Appendix 1

SASKATCHEWAN RESEARCH COUNCIL

Saskatoon Transit Electric Bus Performance Report Updated Jan 2022

Prepared for City of Saskatoon - Saskatoon Transit

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SRC Publication No. 14916-1C22

January, 2022

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Abstract:

Saskatoon Transit completed a trial of an electric bus from November 2020 to October 2021. The Saskatchewan Research Council conducted analysis on operational data provided by Tecium IoT to evaluate the bus' performance under all conditions. The electric bus was tested on regular bus routes during peak morning and afternoon hours. The bus operated reliably in both cold and hot weather. The HVAC system was powered from the electric battery and consumed more energy than the bus motor during the coldest months of the year resulting in a lower effective range per charge. Greenhouse gas emissions were approximately 47% lower for the electric bus during the trial than a comparable diesel bus over the same distance. The total cost of ownership of a Saskatoon-based electric bus is expected to be lower than a diesel bus. Based on the analysis of the data collected during this project, SRC concludes that converting their bus fleet from diesel to electric is a viable option for Saskatoon Transit.

EXECUTIVE SUMMARY

The City of Saskatoon has set a target to convert the municipal transit bus fleet to 100% electric by 2030 to meet environmental sustainability goals. Saskatoon experiences a range of temperatures from -40°C to +40°C and there was a concern as to the reliability of a battery electric bus (BEB) operating in this temperature range. Saskatoon's climate is somewhat colder than other municipalities in North America which have trialed or purchased BEBs. Saskatoon Transit has just completed a one-year demonstration test of a Build Your Dreams (BYD) electric bus from November 2020 to October 2021. The Saskatchewan Research Council worked with Tecium,IoT, an Internet-of-Things (IoT) solutions provider, to equip the bus with data logging technology to collect comprehensive operating data and to evaluate the bus' performance under all ambient conditions. The electric bus was tested on regular bus routes during peak morning and afternoon hours.

The results of this test period showed that:

- In terms of reliability, the electric bus operated as well as and possibly better than a diesel bus in Saskatoon's temperature extremes.
- Charging the bus at the Saskatoon Civic Operations Center proved to be adequate for operating the current bus routes around Saskatoon.
- The bus was ultimately powered from the electricity grid and energy was consumed by the motor, the HVAC system, and other components (doors, lights). The battery was also internally charged during driving sessions via regenerative braking.
- The net energy consumption of the motor was on average 0.7 kWh / km, and relatively consistent throughout the demonstration trial period. The net energy showed no signs of reduction from the start to finish of the test period, which indicates that the battery did not exhibit noticeable aging over the demonstration period. Also, the net motor energy consumption did not vary with external temperature.
- The average bus energy consumption from the grid for the entire test period was 1.4 kWh / km and the monthly average ranged from 0.7 to 2.2 kWh / km. Total bus energy consumption was upon ambient outdoor temperature. It was highest in February and lowest in May. The energy consumption of heating the bus was almost two thirds of the total energy consumption in the month of February. The energy consumption was slightly higher in July, the hottest month, than in May and August, due to higher air conditioning demand.
- The effective range of the battery per charge was between 175 and 361 km throughout the test months of the demonstration period. The effective range is related to the total energy consumption of the bus. Thus, in the coldest months, the effective range of the bus was lowest. The effective

range is the amount the bus can be driven on a single charge from a 100% to a 0% state of charge (SOC).

- From November to September, the monthly average SOC at the start of a charging session, ranged from 56 to 86%. On average, the bus was driven 75 km in between charging sessions (from a starting SOC of 100%).
- While the capital cost of purchasing electric versus diesel buses is higher, electric buses are anticipated to have much lower operating costs:
  - The capital cost of diesel versus electric buses for Saskatoon Transit are approximately $660,000 and $1,200,000, respectively.
  - The annual maintenance costs of a diesel versus electric bus, driving 50,000 km/year, are expected to be $43,000 and $9,000 respectively.
  - Fuel costs to operate a diesel bus are currently significantly greater than the electricity costs to operate a BEB. When driving 50,000 km/year, these are estimated to be $29,100 and $6,990 per year.
- The total cost of ownership of a diesel versus BYD bus, travelling 50,000 km per year and operating over an 18-year lifetime, are estimated to be $1,957,320 and $1,487,800, respectively.
- BEBs achieve significant environmental benefits. The BYD bus is estimated to have 47% lower greenhouse gas (GHG) emissions than a diesel bus. It is anticipated that a BYD bus will reduce GHG emissions by 39.3 tonnes CO_2e per bus per year when travelling 50,000 km/year. Further GHG emission reductions can be achieved by purchasing electricity from cleaner sources.
- In the future, Saskatoon Transit should investigate electric bus models equipped with more efficient heating systems to achieve lower energy consumption, longer effective ranges per charge, and lower GHG emissions during the colder months.
- A BEB with a diesel-powered coolant heater unit may have a slightly increased total cost of ownership compared to a BEB with electric heat ($1,517,150 versus $1,487,800) but would have a much higher effective range in cold weather. An electrically-heated BEB, with a lower effective range in cold weather may result in the need for a larger bus fleet. Therefore, a BEB with a diesel-powered coolant heater may reduce the overall capital costs of an electric bus fleet.
- A BEB with a biodiesel-powered coolant heater will have a smaller carbon footprint than a diesel bus or an electrically-heated BEB. Annual emissions from a BEB with a biodiesel coolant heater travelling 50,000 km/year, are estimated to be 38.4 tonnes CO_2e versus 44.5 tonnes for a BEB with electric heat.
- The bus offers social benefits in terms of noise reduction, odour reduction, and easy Wi-Fi access.

Based on the analysis of the data collected during this project, SRC concludes that converting their bus fleet from diesel to electric is a viable option for Saskatoon Transit.

