websites	√	√	√		
Industry reports	√	√	√	√	√
Literature	√	√			√

*Including electric fleet operators, EVSE suppliers, and researchers

- Users can change charging scenarios, capital cost, electricity rates, etc., to evaluate scenarios of interest

HEVISAM: Station Configuration & Fleet Parameters

HEVISAM Simulation Setup

- # of Vehicles, corresponding battery capacity (kWh), SOC before charging (%), End of charging SOC (%) and charging start time along with the charger type (DC 150) can be assigned in HEVISAM as input parameters

Station Information	
Station Type	w/o energy storage

Click to specify electricity rates

Click to specify charging station details

General Economic Assumptions	
Assumed Start-up Year	2024
Construction Period (Years	1
Operating Days per Year	365
Desired Year Dollars for Co	2020
Real After-tax Discount Ra	10.0%
Analysis Period (Years)	30
Debt Ratio (of total capital	0%
Debt Interest (nominal)	6.0%
Debt Period (Years)	10

Fleet Information

Vehicle group	Number of vehicles	Number of vehicles per dispenser per session	Total vehicle battery capacity (kWh)	SOC before charging (%)	Charging start time	SOC at the end of charging (%)	Accept pantograph charging?	Max vehicle charging rate plug-in (kW)	Max vehicle charging rate pantograph (kW)	Selected dispenser	
Port cargo truck	50	1	180	50%	1:00:00 AM	100%	No	132	330	150kW, Plug-in	OK
Port cargo truck	50	1	180	50%	3:00:00 AM	100%	No	132	330	150kW, Plug-in	OK
Port cargo truck	50	1	180	65%	10:00:00 AM	85%	No	132	330	150kW, Plug-in	OK
Port cargo truck	50	1	180	65%	10:30:00 AM	85%	No	132	330	150kW, Plug-in	OK
Port cargo truck	50	1	180	50%	3:30:00 PM	80%	No	132	330	150kW, Plug-in	OK
Port cargo truck	50	1	180	50%	4:00:00 PM	80%	No	132	330	150kW, Plug-in	OK
Port cargo truck	50	1	180	45%	9:00:00 PM	75%	No	132	330	150kW, Plug-in	OK
Port cargo truck	50	1	180	45%	9:30:00 PM	75%	No	132	330	150kW, Plug-in	OK
Select vehicle type							Pantograph charging?			Select dispenser	
Select vehicle type							Pantograph charging?			Select dispenser	
Designed station fleet size	100	If intending to increase fleet size over time, please enter final fleet information in the table above, and specify fleet size for each year in the table to the right.									OK

Click to Calculate

Economic and Financial Assumptions

- Economic assumptions including start-up year, discount rate, debt ratio, etc. can also be tailored as needed

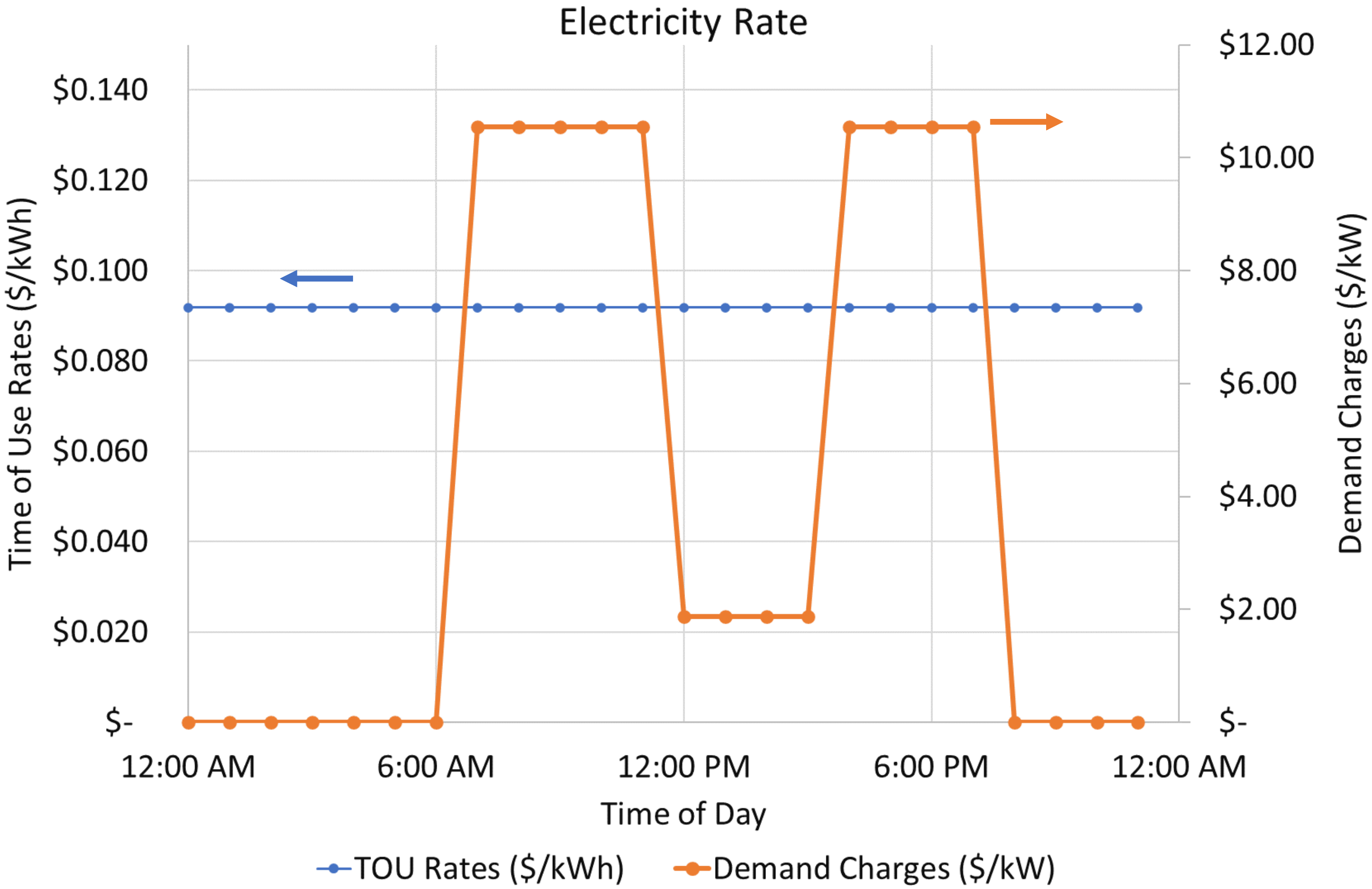
General Economic Assumptions	
Assumed Start-up Year	2024
Construction Period (Years)	1
Operating Days per Year	365
Desired Year Dollars for Cost Estimates	2020
Real After-tax Discount Rate (%)	10.0%
Analysis Period (Years)	30
Debt Ratio (of total capital investment)	0%
Debt Interest (nominal)	6.0%
Debt Period (Years)	10
State Taxes (%)	6%
Federal Taxes (%)	21%
Inflation Rate (%)	2%

Financial Assumptions for Equipment (Default for charger)	
Lifetime (years)	15
MACRS Depreciation Schedule Length (years)	10
Construction Period	1
Startup Time	1
Salvage Value	10%
Decommission Value	10%
% Variable Cost during Startup	75%
% fixed Cost during Startup	100%
% Revenue During Startup	75%
percent of Capital in 1st year	100%
percent of Capital in 2nd year	0%
percent of Capital in 3rd year	0%
percent of Capital in 4th year	0%

Assumptions: Electricity Rate

- Electricity rate can vary substantially by region, season, and the time of day.
- In HEVISAM it is convenient to enter electricity rate (time of use (TOU) & Demand Charges)
- An example of a major utility provider in New England Region is considered here

