Milwaukee County Transit System

Battery Electric Bus & Facilities Analysis

Results & Recommendations

Milwaukee County Board of Supervisors

Transportation, Public Works and Transit Committee

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Project Purpose

Determine financial and operational changes required for MCTS to transition to electric buses:

- Evaluate the capability of commercially available battery buses in MCTS service
- Determine infrastructure requirements for battery bus charging
- Estimate the capital and operating costs associated with fleet transition
- Identify necessary changes to bus maintenance, bus scheduling, and other operating practices to accommodate electric buses
- Develop a Fleet Electrification Business Plan to guide the transition
- Make recommendations for near-term implementation of a pilot program, to include operation of electric buses on the planned BRT route

MJB&A Electric Transit Bus Clients

- LA County Metropolitan Transportation Authority
- Santa Monica Transit
- TransLink/Coast Mountain Bus (Vancouver)
- MTA New York City Transit
- Milwaukee County Transit System
- Washington Metropolitan Area Transit Authority

Commercial 40-ft Electric Buses

- All major North American transit bus manufacturers now offer 40-ft battery buses, including **New Flyer**, **Gillig**, and **NovaBus**
- Two electric-only manufacturers also sell buses in North America: **Proterra** and **BYD**
- Most manufacturers offer a maximum battery size of ~450 kWh
  - Proterra offers batteries up to 660 kWh
  - NovaBus recently announced the availability of 40-ft buses with a 594 kWh battery
- Battery buses cost $750,000 - $900,000+ depending on battery size
- MCTS new diesel buses cost ~$500,000
- This is a dynamic market – battery offerings, other aspects of electric bus design, and cost will continue to evolve