ACRONYMS

BEB	Battery electric bus
BYD	BYD Co. Ltd. (Build Your Dreams) Chinese manufacturing company headquartered in Shenzhen
CO_2e	Carbon dioxide equivalent
GHG	Greenhouse gas
HVAC	Heating, ventilation, and air conditioning
PM10	Particulate matter (diameter < 10 micrometers)
PM2.5	Particulate matter (diameter < 2.5 micrometers)
RFP	Request for Proposal
SOC	The state of charge of the electric bus battery measured in percent
SRC	Saskatchewan Research Council

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1. INTRODUCTION

1.1 Project Description

The City of Saskatoon has initiated a Low Emission Community Plan [City of Saskatoon, 2021]. Included in the 40-point action plan is for the municipal transit fleet to be 100% electric by 2030. Saskatoon experiences a range of temperatures from -40°C to +40°C and there has been a concern as to the reliability of an electric bus operating in this temperature range. Saskatoon Transit placed a Request for Proposal (RFP) to various electric bus venders to study the performance of their electric buses in Saskatoon and BYD was the successful proponent. As such, Saskatoon has just completed the testing of the BYD electric bus from November 2020 to October 2021 and collected data to evaluate its performance under all conditions. The electric bus was tested on regular bus routes and was designated the unit number 1948 for this study.

The electric bus seats 41 passengers and uses a lithium iron ($LiFePO_4$) battery. The weight of the bus is approximately 3000 lbs. heavier than a conventional diesel bus. A photograph of the bus is shown in Fig. 1 [Transit, 2021]. This report analyzes the technical performance of the electric bus. As well, the report quantifies environmental and financial benefits of the bus.

Figure 1 – Saskatoon electric bus

1.2 Objectives

The objectives of this study are to review the operational data collected on an electric bus to:

1. Determine if the electric bus can operate effectively in Saskatoon's temperature extremes.
2. Assess the electric bus performance parameters.
3. Determine charging requirements, energy consumption, and range of the electric bus.
4. Assess the financial implication of an electric bus and examine financial effects of electricity demand customer charge rates.
5. Assess the environmental and social benefits of operating an electric bus.

1.3 Background

The Saskatoon Transit bus fleet is predominantly diesel-based and is a major source of greenhouse gas (GHG) emissions from the City of Saskatoon. Transit organizations in Canada have been hesitant to adopt BEBs because there is a lack of experience for cold-weather operation. Saskatoon's climate is somewhat colder than other municipalities in North America which have trialed or purchased BEBs. The Saskatchewan Research Council (SRC) in collaboration with Saskatoon Transit, conducted a feasibility study in 2019 to build core capacities related to BEBs. The feasibility study concluded that BEBs are a market-ready, yet constantly evolving technology. BEBs have proven to be mechanically reliable, cost-competitive, and an effective means of reducing emissions. Their capital costs continue to decrease as they gain market share and benefit from economies of scale. Decreases in battery costs and improvements to battery energy density and longevity also contribute to the cost-competitiveness of BEBs. A key recommendation of the feasibility study was to conduct a one-year demonstration of an electric bus, capturing as much data and information as possible from operating the BEB in several different routes, throughout all four seasons of climate conditions. The study will enable managers and stakeholders to make informed decisions as to how BEBs will be implemented going forward in Saskatoon.

2. DESCRIPTION OF THE DEMONSTRATION

One BYD electric bus was tested from 6 November 2020 until 6 October 2021, to demonstrate bus performance and reliability in all four seasons, while operating in several different routes. SRC was provided operational data by Tecium IoT, who had installed a data logging system on the bus to record high-resolution, technical data during the entire test period. A total of 80 operational parameters were designated and recorded, to evaluate the BYD bus performance. One of the operational parameters is *session modes* and it has three possible values (Idling, Driving and Charging). Some operational parameters were recorded for certain session modes but were not recorded for others; a total of 62 parameters were recorded for the *Idling* mode, 70 parameters for the *Driving* mode and 38 parameters were recorded for the *Charging* mode. A total of 10 operational parameters were designated to the heating ventilation and air conditioning (HVAC) system yet no data was recorded for any of these parameters as those parameters were not made available by the bus manufacturer, however HVAC energy consumption can be ascertained by considering changes in average load in relation to ambient temperature.

Table 1 summarizes the time spent in each session mode during the test period. Idling includes pauses in between routes, maintenance periods, or parked in the Saskatoon Civic Operations Center garage overnight after charging was complete. The electric bus was typically operated on routes during peak hours in the morning and peak hours in the afternoon [Bracken, 2021a]. The data recorded indicates that the bus had the highest utilization in May, July, August, and September. The low monthly usage for March and April was due to problems with the fire suppression system which was accidently activated and required recharging [Bracken, 2021a]. Data indicates that the bus was not driven from Sept 1st to 24th and was only driven 0.2 hours in October 2021. There was a high amount of charging hours for the month of July, because of an unexplained inconsistency in the data; there were several sessions in July recorded as charging sessions even though the state of charge of the battery was 100% at the start of these sessions. These additional charging sessions should have been recorded as idling sessions.

Table 1 - Monthly operational usage of the electric bus

Month	Year	Idling (hrs)	Driving (hrs)	Charging (hrs)
Nov	2020	444	41	28
Dec	2020	299	29	24
Jan	2021	525	80	58
Feb	2021	484	81	63
Mar	2021	18	12	7
Apr	2021	276	17	7
May	2021	616	106	43
June	2021	147	10	9
July	2021	499	109	*126*
Aug	2021	528	145	58
Sept	2021	690	14	7
Oct	2021	126	0.2	0
Total		4653	645	430

The performance data of the demonstration test is analyzed and presented in Section 3. **Table 2** describes the terms presented in Section 3. In **Table 2**, heading terms in Section 3 are in bold font.