+ a fixed monthly charge of $132.19



Argonne NATIONAL LABORATORY

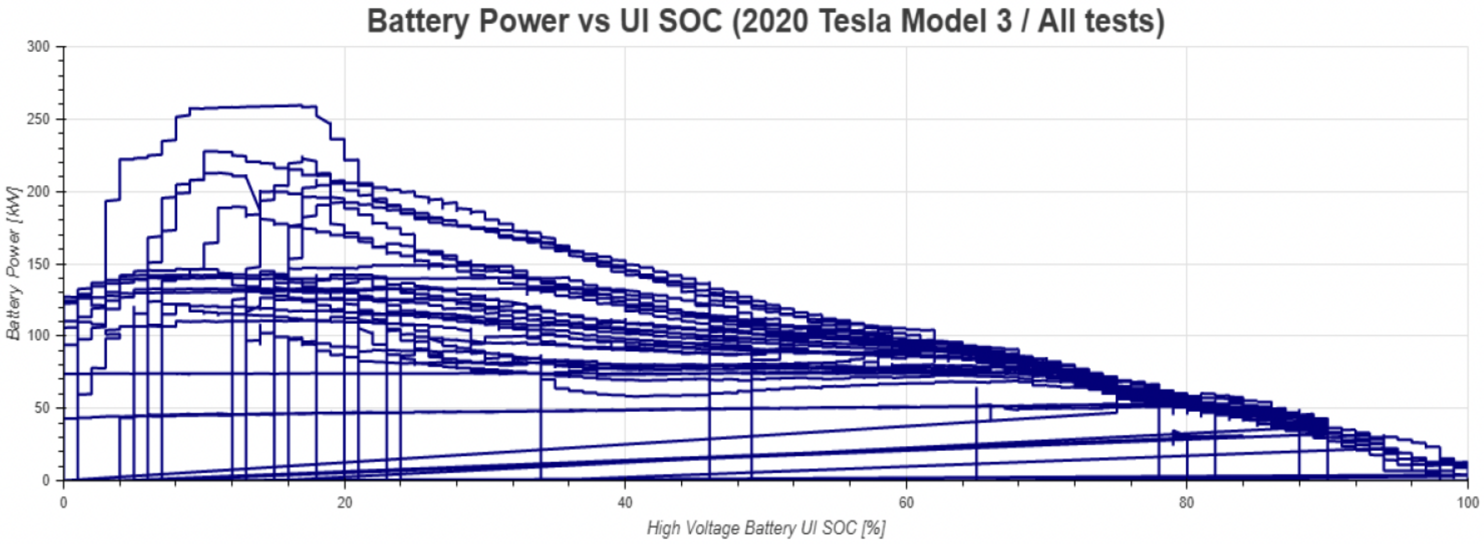
Assumptions: Equipment & Installation Cost Data

- HEVISAM has default assumptions for purchase cost, installation cost and maintenance cost of the standard DC Fast Chargers and amenities including transformer and switchgear

Equipment	Purchase cost ($/piece)	Installation cost ($/piece)	Annual Maintenance cost
150kW charger	$61,000	$36,000	5% of purchase cost
2500kVA transformer	$100,000	$30,200	1% of installed cost
480V switchgear	$75,000	$187,000	1% of installed cost

Battery Charging Profile

Battery charging profile depicts how the charging power changes with the battery SOC, and is particularly important for fleet charging



Source: Stutenberg *et al.*, 2020

Battery charging profile varies with vehicle make/model and charging conditions (starting and ending battery SOC, ambient temperature, etc.)

HEVISAM Default Battery Charging Profile*

Battery SOC range	Charging rate (% of max charging rate)
15-75%	100%
75-85%	75%
85-95%	50%
95-100%	25%

*Based on BatPaC
https://www.anl.gov/cse/batpac-model-software

Model Demonstration: Scenario Analysis for Port Equipment Charging

HEVISAM Case Study: Port Equipment Charging

Port Vehicles Count & Energy Usage

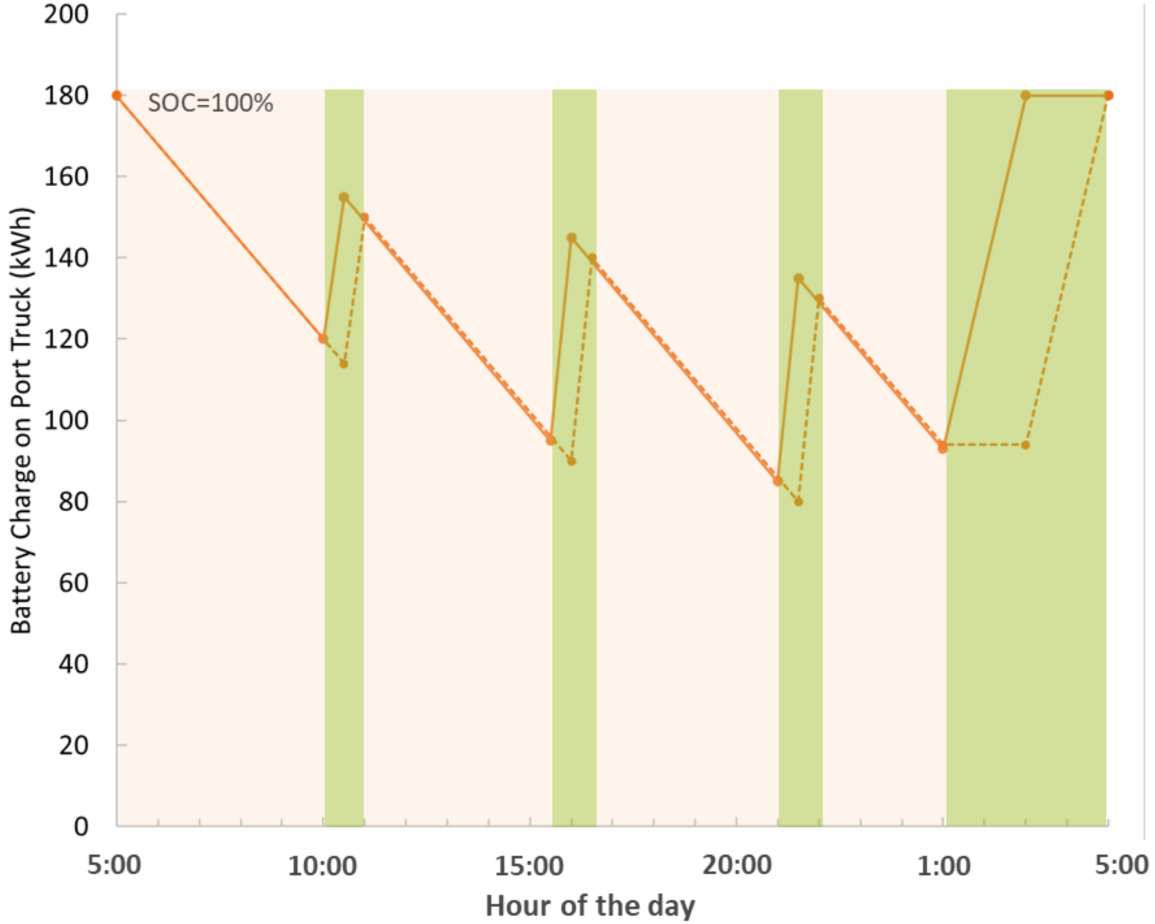
Equipment Name	Equipment Count	Battery Capacity (kWh)	Avg kW use	Preferred Charger (kW)	Designated Charging Sessions
Port Truck (Terminal Tractor)	100	180	12	150	Varying charging sessions throughout the day depending on scenario (discussed later)

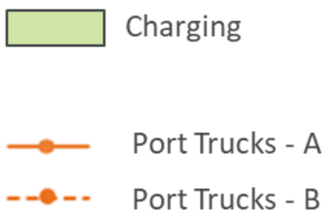
HEVISAM Case Study: Port Equipment Charging

Case 1 (Baseline Case)

Charging Sessions: 100 vehicles divided into 2 groups A & B

Port Equipment	Vehicle Count	Battery Capacity (kWh)	Avg kW use	Working Schedule		Charging Schedule		Working Schedule		Charging Schedule		Working Schedule		Charing Schedule		Working Schedule		Charging Schedule	
Port Trucks – Group A	50	180	12	5:00 AM	10:00 AM	10:00 AM	10:30 AM	10:30 AM	3:30 PM	3:30 PM	4:00 PM	4:00 PM	9:00 PM	9:00 PM	9:30 PM	9:30 PM	1:00 AM	1:00 AM	3:00 AM
	Charging/Discharging Energy			- 60kWh		+ 35 kWh		- 60 kWh		+ 50 kWh		- 60 kWh		+ 50 kWh		- 42 kWh		+87 kWh	
Port Trucks – Group B	50	180	12	5:00 AM	10:30 AM	10:30 AM	11:00 AM	11:00 AM	4:00 PM	4:00 PM	4:30 PM	4:30 PM	9:30 PM	9:30 PM	10:00 PM	10:00 PM	1:00 AM	3:00 AM	5:00 AM
	Charging/Discharging Energy			- 66 kWh		+ 35 kWh		- 60 kWh		+ 50 kWh		- 60 kWh		+ 50 kWh		- 36 kWh		+87 kWh	





