



King County Metro Battery Electric Bus Program



Danny ILIOIU

Zero-Emissions Fleet / Program Manager



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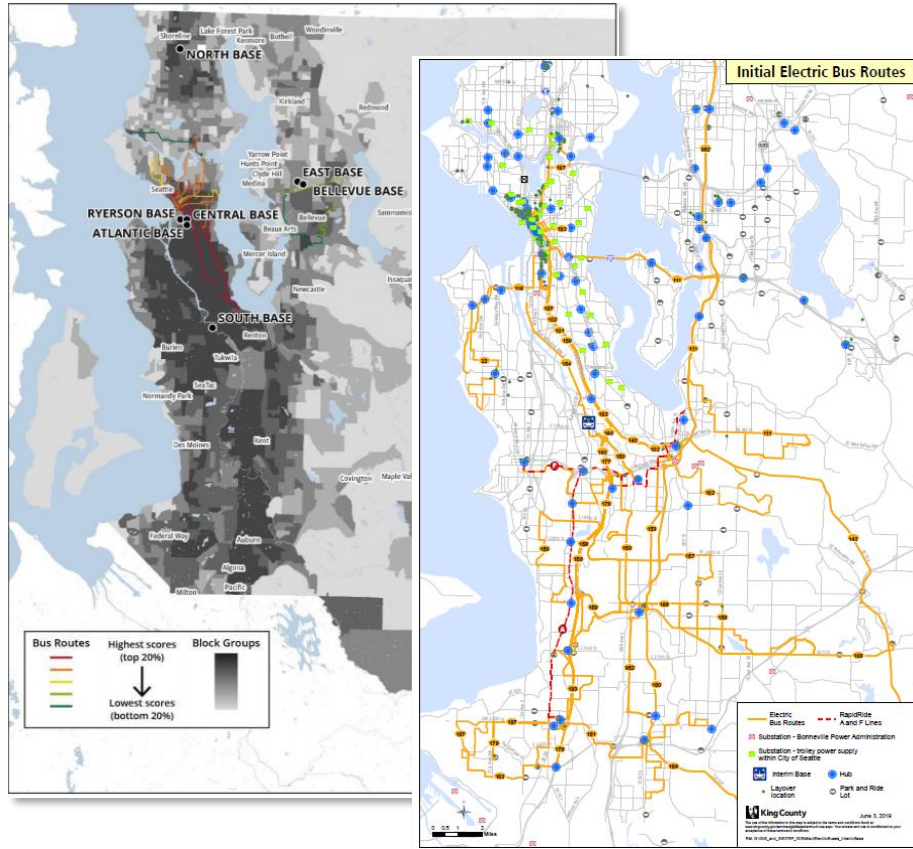
King County Metro

1600 Buses Total (100% of the bus fleet is Diesel-Electric Hybrid, ETB or BEB), in addition we operate Ferry, Light Rail. Streetcar, Access, Van Pool...

- **195 Zero-Emissions Buses**
 - **174** Electric Trolley Buses (ETBs or Trolleys)
 - **11** Fast Charge 40' Battery Electric Buses (BEBs)
 - 10 Extended-Range 40' & 60' Battery Electric Buses (2018-2020) – Leased/Test Completed/Buses returned
 - 40 Extended-Range BEBs (2021-2022)
 - 3 in-service April 2022, 6 in process of commissioning, rest by Q3-2022
 - 330 BEBs (2024-2028)
 - 30 ETBs (2027)



Zero-Emissions by 2035 ?



