REPORT
September, 23, 2024

NYSERDA
Half Hollow Hills Central School District

ZEV TRANSITION PLAN

wendel

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Section 1 Introduction

Introduction

Half Hollow Hills Central School District and NYSERDA have obtained Wendel's services to conduct a study regarding the transition of the district's current diesel and unleaded gasoline school bus fleet to battery electric buses (BEBs) by 2035. The deliverables of the study include a transition plan providing the district a guide to transitioning the fleet based on current NYS mandates. Should the current mandates change, this plan will provide the necessary information for the district to adjust the plan accordingly.

Background

In April 2022, New York State's enacted 2022-2023 State Budget included a zero-emission mandate for NYS school buses. The mandate requires, in part, that by July 1, 2027, all new school bus purchases and leases must be zero-emission and that by July 1, 2035, all school districts must only operate and maintain zero-emission school buses. This mandate defines zero-emission school buses as a school bus that "is propelled by electric motor and associated power electronics and draws electricity from a hydrogen fuel cell or battery; or otherwise operates without direct emission of atmospheric pollutants." Zero-emission school buses are primarily battery electric at this time. Other zero-emission buses such as hydrogen fuel cell are in development but are not readily available commercially.

Half Hollow Hills Central School District elected to prepare for these requirements by developing a transition plan that would provide the district with the planning tools and flexibility necessary to ensure a seamless transition to zero-emission. In December 2023, Half Hollow Hills Central School District contracted with Wendel and NYSERDA through PON 4192 – P12 Schools: Flexible Technical Assistance Program in developing a transition plan that provides a path towards a fully battery electric bus (BEB) fleet by 2035. The program goal is to provide districts with a study that evaluates and recommends infrastructure upgrades that can be used to make informed decisions regarding design and implementation to reduce energy loads and assist in conversion to carbon free fuels. This transition plan can be used as a guide to the district in transitioning and implementing battery electric buses, hereinafter referred to as BEBs.

Scope of Work

The detailed scope of work can be found in Appendix D - Original Scope of Work and include the following major tasks:

Task 1: Project Kickoff and Status Meetings
Task 2: Data Collection
Task 3: Route Analysis
Task 4: Conceptual Charging Strategy
Task 5: Electrical Utility Analysis
Task 6: Concept Development and Phasing Plan
Task 7: Transition Plan Cost Estimates
Task 8: Final Report

Deliverables for each task above detailing the results and findings of the task are included in the appendices. This report is a summary of the findings of the individual letter reports generated from each task.

Note on Technology

BEB technology is emerging and rapidly changing. Electric bus battery capacities are increasing as this technology grows while battery sizes and weights continue to decrease due to charge density improvements. Supporting equipment, such as chargers, are also evolving in terms of charger sizes, an increase in features and improving energy efficiencies. As battery capacities increase, the need for larger chargers also increases to enable fully charging a larger battery in the same amount of time.

During cold weather, battery electric school buses face unique challenges when it comes to charging and performance. Low temperatures can significantly affect battery efficiency and charging speed, as cold weather slows down the electrochemical reactions within the battery cells. This can lead to longer charging times and reduced range per charge, impacting the bus's operational capabilities. Additionally, extreme cold can cause batteries to temporarily lose some of their stored energy, further limiting performance. To mitigate these issues, bus operators need to monitor and manage charging schedules to optimize performance during cold weather conditions.

The recommendations in this report regarding bus battery capacities and charger sizes are based on the route analysis and conceptual charging strategies developed in Tasks 3 and 4, utilizing technology that is currently available as well as manufacturers recommendations. As BEB and charger technology evolves, superior bus capacities and charger configurations may become available. This superior equipment may be substituted for the equipment proposed in this report in order to increase efficiency or bus performance. If an increase in charger size is desired, Half Hollow Hills Central School District should confirm compatibility and capacity with the vendor and their utility provider, prior to purchasing.

It should also be noted that at the time of this report, fire and building codes have not been updated to include recommendations for preventing or managing battery electric fires. Although the frequency of BEB fires is no greater than their diesel counterparts, Lithium-Ion batteries burn much hotter than a diesel fire and are extremely difficult to extinguish. Wendel has developed a fire protection protocol for BEB fires and, working with insurance agencies and various state fire marshals, has obtained approval for implementation of this protocol where BEBs are stored and maintained. It is important to note that the local Authority Having Jurisdiction (AHJ) is the primary authority for approval of fire protection protocols. As the codes are updated to address battery electric fires the recommendations of this report should be reviewed and updated as necessary and/or required.

Section 2 Executive Summary

Executive Summary

Strategy, Goals & Constraints

Wendel developed a transition plan to provide the district with the planning tools and flexibility necessary to ensure a seamless transition to a fully BEB fleet. The goal of the transition plan is to provide a path towards a zero-emission bus fleet by 2035 by providing Half Hollow Hills Central School District with a study that evaluates and recommends infrastructure upgrades that can be used to make informed decisions regarding design and implementation to reduce energy loads and assist in conversion to carbon free fuels. This transition plan can be used as a guide to the district in transitioning to a BEB fleet and implementing BEBs.

Wendel utilized the following guiding principles to develop ZEV transition plans:

- No impact on student experience
- Limit constraints on operations
- Reduce implementation cost and complexity
- Minimize impact on workforce

Wendel has identified the following constraints to transition to a fully BEB fleet:

- Vehicle range limitations
- Charging duration requirements
- Utility demand requirements
- Demand on facilities and operations
- Maintenance knowledge

Analysis Results

Wendel analyzed current bus route data and determined the anticipated energy requirements per route. The anticipated energy requirements per route were then used to determine minimum battery size requirements, charging requirements and charging durations necessary.

Bus Storage/ Charging Locations	Depot Address after electrification:	25 Burrs Ln, Huntington Station, NY 11746
	Number of Buses at this depot location:	59
	Number of chargers at this location:	55
	Ownership of the depot:	district owned
	Bus Ownership:	district owned

Table 1 Bus Storage and Charging Locations Summary

Wendel evaluated eight different bus manufacturers and five different charger sizes ranging from 24 kW to 360 kW. The analysis includes the review of battery capacities, charger levels, and outputs. Wendel has analyzed these bus manufacturers per the existing routes to determine the performance of each bus configuration. The district has stated that they would prefer to utilize IC buses wherever possible, though the use of Lion and Thomas Built is okay if necessary. Thus, Wendel has utilized IC buses as the basis of the investigation for the proposed electric buses. Since Thomas and IC buses do not offer Type A buses, Lion bus was used for the replacement of Type A buses only.

Buses	Bus Size based on District Preferred Manufacturer	Bus Type	Route Buses	Spare Buses	Total Proposed Buses
	168 kWh BEB	Type A	3	2	**5**
	210 kWh BEB	Type C	39	6	**45**
	315 kWh BEB	Type C	7	2	**9**
			49	10	**59**

Table 2 Proposed Bus Summary

Chargers	Charger Size	Route Bus Chargers	Spare Bus Chargers	Total Proposed Chargers	Location: Bus Garage
	24 kW	14	2	**16**	
	60 kW	32	0	**32**	
	120 kW	3	4	**7**	
		55	6	**55**	

Table 3 Proposed Charger Summary

Among the routes for the (59) route buses examined, it was determined that the routes for all (59) of the buses can currently be performed by a BEB as BEBs currently have adequate battery capacity at the existing bus size to meet these route demands.

Total Number of Route Buses:	**59**
Percent of Route Buses that can be electrified with current technology based on their existing daily routes:	**100%**

Table 4 Buses with Route Compliance

It should be noted that light duty student transportation vehicles such as vans were not included in the scope of this study and have been excluded from the above analysis.

Utility Requirements & Impacts

The projected power requirements for the charging of BEBs requires a new utility service feed from PSEG and an additional transformer. The power capacity requested is determined from the charging requirements of the electric buses and the fire protection infrastructure and assumes that a charge management system is used. The utility has completed the feeder study and determined that they can support the project's anticipated required power to charge the electric fleet. The utility (PSEG) has developed a cost estimate of $44,069.51 to provide a new 480 Volt three-phase service powered by a 1000Kva utility transformer. PSEG Make Ready Program will cover 100% of the $44,069 to add additional service.

Before Demand Reduction		
Maximum combined bus electrical demand	904.5	kW
Day of Week Max Demand Occurs	Tuesday	
Time Max Demand Occurs Between	9:00 AM	10:00 AM
After Demand Reduction		
Maximum combined bus electrical demand	611.1	kW
Day of Week Max Demand Occurs	Tuesday	
Time Max Demand Occurs Between	12:00 PM	1:00 PM
Savings		
Demand Reduction	293.3	kW
Percent Demand Reduction	32%	
District-side Infrastructure	- New fire pump electric service, service switch, generator and transfer switch - New electrical service switchboard (can temporarily support first (1) 24kw DC charger with existing service) - New electrical distribution switchboards and panelboards	
Utility-side Infrastructure	- New utility electrical service - New utility transformer - No capacity upgrades were needed	

Table 5 Utility Impact Summary

Phases & Costs

Wendel has estimated the capital cost to implement battery-electric buses and supporting charging infrastructure to achieve 100% zero-emissions bus operations by 2035. Transition plan phases were determined by the bus implementation/procurement schedule provided by Half Hollow Hills Central School District. The bus implementation schedule below determines when infrastructure is required per phase. The transition plan can be adjusted if Half Hollow Central School District decides to purchase buses at a rate that is different that the suggested procurement plan. Based on this transition plan and bus implementation schedule, Half Hollow Hills Central School District will be fully transitioned to a zero emission battery electric fleet by 2035 through (3) proposed phases as seen below

Half Hollow Hills Central School District Anticipated Battery Electric Bus Procurement by Year

	Existing	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	Total
BEB Bus Procurement Schedule	0	0	0	0	0	5	6	6	6	6	6	6	6	12	59
168 kWh BEB	0	0	0	0	0	0	0	0	0	0	0	1	2	2	5
Cumulative 168 kWh BEBs	0	0	0	0	0	0	0	0	0	0	0	1	3	5	
210 kWh BEB	0	0	0	0	0	4	4	6	5	5	6	4	4	7	45
Cumulative 210 kWh BEBs	0	0	0	0	0	4	8	14	19	24	30	34	38	45	
315 kWh BEB	0	0	0	0	0	1	2	0	1	1	0	1	0	3	9
Cumulative 315 kWh BEBs	0	0	0	0	0	1	3	3	4	5	5	6	6	9	
0 kWh BEB	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cumulative 0 kWh BEBs	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0 kWh BEB	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cumulative 0 kWh BEBs	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Total Battery Electric Bus Fleet Size	0	0	0	0	0	5	11	17	23	29	35	41	47	59	59

Figure 1 Anticipated battery electric bus procurement by year

Phase 1 of implementation will require electrical upgrades including a new utility transformer, new service switchboard, new power distribution equipment and fire protection upgrades. Additionally new cable trench from utility pole to utility transformer, new trenched feeders from utility transformer to service switchboard and new trenched feeders from service switchboard to distribution equipment, new trenched feeders from generator system to fire pump equipment, new trenched power feeds and charging equipment for up to 12 chargers.

- PSEG transformer and new three phase service for Phase 1: **$44,069**
- Charging system infrastructure for Phase 1: **$1,644,606**
- Fire Protection infrastructure: **$1,386,521**
- Total Phase 1 estimated cost: **$2,923,640 to $3,226,752**

Phase 2 of implementation will require electrical upgrades including new power distribution equipment, new trenched feeders from service switchboard to distribution equipment, new trenched power feeds and charging equipment for up to 24 additional chargers. The total estimated cost of Phase 2 is **$3,440,644 to $3,802,818.**

Phase 3 of implementation will require electrical upgrades including new power distribution equipment, new trenched feeders from service switchboard to distribution equipment, new trenched power feeds and charging equipment for up to 19 additional chargers. The total estimated cost of Phase 3 is **$3,417,739 to $3,777,501.**

The total estimated cost of the transition is $9,737,954 to $10,763,002.

The costs associated with the BEBs themselves are not included in the above costs per phase or in the cost estimates included in Section 8 Transition Plan Cost Estimates. Below are estimated costs of the recommended BEBs as of the date of this report. Costs may vary based on region, date of procurement, and customization of the buses including add-ons/ and warranties.

Make	Bus Type	Energy Capacity (kWh)	Estimated Cost
Lion	Type A	168	$300,000.00
IC Bus	Type C	210	$394,000.00
IC Bus	Type C	315	$428,000.00

Table 6 BEB Estimated Cost Per Bus

Incentives and Grants

Leveraging financial incentives to fund BEBs and charging infrastructure can help with the transition of diesel or gasoline powered buses to BEBs. Grants, rebates, vouchers, and tax credits can help mitigate the higher upfront vehicle costs and infrastructure investments. Several State and federal programs offer funding opportunities for both BEBs and chargers. The below incentives are not guaranteed and are only applicable as of the date of this report. All information is from NYSERDA's Electric School Bus Guidebook[1], an online resource available to the public. Please contact your NYSERDA representative for more information including eligibility, program requirements, and application process.