Table 2 - Description of the data analysis and terms presented in Section 3

Term	Data Source Analysis	Reference
Monthly travel distance	Sum of the distance traveled (km) for the month over all session modes	Table 3, Table 4
Ave driving speed	Sum of the product of average driving speed (km/h) and session duration over the month divided by the sum of session duration over the month for Driving sessions	Table 3
Grid energy supplied to bus	The sum of energy for charging bus (kWh) over the month for charging sessions This is energy from the electricity grid used to charge the bus; this excludes internal charging from braking during driving sessions and accounts for energy used by motor, HVAC and other bus components	Table 3
Net energy used by motor	Sum of motor energy (kWh) over the month over all session modes	Table 3
Min temp during a driving session	The minimum value of outdoor temperature (degC) of the Driving sessions during the month	Table 3
Monthly average min temp of all driving sessions	Average value of outdoor temperature (degC) in all Driving sessions of the month	Figure 2
Total bus energy consumption	**Grid energy supplied to bus** divided by **Monthly travel distance**	Table 3
Energy consumption of motor	**Net energy used by motor** divided by **Monthly travel distance**	Table 3
Longest driving session	Maximum value of the distance (km) bus is driven in the Driving sessions in the month	Table 4
Effective range of bus	The average of the effective range (km) which the bus can be driven based on available battery charge of all Driving Sessions in the month	Table 4
Driving sessions per month	Counts of Driving sessions in the month	Table 4
Charges per month	Counts of Charging sessions in the month	Table 4
Distance per charge	**Monthly travel distance** divided by **Charges per month**	Table 4
Duration of charge	Monthly average duration of Charging Sessions	Table 4
Min SOC	Minimum monthly value of starting charge (%) in all Charging Sessions	Table 4
Ave SOC before charge session	Monthly average of the starting charge (%) in all Charging Sessions	Table 4

Maximum power draw during charging	Monthly maximum value of the maximum power draw per charging session (kW)	Table 5

3. Electric Bus Technical Performance

The electric bus demonstration test occurred from 6 November 2020 until 6 October 2021 and the BYD electric bus' performance is evaluated over this period. During the entire demonstration, the electric bus travelled a total distance of 15,497 km at an average speed of 34 km / h. A total of 21,262 kWh of energy was supplied to the bus from the electricity grid for this period.

3.1 Energy Consumption

The energy consumption data during this test period is summarized in Table 3. The HVAC system of the BYD bus is powered by the bus' battery and uses a significant amount of energy in cold weather. The difference between the grid supplied to the bus and the net energy used by motor is mainly the energy consumption of the HVAC system, while a minor amount of energy is used for other bus components such as doors, instrumentation and interior lights. The energy consumption of the motor per distance travelled ranges from 0.61 to 0.78 kWh/km, with an average of 0.7 kWh/km. The battery was also charged internally during driving sessions, via regenerative braking.

The actual energy economy in terms of the total energy consumption of the bus (including HVAC) ranges from 0.7 to 2.2 kWh/km. The economy is highest in February, one of the coldest months, when the motor energy demand was just over a third of the total energy charged to the bus from the electricity grid. Energy consumption of the bus is lowest in May and August 2021. June and July in Saskatoon were hotter months and had slightly higher energy usage than May and August due to greater air conditioning demand. **Figure 2** illustrates the overall trend in energy consumption compared to temperature. The energy consumption of the motor remains relatively constant, indicating that the battery did not deteriorate with time. This also indicates that outside temperature does not have a significant impact on the energy consumption of the motor throughout all four seasons.

Table 3 - Energy consumption data for the electric bus

Month	Year	Monthly travel distance (km)	Avg driving Speed (km/h)	Grid energy supplied to bus (kWh)	Net energy used by motor (kWh)	Min temp during a driving session (°C)	Total bus energy consumption (kWh/km)	Energy consumption of motor (kWh/km)
Nov	2020	907	30	1870	645	-15.6	2.1	0.71
Dec	2020	740	36	1509	566	-21.8	2.0	0.76
Jan	2021	1868	33	3610	1394	-35.0	1.9	0.75
Feb	2021	1768	32	3914	1370	-39.0	2.2	0.78
Mar	2021	301	35	490	217	-12.1	1.6	0.72
Apr	2021	327	31	470	230	-3.0	1.4	0.70
May	2021	2534	34	1781	1640	-2.4	0.7	0.65
June	2021	243	33	407	149	12.4	1.7	0.61
July	2021	2744	36	3165	1758	11.2	1.2	0.64
Aug	2021	3759	37	3614	2306	4.0	1.0	0.61
Sept	2021	307	34	431	227	2.0	1.4	0.74
Oct	2021	0	--	--	--	--	--	---
Totals/ Average		**15497**	**34**	**21262**	**10502**	**-9.0**	**1.4**	**0.68**