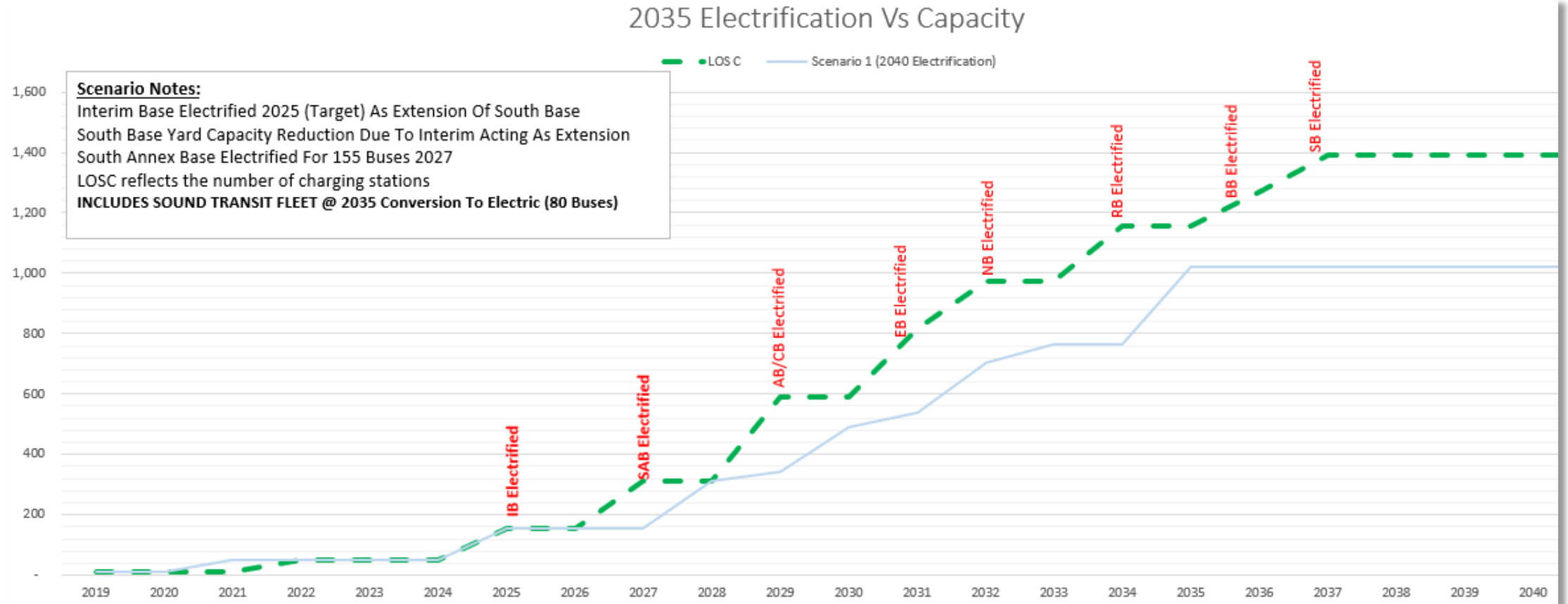
- ▶ Eight to Ten Bases
- ▶ Layover Chargers
- ▶ Align with ESJ plan
- ▶ Eliminate local emissions
- ▶ 70% of work blocks can be satisfied by current BEB technology
- ▶ Mix of Trolley and BEB to reach zero-emissions goals
- ▶ Expand trolley system where the TCO supports



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Zero-Emissions by 2035



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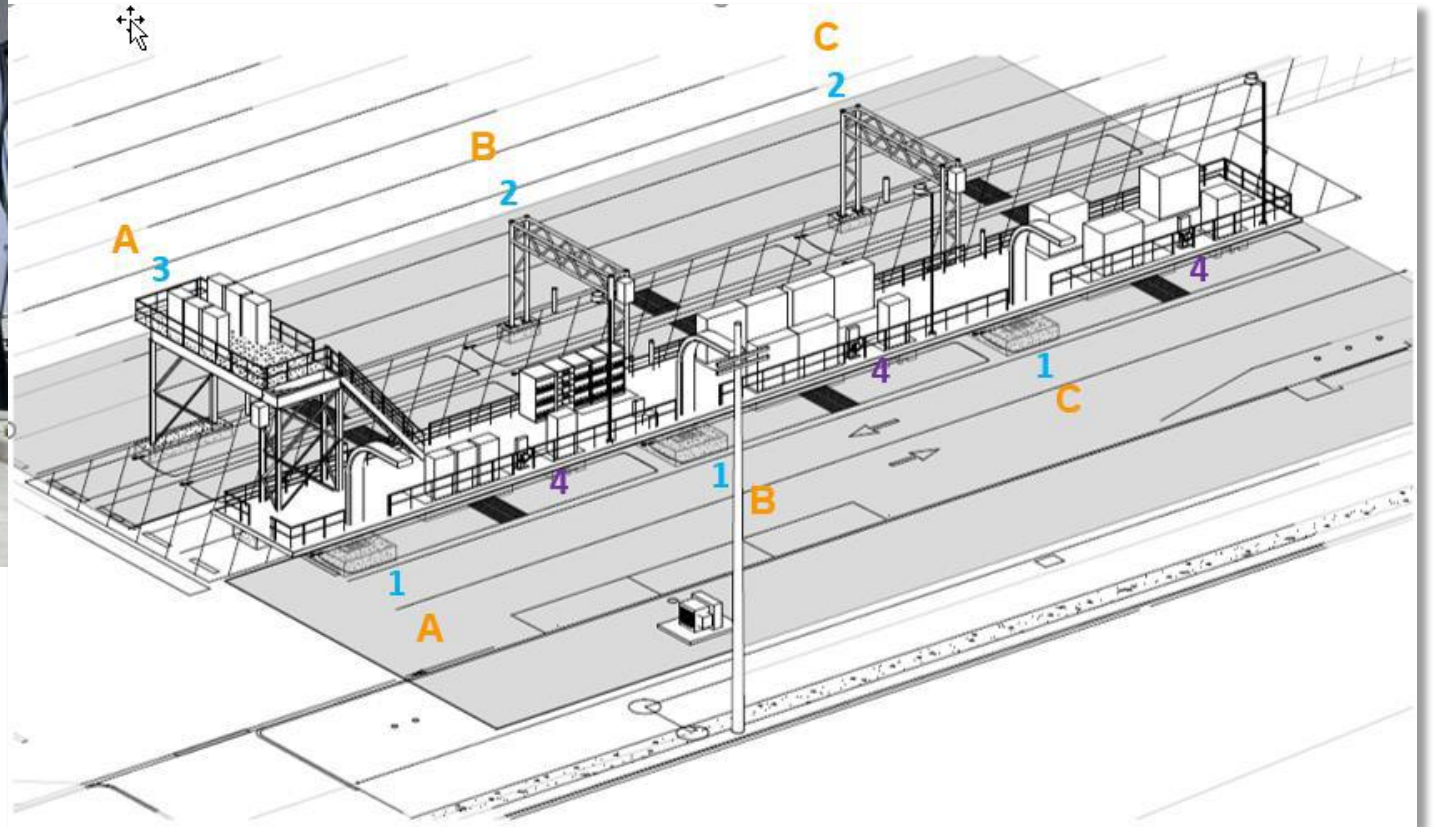
Eastgate Park & Ride



