Lawrence Transit Route, Charge, and Rate Modeling Results

March 3, 2021

Route Modeling Results

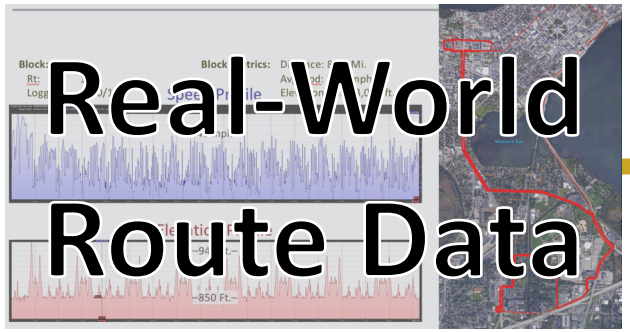
March 3, 2021

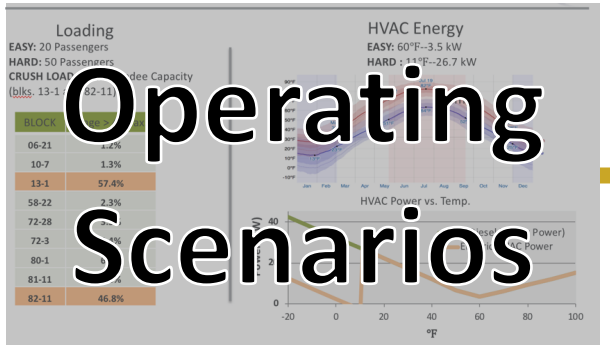
Route Modeling Objectives

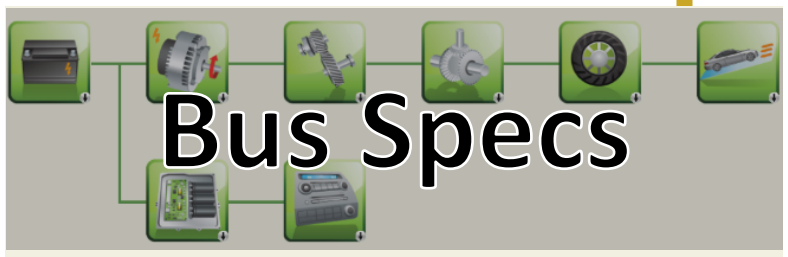
- Estimate the energy required and block achievability to operate Gillig 444 kWh battery electric buses on the proposed routes
  - Nominal conditions
  - Strenuous conditions

- Predict energy usage
- Predict range (distance)
- Predict endurance (time)

Route Modeling Approach







Vehicle Simulation Software

Fuel economy of bus under specified operating conditions.

- Route/Block Feasibility
- Charging Requirements
- Deployment Strategy
- Energy Cost Estimates

Modeling Load Cases & Assumptions

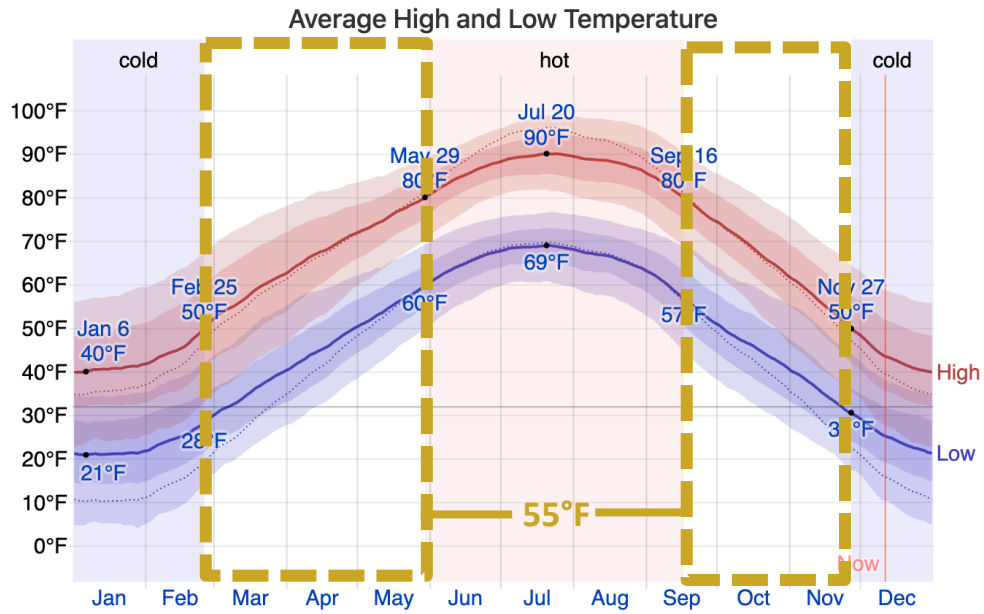
Vehicle	Load Case	Temperature (°F)	Occupants (@150 lbs)	Total Aux Load (kW)	Total Weight (lbs)
Gillig 444 kWh	Nominal	55	12 + Operator	6.5	36,690
	Strenuous	12	64 + Operator	23.5	44,490

- Nominal temperature: average temperature outside of hot and cold season temperatures
- Strenuous temperature: average temperature of the 10th percentile maximum and minimum temperatures on the coldest day of the year, January 4th
- Aux load estimates are based on data provided by Gillig and account for temperature data, battery thermal management, and other hotel loads
- Passenger loading based on projected ridership provided by Lawrence Transit
- Occupant weight based on FTA standard

Temperature Assumptions

Nominal Temperature Assumption

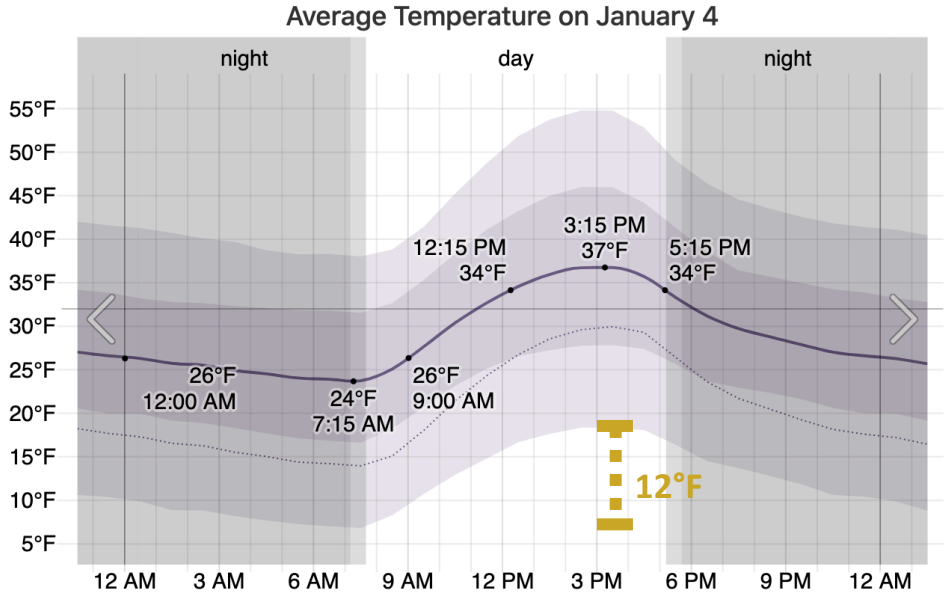
Average Spring & Fall Temperature



The daily average high (red line) and low (blue line) temperature, with 25th to 75th and 10th to 90th percentile bands. The thin dotted lines are the corresponding average perceived temperatures.