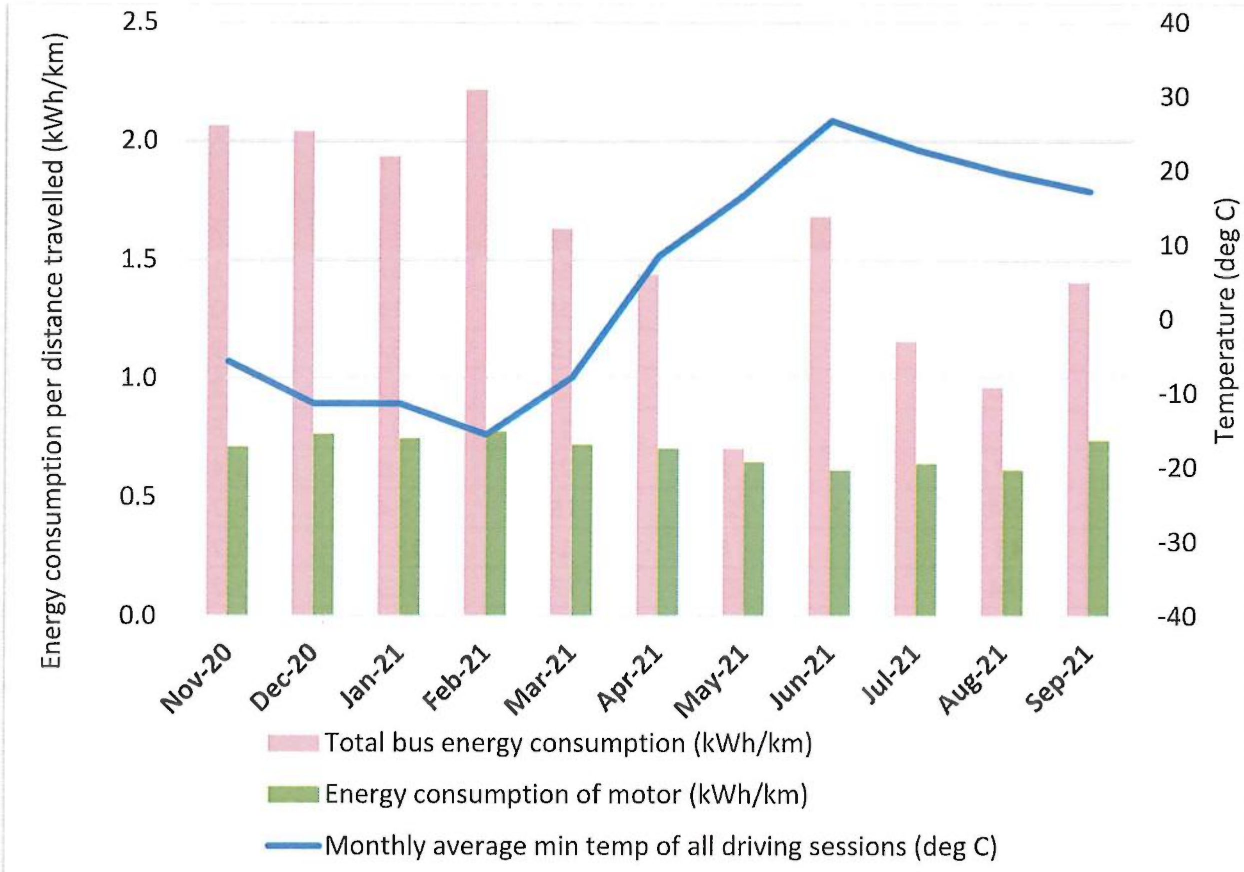

Figure 2 – Total bus and motor energy consumption compared to temperature

3.2 Charging Parameters

BYD supplied a single electric charging station for the electric bus which was installed at the Saskatoon Civic Operations Center. Saskatoon Transit installed the necessary transformer to supply the charger with the correct voltage. Table 4 illustrates features related to charging the bus. From November to September the bus was charged on average when the state of charge (SOC) of the battery was 56 to 86%. The minimum state of charge of the battery was 17% prior to a charging session. The average charging session lasts 1.8 hours. The bus travelled an average distance of 75 km per between charging sessions over the year. In addition, the average distance the bus was driven per charge was highest in May, at 133 km which is close to the annual average distance of 137 km that a bus must drive given a total range of 50,000 km / year driven 365 days / year. The maximum distance of a driving session was 103 km. The bus was typically charged once per day and sometimes twice per day. Throughout the year, there were 224 charging sessions and 1024 driving sessions, which means that on average there were 4 driving sessions between each charging session, however, some driving sessions were very short.

Two examples of high utilization days are as follows: on August 10th, at full 100% battery charge, the bus was driven 75 km in the morning, depleting the battery to 73%; the bus was charged at 11:10 AM for 1.5 hours back to 100%, and then driven for 110 km, depleting the battery to 70%. It was charged again at 9:13 PM for 1.72 hours. Two days later, the bus was driven for 88 km in the morning, and then 105 km after lunch depleting the battery to 37%. Then the battery was charged at 5:59 pm for 3.2 hours.

The effective range of the bus is 175 to 361 km per charge. The effective range is the amount the bus can be driven on a single charge from a 100% to a 0% state of charge. The effective range is related to the total bus energy consumption and is lower in the colder months, when there is a greater energy demand by the HVAC system. The effective range is highest in May and August which had lower air conditioning demand than June and July.

Table 4 - Summary of BYD electric bus charging parameters

Month	Monthly travel distance (km)	Longest driving session (km)	Effective range of bus per charge (km)	Driving sessions per month (Units)	Charges per month (Units)	Distance per charge (km)	Duration of charge (hours)	Min SOC (%)	Average SOC before charge session (%)
Nov	907	81.5	219	53	19	48	1.6	30	73
Dec	740	103.1	N/A	56	17	44	1.4	41	71
Jan	1868	96.7	189	114	31	60	1.9	17	68
Feb	1768	90.9	175	143	35	51	1.9	19	63
Mar	301	90.8	202	14	3	100	2.4	42	56
Apr	327	36.4	290	45	5	65	1.4	70	78
May	2534	75.3	357	169	19	133	1.4	54	76
June	243	32.9	270	23	8	30	1.1	31	76
July	2744	96.6	319	172	46	60	2.4	38	86
Aug	3759	86.9	361	209	34	111	1.8	32	64
Sept	307	56.7	275	25	7	44	1.0	34	96
Oct	0	0.3	N/A	1	0	0	0.0	N/A	N/A
Totals / Averages	**15497**	**85.0**	**266**	**1024**	**224**	**75**	**1.8**	**41**	**N/A**

An option to improve the logistics of charging BEBs is to install bus chargers at locations where the bus may have extended idle time (such as at a bus mall). This would result in extended daily operation and an intrinsic cascaded charging strategy for the electric bus fleet. In addition, when purchasing an electric bus, it is important to ensure there is sufficient on-board energy storage to allow the bus to be operated for long-duration periods.