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South Base Test Facility - 2022



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South Base Test Facility

Outdoor Facility with 12 Charging Infrastructures



Charger OEMs (450 kW)

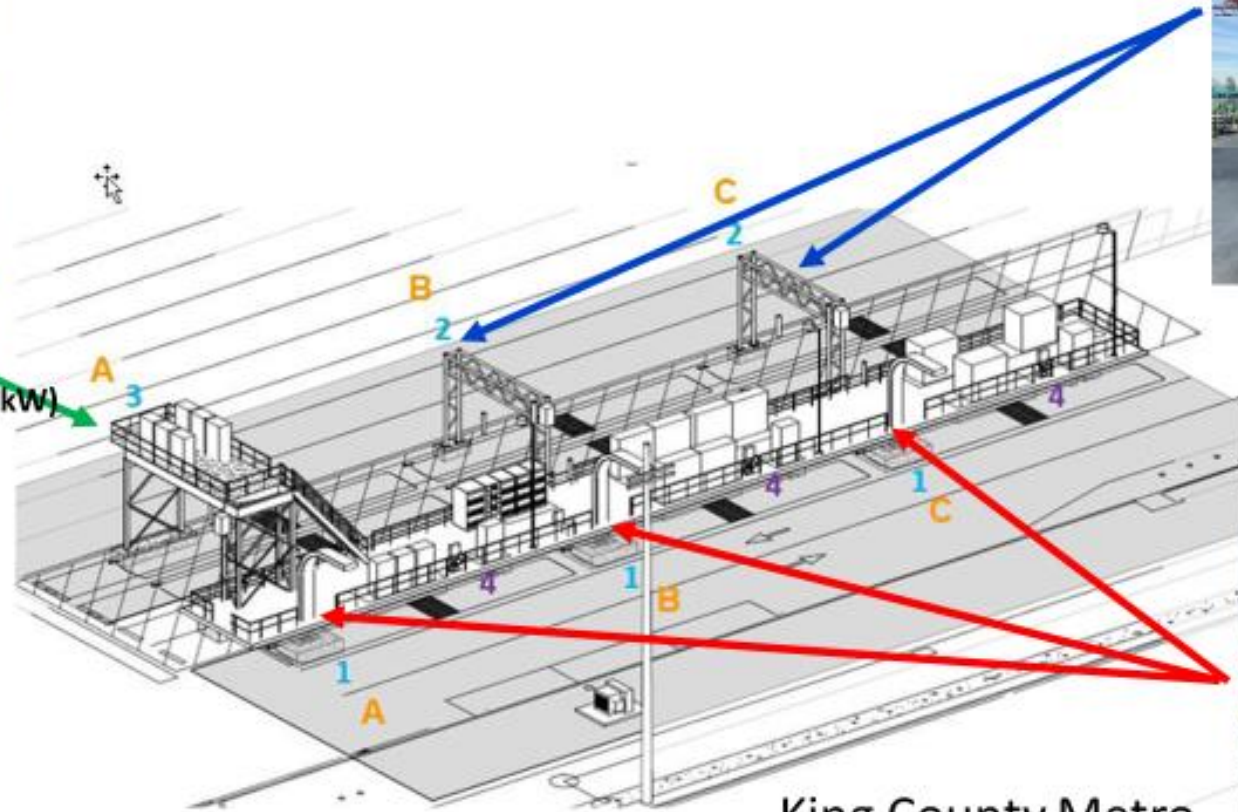
- ABB X 3
- Heliox X 3
- Siemens X 3

Pantograph OEMs

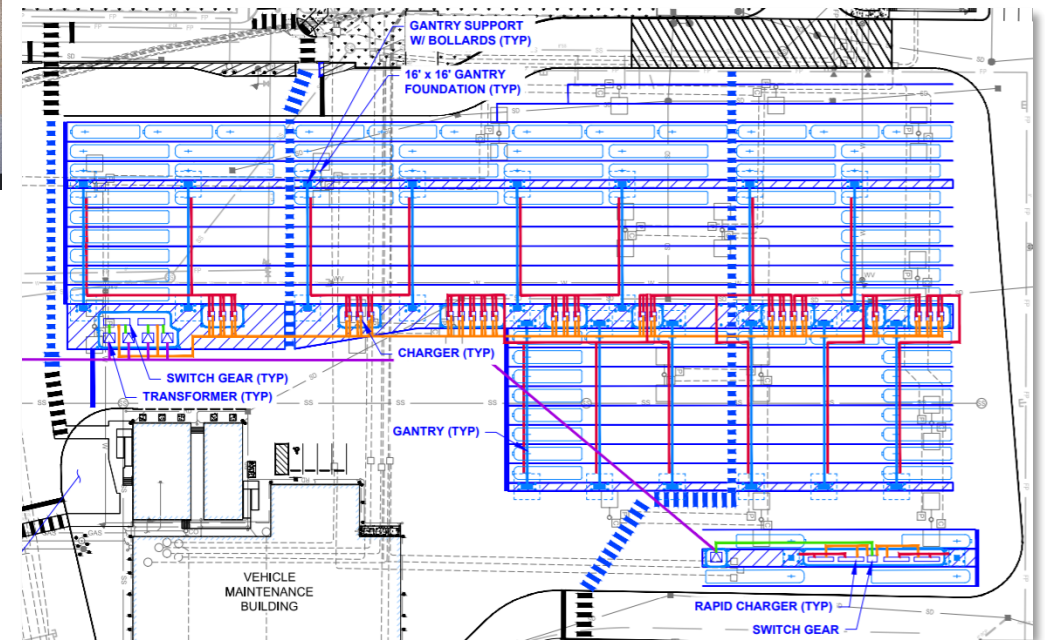
- Schunk X 3
- Stemann X 6

Bus OEMs

- New Flyer X 40
- Nova Bus



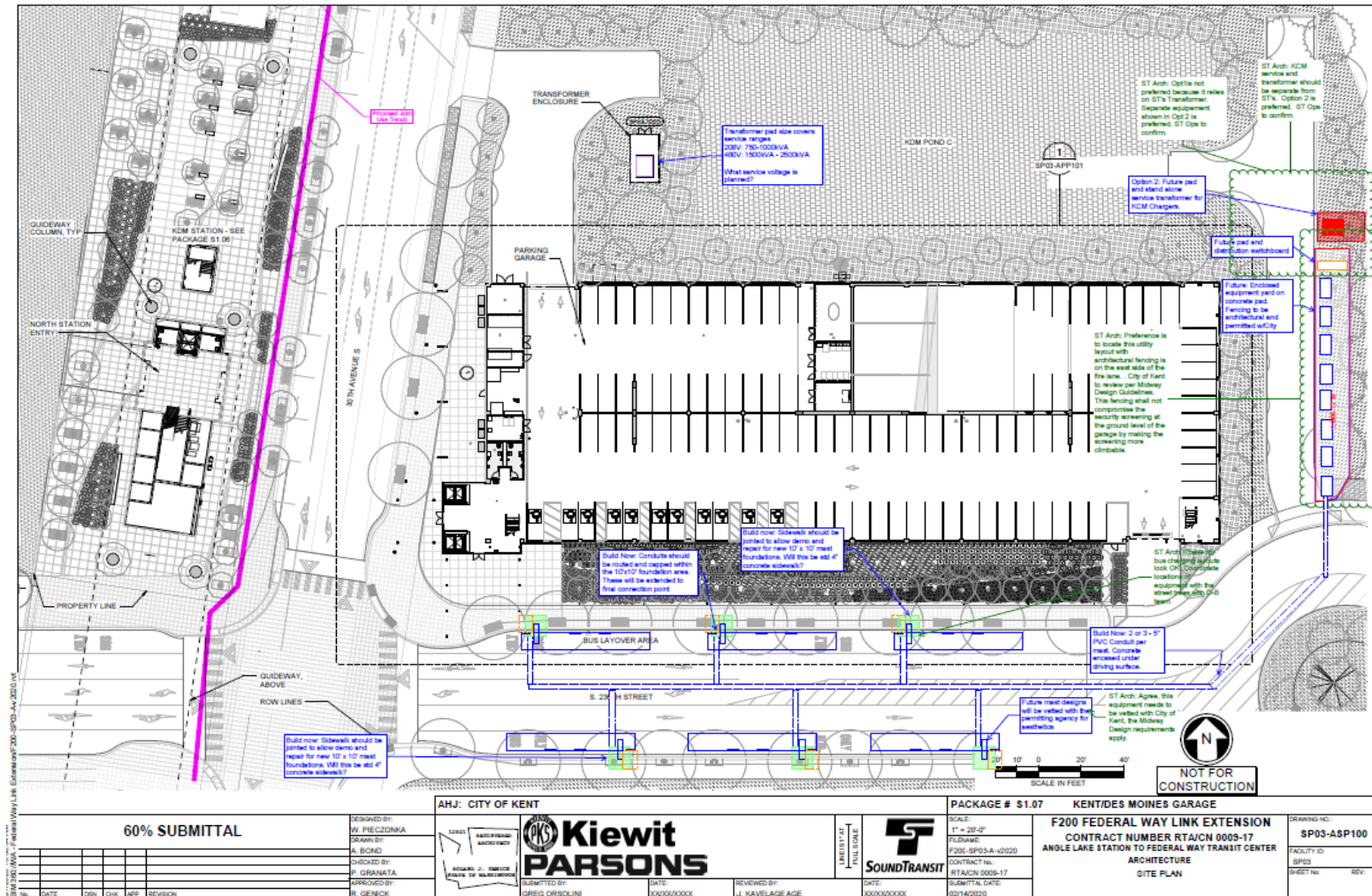
Interim Base - 2025



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Layover Charging (En-Route)



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South Annex Base - 2028



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Programmatic Considerations

Construction

- Design/Bid/Build vs. Progressive Design Build – alternative delivery methods

Commissioning

- Charger and Bus work with each other?
- **J3105-1, 1772, OCPP, Open ADR** compliant?