[1]NYSERDA. (2024, June). Retrieved from Electric School Bus Guidebook Guide 4: Financial Incentives: https://www.nyserda.ny.gov/-/media/Project/Nyserda/Files/Programs/Electric-School-Bus/Financial-Incentives-for-Electric-School-Buses-and-Chargers.pdf

EPA Clean Heavy-Duty Vehicles Grant Program – School Bus Sub-Program

Vehicle Type	EPA Cost Share Percentage of New Vehicle Price	Pre-Vehicle Funding-Cap (Vehicle + Infrastructure)
Battery-Electric School Bus	75%	$280,000

Table 7 EPA Clean Heavy-Duty Vehicles Grant Program – School Bus Sub-Program from NYSERDA's School Bus Guidebook

New York School Bus Incentive Program – School Bus Voucher

School Bus Type Base	Base Voucher	Priority District Bonus	Scrappage Bonus	V2G Add-on	Wheelchair Add-on
New Type A	$114,000	$285,000	$47,500	$9,500	$8,000
New Type C	$147,000	$36,750	$61,250	$12,250	$8,000
New Type D	$156,000	$39,000	$65,000	$13,000	$8,000
Repowered A	$105,000	$21,000	N/A	$7,000	N/A
Repowered C	$135,000	$27,000	N/A	$9,000	N/A

Table 8 NYSBIP School Bus Voucher from NYSERDA's School Bus Guidebook

Eligibility Table		
Coverage	**USMR**	**CSMR**
Public Fleets	100%	0%
Public Transportation	100%	50% (DAC) 20% (NON-DAC)
Incentive Caps		
Public Fleets		$50,000
Public Transportation		$200,000

Table 9 PSEG Make Ready Program Incentives

New York School Bus Incentive Program – Charging Voucher

Type	Base Voucher Amount	Fleet Electrification Plan Bonus
Non-Priority District	$25,000	$55,000
Priority District	$35,000	$65,000

Table 10 NYSBIP Charging Voucher from NYSERDA's School Bus Guidebook

Section 3 Data Collection

DATA COLLECTION

Data collection plays a vital role in understanding, optimizing, and managing BEB transitions. It enables evidence-based decision-making, facilitates operational efficiency, and supports the successful integration of BEBs into existing school district systems.

Wendel submitted an RFI to Half Hollow Hills Central School District on April, 29, 2024, to gather key data required to perform proper analyses. The requested data included:

- Bus Fleet Information – Fleet size (current and projected), bus replacement plan/schedule, preferred EV manufacturer, bus types/size
- Bus Schedules and Route Data – Detailed bus routes, departure and return times, operational hours, mileage, fuel consumption, operational contingency/resiliency plans.
- Bus Parking/Storage Arrangements – Indoor/Outdoor, location
- Fueling – current operational requirements for fueling
- Utility Data – Name of local utility, existing service size (kVA) and voltage, Utility contact
- Existing School Electrical Distribution Information – existing capacity, condition, expansion capability. Any as-built electrical site drawings (one-line distribution drawings)
- Existing Site Plan – CAD file of overall site plan
- Fleet maintenance data and historical cost

Received information can be found in Appendix F - Information Received from Client.

Bus Fleet Information

Bus fleet information is vital for effective planning, replacement strategies, and financial planning related to the transition of BEBs. It forms the foundation for a well-informed and successful BEB transition plan. Half Hollow Hills Central School District provided a bus list containing (59) buses with their associated age, make, model, etc. The following table shows the breakout of these buses by bus type and model number. A full table with bus names and details can be found in Appendix F - Information Received from Client.

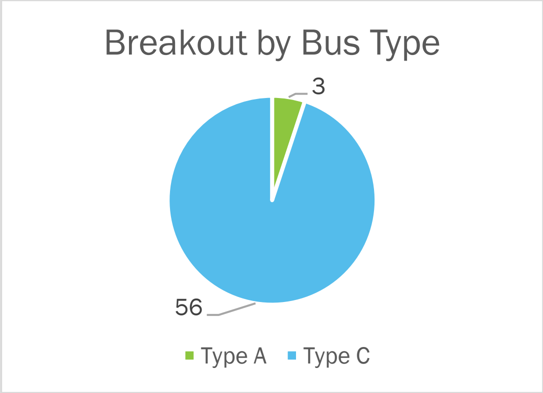

Figure 2 Bus Type Breakout

Vehicle Types & Quantities		
Bus Type	**Model Number**	**Quantity of Buses**
Type C	THOMAS	1
Type C	AMTRAM	6
Type C	BLUEBIRD	8
Type C	INTERNATIONAL	35
Type C	THOMAS	6
Type A	TRANS TECH	2
Type A	THOMAS	1
Grand Total		***59***

Table 11 District Vehicle Types and Quantities

Bus Schedules and Route Data

Vehicle schedules and route data for all buses was provided by Half Hollow Hills School District. The data provides specific information on each individual route that is driven by Half Hollow Hills School District's fleet of school buses. This data included departure and arrival times, total duration, and mileage for each route. Wendel included a 5% safety factor within the calculation, assuming there would be changes to routes. If route changes are greater than 5%, the changes can be addressed in detailed design. Each route duration includes 15 minutes after the bus is taken off the charger to account for energy utilization before the route. The duration and distance of the routes are essential to determine the energy requirements of each route, the viability of opportunity charging, and the bus battery size required.

The routes were then combined into "am" and "pm" routes. Each route group has a cumulative start and finish time, total duration, and total distance. The following table shows a sample of the received routes broken up. The full table can be found in Appendix F - Information Received from Client.

AM & PM Route Schedule					
Vehicle Name	AM/PM	Total Distance (Miles)	Start Time	Finish Time	Duration (Minutes)
2	AM	11	6:20:00 AM	7:05:00 AM	45
2	AM	8	7:05:00 AM	7:40:00 AM	35
2	AM	9	8:23:00 AM	9:05:00 AM	42
2	PM	10	2:06:00 PM	2:48:00 PM	42
2	PM	10	2:48:00 PM	3:01:00 PM	13
2	PM	8	3:11:00 PM	3:50:00 PM	39

Table 12 Sample of Route Grouping

The following additional metrics were calculated to improve the accuracy of the analysis portion of the plan. Wendel calculated the deadhead distance and duration based on an assumption of 10% as approved by the district. Deadhead reflects the bus driving with no students onboard which will yield higher driving efficiencies.

- Active Distance (mi)
- Deadhead Distance (mi)
- Active Duration (Minutes)
- Deadhead Duration (Minutes)
- Resting Duration "On" (Minutes)
- Average Speed (mph)
- Time between AM/PM Routes

Data from previous studies was utilized to enhance the depth and comprehensiveness of the analysis. By leveraging the valuable insights and findings from these earlier investigations, Wendel was able to build upon existing knowledge and establish a stronger foundation for their study.

Section 4 Route Analysis

ROUTE ANALYSIS

Wendel analyzed the available bus route data for each route to determine the time and distance required for a bus to complete the routes. The analysis developed energy requirements per route and determined the minimum battery size requirements, charging requirements, and charging durations necessary per route.

Route Adjustments and Process

- The facility advised that bus 15 should be changed to bus 17.
- Wendel revised routes that had overlapping start and finish times to ensure that we were not double counting the buses time on the road.
- After reviewing the route data received, it was noted by Half Hollow Hills that buses 65, 66, 67, and 68 were listed as Type C buses and drive midday and private school late bus routes. Buses 65, 67, and 68 were proposed as type A buses because the passenger capacity was less than 30 passengers
- All private school late bus routes were assumed to start at 5:00 PM and were assumed to have durations between 30 minutes and 1 hour based on the distance of the route.
- Some of the routes received from the route schedule appeared to be duplicates, so they were removed for the analysis. For instance, bus 24 – Route MD -HSW to CVS Commack 11:50 AM, and bus 43 – MD 6- HSW to C/O with Para – 10:30 were duplicate line items.

Utilizing the provided information from Half Hollow Hills Central School District along with BEB data from previous studies[2], a route analysis was performed to determine the minimum and maximum kWh usage to satisfy each route. Wendel determined the energy associated with the routes to ensure the recommended bus and battery recommendations meet the energy requirements of each route.

Calculations and Assumptions

The BEB efficiency inputs used in the analysis are shown below and are derived from BEB performance data analyzed in previous studies that Wendel conducted as referenced in the paragraph above as well as EPA recommendations.

Battery efficiencies at worst case (High Battery Usage) and best case (Low Battery Usage) were determined by applying the EPA recommended range/efficiency impacts to the Original Equipment Manufacturers (OEM) Rated Efficiencies per BEB manufacture cut sheets. It was assumed a battery would experience within 20% of OEM rated efficiency at Low Battery Usage and within 50% at High Battery Usage. Best case usage assumes little/no HVAC usage, efficient regenerative braking, and/or an outdoor air temperature around 60-70°F. Worst case usage assumes extreme cold/heat, forgetting

[2] Previous studies include CT Transit Hamden Charging Model and CT Greater Bridgeport Transit Low/No Grant which aided in the assessment of charging scenarios to lead to better informed decisions on charging infrastructure, strategies, and operations.

to precondition while charging, traffic/long stops, and/or poor regenerative braking/aggressive driving.

The resting battery usage is associated with the time when a bus is "on" while waiting for its route to begin (a resting duration of 15 minutes before routes was assumed for all buses). The resting battery usage is attributed primarily to keeping the heater on. A usage of 20 kWh/hour was utilized as an assumption based on an average BEB heater size of 20 kW.

Deadhead battery usage is assumed to be more efficient based on the weight of a full bus compared to an empty bus along with an understanding that a bus with no students on it will not be making stops.

BEB Efficiency Inputs:

	Type A	Type B	Type C	Type D	
OEM Rated Efficiency	1.12	N/A	1.58	1.94	kWh per mile
Low Battery Usage	1.55	N/A	2.18	2.68	kWh per mile
Low Deadhead Battery Usage	1.24	N/A	1.74	2.14	kWh per mile
Resting Battery Usage (Heat only)	20.00	N/A	20.00	20.00	kWh per hour
High Battery Usage	2.48	N/A	3.48	4.29	kWh per mile
High Deadhead Battery Usage	2.19	N/A	3.08	3.79	kWh per mile

Table 13 BEB Efficiency Inputs

Analysis Assumptions:

- Maximum resting time with the bus "on" is 15 minutes before routes.
- Heater energy usage is 20 kW at air temperatures below 10 Degrees Fahrenheit.
- Low battery usage represents best case usage with little/no HVAC usage at moderate OA Temperatures.
- High battery usage represents worst case usage with extreme cold/heat, traffic/ long stops.

Charging Variables	
Dead Head Miles	10%
Charging Rate Safety Factor	90%
Route Safety Factor	5%
Efficiency Safety Factor (Distance)	11%
Maximum Battery Level	90%
Anticipated Degradation	90%
Minimum Battery Level	10%

Table 14 Charging Variables

Utilizing the route data, inputs, and assumptions described in the paragraphs above, Wendel calculated the maximum kWh used for each route group with the following formula:

Maximum Energy Usage (kWh) Calculation:
*(Active Distance * High Battery Usage) + (Deadhead distance * High Deadhead Battery Usage) + (Resting Duration * Resting Battery Usage)*

The graph below represents a real-world cold weather example of a BEB in Duluth Minnesota between January 2019 and December 2021[3]. This study performed by National Renewable Energy Laboratory (NREL) exhibits a range decrease of approximately 33% at times of temperatures below 30°F. The results of this case study align with Wendel's route analysis strategy and assumptions.

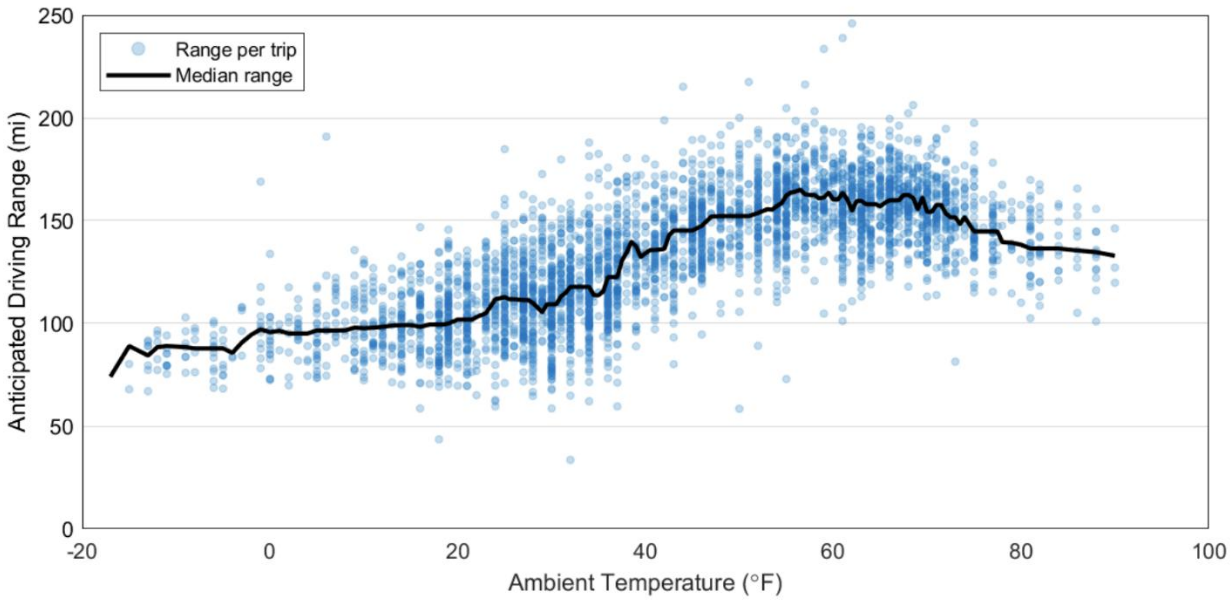

Figure 3 BEB Range in Cold Weather

Energy Requirements of Bus Routes

Wendel reviewed the route information provided by the district, a copy of the route schedule as received has been included in Appendix F - Information Received from Client. The facility advised that bus 15 should be changed to bus 17. Wendel revised routes that had overlapping start and finish times to ensure that we were not double counting the buses time on the road. After reviewing the route data received, it was noted by Half Hollow Hills that buses 65, 66, 67, and 68 were listed as Type C buses and drive midday and private school late bus routes. Buses 65, 67, and 68 were proposed as type A buses because the passenger capacity was less than 30 passengers. All private school late bus

[3] Jeffers, Matthew, Leslie Eudy, Erik Bigelow, Greg Olberding, and Amy Posner. 2022. Duluth Transit Authority Battery-Electric Bus Evaluation. Golden, CO: National Renewable Energy Laboratory. NREL/ TP-5400-83038. https://www.nrel.gov/docs/fy22osti/83038.pdf.

routes were assumed to start at 5:00 PM and were assumed to have durations between 30 minutes and 1 hour based on the distance of the route. Some of the routes received from the route schedule appeared to be duplicates, so they were removed for the analysis. For instance, bus 24 – Route MD - HSW to CVS Commack 11:50 AM, and bus 43 – MD 6- HSW to C/O with Para – 10:30 were duplicate line items. The route information was used to determine the times that buses would be departing and arriving at the bus garage where charging would take place. It was assumed that once a bus returns to the bus garage after its route, it would begin charging if it would not leave for its next route for another 30 minutes.