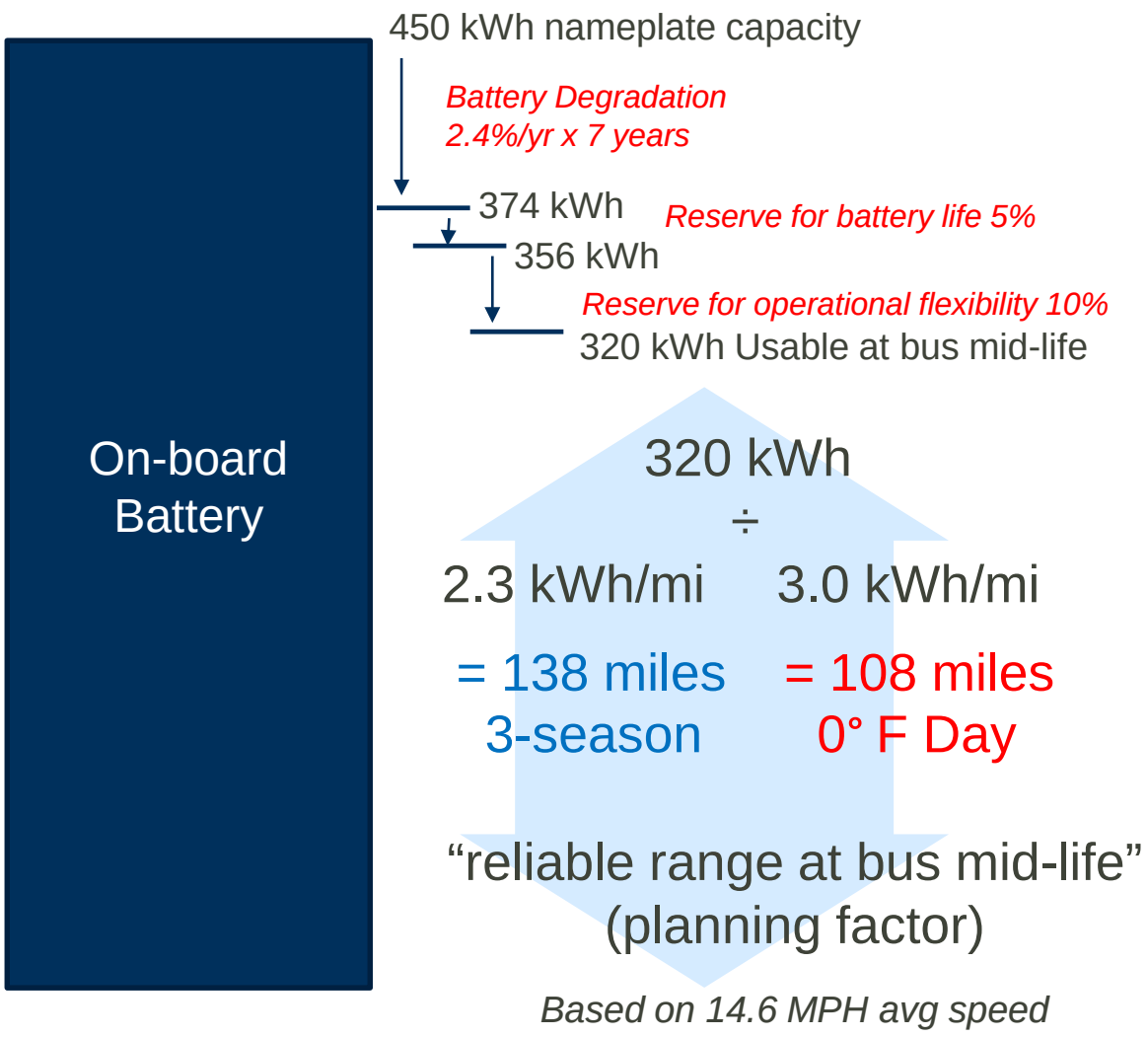
Electric Bus Charging Scenarios

SCENARIO	DEPOT CHARGING	IN-ROUTE CHARGING
CONCEPT	All energy added “overnight”, using 50 kW chargers located at each bus garage	All energy added “in-route”, using 450 kW chargers located throughout service area
COST TRADE-OFFS	• Very large battery required on bus, **high bus cost** • Practical limitation on battery size limits range – in the near term **additional buses will be required** • Large number of chargers required – space claim at Depots	• Smaller battery required on bus, **lower bus cost** • Smaller number of chargers required, **but higher cost/charger** • Siting in-route chargers could be difficult

Depot vs In-route Charging

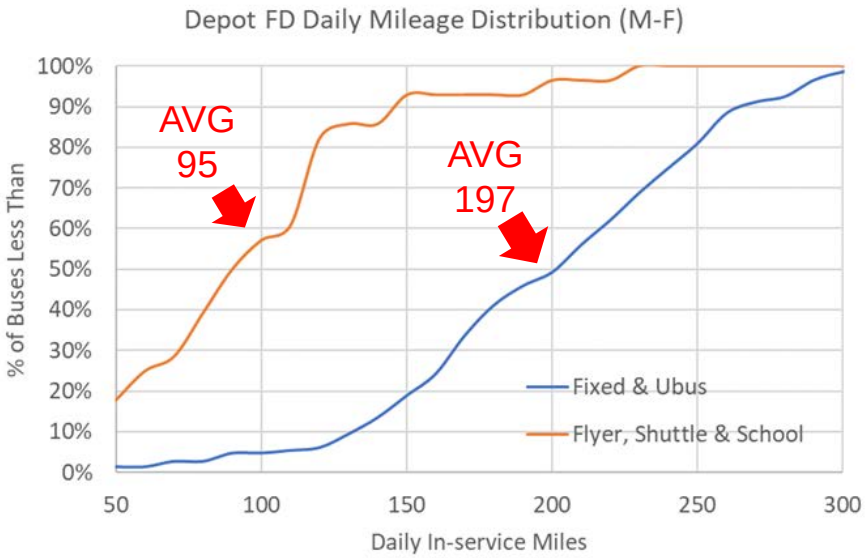
	DEPOT CHARGING	IN-ROUTE CHARGING
PROS (+)	• More direct control over infrastructure • Lower infrastructure costs • Potentially less expensive in the long run • Lower electricity cost (lower demand charges)	• Less expensive now • Do not need to shorten daily bus assignments • No loss of depot parking capacity • Greater resiliency/reliability –a few chargers out of commission won't affect bus operations
CONS (-)	• Space claim for chargers reduces parking capacity • Must re-configure daily bus assignments to shorten them; increased dead-head time • Difficult/costly to provide back-up power to entire depot	• Charger site acquisition & permitting • Less control over infrastructure • Higher infrastructure costs • Higher cost/difficulty of charger maintenance • Additional time in schedules to accommodate charging • Higher electricity cost (higher demand charges)