Charging

- On Base and Layover (aka on route) charging
- Smart Charging

Electricity - Utility

- Clean Energy/Green Power
- Rate structure – Seattle City Light pilot tariff

Operations

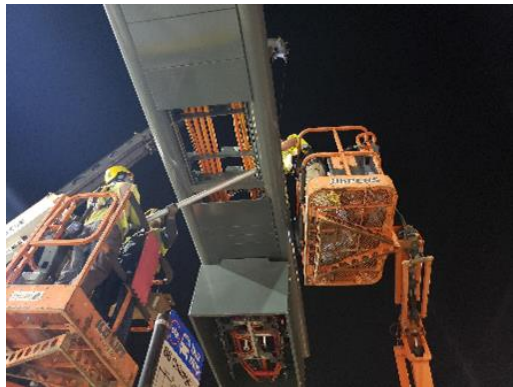
- Employee Training



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Some Challenges



- ▶ Costs – varying estimates
- ▶ Permitting timing
- ▶ Commissioning – Anticipated
- ▶ Manufacturer readiness
- ▶ Space constraints
- ▶ Operational Reliability and Support



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Lessons Learned

- ▶ Agency Culture – groups to involve, when and how
- ▶ Project Delivery Methods
- ▶ Utility Partnerships – SCL and PSE
- ▶ Training – Infrastructure Maintenance, Bus Operations, Service Planning
- ▶ Manufacturer readiness
- ▶ South Base Campus (Interim, Annex) and Strategy for future locations



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South Campus: A Closer Look



South Base Test

South Annex Base



Interim Base



King County Metro

Questions?



2nd Life Test Protocol Development, *Project Overview*

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Crawford, and David Reed (PNNL)

Danny Ilioiu, and Talon Swanson (King County Metro)

Energy Storage Systems

Safety & Reliability Forum May 2022



PNNL is operated by Battelle for the U.S. Department of Energy



2nd Life Test Protocol Development, Project Overview

Project Title

EV/Hybrid Battery 2nd Life Test Protocol Development

Objective

This project will develop a test protocol to re-rate retired mobile battery modules. A sample of retired hybrid bus battery modules will be re-rated to validate the protocol. This project will inform King County Metro (KCM) and their industry peers on the feasibility, cost, and potential economic net benefits from re-using retired mobile battery packs in stationary energy storage applications and delaying ultimate disposal of the batteries.

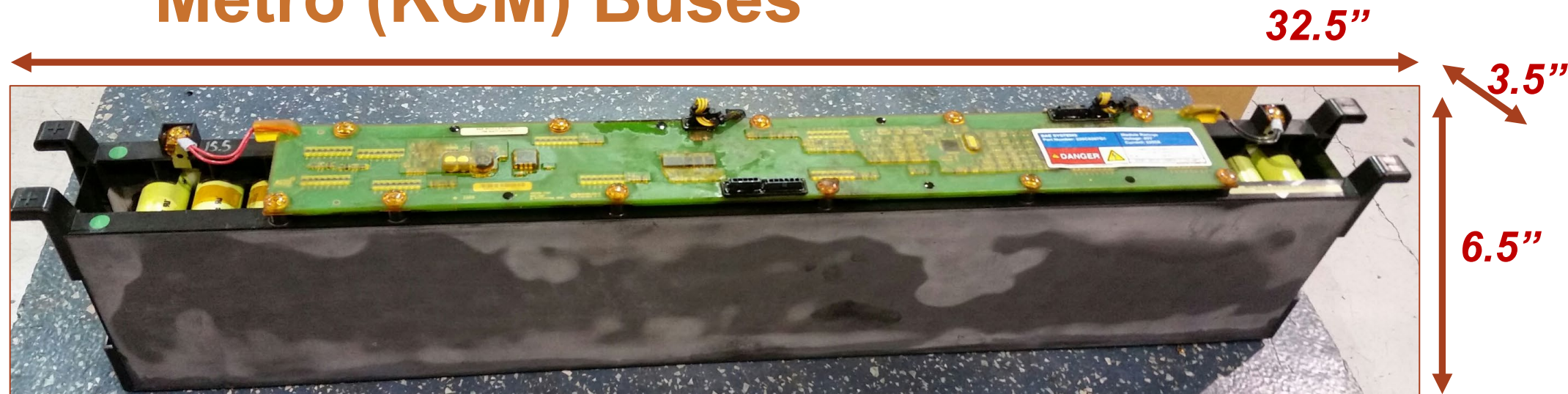
Description

KCM will provide retired bus battery modules and their associated operating history. PNNL will use these modules to develop a test protocol for re-rating retired mobile battery modules. Re-rated modules can be integrated into a small-scale Battery Energy Storage System (BESS) to demonstrate a stationary ES providing peak demand reduction.