3.3 Temperature Performance

The test period experienced a temperature range of -39°C to +39°C. As mentioned previously, the HVAC system of the BYD bus consumed more energy than the motor during cold periods and decreased the distance the bus could travel when fully charged (effective range). However, there were no reliability issues or other subjective concerns regarding the BYD bus performance during colder months. During the demonstration period, the following was reported:

- On days where the temperature dropped below -15°C, the electric bus was the first bus to leave the Saskatoon Transit garage, while the diesel buses warmed up their engines [Bracken, 2021b]. This was due to cold-temperature issues related to the after-treatment system of the typical diesel buses.

- There were no complaints about the performance of the braking system and no observations of excessive sliding or brake failures on icy roads [Bracken, 2021a].

- There were no complaints on the functioning of doors, icing of mirrors and windscreens. [Bracken, 2021a].

This study showed that this BYD electric bus can function as well as, or even better than a diesel bus for the Saskatoon temperatures as diesel buses often have cold-weather related issues due to their integrated emissions reduction systems.

4. Financial Analysis

4.1 Total Cost of Ownership

Table 6 compares the total cost of ownership of an electric BYD to a diesel bus. Although the cost of the electric BYD bus is almost double that of the diesel bus, BEBs typically have much lower maintenance and energy costs. In addition, the capital cost of BEBs is likely to decrease going forward. Saskatoon Transit provided the current pricing of a diesel and an electric bus at $660,000 and $1,200,000, respectively [Bracken, 2021a]. The current cost of diesel fuel for Saskatoon Transit is $1.21/L and the average fuel consumption of their diesel bus fleet is 48.2 L / 100 km (0.482 L / km) based on 2020 data [Bracken, 2021c]. Carbon tax is now added to diesel, and it is reasonable to anticipate further increases to the cost of diesel to account for the cost of carbon over the next several decades.

As per the Electric Bus Feasibility Study completed by the Saskatchewan Research Council for Saskatoon Transit, a typical Saskatoon Transit bus has an annual travel distance of 50,000 km and a lifetime of 18 years; the feasibility study also estimates the maintenance costs of a diesel and an electric bus at $0.86/km and $0.18/km, respectively [Jansen, 2019]. Inflation has not been incorporated into the total cost of ownership analysis in Table 6, and thus all values are represented in 2021 Canadian dollars. The 2019 feasibility study estimated that the energy economy of a BEB would be approximately 1.0 kWh / km [Jansen, 2019]. As a result of the higher HVAC energy demand, the BYD bus tested by Saskatoon Transit this past year, has an average energy economy of 1.4 kWh/km from the grid (the total energy supplied to bus from the grid divided by total distance travelled during demonstration test).

Electricity costs were estimated using the SaskPower E23 customer-owned transformation (< 3MW) rates of $0.06227/kWh plus a $0.006065/kWh federal carbon charge, and a demand charge of $8.405/kVA. It is difficult to account for demand charges in the financial analysis because these will depend both on how many BEBs are charged at the same time, and the overall demand of the Civic Operations Center during the electric bus charging time. Table 5**Table** *5* shows the maximum power draw during charging of the BYD bus for each month over the entire trial. The average monthly maximum power draw over the year is 73 kW. With every bus in a BEB fleet charging at the same time, the maximum power draw would be the number of buses multiplied by 73 kW. Ideally, the Saskatoon Transit Civic Operations Center, with a BEB fleet, would include smart technologies to cascade the load of the fleet during charging sessions as well as schedule charging to occur during off-peak hours.

Table 5 - Maximum power draw during charging sessions of BYD bus

Month	Maximum power draw during charging (kW)
Nov	73
Dec	73
Jan	74
Feb	73
Mar	72
Apr	72
May	73
June	73
July	72
Aug	72
Sept	71
Oct	--

The financial analysis below assumes that with an average charging time of under 2 hours per session, that it would be possible to limit the coincident electricity demand to less than 30% of the maximum power demand. The following total cost of ownership analysis includes the electricity cost for both no demand charges and demand charges based on a maximum power draw of 30% of 73 kW per bus (22 kW per bus) thus assuming that multiple buses are being charged in a cascaded strategy. Please note that it is possible that electric bus charging could be implemented solely during off-peak hours and may incur no demand charges depending on the number of buses and the extent of their usage.

Table 6 - Total Cost of Ownership of a Diesel and an Electric Bus

Input/Total cost	Parameter	Value
Capital Cost	Diesel Bus ($)	660,000
	BYD Electric Bus ($)	1,200,000
Maintenance Costs	Diesel Bus ($/km)	0.86
	BYD Electric Bus ($/km)	0.18
Operational Costs	Diesel fuel efficiency (L/km)	0.481
	Diesel cost ($/L)	1.21
	Electricity kWh/km	1.4
	Additional coincident demand per bus kW/bus/month (30% of maximum additional demand)	22

	Electricity consumption rate $/kWh	0.0683
	Electricity demand rate $/kVA	8.405
Annual Travel	Distance travelled by either a diesel or electric bus (km/bus)	50,000
Bus Lifetime	Lifetime of either a diesel or electric bus (years)	18
Annual Maintenance Costs	Diesel Bus ($/yr)	43,000
	BYD Electric Bus ($/yr)	9,000
Annual Fuel / Electricity Costs	Diesel Bus ($/yr)	29,100
	BYD Electric Bus ($/yr) if there are no demand charges	4,780
	BYD Electric Bus ($/yr), including demand charges (at 30% of maximum additional demand)	6,990
Total Cost of Ownership Over Lifetime of Bus (18 yrs)	Diesel bus ($/lifetime)	1,957,820
	BYD electric bus ($/lifetime) if there are no demand charges	1,448,060
	BYD electric bus ($/lifetime), including demand charges (at 30% of maximum additional demand)	1,487,800

The electricity costs of a BYD bus are projected to be 75% less than fuel costs for a diesel bus. With 30% of the maximum demand accounted for in the electricity charges, the total cost of ownership of the BYD electric bus is $1,487,800 versus $1,957,820 for a diesel bus, over an 18-year lifetime.