Strenuous Temperature Assumption

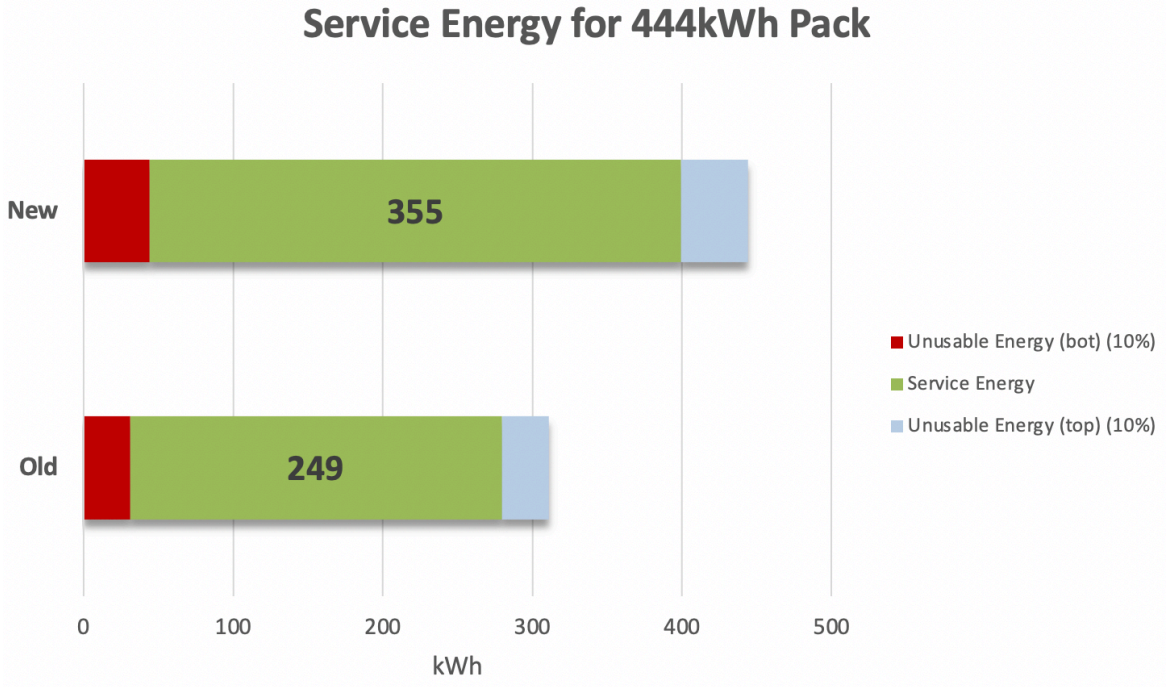
Average temperature of the 10th percentile maximum and minimum temperatures on the coldest day of the year



The hourly average temperature (purple line), with 25th to 75th and 10th to 90th percentile bands. The thin dotted line is the hourly average perceived temperature. Civil twilight and night are indicated by shaded overlays.

Service Energy

- Service energy represents the amount of energy available on the bus for in-service operations
- 80% of the battery capacity is considered usable energy
  - Can select 90% usable instead
- The old battery is representative of degradation to 80%
  - If 90% usable battery capacity is selected, then battery may degrade to 70% of initial capacity
- When operating in the derated SOC range, the bus will start to lose functionality
  - Sluggish movement
  - Load shedding



Selected Routes

Route	Reason for Selection
Route 1	Travels downtown and in East Lawrence.
Route 4	Bridge route
Route 6	Travels downtown and in West Lawrence.
Route 10	Travels along hilly landscape.
Route 11	Route includes many stops.
Route 23	Travels in both East and West Lawrence
Route 43	Campus circulator. Crush Load.
I Line	Travels in both North and South Lawrence

Summary of Collected Route Data

Route	Distance (mi)	Duration (min)	Average Speed* (mph)
Route 1	8.9	49	10.8
Route 4	9.5	47	12.1
Route 6	12.9	66	9.9
Route 10	13.0	51	13.8
Route 11	13.7	90	11.3
Route 23	20.1	91	13.3
Route 43	3.6	22	12.1
I Line	9.0	40	13.6

**Average speed includes time spent at layovers*

Simulated Efficiencies

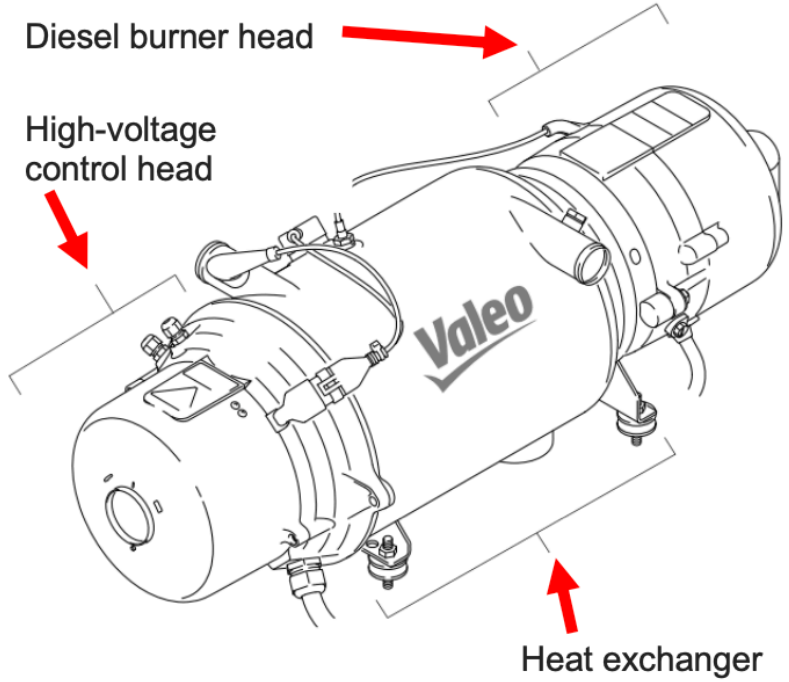
Route	Average Speed* (mph)	Nominal Efficiency** (kWh/mi)	Strenuous Efficiency** - Electric Heating (kWh/mi)	Strenuous Efficiency** - Diesel Heating (kWh/mi)
Route 1	10.8	1.9	3.8	2.0
Route 4	12.1	2.1	3.8	2.3
Route 6	9.9	2.5	4.6	3.0
Route 10	13.8	2.3	4.0	2.7
Route 11	11.3	1.8	3.6	1.5
Route 23	13.3	2.3	3.9	2.7
Route 43	12.1	2.2	4.1	2.1
I Line	13.6	2.3	3.9	2.7