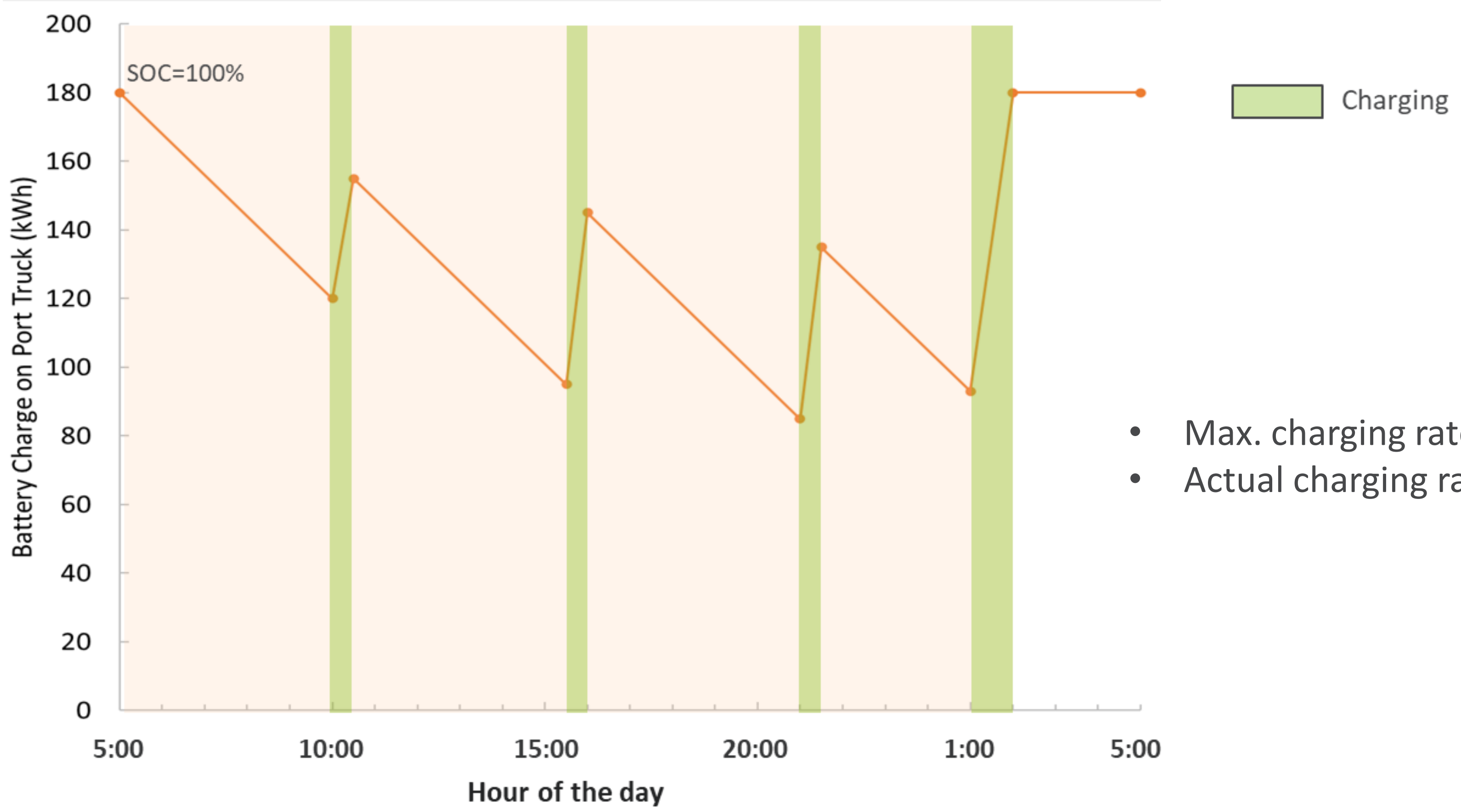
- Max. charging rate is 132 kW (for DC 150 charger).
- Actual charging rate depends up on state of charge of the battery
- 5 minutes allowed between two groups to enable transition.

HEVISAM Case Study: Port Equipment Charging

Case 2

Charging Sessions: 100 vehicles at the same time

Port Equipment	Vehicle Count	Battery Capacity (kWh)	Avg kW use	Working Schedule		Charging Schedule		Working Schedule		Charging Schedule		Working Schedule		Charing Schedule		Working Schedule		Charging Schedule	
Port Trucks	100	180	12	5:00 AM	10:00 AM	10:00 AM	10:30 AM	10:30 AM	3:30 PM	3:30 PM	4:00 PM	4:00 PM	9:00 PM	9:00 PM	9:30 PM	9:30 PM	1:00 AM	1:00 AM	3:00 AM
	Charging/Discharging Energy			- 60kWh		+ 35 kWh		- 60 kWh		+ 50 kWh		- 60 kWh		+ 50 kWh		- 42 kWh		+87 kWh	



- Max. charging rate is 132 kW (for DC 150 charger).
- Actual charging rate depends up on state of charge of the battery

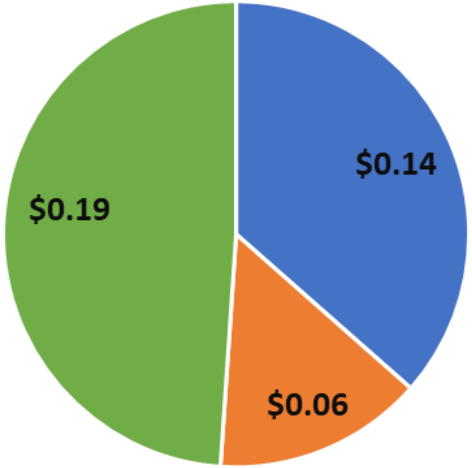
Results: Station Configuration & Cost

Case 1 (Baseline)

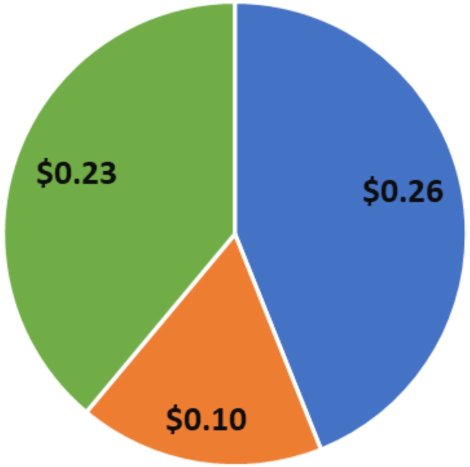
- Case Study for charging 100 vehicles
- 52 DC150 Chargers (Assuming 4% extra)
- No overlap in Charging Sessions of Port Trucks in Group A & Group B

Charger Type: DC150	
Total # of Chargers	52
Transformer: (2,500kVA)	
Total # of Transformers & Switchgears	4

Cost Breakdown



- Capital cost [$/kWh]
- O&M less energy [$/kWh
- Energy [$/kWh]



Case-2

- Case Study for charging 100 vehicles
- 104 DC150 Chargers (Assuming 4% extra)
- Simultaneous charging on 100 Port Trucks

Charger Type: DC150	
Total # of Chargers	104
Transformer: (2,500kVA)	
Total # of Transformers & Switchgears	7

Results Overview		
Total charging cost [$/kWh]	$ 0.39	$0.60
Charging station capital investment	$ 10,584,443	$ 20,667,973
Annual O&M cost (w/energy cost)	$ 2,752,681	$ 3,845,754