4.2 Alternative Heating Option

A diesel coolant heater is likely a more efficient option for heating a BEB and should be considered as an alternative to an HVAC system which uses electric heat from the bus' battery. In reviewing the energy consumption from the grid versus the net motor consumption in Table 3, the approximate energy consumption of the motor and non-HVAC components is estimated to be 1 kWh / km throughout the year. For the months of November to March, the recorded energy consumption from the grid is 11,305 kWh and the total distance driven is 5,584 km (Table 3). If the energy usage of non-HVAC components is 5,584 kWh (5,584 km x 1kWh / km), then the energy consumption to heat the bus during these months is 5,721 kWh (11,305 – 5,584 kWh).

The efficiency of a diesel coolant heater is estimated from the specification sheet of the Hydronic D5S diesel coolant heater (Simplicity Air, 2021). This heater has a high output of 5 kW and has a diesel consumption of up to 0.62 L / h, which equates to 8.06 kWh / L. Given that the diesel heating value is approximately 10.6 kWh / L, this heater has an efficiency of 76%. The total cost of ownership financial analysis is repeated with a diesel coolant heater option in Table 7, where it is assumed that a diesel coolant heater has an efficiency of 70% to allow for transmission losses. A diesel coolant heater would require 771 L of diesel to supply 5,721 kWh of heat which equates to 0.049 L / km of diesel over the total travel distance of the demonstration trial. It is possible that less than 0.049 L/km of diesel would be required to heat a BEB. A BEB with a diesel coolant heater was briefly trialed in the month of February 2016 for the City of Edmonton transit (MARCON, 2016) and the diesel consumption for heating the bus in this month was only 0.02 L/km. Other transit departments have purchased BEBs with diesel coolant heaters and it would be valuable to determine their actual diesel heater usage over the course of a year.

With 30% of the maximum demand accounted for in the electricity charges, the total cost of ownership of a BEB with a diesel coolant heater is $1,517,150 versus $1,957,820 for a diesel bus, while it is $1,487,800 for a BEB with electric heat. However, the main advantage of a BEB with a diesel coolant heater is that the bus will have a longer effective range. Resultantly, a bus can be purchased with a smaller battery at a lower cost and still travel the same distance. As shown in Table 4, the effective range of the BYD electric bus in the coldest months was half the value in warmer months due to electric heating. A varying effective range throughout the year for an electric bus, as well as a low effective range in cold weather, may result in the need for a larger bus fleet, and higher capital costs. In addition, a diesel coolant heater can be fueled with biodiesel which may be a reasonable option in the future as biodiesel supplies grow.

Table 7- Total Cost of Ownership of a Diesel and an Electric Bus with Diesel Heater

Input/Total cost	Parameter	Value
Capital Cost	Diesel Bus ($)	660,000
	Electric Bus with diesel heater ($)	1,200,000
Maintenance Costs	Diesel Bus ($/km)	0.86
	Electric Bus ($/km)	0.18
Operations Costs	Diesel fuel efficiency (L/km)	0.481
	Diesel cost ($/L)	1.21
	Electricity kWh/km	1.0
	Maximum additional coincident demand per bus kW/bus/month (30% of maximum additional demand)	22
	Electricity consumption rate $/kWh	0.0683
	Electricity demand rate $/kVA	8.405
	Efficiency of diesel coolant heater (%)	70
Annual Travel	Distance travelled by either a diesel or electric bus (km/bus)	50,000

Bus lifetime	Lifetime of either a diesel or electric bus (years)	18
Annual Maintenance Costs	Diesel Bus ($/yr)	43,000
	Electric Bus with diesel heater ($/yr)	9,000
Annual Fuel / Electricity Costs	Diesel Bus ($/yr)	29,100
	Electric Bus with diesel heater ($/yr) if there are no demand charges	6,400
	Electric Bus with diesel heater ($/yr.), including demand charges (at 30% of maximum additional demand)	8,620
Total Cost of Ownership Over Lifetime of Bus (18 yrs)	Diesel bus ($/lifetime)	1,957,820
	Electric Bus with diesel heater ($/lifetime) if there are no demand charges	1,477,200
	Electric Bus with diesel heater ($/lifetime), including demand charges (at 30% of maximum additional demand)	1,517,150

5. ENVIRONMENTAL AND SOCIAL IMPACTS

5.1 Environmental Benefits

There are greenhouse gas emissions associated with the electricity which is consumed by the BYD electric bus. This assessment will use 0.646 kg CO_2e/kWh as the overall GHG emission intensity factor for the SaskPower grid electricity [Jansen, 2019]. Greenhouse gas emissions are estimated for the demonstration trial in Table 8. During the trial, the bus covered 15,497 km and its greenhouse gas (GHG) emissions were 13,735 kg of CO_2e. This implies that the electric bus has a total GHG emission factor of 0.89 kg of CO_2e/km.

Table 8 - Greenhouse gas emissions during BYD bus trial (0.646kg CO_2e/kWh)

Month	Year	Monthly travel distance (km)	GHG of BYD bus (kg CO_2e)
Nov	2020	907	1208
Dec	2020	740	975
Jan	2021	1868	2332
Feb	2021	1768	2529
Mar	2021	301	316
Apr	2021	327	304
May	2021	2534	1151
June	2021	243	263
July	2021	2744	2044
Aug	2021	3759	2334
Sept	2021	307	279
Oct	2021	---	----
Totals		**15497**	**13735**