**Average speed includes time spent at layovers*

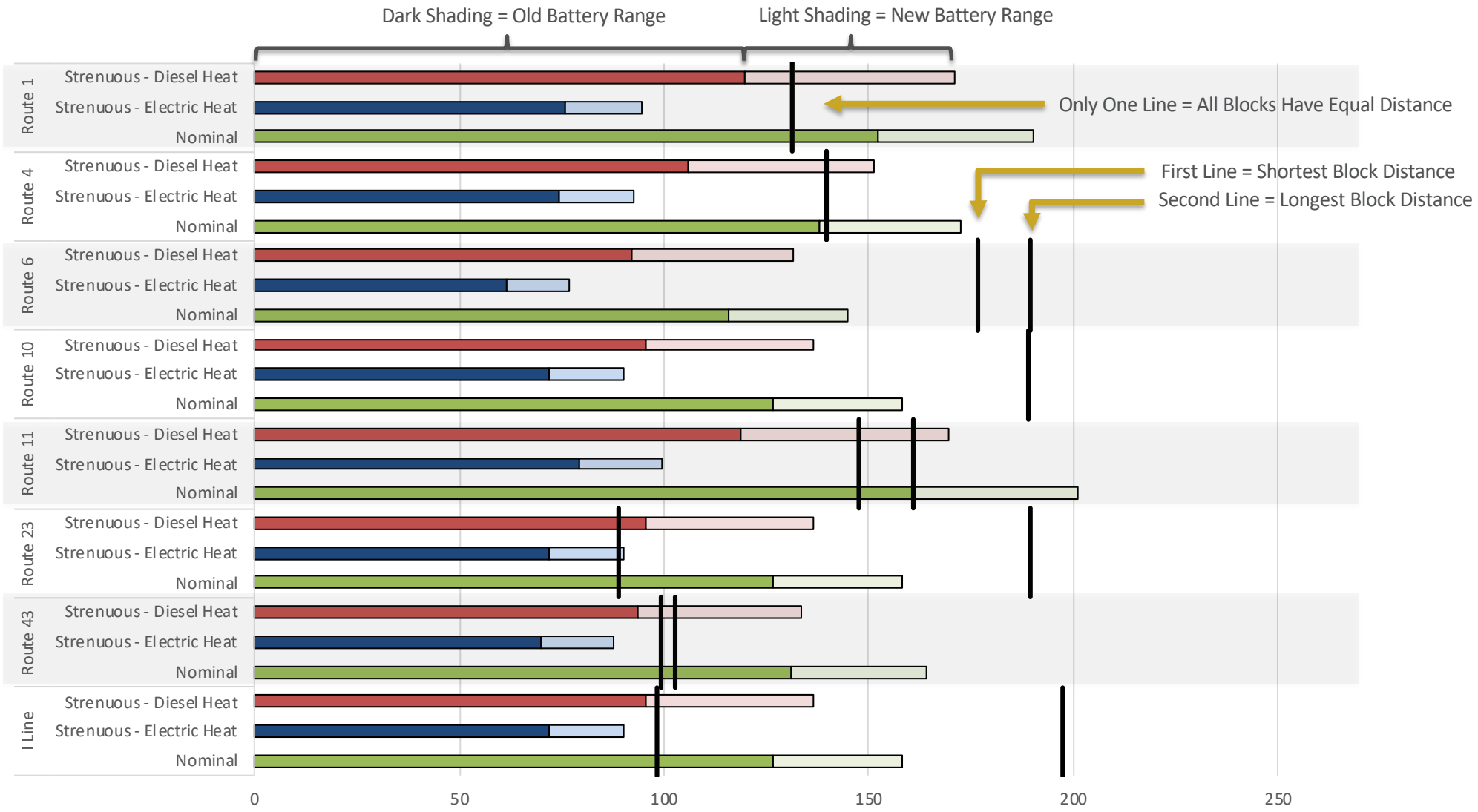
***Nominal and strenuous efficiencies include auxiliary and HVAC energy consumed while bus is stopped at layovers*

Electric vs. Diesel Heat

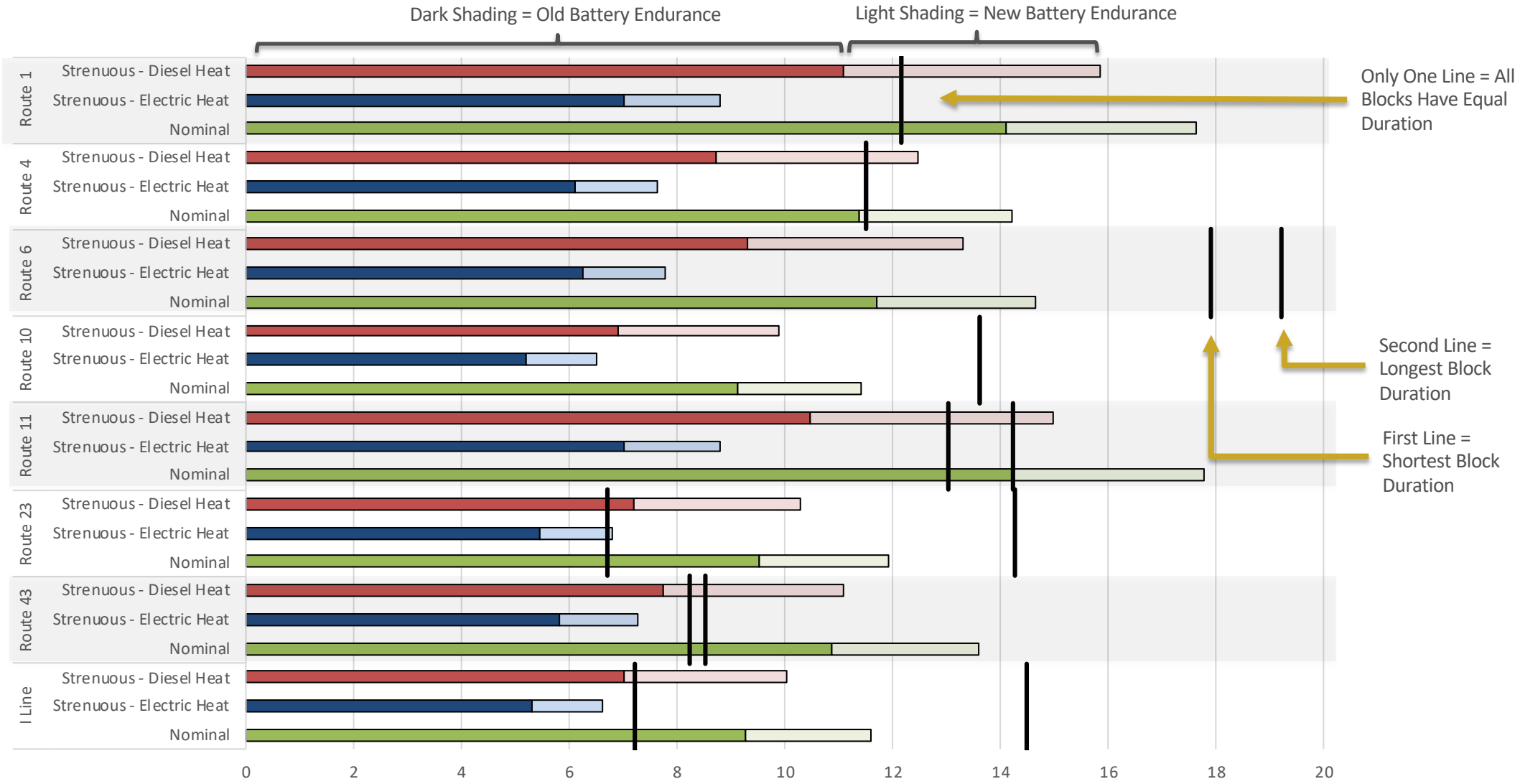
- We assume that the driver has control over the heat source (diesel or electric)
- Under strenuous conditions, no existing blocks are achievable with electric heating
- Diesel heating drastically improves achievability