Outcomes

- Create and publish an open-source test procedure to re-qualify and re-rate retired mobile batteries for stationary energy storage use
- Increase industry understanding of the costs vs. benefits of using retired mobile batteries for stationary use
- Provide economic and environmental benefit to KCM through 2nd Life re-use vs. disposal of their retired hybrid and EV bus batteries.

Hybrid Bus Battery Modules – From Retired Battery Packs Previously Used in King County Metro (KCM) Buses



- Modules from KCM's Hybrid Bus Fleet, *>MWh of capacity already retired*
- 2nd Generation BAE Hybrid Bus Packs
- Battery Modules manufactured by A123 Systems
- 8P12S A123 26650's 39.6V per module.
- Orig.(New) Rating was 0.725kWh each
- Target Re-Rating is 0.56kWh each, (0.5 kWh is considered pass) with target 10 years of 2nd Life use
- Approx. 200 used modules to be tested by PNNL for re-rating, then returned to KCM



Photos provided by King County Metro, Seattle

PNNL 2nd Life Battery Test Pad

- Scope: Battery Module Qualification
 - Modified CONEX boxes designed to safely test used batteries
 - 24 modules under test, 3 racks with 8 modules each
 - Storage for 24 modules either waiting to be tested or returned
- Test site near Richland campus Bldg. 3820
- Supply chain issues on equipment impacting schedule
- Planned hand over from construction June 2022

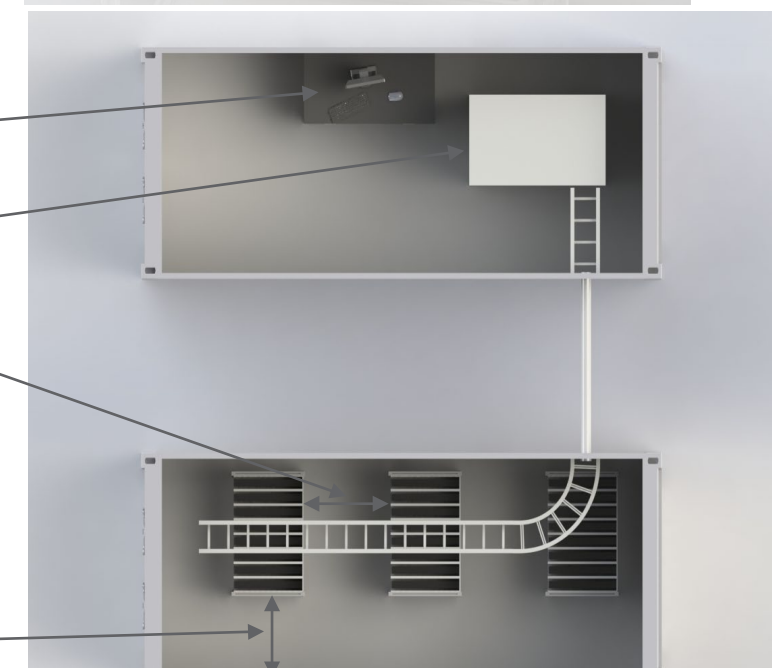


Control Computer

Battery Cycler

40in separation

3ft walkway



Safety Systems



- Battery cyclers and BMS voltage and temperature limits
 - Voltage and current will be kept within safe operating range
 - Individual string voltages will be monitored within each module and kept within safe limits
 - Temperature of each module will be monitored, and test stopped if not within safe limits
- Li-ion tamer system will shut down testing if battery off gas is detected
- Batteries will be separated by insulated board in order to prevent module to module failure
- Space will have a flammable gas detector, and heat detector that will activate room purge system
- Deflagration panels installed to allow pressure relief
- Dry fire department connection installed

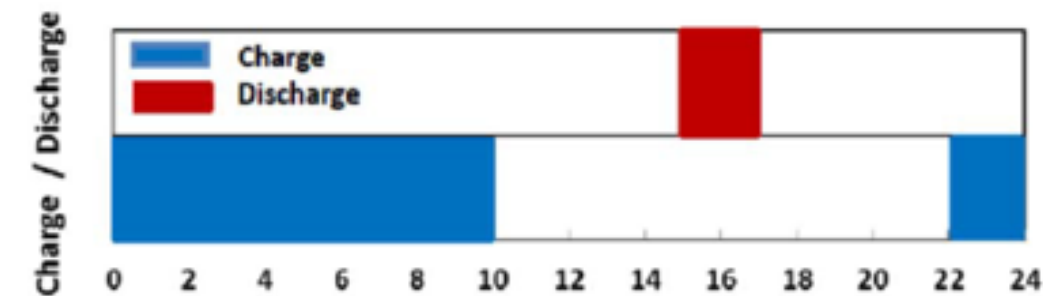
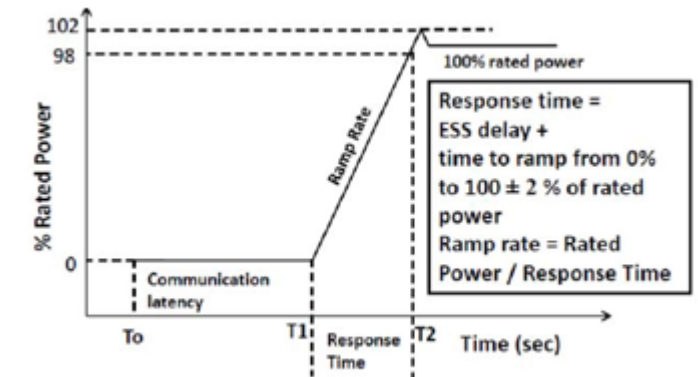
Approach