The current Saskatoon Transit fleet is mainly comprised of diesel buses. Diesel vehicles emit criteria air contaminants including PM2.5 and PM10 particulate matter, non-methane hydrocarbons, carbon monoxide, and the greenhouse gases carbon dioxide, nitrous oxide, and methane [Jansen, 2019]. In addition, there are greenhouse gas emissions from the extraction of fossil fuels and their production into diesel. As per the Electric Bus Feasibility Study completed by the Saskatchewan Research Council for Saskatoon Transit, the total diesel emission factor is estimated to be 3.197 kg CO_2e/L of fuel [Jansen, 2019]. The existing Saskatoon Transit diesel buses travel an average of 50,000 km per year. This equates to a GHG emission rate of 1.70 of CO_2e/km for a diesel bus or 83.8 tonnes CO_2e/year. At 50,000 km per year, the emissions of the BYD bus are estimated to be 44.5 tonnes CO_2e, based on the GHG emission factor of 0.89 kg CO_2e/km. Thus, the emissions related to a BEB are estimated to be 39.3 tonnes CO_2e lower than those of a diesel bus. A source of error in this approximation is that the BYD bus was not operated at a constant rate throughout every month of the year during the demonstration trial.

Figure 3 compares the GHG emissions of a typical diesel bus in the Saskatoon fleet to the GHG emissions of the BYD electric bus during the Saskatoon demonstration test, where GHG emissions of each month are calculated from the monthly electrical consumption. This figure illustrates that emissions from March to September are much lower than those of a diesel bus. In the future, as Saskatchewan reduces the carbon footprint of the province's electrical grid, there will be further reductions in GHG emissions from electric versus diesel buses. In addition, Saskatoon Transit has the option of reducing the carbon footprint of their electric fleet by self-generating using low-carbon generation sources such as wind, solar, or biomass, or by purchasing low-carbon energy and wheel it through the SaskPower grid. Saskatoon Transit should investigate electric bus models equipped with more efficient heating systems to achieve lower energy consumption, longer effective ranges in between charges, and lower GHG emissions during the colder months. A biodiesel-powered HVAC unit may be a good option if it can operate reliably at low temperatures.

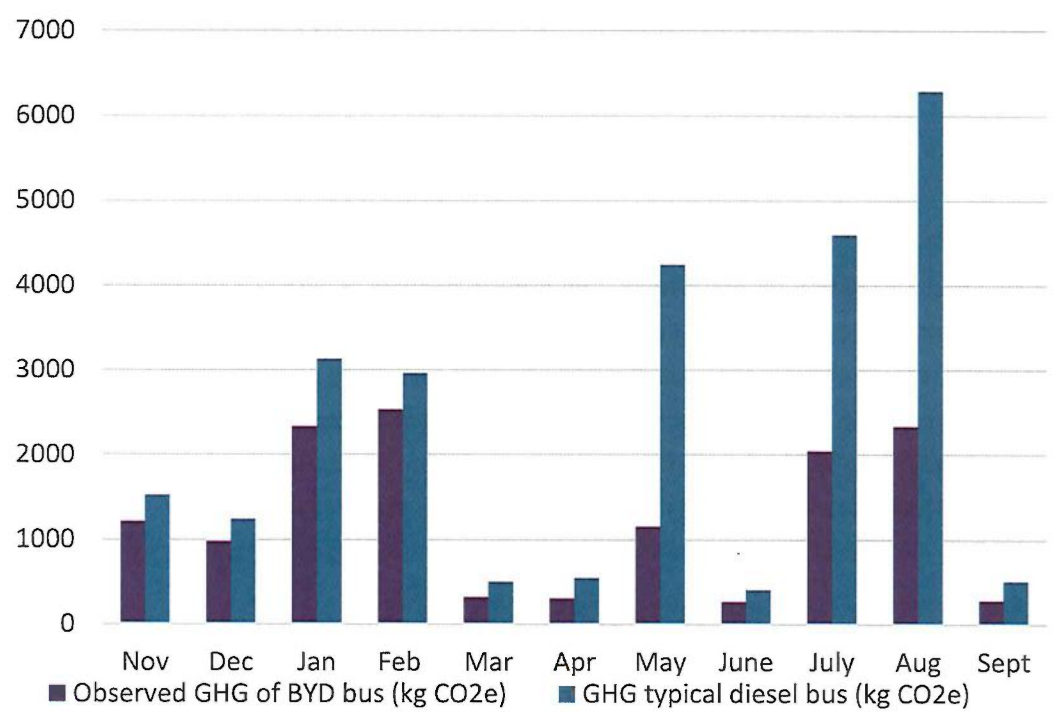

Figure 3 - Comparison of observed GHG emissions of BYD bus versus a typical diesel bus

As shown previously in Table 3, the electricity consumption of the BYD bus is much higher in the colder months when energy is used to run the HVAC. The consumption is much improved from March through to September. As mentioned in Section 4.2, a diesel coolant heater would be more efficient than an electric HVAC system. The carbon footprint of a diesel coolant heater could be reduced by fueling it with biodiesel. The greenhouse gas emission intensity of 100% biodiesel is approximately 2.49 kg CO_2e/L (The Climate Registry, 2020). Assuming 100% biodiesel, and the same fuel economy for a biodiesel and diesel heater (0.049 L/km), the emissions for a biodiesel-powered coolant heater are approximately 0.21 kg CO_2e/km. The electricity usage of an electric bus with a diesel coolant heater is estimated at 1 kWh/km (Table 7). At 0.646 kg CO_2e/kWh, the emissions from the electricity usage of an electric bus (without electric heat) would be 0.646 kg CO_2e/km. The overall emission factor for the biodiesel-powered coolant heater bus is then 0.77 kg CO_2e/km. Table 9 compares the expected emissions from a diesel, BYD electric bus with electric heat, and a BEB with a biodiesel-powered coolant heater, operating year-round in Saskatoon, driving 50,000 km/year:

Table 9 - Annual GHG emissions, at 50,000 km/year

	GHG Emissions (kg CO_2e/km/bus)	Annual GHG Emissions (Tonnes CO_2e/bus)	Difference (%)
Diesel Bus	1.7	83.8	---
BYD Electric Bus with Electric Heat	0.89	44.5	-47%
Electric Bus with Biodiesel Coolant Heater	0.77	38.4	-54%

5.2 Social Benefits

The electric bus is quieter than a diesel bus and reduces noise pollution. A study in Germany found that electric buses produce 14 dB(A) less noise pollution that diesel buses at low speeds in isolated cases. Typically, electric buses were found to reduce ambient noise by approximately 5 dB(A). (Laib, 2019.) Furthermore, diesel bus exhaust has an unpleasant odor and emits particulate matter in the PM2.5 and PM10 ranges which can have negative health effects, while there is no direct exhaust from BEBs. As well, modern BEBs are equipped with Wi-Fi and other conveniences such as USB-chargers making the passenger experience more convenient and pleasant.