Gillig 444kWh Range

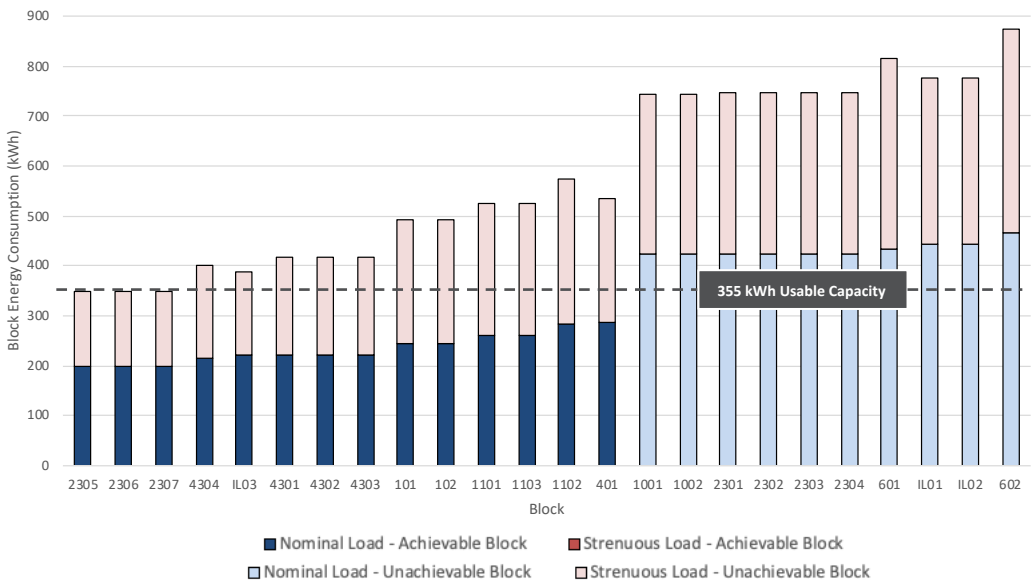


Gillig 444kWh Endurance



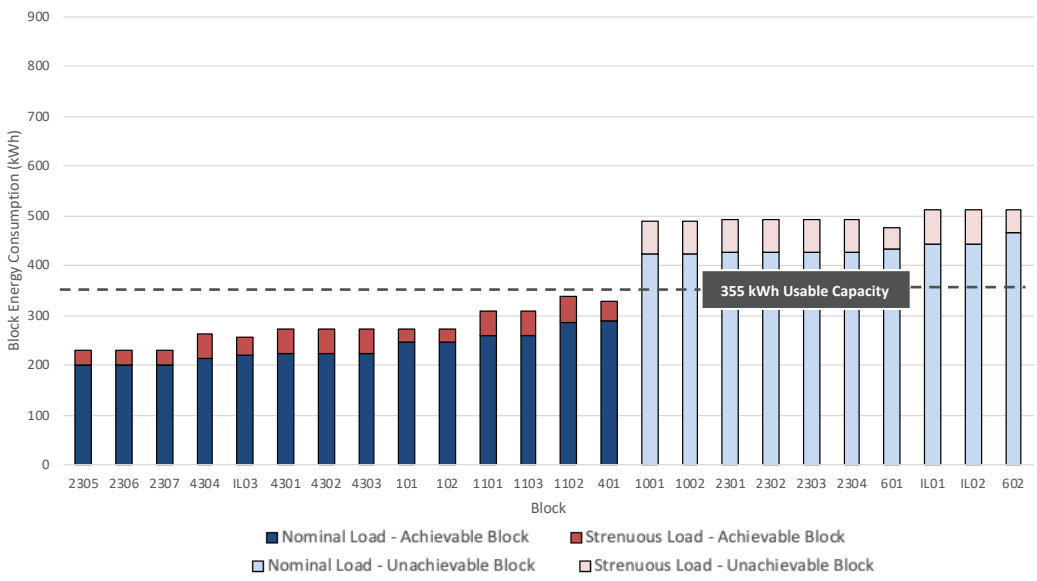
Block Achievability: New Battery

Electric Heat



Electric Heat: Achievable Blocks	
Nominal Case	14
Strenuous Case	0

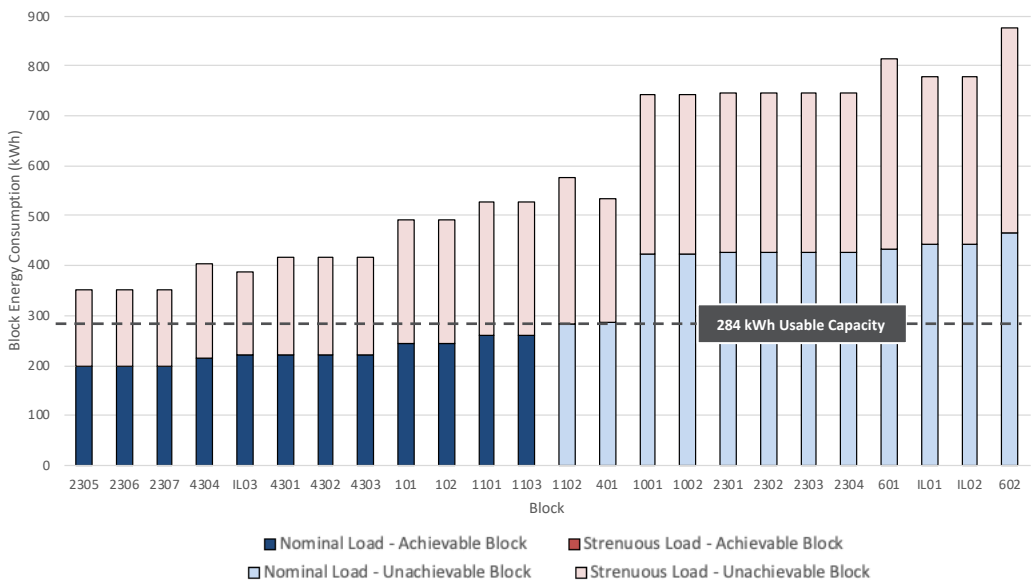
Diesel Heat



Diesel Heat: Achievable Blocks	
Nominal Case	14
Strenuous Case	14

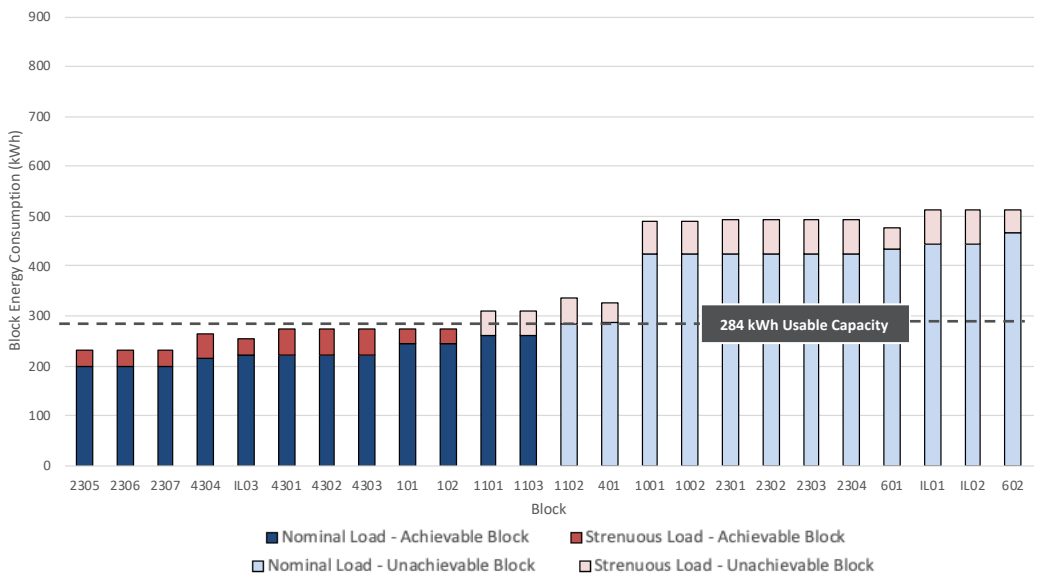
Block Achievability: Old Battery

Electric Heat



Electric Heat: Achievable Blocks	
Nominal Case	12
Strenuous Case	0

Diesel Heat



Diesel Heat: Achievable Blocks	
Nominal Case	12
Strenuous Case	10

Block Achievability

Block	New Battery			Old Battery		
	Nominal	Strenuous Electric Heat	Strenuous Diesel Heat	Nominal	Strenuous Electric Heat	Strenuous Diesel Heat
101	✓	✗	✓	✓	✗	✓
102	✓	✗	✓	✓	✗	✓
401	✓	✗	✓	✗	✗	✗
601	✗	✗	✗	✗	✗	✗
602	✗	✗	✗	✗	✗	✗
1001	✗	✗	✗	✗	✗	✗
1002	✗	✗	✗	✗	✗	✗