The route analysis utilizes the received route distances to develop the anticipated energy requirements per route and then uses those energy requirements to determines the minimum BEB battery size requirements. The analysis then determines the minimum charger size and charging durations necessary per route based on the minimum battery size requirements and the anticipated energy requirements.

The following table shows the maximum energy usage calculated by the route analysis.

Bus Number	Bus Type	Max Energy Usage (kWh)
2	Type C	115.81
8	Type C	155.56
9	Type C	101.73
10	Type C	109.09
11	Type C	142.04
12	Type C	139.40
17	Type C	125.64
18	Type C	145.37
20	Type C	148.12
21	Type C	127.14
22	Type C	119.25
24	Type C	167.19
27	Type C	196.57
28	Type C	100.76
29	Type C	138.95
30	Type C	147.46
31	Type C	122.62
32	Type C	136.79
33	Type C	126.51
34	Type C	128.95
35	Type C	103.04
36	Type C	198.03
37	Type C	99.74
41	Type C	119.08
42	Type C	117.31
43	Type C	126.39
44	Type C	125.43
45	Type C	149.80
46	Type C	139.87
47	Type C	107.90
48	Type C	126.98
49	Type C	130.80
50	Type C	113.66
51	Type C	137.54
53	Type C	151.16
54	Type C	194.26
57	Type C	80.29
58	Type C	114.05
59	Type C	114.43

Bus Number	Bus Type	Max Energy Usage (kWh)
65	Type A	30.95
66	Type C	170.75
67	Type A	66.92
68	Type A	69.49
71	Type C	144.24
73	Type C	149.80
74	Type C	122.89
76	Type C	120.97
78	Type C	149.80
93	Type C	167.86
Spare - 92	Type C	0.00
Spare – 89	Type C	0.00
Spare – 79	Type C	0.00
Spare – 72	Type C	0.00
Spare – 56	Type C	0.00
Spare – 55	Type C	0.00
Spare – 52	Type C	0.00
Spare – 40	Type C	0.00
Spare - 26	Type A	0.00
Spare - 25	Type A	0.00

Table 15 Max Energy Usage by Bus

Battery Electric Bus Selection

The recommendations in this report regarding bus battery capacities and charger sizes are based on utilizing technology that is currently available as well as manufacturers recommendations. Each school bus manufacturer has a different bus battery and charge configuration that they offer. Wendel analyzed eight manufacturers and bus types based on the existing routes to determine performance of each bus configuration.

Wendel evaluated the following list of electric buses based on their available battery sizes, vehicle to grid capabilities, and existing relationship with the district.

- Blue Bird
- BYD
- Collins
- Greenpower
- IC
- Lion
- Thomas

The district has stated that they would prefer to utilize IC buses wherever possible, though the use of other manufacturers is okay if necessary. Thus, Wendel has utilized IC as the basis of the investigation for the proposed electric buses. Since Thomas and IC buses do not offer Type A buses, Lion bus was used for the replacement of Type A buses only.

Bus Type	Manufacturer	Model	kWh	OEM rated Range (miles)	Seats
Type C	IC	IC eCE	210	135	78
Type C	IC	IC eCE	315	200	78
Type A	Lion	Lion A	168	150	24

Table 16 BEB models and OEM rated ranges as of this report date

The route analysis utilizes the received route distances to develop the anticipated energy requirements per route and then uses those energy requirements to determines the minimum BEB battery size requirements. The following table shows the minimum bus size required based on the maximum energy usage calculated by the route analysis.

Bus Number	Bus Type	Max Energy Usage (kWh)	Minimum Bus Size based on Max Energy Usage (kWh)	Minimum Bus Size Available Based on Current Manufacturers	Proposed Bus Size and Type Based on District Preferences
2	Type C	115.81	161	210 kWh - IC	210 kWh - IC
8	Type C	155.56	216	315 kWh - IC	315 kWh - IC
9	Type C	101.73	141	155 kWh - Bluebird	210 kWh - IC
10	Type C	109.09	152	155 kWh - Bluebird	210 kWh - IC
11	Type C	142.04	197	210 kWh - IC	210 kWh - IC
12	Type C	139.40	194	210 kWh - IC	210 kWh - IC
17	Type C	125.64	174	210 kWh - IC	210 kWh - IC
18	Type C	145.37	202	210 kWh - IC	210 kWh - IC
20	Type C	148.12	206	210 kWh - IC	210 kWh - IC
21	Type C	127.14	177	210 kWh - IC	210 kWh - IC
22	Type C	119.25	166	210 kWh - IC	210 kWh - IC
24	Type C	167.19	232	315 kWh - IC	315 kWh - IC
27	Type C	196.57	273	315 kWh - IC	315 kWh - IC
28	Type C	100.76	140	155 kWh - Bluebird	210 kWh - IC
29	Type C	138.95	193	210 kWh - IC	210 kWh - IC
30	Type C	147.46	205	210 kWh - IC	210 kWh - IC
31	Type C	122.62	170	210 kWh - IC	210 kWh - IC
32	Type C	136.79	190	210 kWh - IC	210 kWh - IC
33	Type C	126.51	176	210 kWh - IC	210 kWh - IC
34	Type C	128.95	179	210 kWh - IC	210 kWh - IC
35	Type C	103.04	143	155 kWh - Bluebird	210 kWh - IC
36	Type C	198.03	275	315 kWh - IC	315 kWh - IC
37	Type C	99.74	139	155 kWh - Bluebird	210 kWh - IC
41	Type C	119.08	165	210 kWh - IC	210 kWh - IC
42	Type C	117.31	163	210 kWh - IC	210 kWh - IC
43	Type C	126.39	176	210 kWh - IC	210 kWh - IC
44	Type C	125.43	174	210 kWh - IC	210 kWh - IC
45	Type C	149.80	208	210 kWh - IC	210 kWh - IC
46	Type C	139.87	194	210 kWh - IC	210 kWh - IC
47	Type C	107.90	150	155 kWh - Bluebird	210 kWh - IC
48	Type C	126.98	176	210 kWh - IC	210 kWh - IC
49	Type C	130.80	182	210 kWh - IC	210 kWh - IC
50	Type C	113.66	158	210 kWh - IC	210 kWh - IC

Bus Number	Bus Type	Max Energy Usage (kWh)	Minimum Bus Size based on Max Energy Usage (kWh)	Minimum Bus Size Available Based on Current Manufacturers	Proposed Bus Size and Type Based on District Preferences
51	Type C	137.54	191	210 kWh - IC	210 kWh - IC
53	Type C	151.16	210	210 kWh - IC	210 kWh - IC
54	Type C	194.26	270	315 kWh - IC	315 kWh - IC
57	Type C	80.29	112	155 kWh - Bluebird	210 kWh - IC
58	Type C	114.05	158	210 kWh - IC	210 kWh - IC
59	Type C	114.43	159	210 kWh - IC	210 kWh - IC
66	Type C	170.75	237	315 kWh - IC	315 kWh - IC
71	Type C	144.24	200	210 kWh - IC	210 kWh - IC
73	Type C	149.80	208	210 kWh - IC	210 kWh - IC
74	Type C	122.89	171	210 kWh - IC	210 kWh - IC
76	Type C	120.97	168	210 kWh - IC	210 kWh - IC
78	Type C	149.80	208	210 kWh - IC	210 kWh - IC
93	Type C	167.86	233	315 kWh - IC	315 kWh - IC
Spare - 92	Type C	0.00	0	155 kWh - Bluebird	210 kWh - IC
Spare - 89	Type C	0.00	0	155 kWh - Bluebird	210 kWh - IC
Spare - 79	Type C	0.00	0	155 kWh - Bluebird	210 kWh - IC
Spare - 72	Type C	0.00	0	155 kWh - Bluebird	210 kWh - IC
Spare - 56	Type C	0.00	0	155 kWh - Bluebird	210 kWh - IC
Spare - 55	Type C	0.00	0	155 kWh - Bluebird	210 kWh - IC
Spare - 52	Type C	0.00	0	155 kWh - Bluebird	315 kWh - IC
Spare - 40	Type C	0.00	0	155 kWh - Bluebird	315 kWh - IC

Table 17 Minimum Bus Size Required by Bus

Proposed Bus Size Based on Preferred Manufacturer	Bus Type	Route Buses	Spare Buses	Total Proposed Buses
168 kWh - Lion	Type A	3	2	5
210 kWh - IC	Type C	39	6	45
315 kWh - IC	Type C	7	2	9
		49	10	59

Table 18 Proposed Bus Battery Sizes Summary

The route analysis shows that the maximum energy usage of any one route would be 198 kWh which was associated with a Type C – 315 kWh bus. Among the routes for the (59) buses examined, it was determined that all the routes for the buses worked.

The analysis shows that the maximum energy usage per route within current battery capacity constraints is 198 kWh which, according to the district preferred manufacturer, would require a 315 kW BEB. The anticipated energy usage for each route can be found in the attached spreadsheet.

Extracurricular Trips

Extracurricular bus runs such as field trips and sports trips were not included in the route analysis due to the unpredictable nature of these trips. For example, the buses that perform these trips vary as well as the start and end times of the trips and the mileage associated with them. It is recommended that the district should first determine the total mileage of each trip and use the below table to determine whether their proposed electric buses will be able to complete the trips. The ranges listed assumes the buses are fully charged to their recommended capacity (90%).

These ranges were calculated using the specific OEM rated efficiency (as of the date of this report) plus Wendel's efficiency safety factors which can be found in the Calculations and Assumptions section. It should be noted that unlike the student pick up / drop off routes, the buses performing sports and field trips would have the ability to charge at either another school (assuming they have spare chargers) or public charging stations during the sporting / field trip event itself which can increase this range. The amount of additional range provided by these public charging stations would depend on the charger itself and cannot be estimated by Wendel.

Bus Type	Bus Size and Manufacturer	Calculated Range at High Energy Usage (miles)	Calculated Range at Low Energy Usage (miles)
Type A	168 kWh - Lion	44	71
Type C	315 kWh - IC	61	94
Type C	210 kWh - IC	40	63

Table 19 Allowable Range by Bus Size

Based on the mileage of the athletic trips provided by the district, 94% of the trips could be performed by the proposed BEB buses. Based on the mileage of the field trips provided by the district, 85% of the trips could be performed by the proposed BEB buses. Both percentages are based on the calculated ranges at high energy usage seen in table above, which represent worst-case conditions.

See below table summarizing the feasibility of using the proposed battery electric school buses to drive sports trips and field trips for Half Hollow Central School District.

Trip Type	Total Number of Trips Received	Number of trips not feasible by BEBs being proposed by this study	Percent of trips not feasible by BEBs being proposed by this study
Athletic Trips	1147	68	6%
Field Trips	876	128	15%

Table 20 Extracurricular Trips Feasibility Summary

Charging Requirements

Five charger sizes were reviewed and include a 24 kW DC charger, 60 kW DC charger (fast charger), 120 kW DC charger (fast charger), 180 kW DC charger (fast charger), and a 360 kW DC charger (fast charger). Charger recommendations are based on utilizing one charger per route bus to remain conservative. The district may choose to utilize higher kW chargers of at least twice the recommended size which would allow for the charging of two school buses per charger. This would decrease installation and overall charger costs. Another advantage of this approach would be if only one school bus is utilizing the two-port charger at any time, that bus's required charging time would decrease as it would be able to take advantage of the full charger output.

Based on the route analysis, the proposed charging duration between AM and PM routes ranges from 50 minutes to 4 hours and 43 minutes. The largest charger size proposed is 120 kW. The charging durations for each route can be found in the attached spreadsheet. Wendel has determined that the routes the district has provided will require (7) 120 kW chargers, (32) 60 kW chargers, and (16) 24 kW chargers. Of the proposed chargers (2) of the 24 kW chargers and (4) of the 120 kW are for spare buses. The (4) 120 kW spare chargers are proposed to be used as a 2:1. It is assumed that spare buses are used only to replace out of service route buses or for field trips and sports trips. The specific charger sizes and durations needed to charge by charger size can be found below for each of the (6) route buses.

Charger Size	Route Bus Chargers	Spare Bus Chargers	Total Proposed Chargers
24 kW	14	2	16
60 kW	32	0	32
120 kW	3	4	7
	49	6	55

Table 21 Proposed Charger Quantities

These proposed charger sizes are based on selecting the smallest size charger needed out of the five charger sizes reviewed (24 kW, 60 kW, 120 kW, 180 kW, and 360 kW). It is recommended that the district look into limiting the number of different chargers sized to ease operations and ordering. Charger sizes procured that vary from the Required Charging Size should be greater in kW.

Section 5 Conceptual Charging Strategy

CONCEPTUAL CHARGING STRATEGY

Wendel developed a conceptual charging strategy for the fleet based on the bus route data collected and the route analyses developed in previous tasks. The goal of the conceptual charging strategy is to determine the smallest available battery size that meets the district's route needs and the associated electrical impact. The charging strategy identified the following items:

- Optimum charger size – assuming a 1 to 1 charger to dispenser configuration
- Anticipated peak demand
- Number, types, and sizes of chargers required to charge the fleet in the allotted time frames – assuming a battery degradation of 10%, a lower limit of 10% state of charge, and an upper limit of 90% state of charge. This is illustrated in the graphic below.