Range per Charge – MCTS



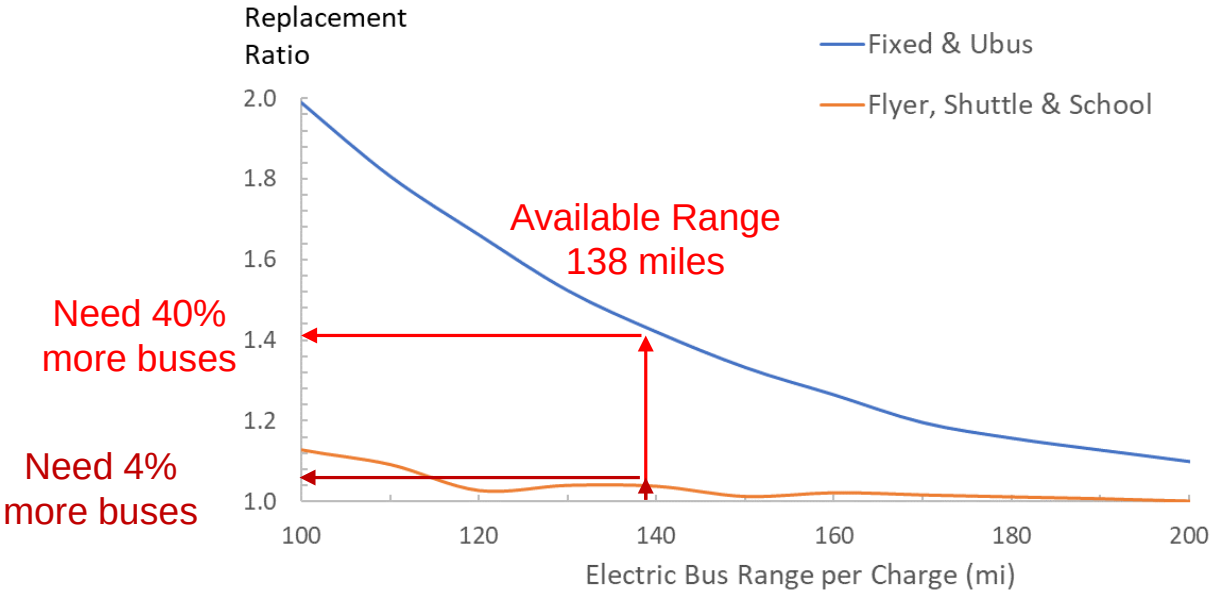
- Batteries degrade over time, losing effective capacity
- Most battery manufacturers don't recommend bringing batteries all the way down to zero state of charge every day – maintain a reserve of 5% - 20%
- Daily energy use can vary from the average by 10% or more on a given day
- Electric bus planning should be based on a "reliable" range per charge that accounts for these factors – not on name plate range of a new battery and average energy use

Bus Scheduling – MCTS Miles per Day



- MCTS operates two types of routes – with significantly different daily mileage
- On Fixed routes buses average 200 miles/day – but some go over 300 miles
- On Shuttle routes buses average 95 miles/day – but a few go over 150 miles

- If available range is less than daily mileage, long blocks will need to be shortened
- **This will increase required peak buses**