1101	✓	✗	✓	✓	✗	✗
1102	✓	✗	✓	✗	✗	✗
1103	✓	✗	✓	✓	✗	✗
4301	✓	✗	✓	✓	✗	✓
4302	✓	✗	✓	✓	✗	✓
4303	✓	✗	✓	✓	✗	✓
4304	✓	✗	✓	✓	✗	✓

Block Achievability

Block	New Battery			Old Battery		
	Nominal	Strenuous Electric Heat	Strenuous Diesel Heat	Nominal	Strenuous Electric Heat	Strenuous Diesel Heat
2301	✗	✗	✗	✗	✗	✗
2302	✗	✗	✗	✗	✗	✗
2303	✗	✗	✗	✗	✗	✗
2304	✗	✗	✗	✗	✗	✗
2305	✓	✓	✓	✓	✗	✓
2306	✓	✓	✓	✓	✗	✓
2307	✓	✓	✓	✓	✗	✓
IL01	✗	✗	✗	✗	✗	✗
IL02	✗	✗	✗	✗	✗	✗
IL03	✓	✗	✓	✓	✗	✓

Charge and Rate Modeling Results

March 3, 2021

Charge and Rate Modeling Objectives

- Explore the impact and cost of various charging configurations and load cases
  - Utility rate structure
  - 2022 charging scenarios
  - Futureproofing charging scenarios

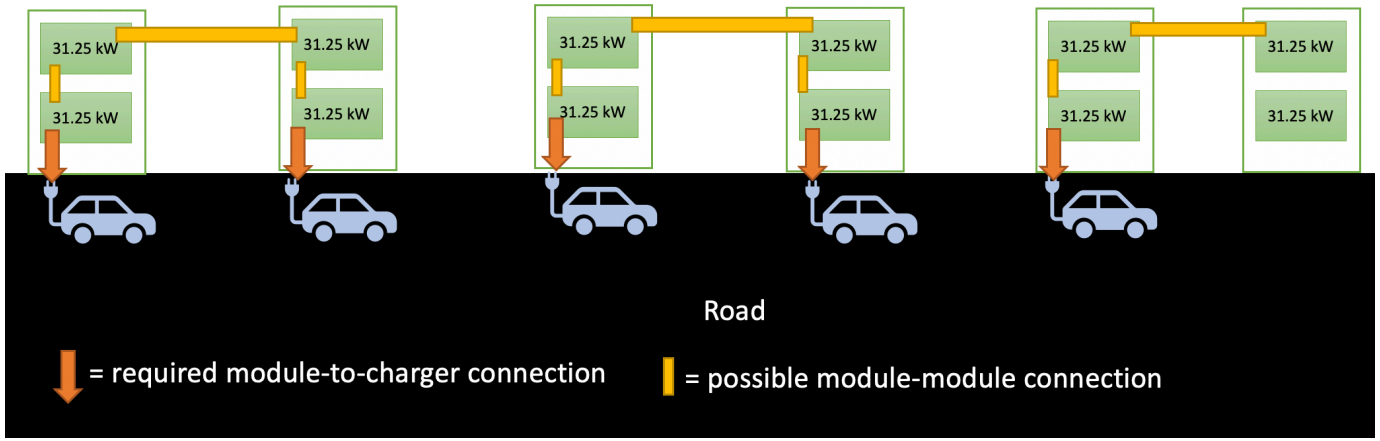
Utility Rate Structure

Schedule	Day	Time	Classification
	M-F	18:00-6:00	Off-Peak
	M-F	6:00-18:00	On-Peak
	Weekend, 6 Holidays	0:00-23:59	Off-Peak