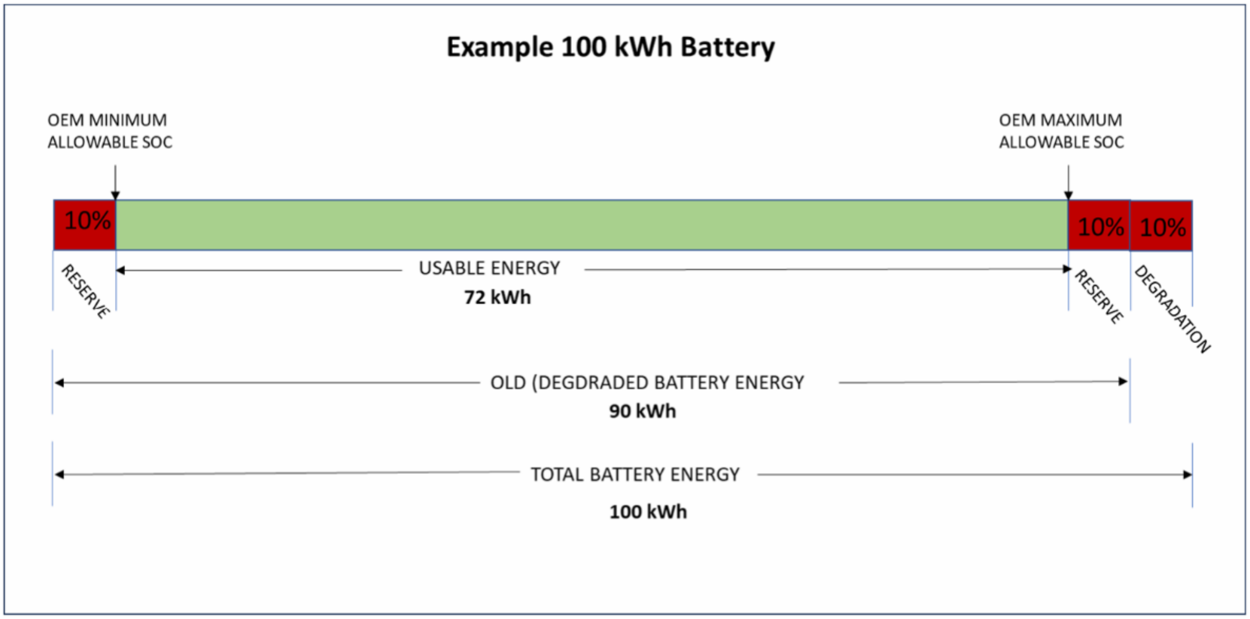

Figure 4 Illustration of Usable Battery

Charging Model Development Process:

An overview of the process Wendel utilized for the charging strategy modeling process is shown below:

Step 1 Analyze the route data and organize the data into numerical values that represent the times at which each bus that serves the associated route would depart and arrive at Half Hollow Central School District for a standard week.

Step 2 Develop a model reflecting when all (280) route buses **arrive and depart** Half Hollow Central School District over a winter month with an additional 15 minutes added to route durations representing the time after the bus is removed from the charger and before it leaves to begin each route.

Step 3 Develop a model reflecting bus **charge hours** for each hour of a 1-month period. This shows how many hours the bus has left to charge at any hour.

Step 4 Develop a weekly model reflecting the **battery state of charge** throughout the month. The 1-month period utilizes TMY3 (typical meteorological year) weather data based on region 1 for January – which is considered the coldest month of the year in NYS to simulate a representative year's coldest month.

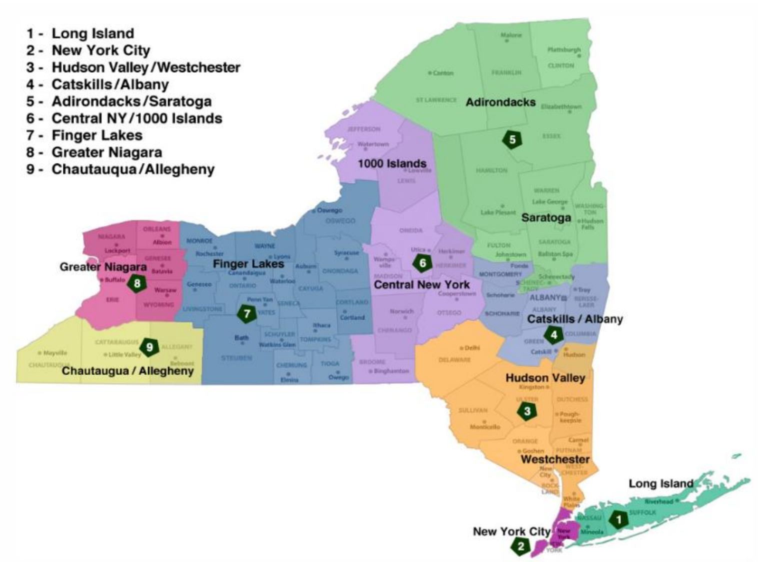

Figure 5 NYS Weather Regions

Step 5 Develop a 1-month model utilizing the state of charge model to reflect the charging of the battery throughout the week. This model shows the charging **impact on the battery** each hour throughout the 1-month period.

Step 6 Develop a 1-month model utilizing the impact on battery model to reflect the **impact on the facility (Facility Demand)** while charging. This model utilized an assumed charging efficiency to convert the impact on the battery to the actual impact on Half Hollow Central School District usage.

Battery Electric Bus Requirements

As stated by Half Hollow Central School District all routes provided by the district are driven by (49) buses (Route Buses). The district also has (10) additional buses that are used as spares (Spare Buses) for a total fleet of (59) district buses. Using the route information provided and energy usage rates calculated in the route analysis, Wendel performed a charging analysis of all district owned buses (excluding spare buses). This information can be found in the section below titled Basis of Design.

The charging analysis consisted of modeling battery life at each hour throughout the month of January to model conditions during the coldest month on average. This was done as low temperatures have been shown to impact the efficiency of BEB batteries negatively. These models also determined the amount of charge delivered to the bus batteries for each hour throughout the month and the amount of charge delivered from the district for each hour throughout the month.

From these models, Wendel was able to confirm the quantity and sizes of buses required, assuming all buses would remain the same Type (Type A, Type C, etc.). Wendel utilized Lion and IC buses as the basis of the investigation for the proposed electric buses per the district's request.

Charger Requirements

The charging strategy focuses on charging for long periods of time at low charging speeds. The model shows the batteries' charging rate based on the duration of time to charge. The maximum single bus charging rate for any hour throughout the winter month was modeled to be 73 kW. A breakdown of the charging requirements is shown below:

- 0 Buses require between 120 kW and 180 kW of charge
- 0 Buses require between 100 kW and 120 kW of charge
- 0 Buses require between 80 kW and 100 kW of charge
- 1 Buses require between 60 kW and 80 kW of charge
- 6 Buses require between 40 kW and 60 kW of charge
- 4 Buses require between 20 kW and 40 kW of charge
- 38 Buses require less than 20 kW of charge

The breakdown above shows the variety of chargers that could be utilized by Half Hollow Hills Central School District to charge their school bus fleet. Wendel only used three charger sizes to reduce the operational impact on the school district when transitioning to BEBs.

Basis of Design

To provide a complete demand profile for all buses, the charging model assumes that the battery capacities needed for routes that are currently too long will become available in the future and that the largest charger size needed for that bus size would be used. Buses with route distances or charging requirements that are not feasible were excluded from this study. For this analysis, it was assumed that the maximum number of buses charging during peak time (mid-day) is (49) buses, this does not include the spare buses or the buses excluded. This approach assumes that spare buses would be charged outside of mid-day peak hours.

The below information calculated during the route analysis was used as the basis for the conceptual charging strategy model.

Bus	Bus Size (kWh)	Charger Size (kW)	Max AM Usage Rate (kWh / hr)	Max PM Usage Rate (kWh / hr)	Max PM2 Usage Rate (kWh / hr)	PM Route Usage (kWh)	PM2 Route Usage (kWh)
2	210	60	33.09	45.15	0.00	112.12	0.00
8	315	24	21.62	53.64	0.00	155.56	0.00
9	210	24	25.19	36.77	0.00	101.73	0.00
10	210	24	33.57	41.62	0.00	100.58	0.00
11	210	60	37.60	43.93	0.00	142.04	0.00
12	210	60	36.37	30.37	40.93	48.08	113.91
17	210	24	34.27	37.53	0.00	101.97	0.00
18	210	60	39.47	42.74	0.00	127.51	0.00
20	210	60	35.26	45.81	0.00	148.12	0.00
21	210	24	34.83	36.66	0.00	100.22	0.00
22	210	60	40.49	52.98	43.10	36.20	119.25
24	315	60	27.12	33.55	0.00	167.19	0.00
27	315	60	30.25	35.52	0.00	196.57	0.00
28	210	24	28.00	39.78	0.00	100.76	0.00
29	210	60	31.72	46.74	111.16	74.79	138.95
30	210	120	41.43	77.47	46.08	142.04	147.46
31	210	60	32.73	37.92	0.00	122.62	0.00
32	210	60	33.61	42.31	0.00	136.79	0.00
33	210	60	37.39	44.62	0.00	122.69	0.00
34	210	60	30.99	44.21	0.00	128.95	0.00
35	210	24	26.54	39.63	0.00	103.04	0.00
36	315	60	26.23	42.59	0.00	198.03	0.00
37	210	24	27.60	36.94	0.00	99.74	0.00
41	210	60	33.70	39.75	0.00	109.30	0.00
42	210	60	34.85	41.15	0.00	107.00	0.00
43	210	60	24.38	31.81	0.00	85.36	0.00
44	210	60	35.17	43.73	0.00	123.89	0.00
45	210	60	41.24	41.59	119.84	71.40	149.80
46	210	120	31.75	83.92	41.60	139.87	136.57
47	210	60	29.52	40.21	0.00	107.90	0.00
48	210	60	33.71	43.67	0.00	117.19	0.00
49	210	120	38.47	65.06	44.45	108.43	125.20
50	210	60	40.19	50.28	113.66	71.23	113.66
51	210	60	32.82	49.42	0.00	137.54	0.00
53	210	60	50.11	36.34	0.00	104.16	0.00
54	315	60	23.24	30.59	0.00	194.26	0.00

Bus	Bus Size (kWh)	Charger Size (kW)	Max AM Usage Rate (kWh / hr)	Max PM Usage Rate (kWh / hr)	Max PM2 Usage Rate (kWh / hr)	PM Route Usage (kWh)	PM2 Route Usage (kWh)
57	210	60	24.45	42.73	30.23	71.21	72.55
58	210	24	33.22	31.14	0.00	83.03	0.00
59	210	24	29.38	39.01	0.00	114.43	0.00
65	168	24	41.26	0	0.00	0.00	0.00
66	315	24	52.54	74.45	0.00	55.84	0.00
67	168	24	66.92	0	0.00	0.00	0.00
68	168	24	69.49	0	0.00	0.00	0.00
71	210	60	37.35	48.89	0.00	144.24	0.00
73	210	60	42.10	41.17	119.84	63.82	149.80
74	210	60	34.46	41.60	0.00	110.93	0.00
76	210	60	31.75	39.66	0.00	120.97	0.00
78	210	60	35.99	37.81	119.84	63.64	149.80
93	315	60	43.15	134.29	0.00	167.86	0.00
Spare - 92	210	0	-	-	0	0.00	0.00
Spare - 89	210	0	-	-	0	0.00	0.00
Spare - 79	210	120	-	-	0	0.00	0.00
Spare - 72	210	0	-	-	0	0.00	0.00
Spare - 56	210	120	-	-	0	0.00	0.00
Spare - 55	210	0	-	-	0	0.00	0.00
Spare - 52	315	120	-	-	0	0.00	0.00
Spare - 40	315	0	-	-	0	0.00	0.00
Spare - 26	168	24	-	-	0	0.00	0.00
Spare - 25	168	24	-	-	0	0.00	0.00

Table 22 Charging Strategy Inputs

State of Charge

Wendel assumed a battery degradation of 10%, a lower limit of 10% state of charge, and an upper limit of 90% state of charge. A weekly model reflecting the **battery state of charge** throughout the 5 weeks was completed based on these assumptions. The following figure shows an example of ten buses state of charge throughout the date during a 5 week winter period.

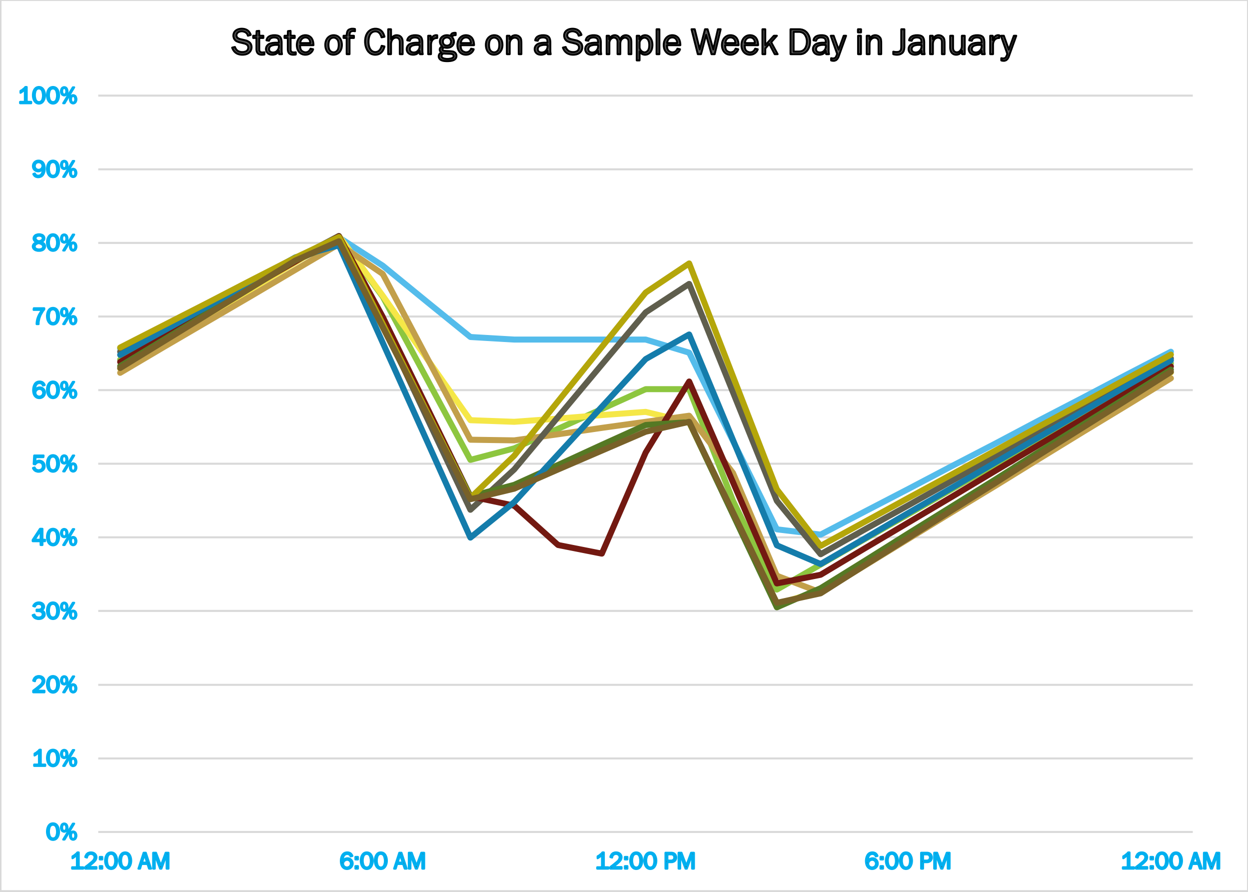

Figure 6 State of Charge on Sample Week Day

Demand Impact

Demand is the power drawn from the utility at any one point in time, measured in kW. Peak demand is the maximum demand required from the utility, during the utilities peak demand period, over a one-month period and is also measured in kW. The peak demand is the cumulative demand of all loads connected to the utility transformer.