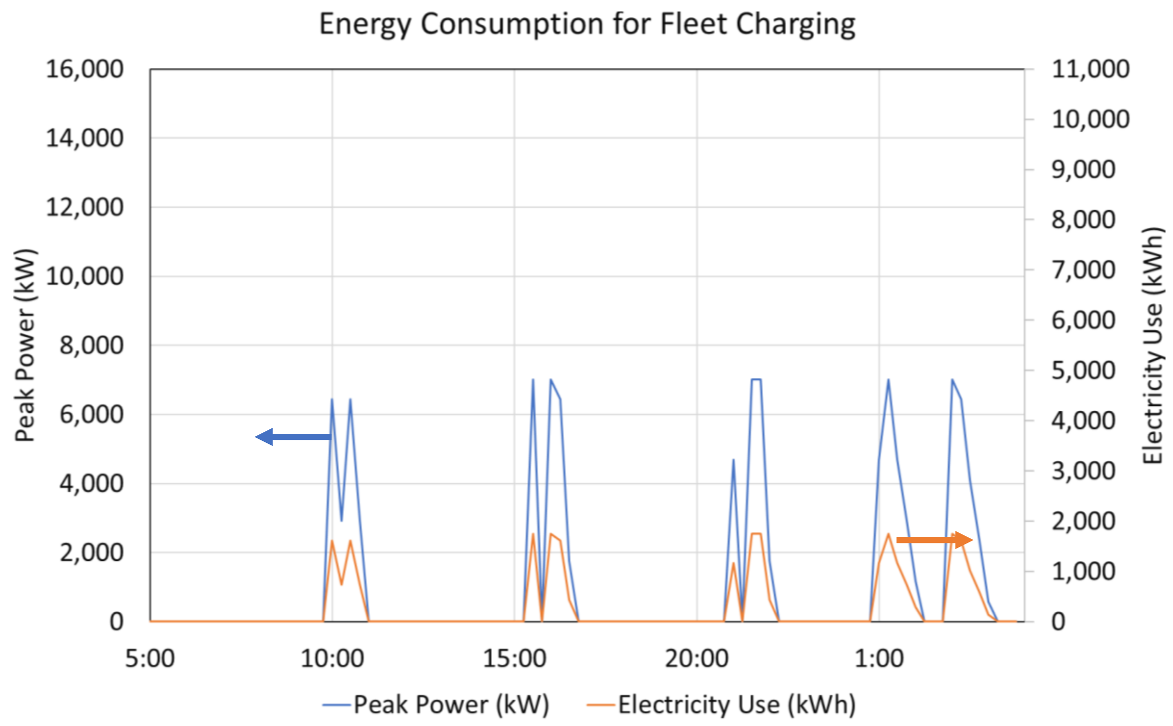
Larger number of chargers

High peak power drawn from grid

Argonne NATIONAL LABORATORY

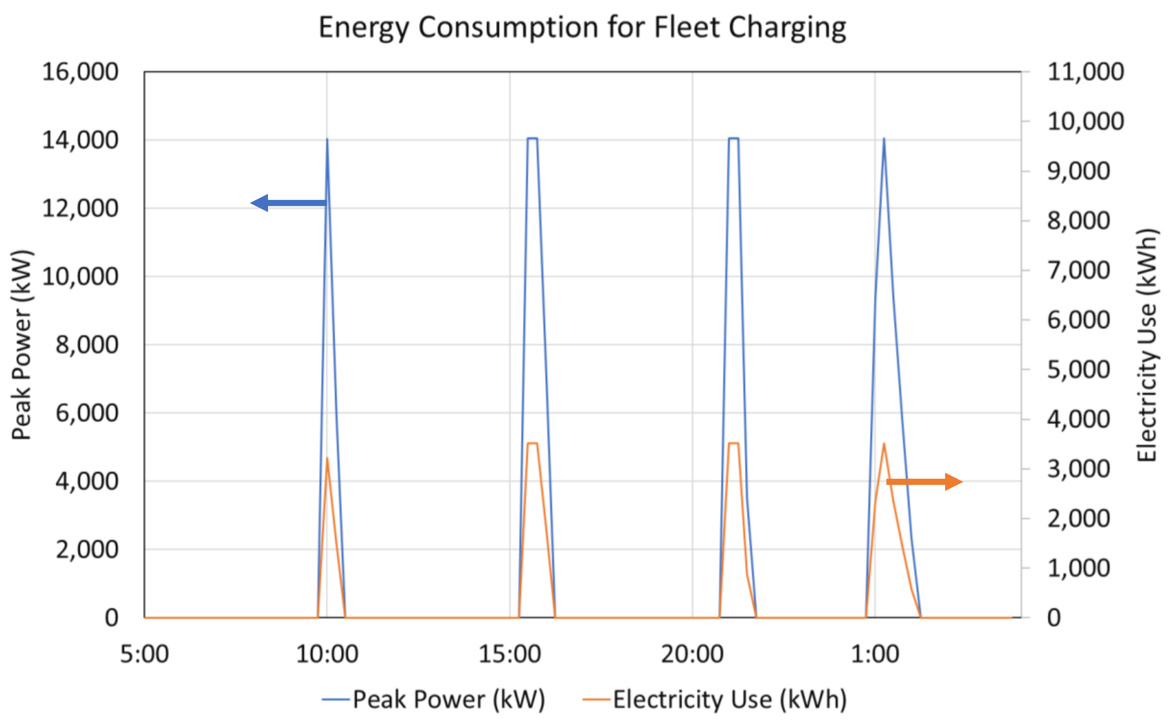
Results: Electricity Use & Peak Power

Case 1 (Baseline Case)



Case 2

Low utilization of charger
High peak power drawn from grid



HEVISAM offers technoeconomic analysis of innovative charging solution by employing stationary Battery Energy Storage (BES) system that can offset the peak power during charging & reduce the cost of charging by lowering the demand charges.

**Plot for Electricity use in kWh is based on 15 min interval*

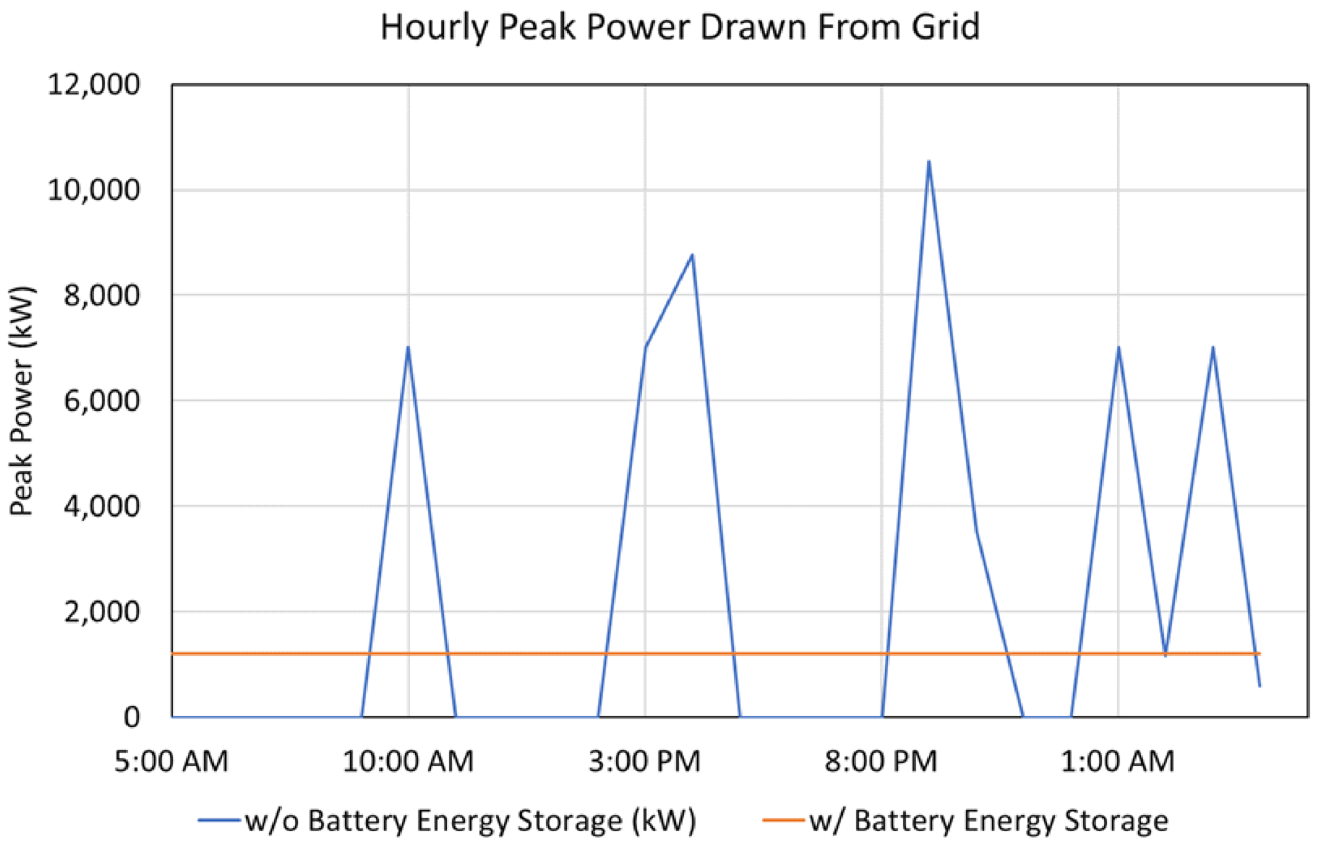
Results: Charging Station with BES

Case 3 Charger with Battery Energy Storage (BES)

Assumptions:

- Charging session: Consistent to Case 1
- Peak power drawn from grid is limited to 1200 kW
- Battery size: 8,000 kWh ($2,282,145 Capital Cost)
- Average discharging rate 2,000 kW
- Battery Life: 30 years
- Cost of BES: *($219*(kWh)+$838*(kW)+$192,207)*
  - *$35/kWh (Manufacturing Tax Credit)*
  - *30% of Total (Investment Tax Credit)*

ATB | NREL
Publication 5886 (11-2023) (irs.gov)
Battery Storage Technology Tax Credit | ENERGY STAR



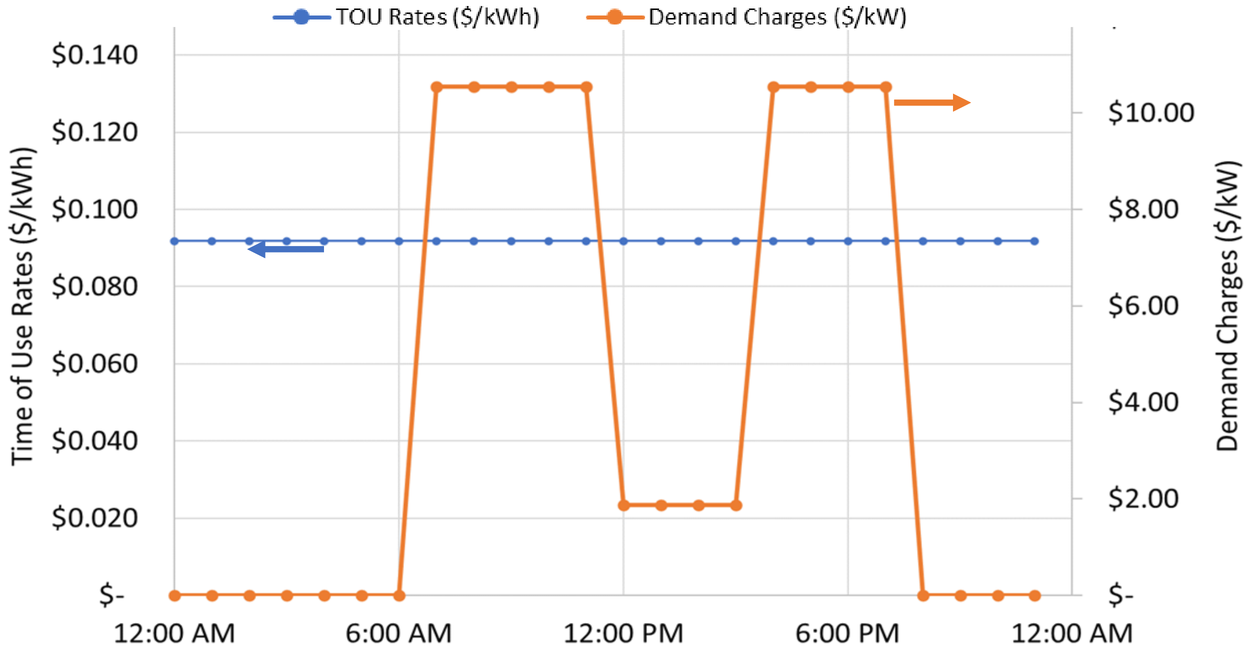
- BES charges during the time when electricity rate is low and discharges during the time when electricity rate is high
- Lower number of transformer/switch gears → lowering station capital cost that may partially offset battery cost
- BES offers buffer for energy storage thus providing lower impact to grid
- Savings in terms of lower grid upgrade cost & lower demand charge of electricity (not included in this analysis)

Results: Charging Station with BES

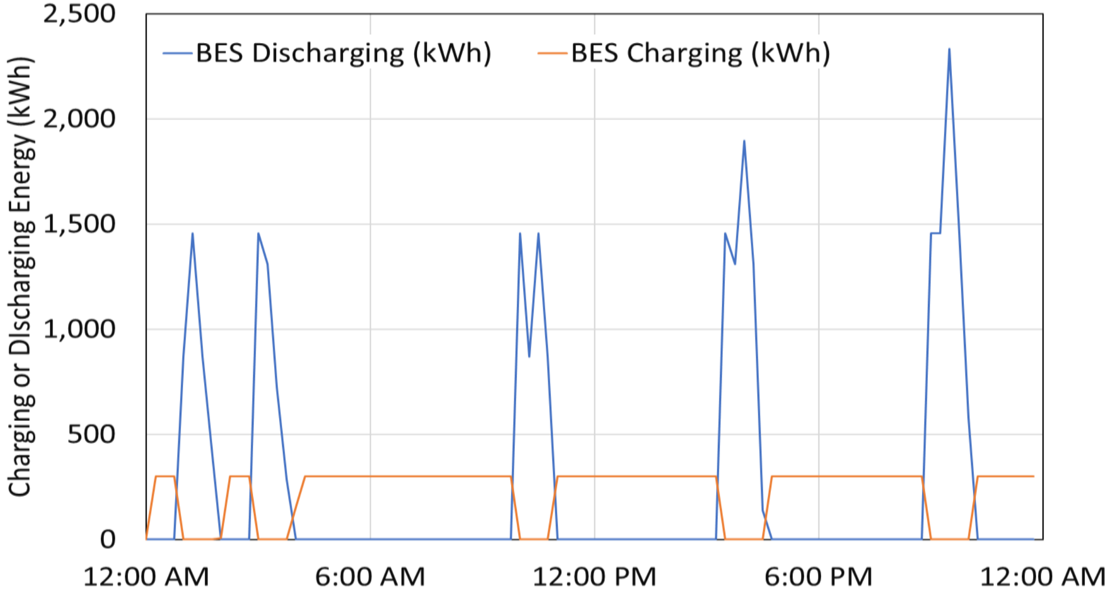
Case 3 Charger with Battery Energy Storage (BES)

Charger Type: DC150	
Total # of Chargers	52
Transformer: (2,500kVA)	
Total # of Transformers & Switchgears	1

Electricity Rates



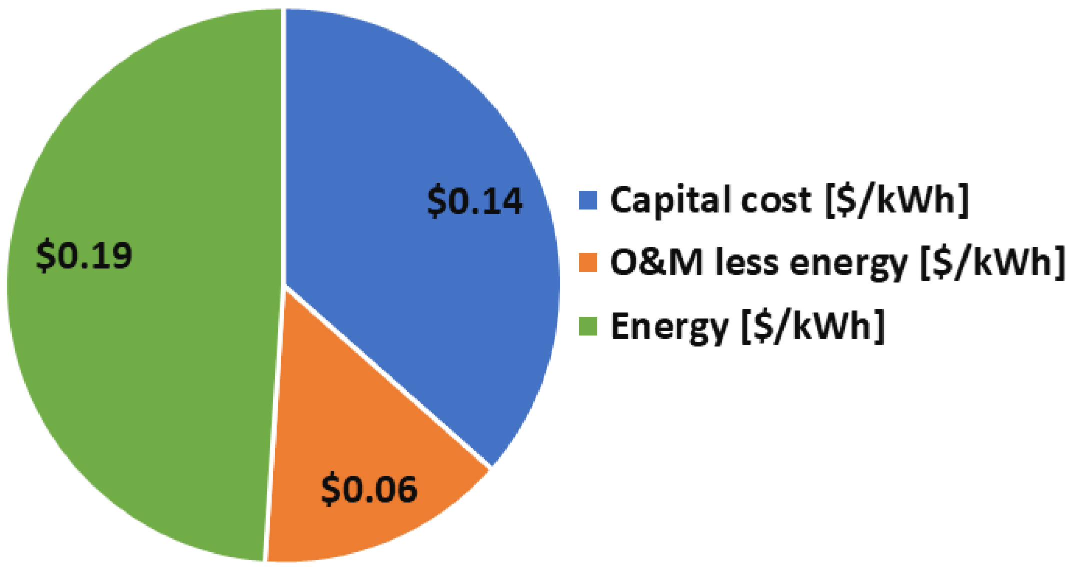
BES Charging & Discharging Profile



Results: Comparison of Baseline & w/ BES Scenario

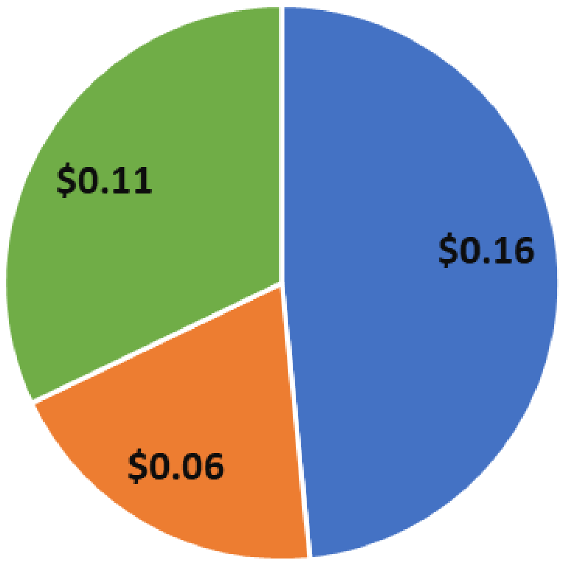
Case 1

Charging Cost at Baseline



Case 3

Charging Cost with Integrated BES



Results Overview		
Total charging cost [$/kWh]	$ 0.39	$0.33
Charging station capital investment	$ 10,584,443	$ 11,802,064
Annual O&M cost (w/energy cost)	$ 2,752,681	$ 1,766,564