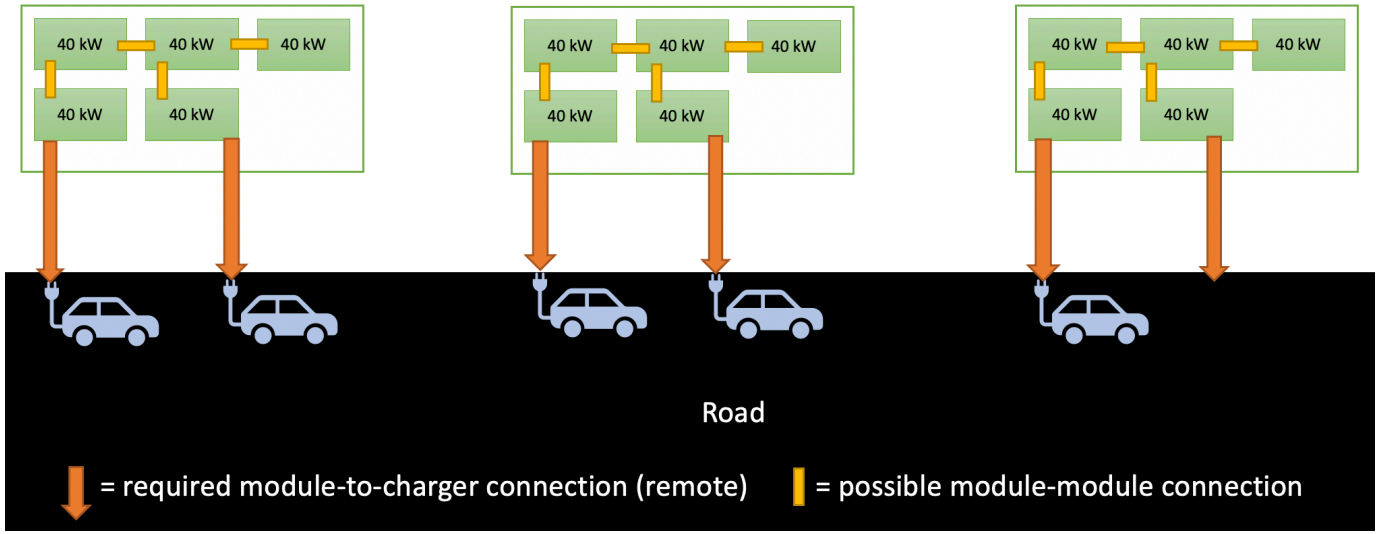
Fee		Cost
Monthly Basic Service Fee		$ 29.00
Energy Charges ($/kWh)	Off-Peak	$ 0.0208
	On-Peak	$ 0.1423
Energy Surcharges ($/kWh)	RECA	$ 0.0178
	PTS	$ 0.0010
	TDC	$ 0.0144
	ECRR	$ -
	REPR	$ -
	EER	$ 0.0002
	TA	$ -
Total Energy Charges ($/kWh)	Off-Peak	$ 0.0542
	On-Peak	$ 0.1756

2022 Charging Scenarios

Scenario 1:
CPE250 Chargers



Scenario 2:
Express Plus with Remote Dispensers



2022 Scenario 1: CPE250

Assumptions:

- 5 bus operation
- Off-peak charging
- Simultaneous charging
- Existing blocks
- 85% availability
- 33% additional grid energy consumption due charger and charge management inefficiencies
- Nominal load case used in monthly estimates
- 1 hour of preconditioning

			Daily Charge Durations (h)			Daily Charge Costs ($)		
Dispenser Number	Dispenser Power (kW)	Block Number	Nominal	Strenuous - Electric Heat	Strenuous - Diesel Heat	Nominal	Strenuous - Electric Heat	Strenuous - Diesel Heat
1	62.5	4304	5.6	9.6	6.6	$15.83	$30.28	$20.26
2	62.5	4301	5.7	9.9	6.8	$16.39	$31.34	$20.94
3	62.5	4302	5.7	9.9	6.8	$16.39	$31.34	$20.94
4	62.5	4303	5.7	9.9	6.8	$16.39	$31.34	$20.94
5	93.75	101	4.5	8.0	4.9	$17.99	$36.73	$20.90
		Average	**5.5**	**9.4**	**6.4**	**$16.60**	**$32.20**	**$20.80**

Average Monthly Estimates (KU Semester)		
Distance	Fuel Cost	Cost/Mile
10,223 mi	$1,594	$0.16

2022 Scenario 2: Express Plus

Assumptions:

- 5 bus operation
- Off-peak charging
- Simultaneous charging
- Existing blocks
- 85% availability
- 33% additional grid energy consumption due charger and charge management inefficiencies
- Nominal load case used in monthly estimates
- 1 hour of preconditioning

			Daily Charge Durations (h)			Daily Charge Costs ($)		
Dispenser Number	Dispenser Power (kW)	Block Number	Nominal	Strenuous - Electric Heat	Strenuous - Diesel Heat	Nominal	Strenuous - Electric Heat	Strenuous - Diesel Heat
1	80	4304	4.6	7.7	5.4	$15.83	$30.28	$20.26
2	120	4301	3.5	5.6	4.0	$16.39	$31.34	$20.94
3	80	4302	4.7	7.9	5.5	$16.39	$31.34	$20.94
4	120	4303	3.5	5.6	4.0	$16.39	$31.34	$20.94
5	120	101	3.7	6.5	4.0	$17.99	$36.73	$20.90
		Average	**4.0**	**6.7**	**4.6**	**$16.60**	**$32.20**	**$20.80**

Average Monthly Estimates (KU Semester)		
Distance	Fuel Cost	Cost/Mile
10,223 mi	$1,594	$0.16