Not all buses will need a maximum charge rate from the charger to reach a full charge in the available time frame. Charging a bus at a reduced charge rate increases the life of the battery and reduces overall demand on the utility system. Demand reduction is evaluating the state of charge when the bus arrives back at the garage and determining the minimum charge level required to charge the bus in the allotted time, to ensure the bus is adequately charged when it needs to begin a new route. A charge management system should implement demand reduction, further details can be found in the Charge Management section below. If demand reduction is implemented in every bus in the fleet, the overall utility demand will be greatly reduced, reducing utility demand charges, and extending the life of the batteries. A model of what this might look like in terms of daily demand for Half Hollow Hills Central School District can be seen below.

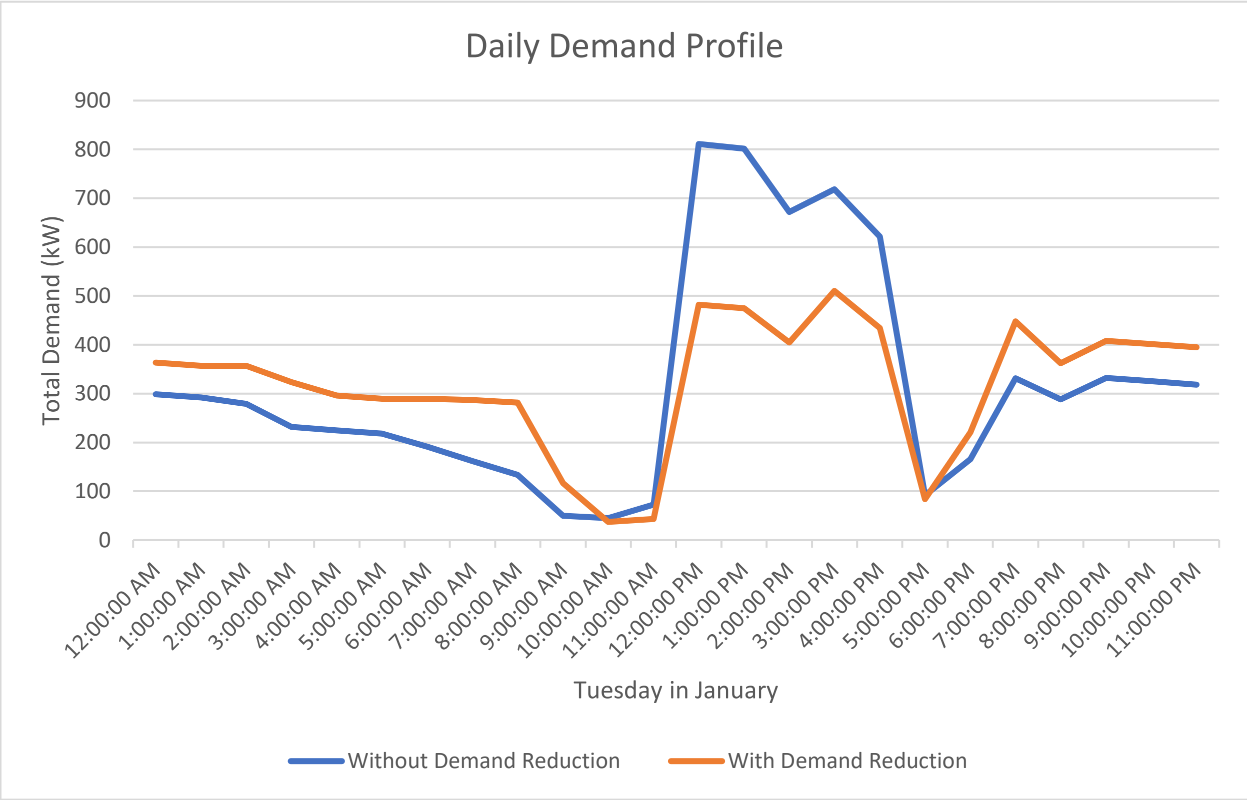

Figure 7 Daily Demand Profile at Maximum Peak Demand

**This demand profile represents the maximum daily demand based on the charging model. Demand Peaks fluctuate per day and may be lower than the above.*

The maximum combined bus electrical demand when all (59) route buses are converted to BEBs during a winter month was calculated to be 611.1 kW which occurs between 12 PM and 1 PM on Tuesdays. Before the demand reduction strategy was implemented, the peak demand was 904.5 kW which would occur at 9 AM and 10 AM on Tuesdays.

Based on the state of charge when the buses arrive back at the garage and the minimum charge level required to charge the bus in between AM and PM routes, Wendel modeled how demand reduction strategies would impact the district’s proposed demand profile if implemented. It was determined that the implementation of this demand reduction strategy could yield savings of 293.3 kW of peak daily demand or 32%, resulting in utility cost savings. This highlights the importance of implementing a charge controller optimization strategy or a charge management system.

Before Demand Reduction		
Maximum combined bus electrical demand	904.5	kW
Day of Week Max Demand Occurs	Tuesday	
Time Max Demand Occurs Between	9:00 AM	10:00 AM
After Demand Reduction		
Maximum combined bus electrical demand	611.1	kW
Day of Week Max Demand Occurs	Tuesday	
Time Max Demand Occurs Between	12:00 PM	1:00 PM
Savings		
Demand Reduction	293.3	kW
Percent Demand Reduction	32%	

Table 23 Demand Summary

The overall demand profiles below show the projected impact for each hour over a five-week period. The goal is to flatten demand as much as possible, especially during peak hours. A graph showing the demand profile over a sample week in January is shown below:

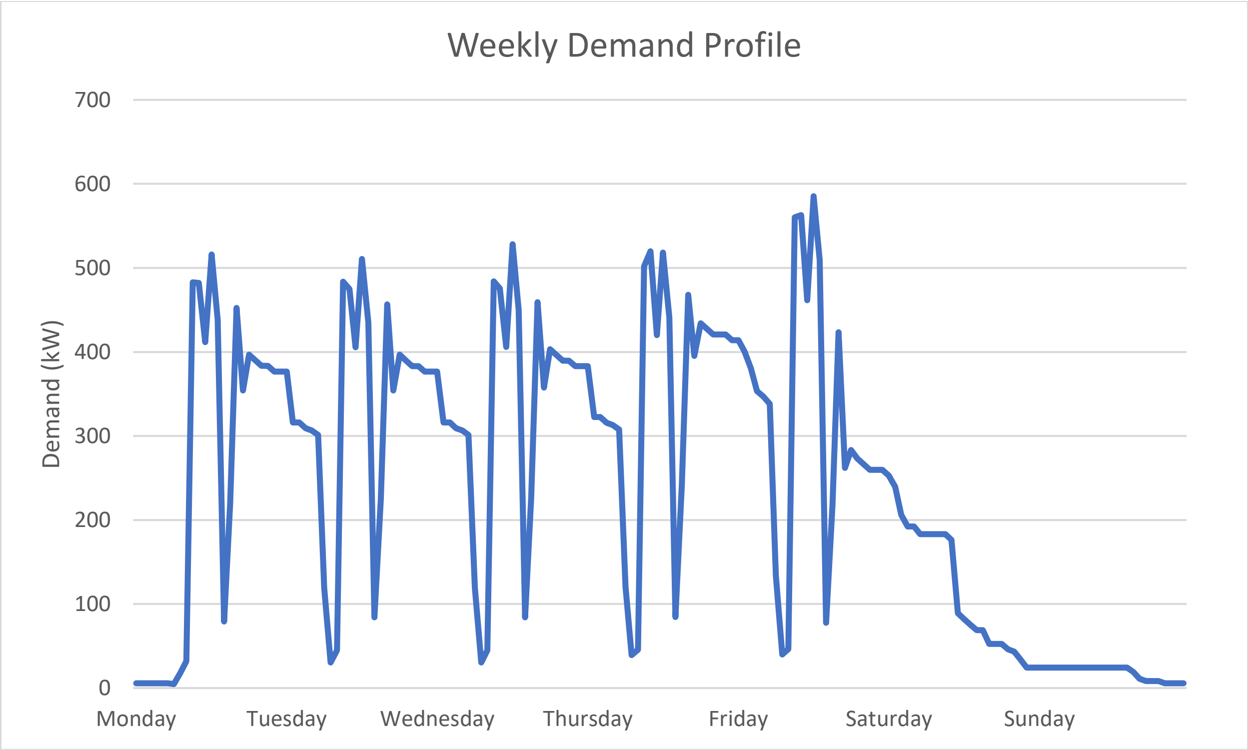

Figure 8 Weekly Demand Profile

**Includes Demand Reduction Strategies being implemented*

Charge Management

Charge management[4] is an essential part of a successful BEB transition plan. Charge management will manage charging operations and energy management. An ideal charging strategy focuses on charging for long periods of time at low charging speeds while ensuring the buses are sufficiently charged to complete their routes. Lower charging rates help to keep a more consistent demand profile, a lower peak demand and extend battery life. Additional strategies like “on” and “off” peak charging can be added to the charging strategy as well to minimize the cost impact on the district.

A charge management system is a software system that provides real time demand reduction analysis and automatically manages the fleet of chargers based on each of the bus’s needs. Charge management systems utilize bus telemetric data, route data, and battery data to perform their analysis. Today’s systems can limit the overall utility demand to preset limits, based on the power distribution systems designed for charging.

Charge management systems are available through independent third-party suppliers, such as Mobility House, SYNOP, and BP Pulse. Some bus manufacturers also sell charge management systems.

Wendel strongly recommends implementing a charge management system for managing charging operations and energy management. An optimized charge management system which includes demand reduction strategies will also minimize the need for utility side infrastructure upgrades and facility electrical infrastructure upgrades. A peak demand reduction has been incorporated into the analyses and results of this study which mimics an optimized charge management system.

Alternatives

Charging Ports

Wendel’s basis of design utilized a 1:1 ratio of chargers to buses, primarily for operational efficiency and flexibility. An alternative to the base charging strategy would be to utilize 2:1 charging for applicable buses. The district may choose to utilize higher kW chargers of at least twice the recommended size which would allow for the charging of two school buses per charger. This would decrease the number of chargers required and associated overall costs. Some disadvantages of utilizing a 2:1 charging strategy are that charger failures affect two buses instead of one and the operational challenges of specific buses to be parked in specific spots for charging. It is also important to note that many 2:1 chargers require both buses to be charged at the same rate simultaneously.

Limiting Unique Bus Models and Charger Sizes

The recommended bus models are based on the smallest available sizes that meet the requirements determined by the route analysis and charging strategy. Though the district’s preferred manufacturer is used as the basis of design, if the preferred manufacturer does not offer a bus with the necessary battery size and a different manufacturer does, that manufacturer’s bus model is recommended. For

[4] Charge Management System – end to end software solution to manage EV charging operations & energy management.

example, Half Hollow Hills Central School District's current preferred manufacturer is IC, however IC does not offer Type A Buses, so Lion buses were specified for Type A buses.

Many manufacturers have a limited number of battery sizes available today which will likely change as technology becomes more readily available. It is recommended that the district try to limit the number of different manufacturers / models in their fleet to ease operations and ordering. This may be done by waiting for IC to come out with a Type A bus and by selecting the largest proposed BEB sizes for each bus type instead of the smallest available size proposed in this study. Choosing a larger bus size may increase bus costs and increase peak demand. This should be taken into consideration during design.

Proposed charger sizes are based on selecting the smallest size charger needed out of the five charger sizes reviewed (24 kW, 60 kW, 120 kW, 180 kW, and 360 kW). It is recommended that the district investigate limiting the number of different charger sizes to ease operations and ordering. Charger sizes procured that vary from the Proposed Charger Size should be greater in kW than proposed.