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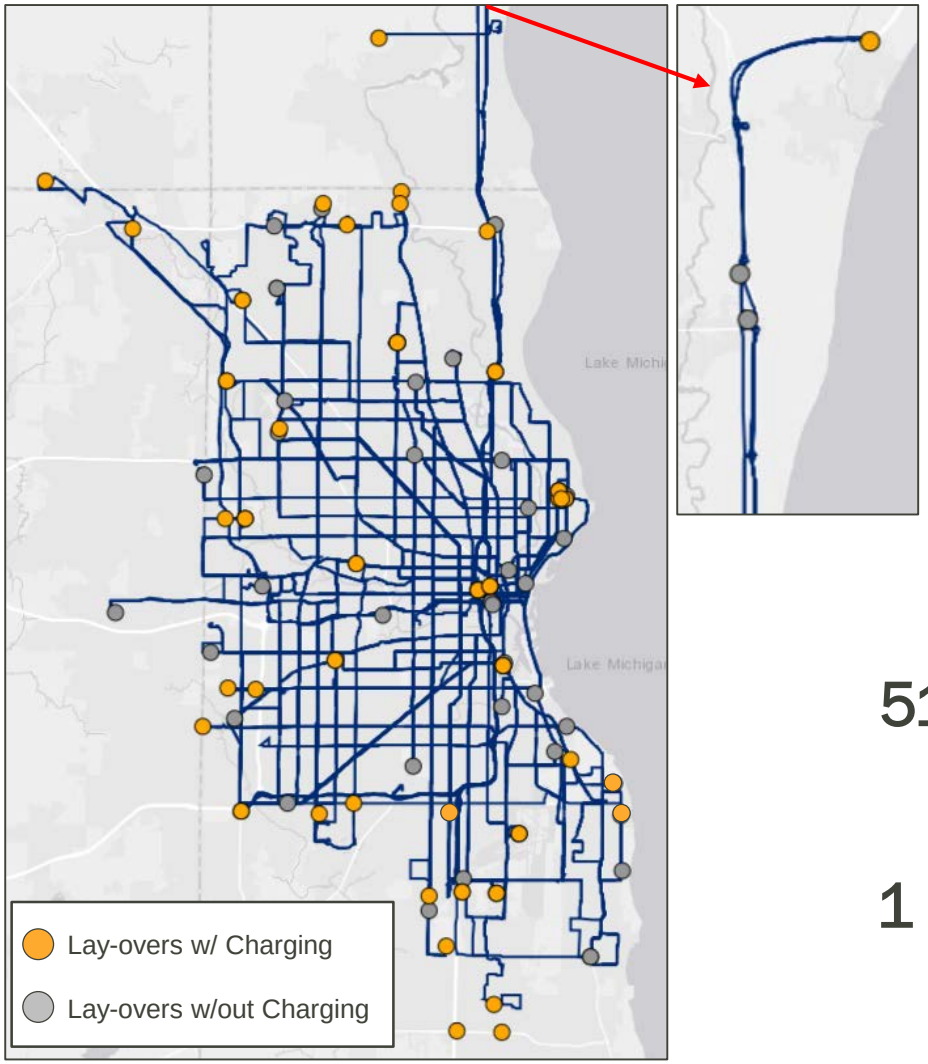
MCTS In-Route Charge Network (conceptual)



- 450 kW chargers
- All but 4 routes require charging at only one terminus
- All routes require only one charger to handle peak service
- 12 routes can share a location & charger with one other route

51 chargers at 44 different locations

1 charger for every 8 buses

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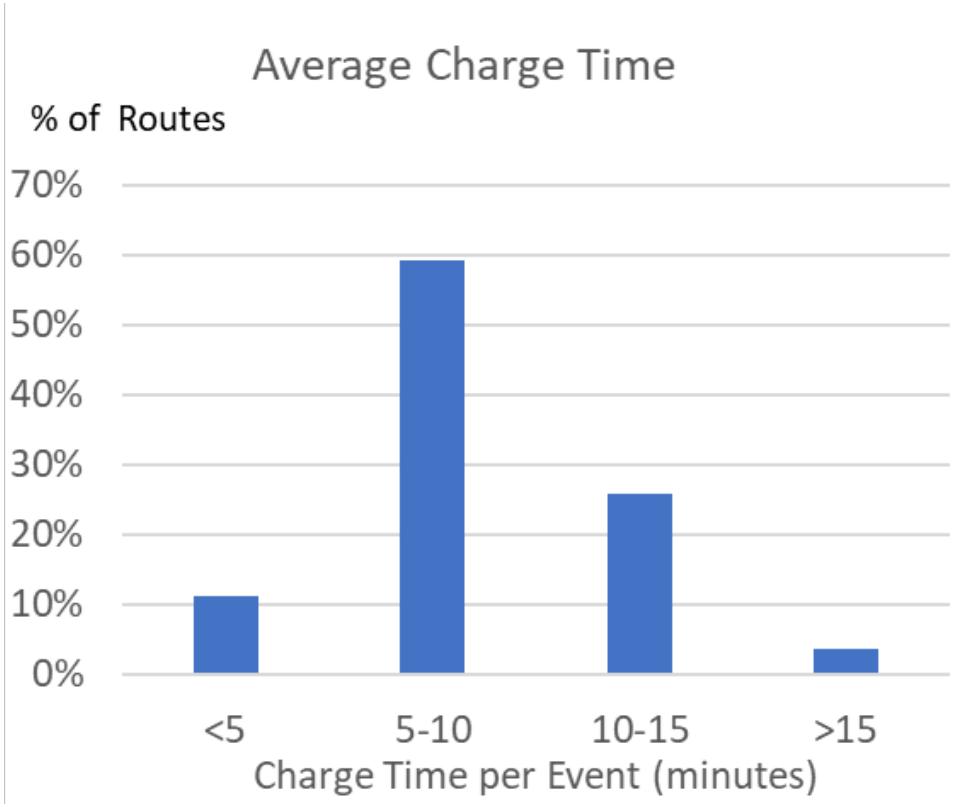
MCTS In-Route Charge Time