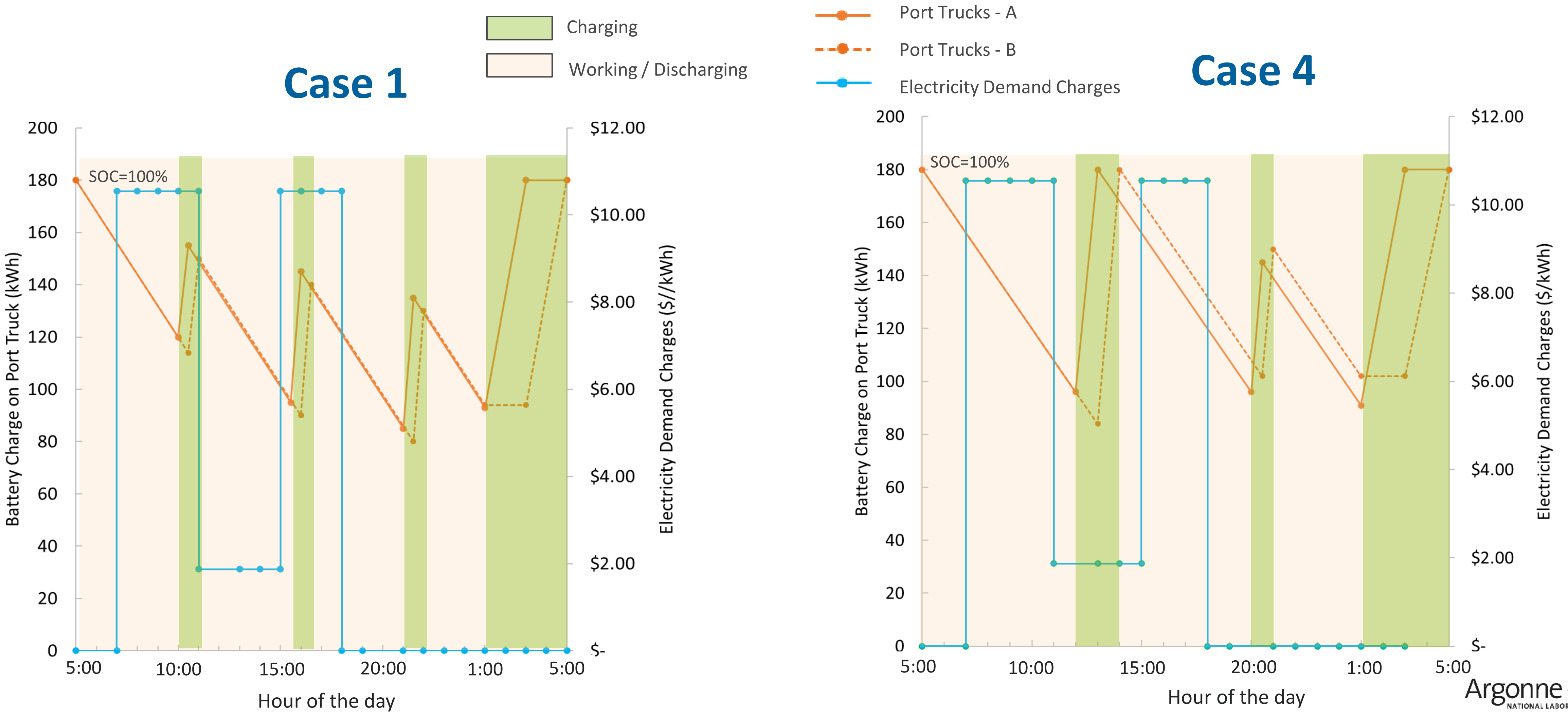
Despite a higher capital cost, associated with BES System, significant saving on levelized charging cost can be achieved.

**Plot for Electricity use in kWh is based on 15 min interval*

HEVISAM Case Study: Port Equipment Charging

Case 4 Opportunity Charging w/o BES

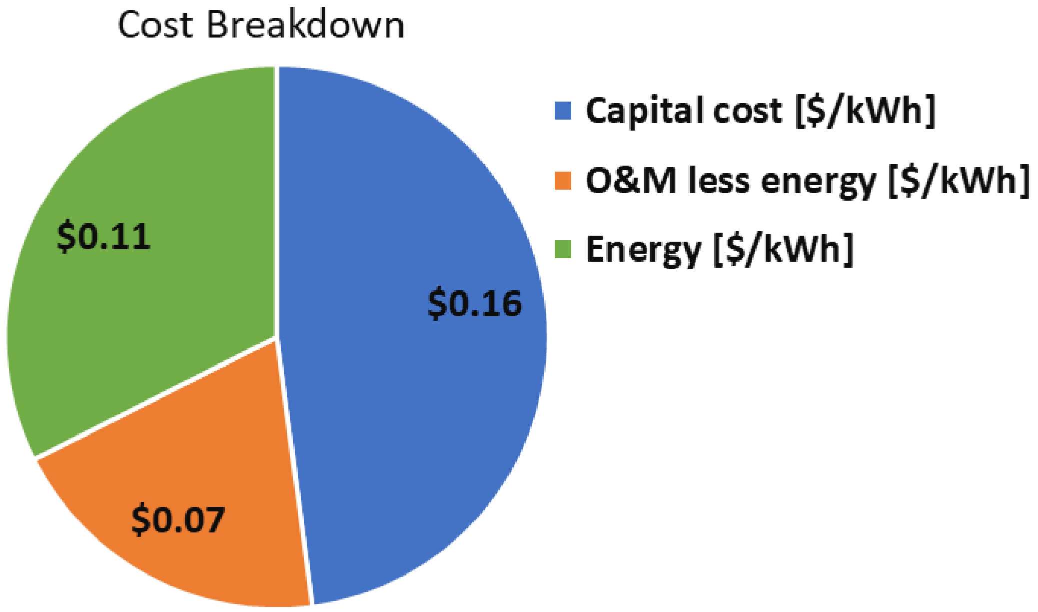
- Charging the fleet in 2 groups, consistent to Case 1 (Baseline)
- Synchronizing the charging session with the time of the day during which demand charges are low
- Potential option for ports with flexible charging/working schedules



Results: Station Configuration & Cost

Case 4 Opportunity Charging w/o BES

- Case Study for charging 100 vehicles
- 52 DC150 Chargers (Assuming 4% extra)
- No overlap in Charging Sessions of Port Trucks in Group A & Group B



Charger Type: DC150	
Total # of Chargers	52
Transformer: (2,500kVA)	
Total # of Transformers & Switchgears	4

Results Overview	
Total charging cost [$/kWh]	$ 0.33
Charging station capital investment	$ 10,584,443
Annual O&M cost (w/energy cost)	$ 1,667,635