2022 Charging Scenario Comparison

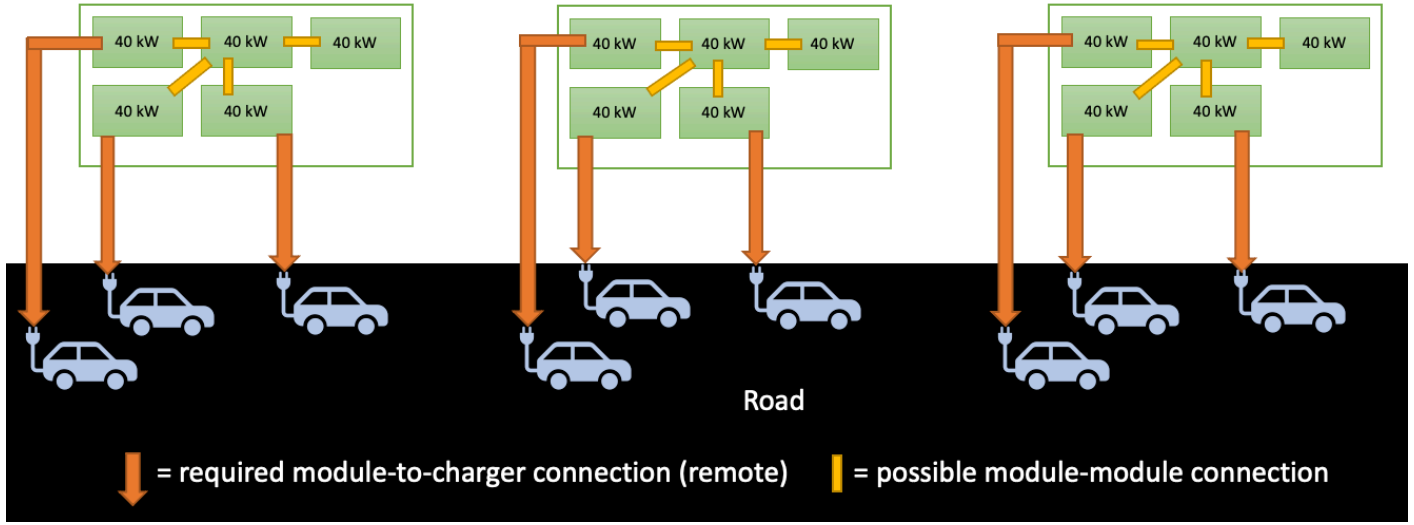
Daily Charge Duration (h)			
	Nominal	Strenuous – Electric Heat	Strenuous – Diesel Heat
CPE250 Average	5.5	9.4	6.4
Express Plus Average	4.0	6.7	4.6
Time Saved with Express Plus (h)	1.5	2.8	1.8
Time Saved with Express Plus (%)	27%	29%	28%

Average Monthly Estimates (KU Semester)	
Metric	Scenario 1 & 2
Distance	10,223 mi
Fuel Cost	$1,594
Fuel Cost per Mile	$0.16

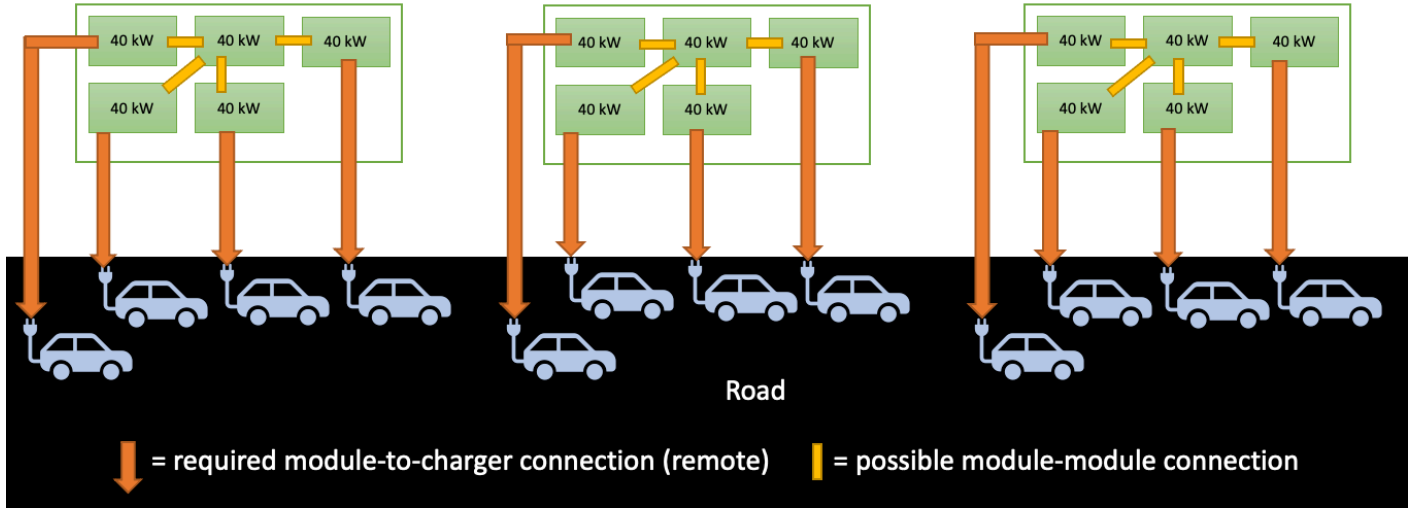
- If Express Plus is chosen, charge time will be reduced by at least 27% in all load cases

Futureproofing Charging Scenarios

Scenario A:
Express Plus with 3 Remote Dispensers



Scenario B:
Express Plus with 4 Remote Dispensers



Futureproofing Scenario A: 3 Remote Dispensers and 9 Buses

Assumptions:

- 5 bus operation
- Off-peak charging
- Simultaneous charging
- Existing blocks
- 85% availability
- 33% additional grid energy consumption due charger and charge management inefficiencies
- Nominal load case used in monthly estimates
- 1 hour of preconditioning

			Daily Charge Durations (h)			Daily Charge Costs ($)		
Dispenser Number	Dispenser Power (kW)	Block Number	Nominal	Strenuous - Electric Heat	Strenuous - Diesel Heat	Nominal	Strenuous - Electric Heat	Strenuous - Diesel Heat
1	40	2305	7.6	12.6	8.7	$14.71	$26.50	$17.90
2	80	2306	4.3	6.8	4.8	$14.71	$26.50	$17.90
3	80	2307	4.3	6.8	4.8	$14.71	$26.50	$17.90
4	40	4304	8.1	14.4	9.8	$15.83	$30.28	$20.26
5	80	IL03	4.7	7.4	5.3	$15.83	$29.22	$19.70
6	80	4301	4.7	7.9	5.5	$16.27	$31.34	$20.94
7	40	4302	8.4	14.9	10.1	$16.39	$31.34	$20.94
8	80	4303	4.7	7.9	5.5	$16.39	$31.34	$20.94
9	80	101	5.1	9.2	5.5	$17.99	$36.73	$20.90
		Average	**5.8**	**9.8**	**6.7**	**$15.93**	**$29.97**	**$19.71**