- Most MCTS buses would need to charge for <10 minutes at the end of every round-trip
- Existing schedules include lay-over time at each route terminus, which can be used for charging

- Some routes may require additional lay-over time to accommodate charging – up to 30 minutes/day/bus

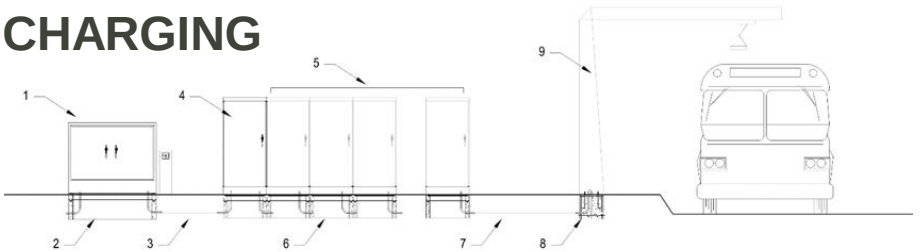
MCTS Charging Infrastructure Cost (Conceptual)

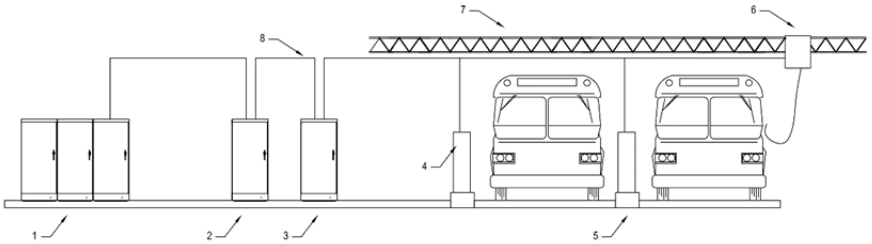
DEPOT CHARGING

	DEPOT CHARGING	
	FD	**KK**
Electrical	$9,743,657	$7,975,767
Civil/Struictural	$581,370	$419,301
Architectural	$350,000	$350,000
Remote Monitoring	$250,000	$250,000
sub-total	*$10,925,027*	*$8,995,068*
Contingency (20%)	$2,185,005	$1,799,014
sub-total	*$13,110,033*	*$10,794,082*
Design	$439,000	$359,000
Utility service [1]	$0	$0
TOTAL	**$13,549,033**	**$11,153,082**
Number of buses	148	132
Average per bus	**$91,548**	**$84,493**

	In-route 450 kW
Charger Installation	$481,488
Site Work	$100,000
Remote Monitoring	$25,000
sub-total	*$606,488*
Contingency (20%)	$121,298
sub-total	*$727,785*
Design	$22,000
Utility service	$100,000
TOTAL	**$849,785**
Total Chargers	51
Total Buses	402
Average $/bus	**$107,809**

IN-ROUTE CHARGING





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Electric Bus Economics

- Electric buses are more expensive to purchase than diesel, hybrid, or CNG buses
- Charging infrastructure is expensive – but less so than incremental cost of buses
- Batteries will (likely) need to be replaced at mid-life

CAPITAL

- Small increase in bus operator labor
- Charger maintenance costs
- Electricity is cheaper than diesel
- Potential for modest maintenance cost savings