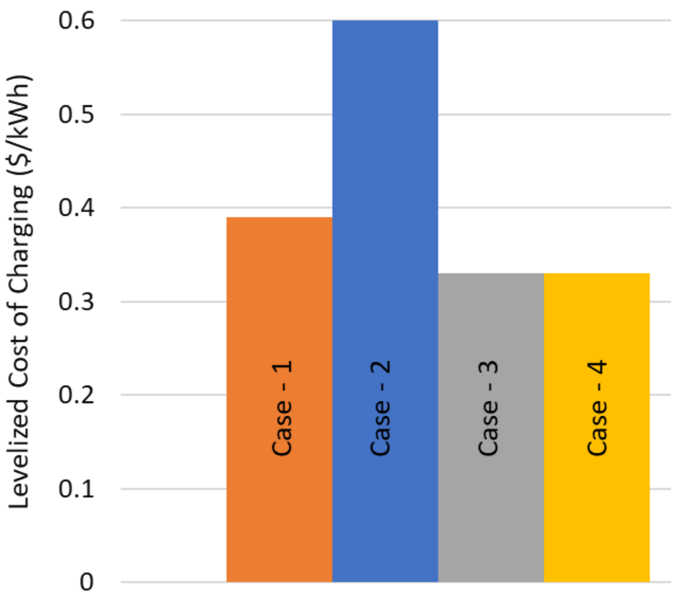
Argonne NATIONAL LABORATORY

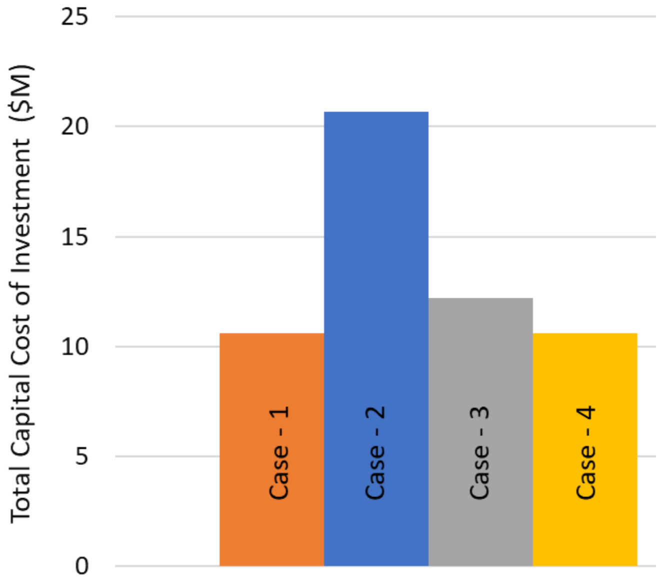
HEVISAM Case Study: Port Equipment Charging

Summary of Cases

- **Case 1 (Baseline)**
  - 100 port trucks divided into 2 groups
  - Total Number of Chargers Required: **52**
- **Case 2**
  - 100 port trucks with simultaneous charging on all
  - Total Number of Chargers Required: **104**
- **Case 3**
  - 100 port trucks divided into 2 groups
  - Charging with Battery Energy Storage (BES)
  - Total Number of Chargers Required: **52**
- **Case 4**
  - 100 port trucks divided into 2 groups
  - Opportunity Charging without Battery Energy Storage (BES)
  - Total Number of Chargers Required: **52**

✓ Higher demand charges in case 4 offsets slightly higher capital in case 3





Model Demonstration: Scenario Analysis for Bus Fleet Charging

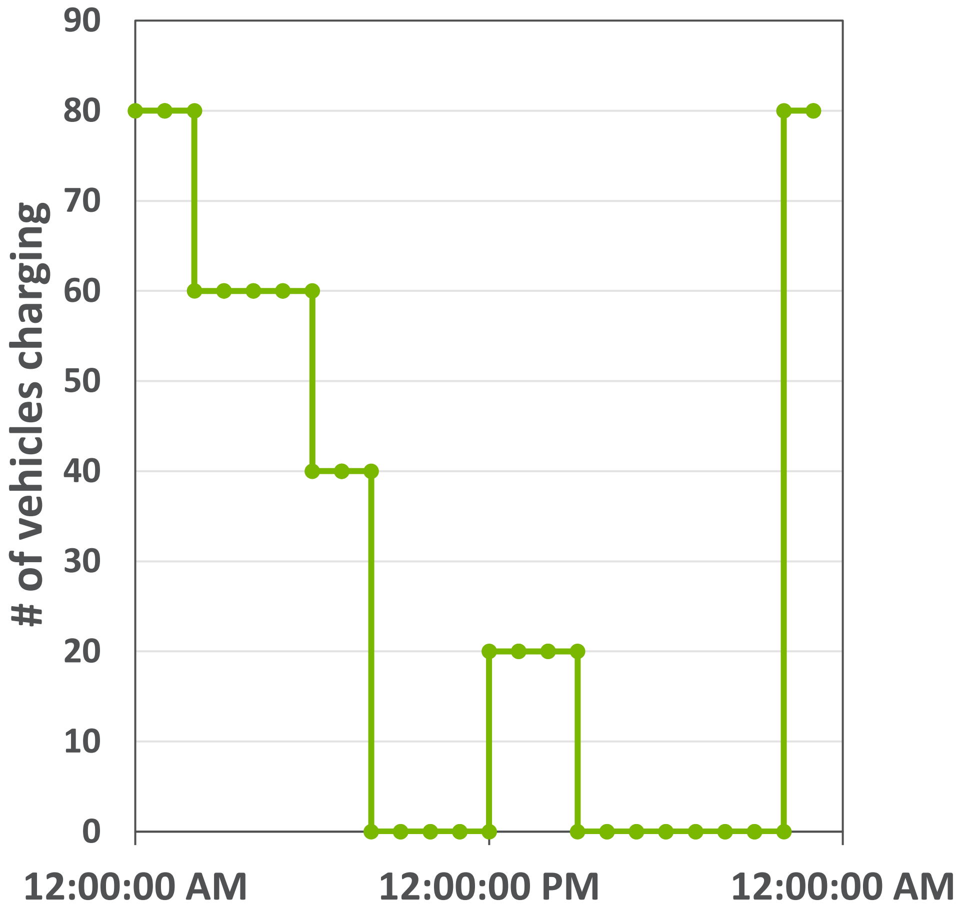
Argonne NATIONAL LABORATORY

HEVISAM : Battery Electric Bus Fleet

80 battery electric buses (440 kWh each) to be charged at a depot overnight, with opportunity charging during the day.

		Group 1	Group 2	Group 3
# of buses		**40**	**20**	**20**
Overnight	# of buses per charger	1	1	1
	Charger rating (kW)	50	150	50
	Starting battery SOC	30%	30%	50%
	Charging start time	10pm	10pm	10pm
	Charging duration (hr)	9.16	3.50	7.25
Opportunity	# of buses per charger	N/A	N/A	1
	Charger rating (kW)	N/A	N/A	150
	Starting battery SOC	N/A	N/A	50%
	Charging start time	N/A	N/A	12pm
	Charging duration (hr)	N/A	N/A	2.75