Average Monthly Estimates (KU Semester)		
Distance	Fuel Cost	Cost/Mile
20,234 mi	$3,303	$0.16

Futureproofing Scenario B: 4 Remote Dispensers and 12 Buses

Assumptions:

- 5 bus operation
- Off-peak charging
- Simultaneous charging
- Existing blocks
- 85% availability
- 33% additional grid energy consumption due charger and charge management inefficiencies
- Nominal load case used in monthly estimates
- 1 hour of preconditioning

Average Monthly Estimates (KU Semester)		
Distance	Fuel Cost	Cost/Mile
31,307 mi	$4,633	$0.15

			Daily Charge Durations (h)			Daily Charge Costs ($)		
Dispenser Number	Dispenser Power (kW)	Block Number	Nominal	Strenuous - Electric Heat	Strenuous - Diesel Heat	Nominal	Strenuous - Electric Heat	Strenuous - Diesel Heat
1	40	2305	7.6	12.6	8.7	$14.71	$26.50	$17.90
2	40	2306	7.6	12.6	8.7	$14.71	$26.50	$17.90
3	40	2307	7.6	12.6	8.7	$14.71	$26.50	$17.90
4	80	4304	4.6	7.7	5.4	$15.83	$30.28	$20.26
5	40	IL03	8.3	13.9	9.5	$16.27	$29.22	$19.70
6	40	4301	8.4	14.9	10.1	$16.39	$31.34	$20.94
7	40	4302	8.4	14.9	10.1	$16.39	$31.34	$20.94
8	80	4303	4.7	7.9	5.5	$16.39	$31.34	$20.94
9	40	101	9.1	17.4	10.1	$17.99	$36.73	$20.90
10	40	102	9.1	17.4	10.1	$17.99	$36.73	$20.90
11	40	1101	9.6	18.5	11.3	$19.09	$39.23	$23.52
12	80	1103	5.3	9.8	6.1	$19.09	$39.23	$23.52
		Average	**7.5**	**13.3**	**8.7**	**$16.63**	**$32.08**	**$20.44**

Futureproofing Scenario C: 2 Remote Dual Dispensers and 9 Buses

Assumptions:

- 5 bus operation
- Off-peak charging
- Simultaneous charging
- Existing blocks
- 85% availability
- 33% additional grid energy consumption due charger and charge management inefficiencies
- Nominal load case used in monthly estimates
- 1 hour of preconditioning

			Daily Charge Durations (h)			Daily Charge Costs ($)		
Dispenser Number	Dispenser Power (kW)	Block Number	Nominal	Strenuous - Electric Heat	Strenuous - Diesel Heat	Nominal	Strenuous - Electric Heat	Strenuous - Diesel Heat
1	80	2305	4.3	6.8	4.8	$14.71	$26.50	$17.90
2	120	2306, 2307	6.4	9.8	7.1	$29.43	$52.99	$35.79
3	80	4304	4.6	7.7	5.4	$15.83	$30.28	$20.26
4	120	IL03, 4301	6.9	10.9	7.9	$32.66	$60.56	$40.64
5	80	4302	4.7	7.9	5.5	$16.39	$31.34	$20.94
6	120	4303, 101	7.2	12.1	8.0	$34.38	$68.06	$41.84
		Average	**5.7**	**9.2**	**6.5**	**$23.90**	**$44.96**	**$29.56**

Average Monthly Estimates (KU Semester)		
Distance	Fuel Cost	Cost/Mile
20,234 mi	$3,303	$0.16

Futureproofing Scenario D: 2 Remote Dual Dispensers and 12 Buses

Assumptions:

- 5 bus operation
- Off-peak charging
- Simultaneous charging
- Existing blocks
- 85% availability
- 33% additional grid energy consumption due charger and charge management inefficiencies
- Nominal load case used in monthly estimates
- 1 hour of preconditioning

			Daily Charge Durations (h)			Daily Charge Costs ($)		
Dispenser Number	Dispenser Power (kW)	Block Number	Nominal	Strenuous - Electric Heat	Strenuous - Diesel Heat	Nominal	Strenuous - Electric Heat	Strenuous - Diesel Heat
1	80	2305, 2306	8.6	13.6	9.7	$30.54	$56.78	$38.15
2	120	2307, 4304	6.6	10.3	7.5	$32.66	$74.00	$ 40.64
3	80	IL03, 4301	9.4	15.4	10.8	$32.77	$62.67	$ 41.89
4	120	4302, 4303	6.9	11.2	8.1	$35.98	$115.75	$ 41.80
5	80	101, 102	10.1	18.4	11.1	$38.18	$78.46	$ 47.04
6	120	1101, 1103	7.8	13.7	8.8	$33.26	$73.44	$ 40.89
		Average	**8.2**	**13.8**	**9.3**	**$33.90**	**$76.85**	**$ 41.73**

Average Monthly Estimates (KU Semester)		
Distance	Fuel Cost	Cost/Mile
31,307 mi	$4,633	$0.15

Futureproofing Charging Scenario Comparison

Daily Charge Duration (h)			
	Nominal	Strenuous – Electric Heat	Strenuous – Diesel Heat
2022 CPE250 Average	5.5	9.4	6.4
2022 Express Plus Average	4.0	6.7	4.6
Futureproofing 3 Dispensers, 9 Buses Average (A)	5.8	9.8	6.7
Futureproofing 4 Dispensers, 12 Buses Average (B)	7.5	13.3	8.7
Futureproofing 2 Dispensers, 9 Buses Average (C)	5.7	9.2	6.5
Futureproofing 2 Dispensers, 12 Buses Average (D)	8.2	13.8	9.3
2022 vs. 3 Dispensers Charge Time (% time added)	45%	47%	45%
2022 vs. 4 Dispensers Charge Time (% time added)	89%	100%	89%
4 Dispensers vs. 3 Dispensers Charge Time (% time added)	31%	36%	30%
9 Buses 3 vs. 2 Dispensers Charge Time (% time added)	38%	27%	34%
12 Buses 4 vs. 2 Dispensers Charge Time (% time added)	21%	13%	19%

- As more dispensers are added, required charge time increased due to:
  - Less power delivery per dispenser
  - Added blocks consume more energy
- Despite yielding lower average charge durations, using 2 dispensers with 9 or 12 buses increases the maximum dispenser charging time
  - Risk failing to charge before start of service
  - Risk paying on-peak energy prices

Average Monthly Estimates (KU Semester)		
Metric	Scenario A,C (9 Buses)	Scenario B,D (12 Buses)
Distance	23,937 mi	37,139 mi
Fuel Cost	$3,303	$4,633
Fuel Cost per Mile	$0.16	$0.15

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