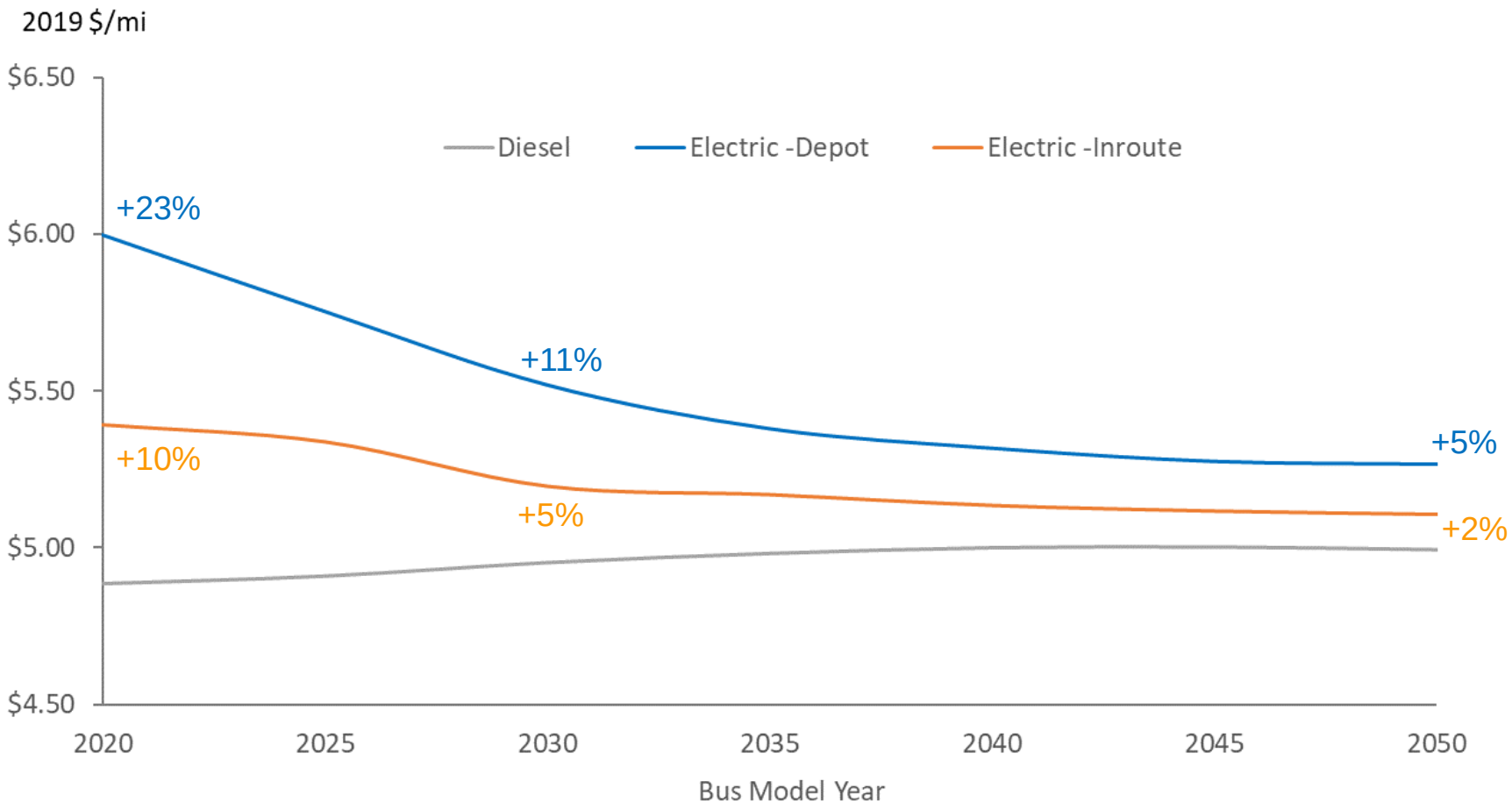
OPERATING

CAPITAL / OPERATING COST TRADE-OFFS

"BREAK EVEN" (vs Diesel) IS PRIMARILY INFLUENCED BY RELATIVE COST OF DIESEL FUEL & ELECTRICITY

THERE ARE OTHER COST & OPERATIONAL TRADE-OFFS BASED ON CHARGING STRATEGY

MCTS Projected Electric Bus Life-Cycle Cost



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Electrification - Full Fleet Transition Cost