Selecting a Bus varying from Proposed Bus Size

It is recommended that the district utilize the *Table 24 Bus and Charger* Selection Criteria table below when procuring their BEBs and to try to limit the number of different manufacturers / models in their fleet to ease operations and ordering. Buses procured that vary from the Proposed Bus Size and Type Based on Preferred Manufacturer should meet the following criteria:

1. Be greater in kWh than the Minimum Bus Size column below
2. Have an OEM rated efficiency less than or equal to the Maximum OEM Rated Efficiency column below. This is equivalent to the Bus size in kWh divided by the OEM stated range in miles.
3. Be able to accept a charge equal to or greater than the Minimum Charger Size column below

Bus Number	Bus Type	Minimum Bus Size based on Maximum Energy Usage (kWh)	Maximum Charger Size Needed	Maximum OEM Rated Efficiency
2	Type C	161	26 kW	1.58
8	Type C	216	22 kW	1.58
9	Type C	141	21 kW	1.58
10	Type C	152	21 kW	1.58
11	Type C	197	31 kW	1.58
12	Type C	194	60 kW	1.58
17	Type C	174	24 kW	1.58
18	Type C	202	30 kW	1.58
20	Type C	206	30 kW	1.58
21	Type C	177	23 kW	1.58
22	Type C	166	45 kW	1.58
24	Type C	232	41 kW	1.58
27	Type C	273	44 kW	1.58
28	Type C	140	24 kW	1.58
29	Type C	193	45 kW	1.58

Bus Number	Bus Type	Minimum Bus Size based on Maximum Energy Usage (kWh)	Maximum Charger Size Needed	Maximum OEM Rated Efficiency
30	Type C	205	120 kW	1.58
31	Type C	170	27 kW	1.58
32	Type C	190	26 kW	1.58
33	Type C	176	29 kW	1.58
34	Type C	179	24 kW	1.58
35	Type C	143	19 kW	1.58
36	Type C	275	31 kW	1.58
37	Type C	139	22 kW	1.58
41	Type C	165	25 kW	1.58
42	Type C	163	25 kW	1.58
43	Type C	176	28 kW	1.58
44	Type C	174	29 kW	1.58
45	Type C	208	60 kW	1.58
46	Type C	194	120 kW	1.58
47	Type C	150	25 kW	1.58
48	Type C	176	27 kW	1.58
49	Type C	182	120 kW	1.58
50	Type C	158	60 kW	1.58
51	Type C	191	29 kW	1.58
53	Type C	210	24 kW	1.58
54	Type C	270	49 kW	1.58
57	Type C	112	60 kW	1.58
58	Type C	158	19 kW	1.58
59	Type C	159	21 kW	1.58
65	Type A	43	3 kW	1.12
66	Type C	237	20 kW	1.58
67	Type A	93	6 kW	1.12
68	Type A	97	6 kW	1.12
71	Type C	200	30 kW	1.58
73	Type C	208	45 kW	1.58
74	Type C	171	26 kW	1.58
76	Type C	168	27 kW	1.58
78	Type C	208	45 kW	1.58

Table 24 Bus and Charger Selection Criteria

Section 6 Electric Utility Analysis

ELECTRIC UTILITY ANALYSIS

Wendel has engaged with the District's electric utility provider, PSEG, to get a better understanding of the utility's ability to provide the required power for the proposed transition to a BEB fleet. Wendel has provided PSEG with the proposed future load information the district will incur once the BEBs are implemented. Based on the developed energy requirements and charging strategy, Wendel has worked with the PSEG to determine options for obtaining power.

The utility has provided information regarding their availability to supply the required power and preferred utility power interface such as:

- Provide a new service for just the bus charging requirements and reliability of the bus charging service feed.

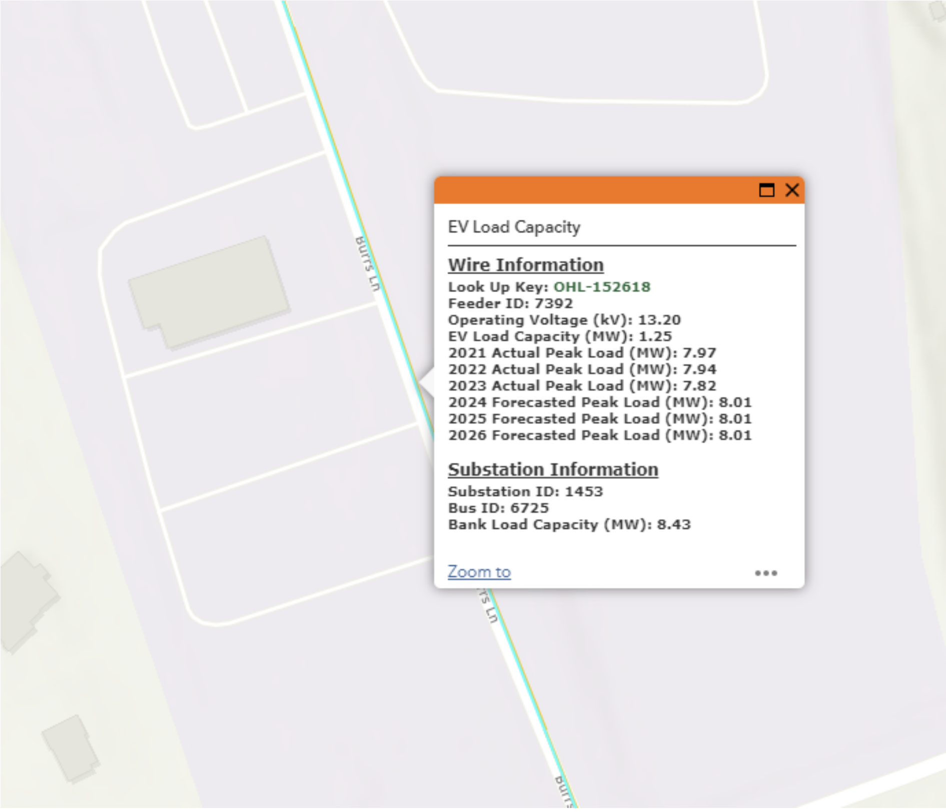

Figure 9 PSEG Hosting Capacity Maps EV Load Capacity Info for Half Hollow Hills Transportation Center

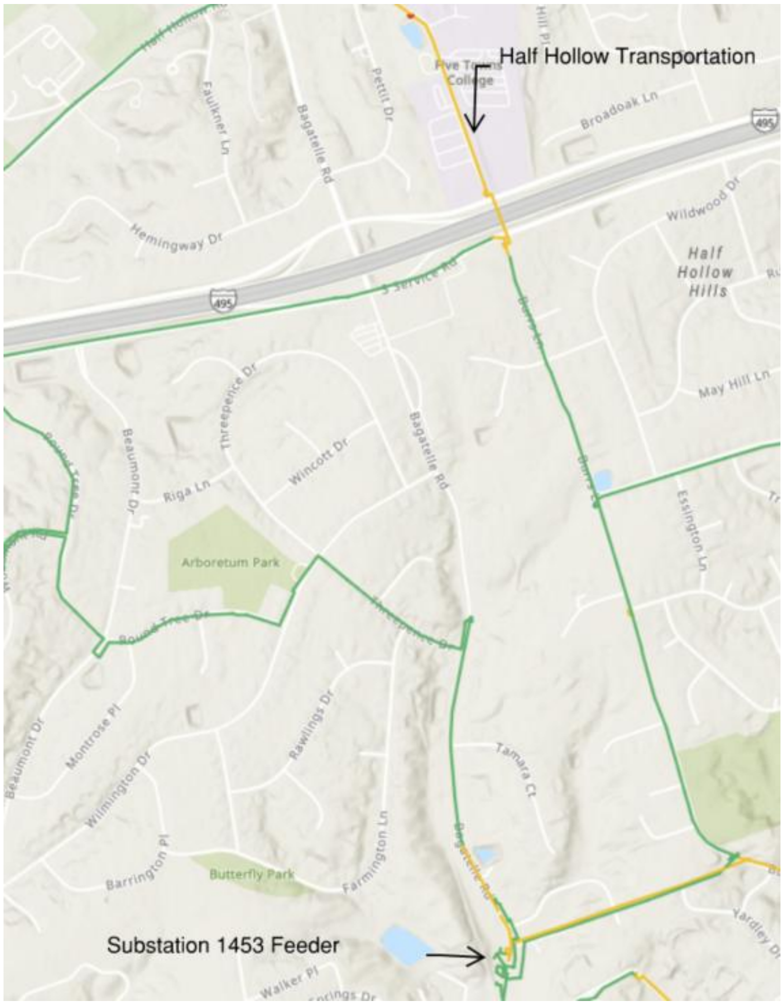

Figure 10 PSEG Hosting Capacity Maps Half Hollow Hills Overview

Utilizing the PSEG online electrification map, it appears that the utility will be able to supply the required power for bus charging from substation 1453. The 13.2kV Feeder 7392 is listed as having 1.25MVA available EV capacity. This means a feeder upgrade from the substation would likely not be required.

The reliability of the bus charging service feed is determined by how the service is fed, if there is a loop, and if the utility can provide power from another feed in the event the service is out on the main feed to the site.

Wendel has also coordinated with the utility to determine what the overall costs of the utility upgrades would be and what portion of those costs would be borne by the school district and its stakeholders. The district would be responsible for the additional transformer and building a three-phase riser which the utility estimates at approximately $44,069. PSEG Make Ready Program will cover 100% of the $44,069 to add additional service.

Section 7 Concept Development & Phasing Plan

CONCEPT DEVELOPMENT & PHASING PLAN

The concept development and phasing plan is the culmination of the previous tasks in the study. The phasing plan incorporates several components and include:

1. Deadlines issued as part of the state mandate including:
    a. By July 1, 2027, all new school buses purchased and or leased must be zero-emission
    b. By July 1, 2035, all school buses on the road must be zero-emission
2. Half Hollow Hills Central School District preferred BEB procurement schedule
3. On-site electrical distribution/charger equipment procurement and construction lead times
4. Utility service upgrade equipment and construction lead times
5. Availability of capital funding including state aid, school capital programs and grant funds

Bus Procurement Schedule

Half Hollow Hills Central School District currently has (59) school buses in their fleet. A sample of the projected battery electric school bus (BEB) procurement schedule for Half Hollow Hills Central School District can be found on the following page. The full procurement schedule can be found in Appendix B - Deliverables.

Bus Number / Name	Proposed New Bus Size	Proposed New Charger Size	Year Bus Procured (age)	Estimated Bus Replacement Year (Replacement Cycle)	Proposed Conversion Year
2	210	60	2010	2024	2035
8	315	24	2010	2024	2035
9	210	24	2019	2033	2030
10	210	24	2019	2033	2030
11	210	60	2019	2033	2030
12	210	60	2019	2033	2030
17	210	24	2009	2024	2035
18	210	60	2010	2024	2035
20	210	60	2011	2025	2027
21	210	24	2009	2024	2035
22	210	60	2012	2026	2027
24	315	60	2012	2026	2027
27	315	60	2013	2027	2028
28	210	24	2023	2037	2033
29	210	60	2023	2037	2033
30	210	120	2023	2037	2033
31	210	60	2023	2037	2033
32	210	60	2014	2028	2028
33	210	60	2013	2027	2028
34	210	60	2013	2027	2028
35	210	24	2015	2029	2028
36	315	60	2015	2029	2028
37	210	24	2015	2029	2029
41	210	60	2015	2029	2029
42	210	60	2016	2030	2029
43	210	60	2016	2030	2029
44	210	60	2016	2030	2029
45	210	60	2016	2030	2029
46	210	120	2020	2034	2031
47	210	60	2020	2034	2031
48	210	60	2020	2034	2031
49	210	120	2020	2034	2031
50	210	60	2020	2034	2031
51	210	60	2021	2035	2032

Bus Number / Name	Proposed New Bus Size	Proposed New Charger Size	Year Bus Procured (age)	Estimated Bus Replacement Year (Replacement Cycle)	Proposed Conversion Year
53	*210*	*60*	*2021*	*2035*	*2032*
54	*315*	*60*	*2020*	*2034*	*2031*
57	*210*	*60*	*2021*	*2035*	*2032*
58	*210*	*24*	*2022*	*2036*	*2032*
59	*210*	*24*	*2022*	*2036*	*2032*
65	*168*	*24*	*2022*	*2036*	*2033*
66	*315*	*24*	*2022*	*2036*	*2033*
67	*168*	*24*	*2024*	*2038*	*2034*
68	*168*	*24*	*2024*	*2038*	*2034*
71	*210*	*60*	*2024*	*2038*	*2034*
73	*210*	*60*	*2024*	*2038*	*2034*
74	*210*	*60*	*2021*	*2035*	*2032*
76	*210*	*60*	*2023*	*2037*	*2034*
78	*210*	*60*	*2016*	*2030*	*2030*
93	*315*	*60*	*2016*	*2030*	*2030*
Spare - 92	*210*	*0*	*2024*	*2038*	*2034*
Spare - 89	*210*	*0*	*2012*	*2026*	*2027*
Spare - 79	*210*	*120*	*2024*	*2038*	*2035*
Spare - 72	*210*	*0*	*2012*	*2026*	*2027*
Spare - 56	*210*	*120*	*2006*	*2024*	*2035*
Spare - 55	*210*	*0*	*2006*	*2024*	*2035*
Spare - 52	*315*	*120*	*2006*	*2024*	*2035*
Spare - 40	*315*	*0*	*2005*	*2024*	*2035*
Spare - 26	*168*	*24*	*2005*	*2024*	*2035*
Spare - 25	*168*	*24*	*2005*	*2024*	*2035*

Table 25 Sample of BEB Procurement Schedule

**Replacement is based on 14 cycle. If replacement year is before 2027, it is assumed the bus will be replaced with a diesel bus.*
***This proposed BEB procurement schedule is subject to change based on client procurement.*

Based on the proposed procurement schedule, the route analysis and the charging strategy developed for Half Hollow Hills Central School District the projected charger load growth over time is as follows:

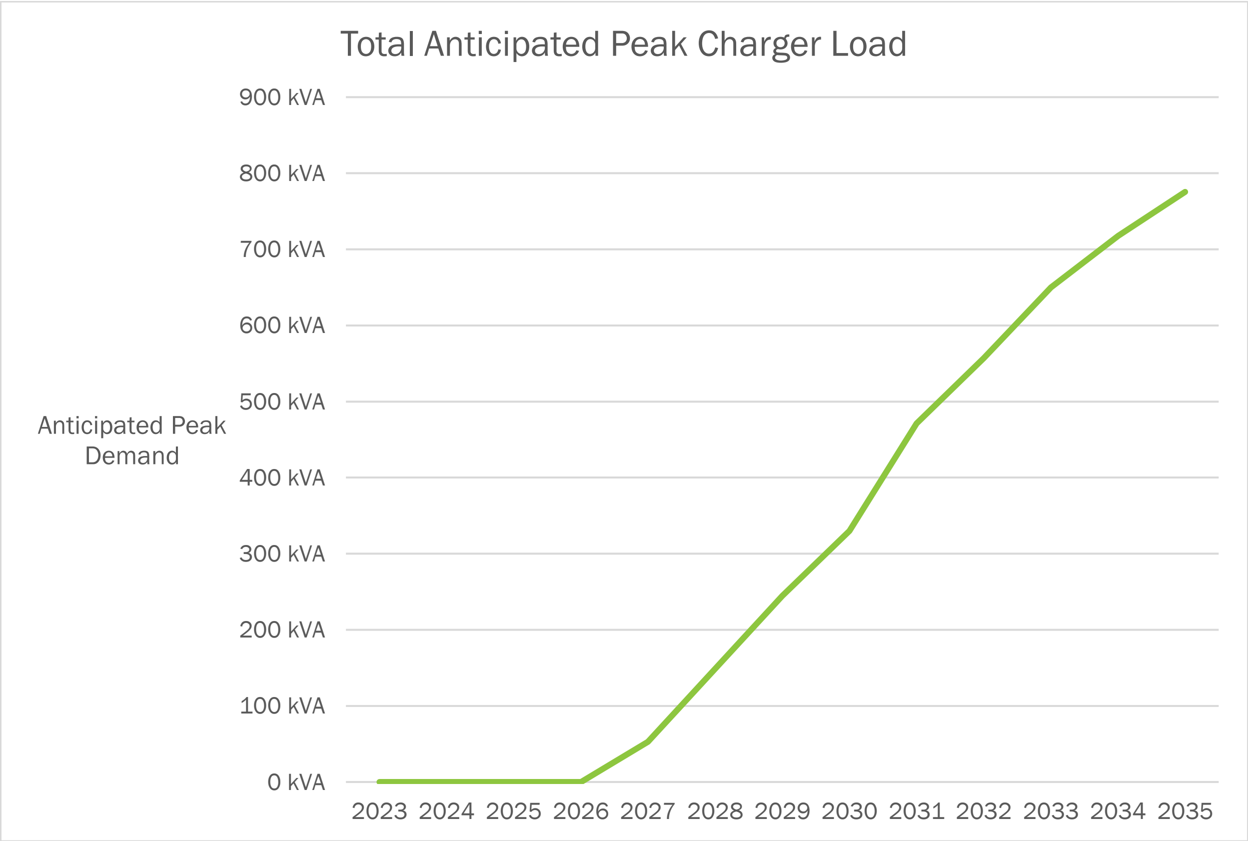

Figure 11 Total Anticipated Charger Peak Load

Phasing Plan

The proposed phasing plan for Half Hollow Hills Central School District consists of three phases. The district can add buses at their preferred rate and the infrastructure will be available and ready to charge BEBs. The proposed equipment layout is included in Appendix C - Concept Development & Phasing Plan Drawings of this report.

Phase 1

Phase 1 incorporates several components necessary for the overall site development.

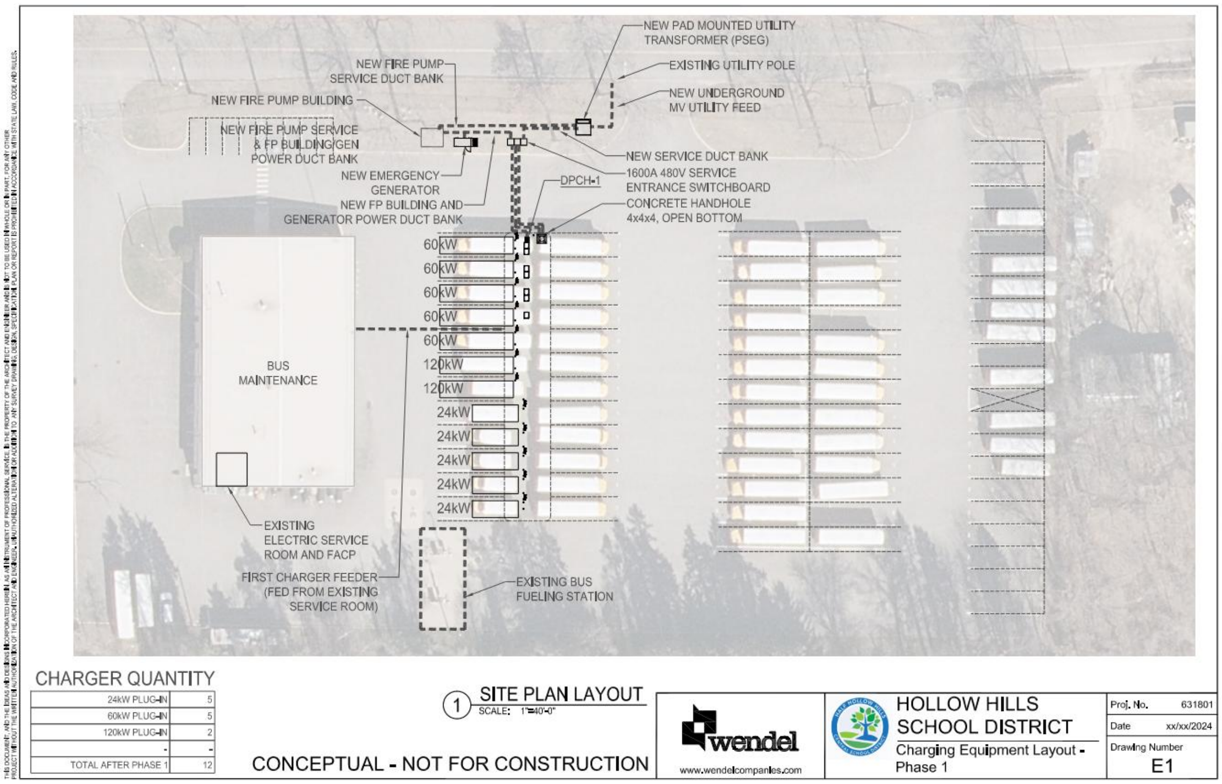

Figure 12 Phase 1 Site Layout

New utility transformer – The BEB charging infrastructure for Half Hollow Central School District should be powered through a new utility service feed from their municipal service. The proposed location for the new pad mounted 1000 kVA transformer is located on the grassy area near the street entrance to the bus parking area as seen on the Phase 1 Implementation layout in Appendix C - Concept Development & Phasing Plan Drawings of this report.

New power distribution equipment – There will be a 1600A service switchboard and 1200A distribution equipment to feed the chargers.

Utility and distribution trenches from new service to power distribution equipment – An underground duct bank should be installed from the new transformer to the new service switchboard and continue to the new electrical distribution equipment.
Power feeds and charging equipment for up to ***12 new chargers*** – New power feeds should be installed behind bus parking spaces 1-12. Five 24 kW chargers, five 60 kW chargers, and two 120 kW chargers should be installed behind the bus lanes.

Fire protection system upgrades – The maintenance facility should be provided with a fire sprinkler system to increase protection against battery electric bus fires. This system should include a new 6" water service from the street, 6" backflow preventer, fire pump, and an external fire pump building. The fire pump building will be approximately 15' x 13' and is being proposed to go in the grassy area near the street. This location will not impact the current bus parking and will be positioned well to intercept the new incoming water service. Water will be supplied underground from the street, up into this building, through a backflow preventer, through the pump, and back underground to the facility. The building location can shift during design if Half Hollow Hills CSD has a different preference.

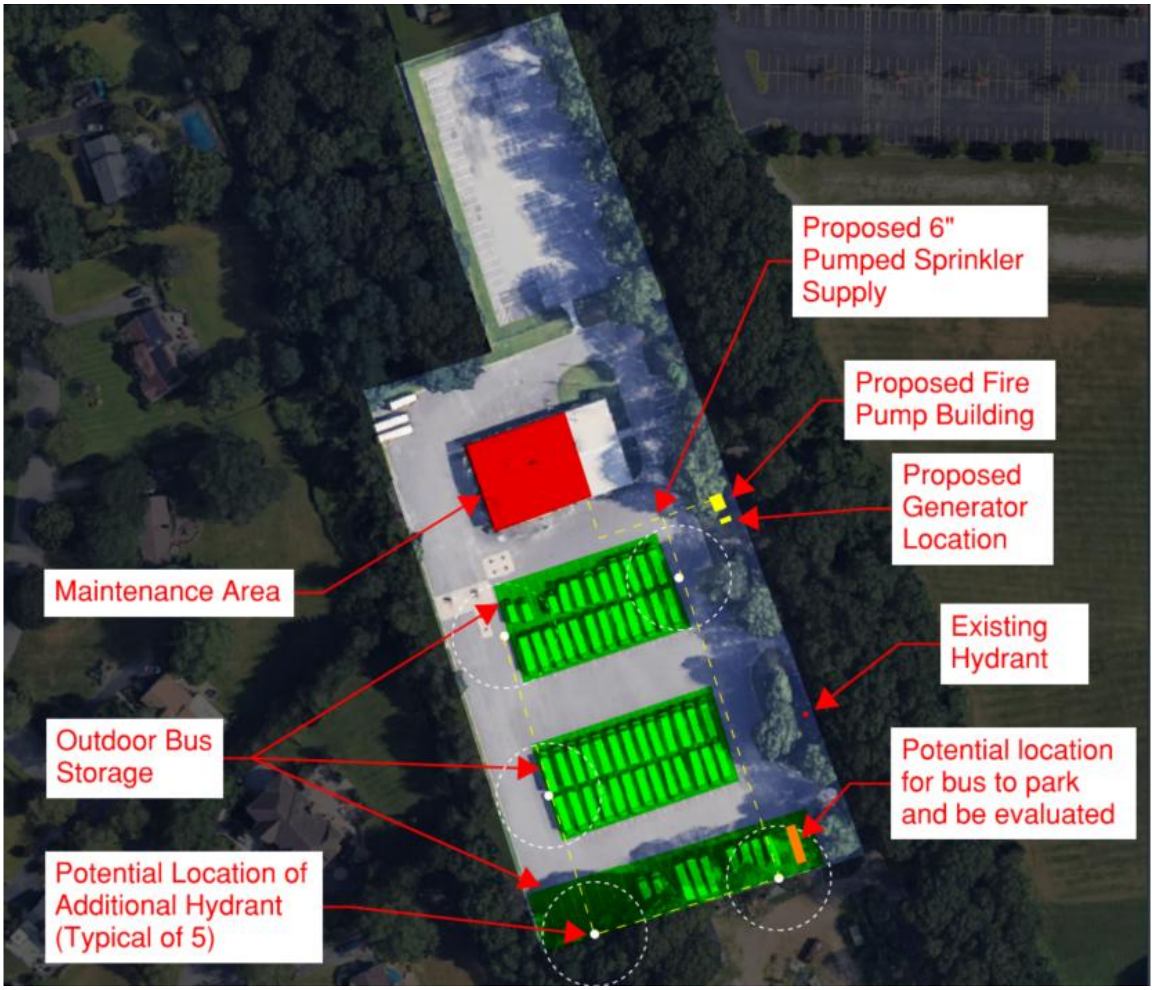

Figure 13 Fire Pump Room Addition

Since we are only intending on providing sprinkler protection in the maintenance area, the new pumped supply will enter the facility near bus maintenance. There is currently a trench drain along the South wall of the maintenance area, so we propose entering under the existing man door. In the design phase, head locations will need to be closely coordinated with existing equipment and systems to ensure full sprinkler coverage without obstructions. The new 6-inch

service from the road, through the pump building, and into the facility will be approximately 200 feet. The area of the new sprinkler system is approximately 6,000 square feet total, between the maintenance and storage areas.

Since this facility has only external parking, the design described for maintenance areas would not apply to exterior charging. In this case we would recommend installing fire hydrants every 100 feet, approximately, throughout the parking area. This would aid the fire department in supplying large amounts of water if a bus were to catch fire. The proximity of hydrants may allow for the use of multiple hydrants to contain the fire if needed. The water service required to serve the fire hydrants could be upstream or downstream of the fire pump. Either option could be incorporated. At this location, that would result in roughly five (5) additional hydrants and about 850 feet of 6-inch pipe. Based on available budget during design, this approach could be scaled back to a hydrant every 200 feet, or whatever is deemed reasonable by the district.

Electric fire pumps require an alternate source of power in case the primary (typically the utility) is lost. This alternate source of power is typically an emergency generator that would provide necessary backup power for the fire pump. The diesel generator would be located alongside the fire pump building to reduce the length of run for connection. A new fire pump electrical service would also be required to feed the fire pump building.

The actual size of the fire pump will be confirmed during the design but at this time, we expect the pump would likely be around 1250 gpm, 60 psi, and 75 hp.

If space is available, best practice is to have a dedicated location outside for a bus that may have a maintenance or battery concern and needs to be evaluated. We would recommend that this dedicated area have clearance of at least 15ft on each side of the bus from any other combustibles. If it catches on fire, it would be isolated and minimize risk. If a space like this is identified for this site, we would suggest providing a private fire hydrant within 50 feet, for fire department use. This hydrant could be served from the fire pump and significantly help in controlling a bus fire.

Costs

- Charging system infrastructure for Phase 1: **$1,562,376 to $1,726,836**
- PSEG Service Upgrades: **$44,069**
- Fire Protection infrastructure: **$1,317,195 to $1,455,847**
- Total Phase 1 estimated cost: **$2,923,640 to $3,226,752**
  Detailed cost estimates are included in the appendix E. Cost estimates do not include bus purchases.

Phase 2

Phase 2 incorporates several components necessary for the overall site development.