- KCM will perform visual inspection for damage and an open circuit voltage measurement of module prior to shipping
- Communication protocol related issue with using current module BMS board
 - Multiple pathways explored for using existing board
 - Easier option was to use new BMS to monitor individual cell voltages and provide for cell balancing
- We plan to test a new module to get baseline values for capacity, internal resistance, and dV/dQ
- Estimated energy capacity when taken off the bus: 0.56 kWh
 - Rerated to 0.53 kWh
- Assign 0% State of Health when energy capacity is 55% of initial value of 0.725 kWh
- SOH of battery modules when taken off the bus – 33% based on re-rated energy (or battery has 33% of its life left)
- As a second SOH metric, assign 0% SOH when internal resistance is 1.3X of initial value
- Primary Pass Criterion: Battery energy capacity > 0.525 kWh (25% SOH) for Reference Performance Tests done before and after duty cycles at C/4 rate
- Secondary Pass Criterion: Internal resistance is < 1.225x initial value (25% SOH)

Test Procedure

Reference Performance Test

- Energy capacity determined at three rates, C, C/4, C/10
 - Gives effect of rate, proxy for internal resistance measurement
 - Perform dV/dQ analysis using C/10 rate data
- Internal resistance measurement for charge and discharge at various SOC
 - Provides ramp rate information as well
- Performed before and after duty cycles



<https://energystorage.pnnl.gov/pdf/PNNL-22010Rev2.pdf>

Duty Cycle

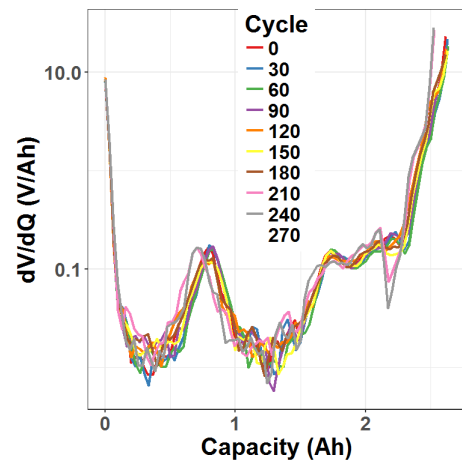
- Perform peak shaving duty cycle using C/4 rate charge and discharge
- Maintain an SOC range of 30 to 100%
- Perform Reference Performance Test after 50 cycles
- 30 days of testing per module

Building off Knowledge Gained Testing New Cells in the Battery Reliability Test Lab

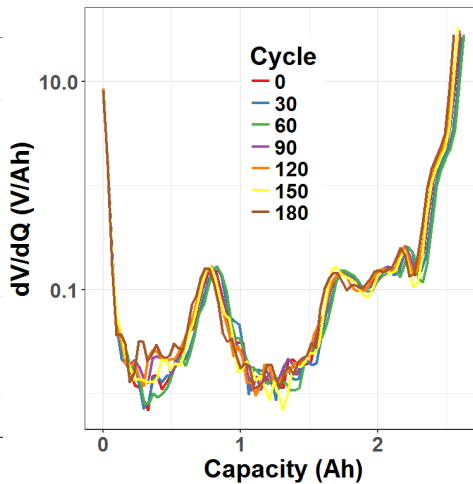
dV/dQ plots for LFP cells for various duty cycles

EV: Electric Vehicle
FR: Frequency Regulation
PS: Peak Shaving
All duty cycles start at 80% SOC