All new buses after 2025 battery electric

Full fleet electrification by 2040

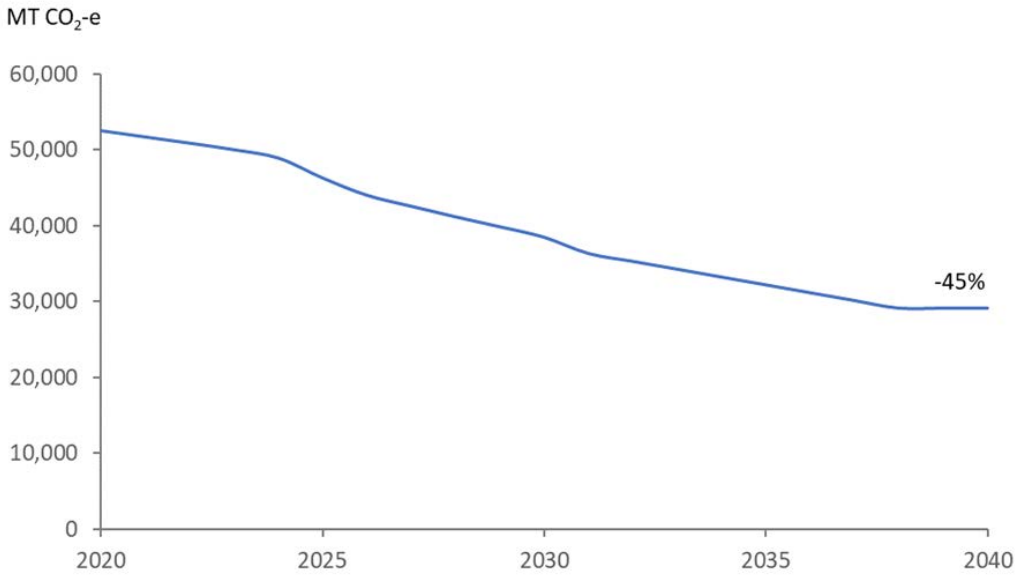
	DEPOT CHARGING	IN ROUTE CHARGING
Incremental Capital [1]	$228 million	$159 million
Operating Savings [2]	($28 million)	($40 million)
NET COST (2025 – 2040)	**$200 million** **$13 mill/yr**	**$118 million** **$7 mill/yr**
Additional Buses	58 buses	NA
Additional Depot Space	170 parking spaces	NA
In-route Chargers	NA	50 chargers Up to 44 locations

[1] Increased cost of battery buses compared to diesel buses, plus cost of chargers

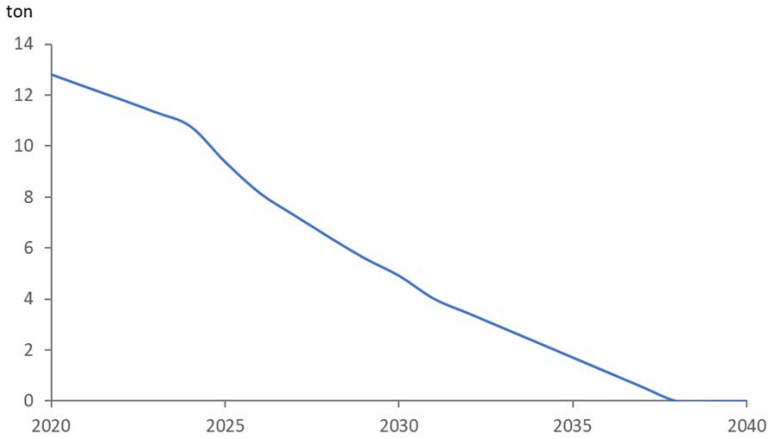
[2] Fuel and maintenance cost savings, net of increased operator labor and charger maintenance