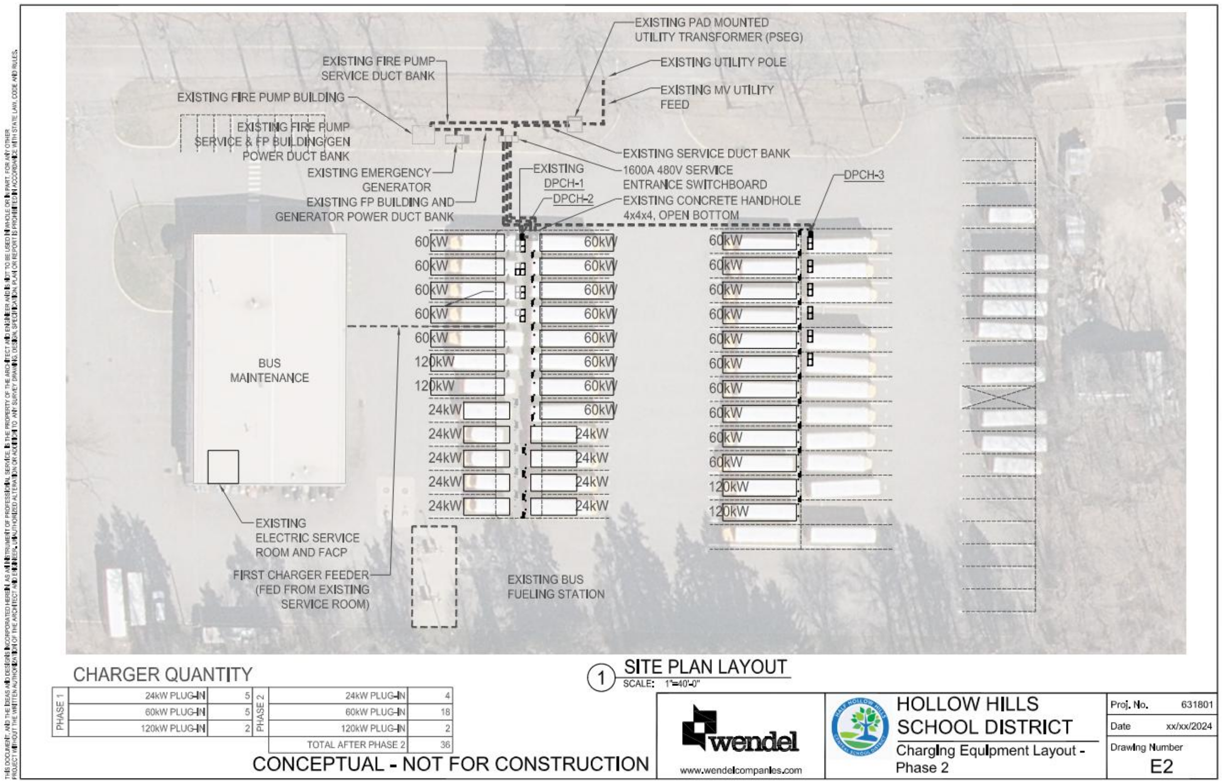

Figure 14 Phase 2 Site Layout

New power distribution equipment – There will be a 1000A and 1200A switchboard to feed the chargers.

Distribution trenches from service switchboard to power distribution equipment – An underground duct bank should be installed from the service switchboard to the new electrical distribution equipment.

*Power feeds and charging equipment for up to **24 new chargers*** – New power feeds should be installed behind bus parking spaces 13-36. Four 24 kW chargers, eighteen 60 kW chargers, and two 120 kW chargers should be installed behind the bus lanes.

Costs

- Charging system infrastructure for Phase 2: **$3,440,644 to $3,802,818**
- Total Phase 2 estimated cost: **$3,440,644 to $3,802,818**
  Detailed cost estimates are included in the appendix E. Cost estimates do not include bus purchases.

Phase 3

Phase 3 incorporates several components necessary for the overall site development.

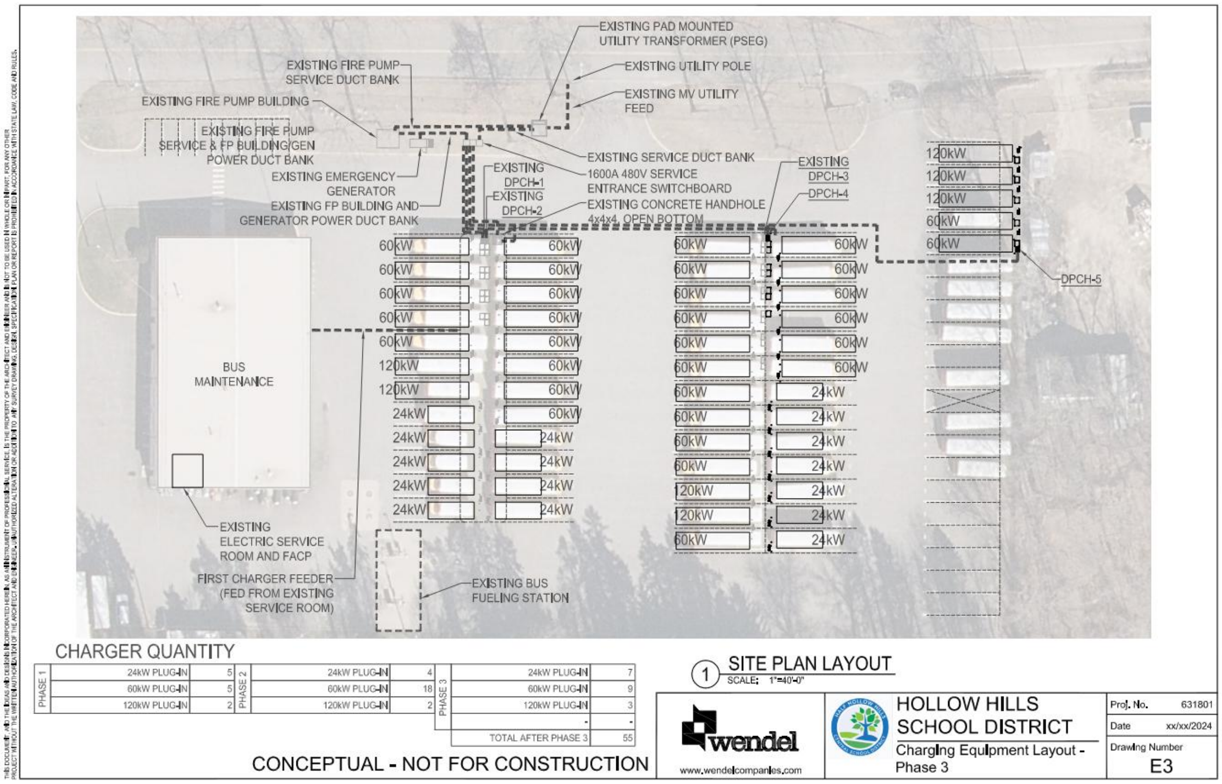

Figure 15 Phase 3 Site Layout

New power distribution equipment – There will be an 800A and 1000A distribution panels to feed the chargers.

Distribution trenches from service switchboard to power distribution equipment – An underground duct bank should be installed from the service switchboard to the new electrical distribution equipment.

Power feeds and charging equipment for up to ***19 new chargers*** – New power feeds should be installed behind bus parking spaces 37-55. Seven 24 kW chargers, nine 60 kW chargers, and three 120 kW chargers should be installed behind the bus lanes.

Costs

- Charging system infrastructure for Phase 3: **$3,417,739 to $3,777,501**
- Total Phase 3 estimated cost: **$3,417,739 to $3,777,501**
  Detailed cost estimates are included in the appendix E. Cost estimates do not include bus purchases.

Fire protection approach

It is common industry belief that standard sprinkler protection for parking garages and maintenance areas is inadequate for battery electric school buses, and we agree. Since there are not currently code requirements for sprinkler protection of this scenario, we have developed a custom approach. Our approach on the Transit bus side has currently been reviewed and accepted by FM Global, State Fire Marshal's in CT, MA, and NY, CTDOT, and a variety of insurance companies. On the school bus side this approach has been recommended at several different districts as they move forward to BEB. Typically, the exterior shell of a school bus does contain a bit more metal than a transit bus, but many exterior parts like bumper, moldings, side mirror covers, and mud flaps are still made of plastic, which are quicker to catch if an adjacent bus is on fire. Additionally, to extend battery range, more and more buses are being constructed of lighter weight, alternative materials. We strongly recommend the same fire protection approach for all battery powered buses until NFPA releases specific code requirements. Due to the chemistry of lithium-ion batteries, it is nearly impossible to completely extinguish them once the chemical reaction has started. They can reignite for up to 24 hours in most cases. The current recommendation from NFPA for Lithium-Ion fires is large amounts of water to suppress the fire.

When buses are indicating warnings, damaged, or have problems, they are typically brought to maintenance. Although a bus may be left outside if the battery is a concern, maintenance is still a likely location for problems to occur. Additionally, maintenance areas are often equipped with portable chargers. This enhanced sprinkler coverage will allow the flexibility of locally charging any of the buses as well.

In all areas where battery electric school buses will be charged or maintained, we recommend providing a sprinkler system capable of 0.7 gallons per minute, per square foot (gpm/sf). Utilizing Control Mode Specific Application (CMSA) type sprinkler heads will require calculating the most remote 15 heads, to ensure the remaining system has adequate capacity. The shell of the bus prevents water from getting directly to the source of the fire. Additionally, batteries are usually located within a compartment that also prevents water from reaching. This sprinkler design approach has been developed to suppress an electric bus fire and prevent the fire from spreading to adjacent buses. This helps to protect the building and buy time for people to get out safely. It is also in place to contain the fire long enough for fire department to respond and take the proper measures from there.

The existing facility does not currently have a sprinkler system and the existing domestic water service would be inadequate to support this type of design. The fire pump needed by the proposed system does not appear to be able to fit indoor, so an outdoor pump house will be utilized.

There are three maintenance bays used regularly to maintain buses. A fourth, separate bay has a lift but is mostly used for storage. Since this bay could be used, we are proposing to extend the sprinkler system and protect all four bays. This will also provide flexibility to Half Hollow Hills CSD to maintain any vehicle in any of the available spaces.

Maintenance of the fire protection system is critical to ensure longevity and performance during time of need. Ongoing compliance with NFPA 25 will be essential for the entire sprinkler system.

Schedule

A preliminary schedule was developed as a guide for the implementation of Phase 1 of the transition plan. This preliminary schedule is heavily impacted by current supply chain issues associated with electrical equipment, particularly electrical switchgear. The current lead time for switchgears is estimated to be 20 months.

Phase 1 Preliminary Schedule

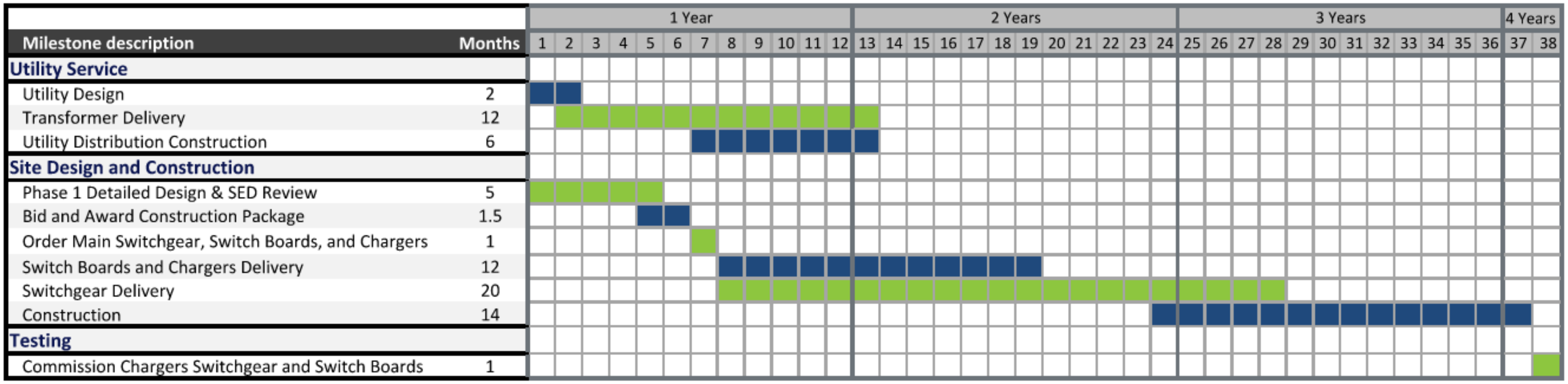

Figure 16 Phase 1 Preliminary Construction Schedule

Section 8 Transition Plan Cost Estimates

Transition Plan Cost Estimates

Wendel has developed a high-level opinion of probable costs to implement the transition plan described in the previous section. Estimates from previous studies were utilized as the basis of the transition plan cost estimate and scaled for Half Hollow Central School District. The estimates include the phased implementation costs of the following major items:

1. Electrical equipment and installation costs for the utility interface
2. Bus charging system distribution equipment and installation costs including switchgear, panelboards, wiring
3. Charger and dispenser and installation costs
4. Associated sitework and civil costs
5. Other costs associated with a transition, an addition, renovations, etc.

The following items were excluded from the estimates:

1. Utility fees
2. Construction Management (CM) fees
3. Phasing costs within each phase
4. Costs of the BEBs themselves

Wendel has submitted all necessary information to the utility, PSEG, and has requested they provide the upgrades required to support the necessary loads, overall costs of the utility upgrades and responsibility of the costs. As of the date of this report, PSEG has provided the necessary upgrades and associated cost. Utility incentives and grants should be explored during design to help mitigate the impact of these costs.

The estimated costs for the proposed BEBs themselves can be found below. These costs were acquired in the Spring of 2024 and may vary based on region, bus supplier, warranty option selected, and bus customization / add-ons. These costs do not include escalation.

Make	Bus Type	Bus Size (kWh)	Estimated Cost per Bus
Lion	Type A	168	$300,000.00
IC Bus	Type C	210	$394,000.00
IC Bus	Type C	315	$428,000.00

Table 26 Estimated BEB Costs

Section 9 Appendix

Appendix A – Abbreviations

Appendix B - Deliverables

Appendix B.1 - Minutes

Appendix B.2 – Task Memos

*** Please note that information within the Task Memos may differ from the report and Final Calculations / Models. This is part of the iterative process.**

Appendix B.3 – Final Calculations and Models

Appendix C - Concept Development & Phasing Plan Drawings

Appendix D - Original Scope of Work

Appendix E - Cutsheets

Appendix F - Information Received from Client