6. Conclusions and Recommendations

Conclusions and recommendations from this performance evaluation are as follows:

1. The Saskatoon electric bus demonstration has shown that an electric bus can operate as well as and possibly better than a diesel bus in Saskatoon's temperature extremes.

2. Charging the bus at the Saskatoon Civic Operations Center has proved to be adequate for operating the current bus routes around Saskatoon.

3. In the future, Saskatoon Transit should investigate electric bus models equipped with more efficient HVAC systems to achieve lower electricity consumption and longer effective ranges in between charges, especially during the colder months. A biodiesel-powered HVAC unit may be a good option.

4. The net energy consumption of the motor was on average 0.7 kWh/km, and relatively consistent throughout the demonstration trial period. The net energy showed no signs of reduction from the start to finish of the test period, which indicates that the battery did not noticeably deteriorate over time. Also, the net motor energy consumption did not vary considerably with external temperature.
5. The bus was ultimately powered from the electricity grid and energy was consumed by the motor, the HVAC system, and other components (doors, lights).
6. The total energy consumption for the entire test period was 1.4 kWh/km and the monthly average ranged from 0.7 to 2.2 kWh / km. The total energy consumption was correlated with outdoor temperature. It was highest in the coldest months and lowest in the late Spring and early Summer. The energy consumption of heating the bus was almost two thirds of the total energy consumption in the month of February. The energy consumption was slightly higher in the hottest months of the year than in the shoulder seasons due to higher air conditioning demand.

7. The effective range of the battery was between 175 and 361 km throughout the test months of the demonstration period. The effective range is related to the total energy consumption of the bus. Thus, in the coldest months, the effective range of the bus was lowest. The effective range is the amount the bus can be driven from 100% to 0% state of charge (SOC).
8. Between November and September, on average, the bus was recharged when the battery SOC was 56 to 86%, and on average, the bus was driven 75 km between charging sessions.
9. Saskatoon Transit should consider locating bus chargers at locations where the bus may have extended idle time (such as at a bus mall). This would result in extended daily operation and an intrinsically-cascaded charging strategy for the electric bus fleet which would help reduce demand charges.
10. When purchasing an electric bus, ensure there is sufficient on-board energy storage to allow the bus to be operated on typical diesel bus routes to make certain the BEB does not become relegated to be used only at select times or in special situations.
11. The fire suppression system on the BYD electric bus was accidently activated resulting in an excessive maintenance period to recharge. This maintenance item is unrelated to the BYD bus electric battery [Bracken, 2021a]. Future buses should have both replacement parts and fire suppression recharging capacity nearby.
12. While the capital cost of purchasing electric versus diesel buses is higher, electric buses have much lower operating costs:
    a. The capital cost of diesel versus electric buses for Saskatoon Transit are approximately $660,000 and $1,200,000, respectively.
    b. Electric buses are known to have lower operating costs than diesel buses. The annual maintenance costs of a diesel versus electric bus, driving 50,000 km/year, are expected to be $43,000 and $9,000 respectively.
    c. Fuel costs to operate a diesel bus are currently significantly greater than the electricity costs to operate a BEB for the same distance. When driving 50,000 km/year, these are estimated to be $29,100 and $6,990 per year.
13. The total cost of ownership of a diesel versus BYD bus travelling 50,000 km per year, operating over an 18-year lifetime is expected to be $1,957,320 and 1,487,800, respectively.

14. BEBs achieve significant environmental benefits. The BYD bus is estimated to have 47% lower greenhouse gas (GHG) emissions than a diesel bus travelling the same distance. It is anticipated that a BYD bus will reduce GHG emissions by 39.3 tonnes CO_2e per bus per year, or from 83.8 tonnes CO_2e to 44.5 tonnes CO_2e per bus per year, when travelling 50,000 km per year. Further GHG emission reductions can be achieved by purchasing electricity from cleaner sources.
15. If a diesel-powered coolant heater unit were used to provide cabin heating for a BEB, the total cost of ownership is expected to be slightly increased from $1,487,800 to $1,517,150, but the effective range of the BEB would double in the coldest months. An electrically-heated BEB, with a low effective range in cold weather and large variations in effective range throughout the year, may result in the need for a larger bus fleet. Therefore, a BEB with a diesel-powered coolant heater may reduce the overall capital costs of an electric bus fleet.
16. It is recommended to follow up with the transit departments of Edmonton and St. Albert, Alberta which may have diesel coolant heater BEBs and determine their actual diesel consumption during cold weather.
17. A BEB with a biodiesel-powered coolant heater may have a smaller carbon footprint than a diesel bus or an electrically heated BEB. Annual emissions from a BEB travelling 50,000 km/year, with a biodiesel coolant heater are estimated to be 38.4 tonnes CO_2e versus 44.5 tonnes for a BEB with electric heat and 83.8 tonnes for a diesel bus.
18. The bus offers social benefits in terms of noise reduction, odour reduction, and easy Wi-Fi access.

It is recommended that Saskatoon Transit consider investing in electric buses to both help meet the City's GHG emissions reductions targets and to further improve the financial viability of Saskatoon Transit.

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