Electrification - Full Fleet Transition Emissions

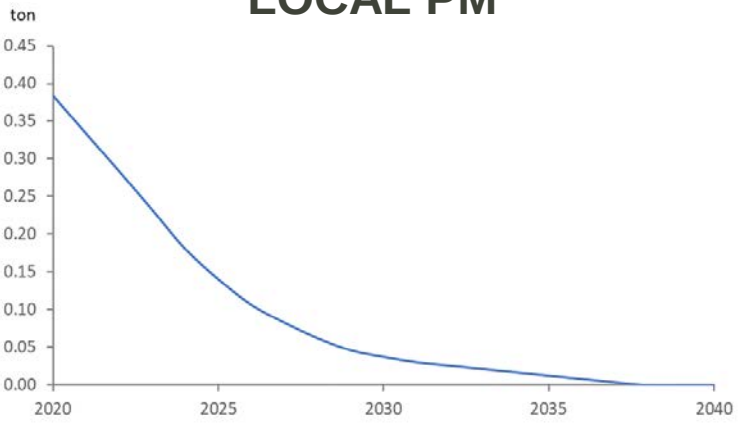
LIFE-CYCLE GHG



LOCAL NOx



LOCAL PM



- Based on current electric grid mix
- Greater use of low-carbon electricity generating sources would reduce emissions further

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Electrification - Full Fleet Transition Emissions

- MCTS diesel bus fleet is estimated to emit 52,500 metric tons (MT) of GHGs per year.
  - 12.8 tons of NOx and 0.38 tons of PM per year in the Milwaukee metro area

- Once the fleet is converted to all electric buses annual GHG emissions will fall to 29,100 MT, a reduction of 45 percent.

- Since electric buses have no tailpipe emissions, annual fleet NOx and PM emissions will fall to zero as the MCTS fleet is electrified.
  - MCTS fleet electrification could contribute to improvements in local air quality in Milwaukee, with associated reductions in negative health effects.

Recommendations – Full Fleet Electrification

- If pursuing full fleet electrification, MCTS should use **in-route charging** rather than depot charging
  - Significantly lower net cost of transition
  - Will not require a 3rd bus depot
  - After 2040 net annual cost savings compared to a diesel fleet
- Fleet electrification can proceed route-by route as funding is available
  - Most individual routes require only one in-route charger and 5 – 15 buses
  - Incremental capital costs (buses + charger) are $3 - $6 million per route
- Potential interim strategy is replacing some retiring diesel buses with **hybrid buses** during the transition
  - No charging infrastructure required
  - Estimated 17% lower fuel use and GHG emissions than diesel buses
  - Estimated 6% higher life-cycle costs than diesel due to higher purchase cost

Fleet Electrification – Operational Changes

To accommodate electric buses MCTS will need to make significant changes to all of their operations:

- Add lay-over time to some schedules to accommodate in-route charging
- Consider changes to route structure to allow sharing of in-route charging locations between routes
- Evolve bus maintenance programs to accommodate high-voltage electric drive systems
- Develop tools and procedures to monitor bus charging and battery state of charge for all in-service electric buses
- Develop capabilities to maintain and repair chargers
- Acquire mobile electric generation capacity to maintain charging during interruptions to grid power

Recommendations – BRT & Pilot Program

- Purchase 15 identical buses, to be used on BRT route and in pilot service on other routes
  - 450 kWh battery
  - Overhead conductive charge port
  - Supplemental fuel heaters
- Install two 450 kW overhead pantograph chargers
  - One at Watertown Plank Park & Ride
  - One at depot housing buses
- 9 buses per day required on BRT route
  - These buses will charge at Watertown Plank, for ~8 minutes on each trip
- Up to 6 buses per day available to operate on select blocks on other routes
  - These buses will charge at the depot overnight, ~ 1hr/bus/day charge time
  - Depot charger will serve as back-up to Watertown Plank charger

BRT & Pilot Program Cost

	Number	Unit Cost	TOTAL
Electric Buses	15	$900,000	$13,500,000
Chargers	2	$850,000	$1,700,000
TOTAL			**$15,200,000**

- Incremental cost of $7.5 million compared to purchasing 15 new diesel buses
- BRT and pilot fleet projected to accumulate 675,000 electric miles annually
- Net fuel cost savings of ~$150,000/year compared to diesel buses
- Will need to ensure that BRT schedules have sufficient lay-over time to accommodate in-route charging
- Electric buses on routes other than BRT route limited to ~130 miles/10 hours per day before re-charge
- To minimize electricity costs depot charging should not start until after 9 PM

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