Fleet Charging Schedule



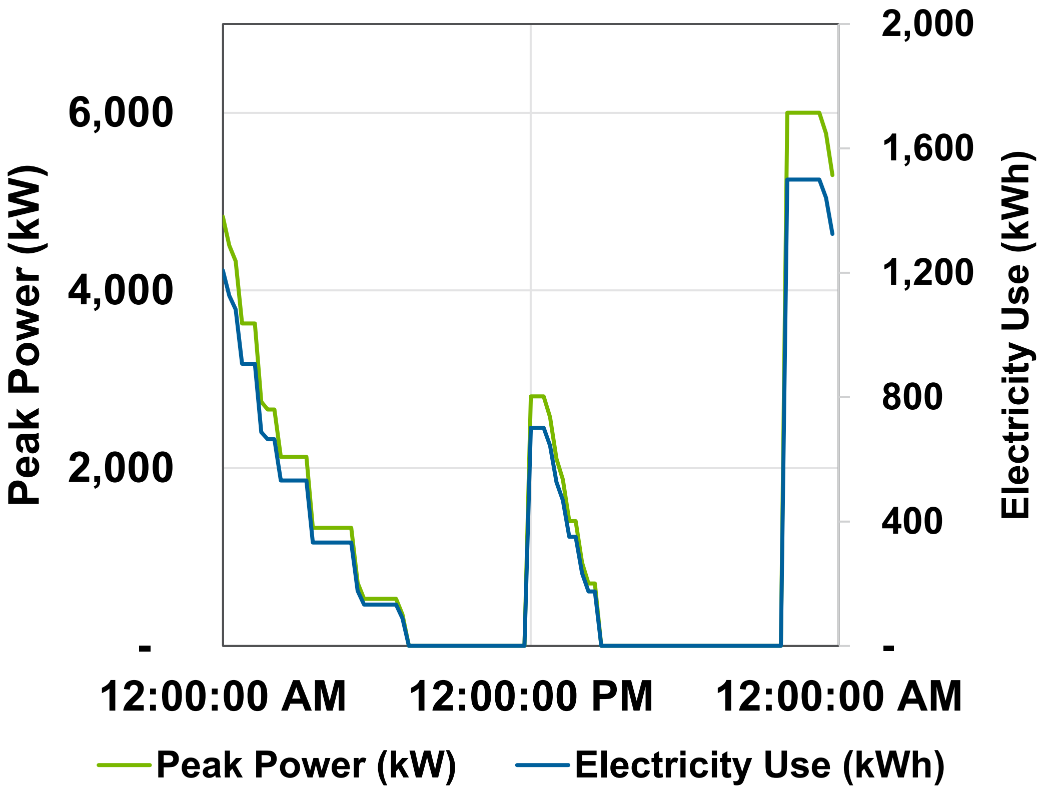
Argonne NATIONAL LABORATORY

HEVISAM Case Study 2: Battery Electric Bus Fleet

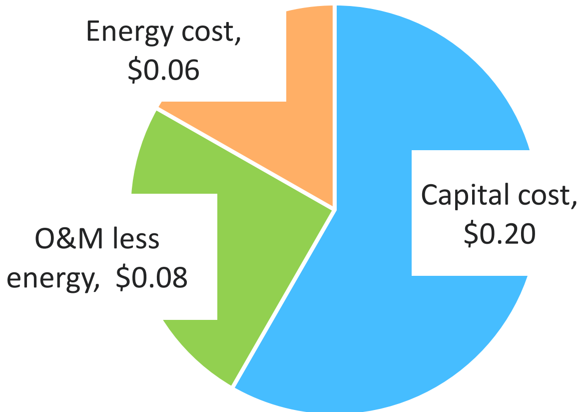
Station Configuration

Charger	
Overnight charger type	50kW, plug-in
# of units	60 active + 3 backup
Opportunity charger type (also used for overnight charging)	150kW, plug-in
# of units	20 active + 1 backup
Transformer (2,500kVA)	
# of units	3
Switchgear (480V)	
# of units	3

Station Charging Power and Energy

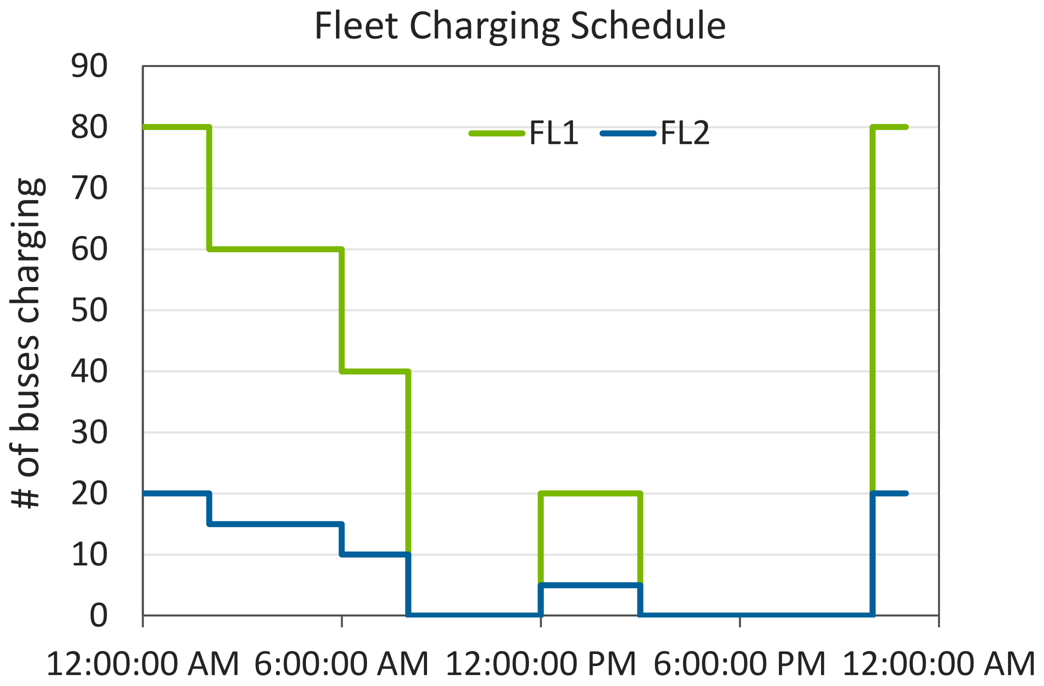


Results: Levelized Charging Cost

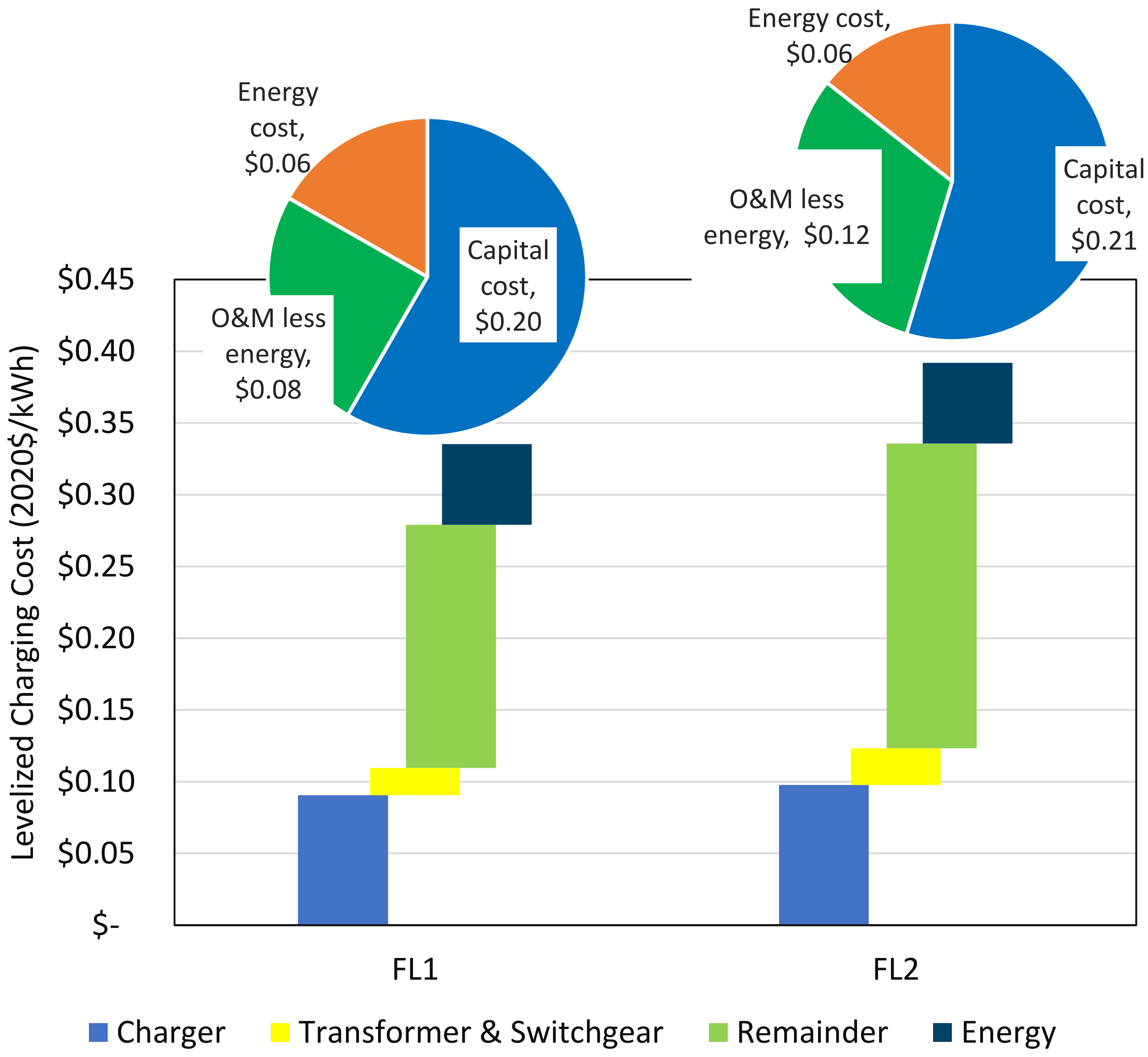


HEVISAM Case Study 2: Battery Electric Bus Fleet

Results: Fleet Size Impact



FL1 (80 buses)	FL2 (20 buses)
• 63 plug-in chargers (50kW) • 21 plug-in chargers (150kW)	• 16 plug-in chargers (50kW) • 6 plug-in chargers (150kW)



Argonne NATIONAL LABORATORY

Acknowledgement

- **HEVISAM was supported by DOE's Vehicle Technologies Office (VTO)**

THANK YOU

Amgad Elgowainy
aelgowainy@anl.gov

Krishna Reddi
kreddi@anl.gov

Sajag Poudel
spoudel@anl.gov

Web Site:
https://hdsam.es.anl.gov/index.php?content=hevisam