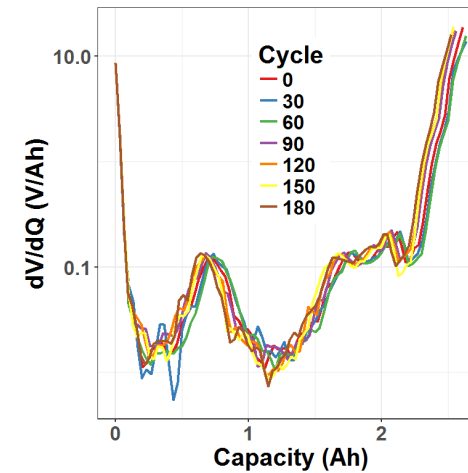
OCV at 30% SOC



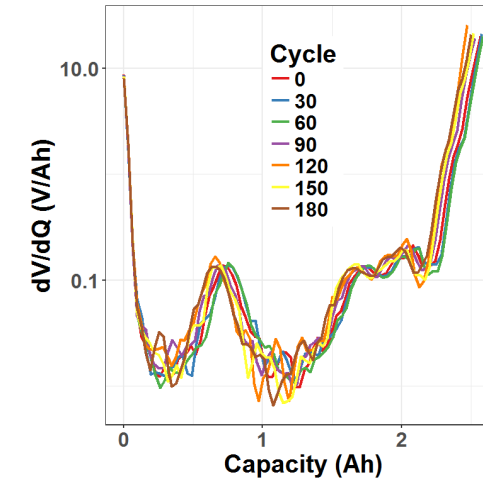
OCV at 70% SOC



EV 20% DOD



EV 60% DOD



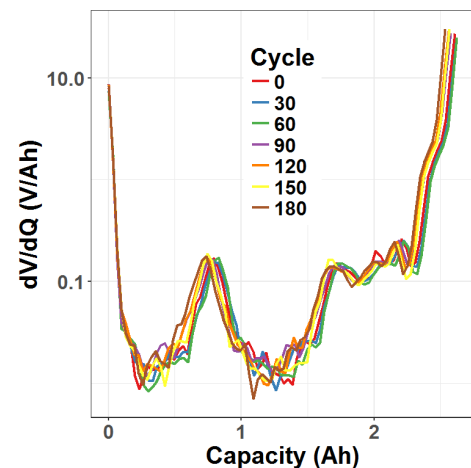
Peaks related to graphite

Peak movement to left due to loss of lithium

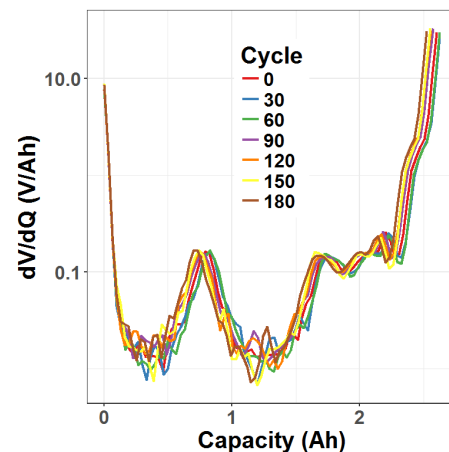
Reduction of distance **d** between peaks due to loss of graphite active material

Compare dV/dQ curves for fresh modules with aged modules

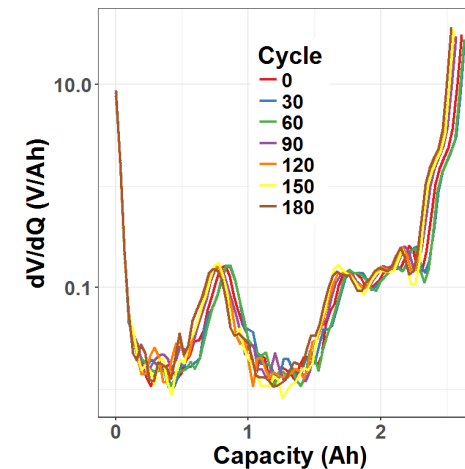
Look for signatures for active material loss and loss of lithium, and relate with energy capacity measurements



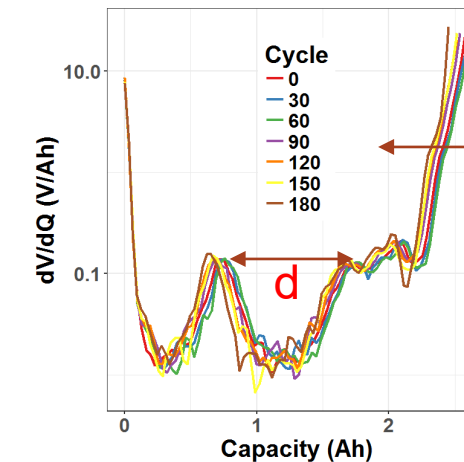
FR 20% DOD



FR 60% DOD



PS 20% DOD



PS 60% DOD

2nd Life Test Protocol Development, Schedule

Milestone	Key Dates
Initial Clean Energy Fund proposal	11/13/2018
DOE OE ES Decision (approved for FY2020 AoP)	7/2019
PNNL 2 nd Life Hazard Analysis completed Related safety analysis.	8/2020
PNNL start 2 nd Life testing lab upgrade design.	10/2020
PNNL complete 2 nd Life testing lab upgrades. KCM start delivery of used modules & related operational data to lab.	7/2022
PNNL start lab battery testing. And development of 2 nd Life Re-Rating protocol	8/2022
PNNL complete testing of 180kWh of used batteries. 25kWh 'net' re-rated assumed available for 2 nd Life demo.	6/2023
PNNL complete report on re-rating test protocol, and initial test results, and results of econ. screening analysis of 2 nd Life application (peak shifting) at a KCM facility	9/2023

Acknowledgments

Dr. Imre Gyuk, DOE – Office of Electricity



Mission – to ensure a resilient, reliable, and flexible electricity system through research, partnerships, facilitation, modeling and analytics, and emergency preparedness.

<https://www.energy.gov/oe/activities/technology-development/energy-storage>