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Canada Post Solectria-Grumman LLV Electric Postal Delivery Truck

Comparative Performance Evaluation

Transport Canada
Transportation Development Centre

Environment Canada
Environmental Technologies Centre

TP 13528E

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Canada Post Solectria-Grumman LLV Electric Postal Delivery Truck

Comparative Performance Evaluation

by

Claude Guérette
Transportation Development Centre
Transport Canada

and

Michel Souligny
Environmental Technologies Centre
Environment Canada

February 2000

PROJECT TEAM

Michel Lamarche:	responsible for the dynamic performance testing at PMG Technologies
Michel Souligny:	responsible for the environmental performance testing at Environment Canada, Emissions Research and Measurement Division
Claude Guérette:	Test Program Manager, Transport Canada, Transportation Development Centre

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Claude Guérette and Michel Souligny

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Environmental Technologies Centre
3439 River Road South
Gloucester, Ontario
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Claude Guérette
E-mail: *gueretc@tc.gc.ca*

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16. Abstract

Transport Canada, Environment Canada, and Canada Post collaborated on an assessment and comparison of the dynamic and environmental performances of two Mini-Grumman long-life right-hand drive delivery vehicles.

One has a conventional internal combustion engine and the other was converted to an electric drive system by Solectria Corporation and equipped with a lead-acid traction battery.

Both vehicles were tested on a chassis dynamometer, using a typical postal route duty cycle at both 20°C and -20°C to measure their energy, the range of the electric truck, and the vehicles' acceleration, hill climbing, braking, and maximum speed. Dynamic testing of the electric vehicle (EV) was carried out using the EV America testing protocols.

The tests indicated that the electric truck is a viable and more environmentally sustainable mail delivery vehicle for Canada Post. Improvements to the EV's maximum speed, acceleration, and range performance are recommended.

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Claude Guérette
Courriel : *gueretc@tc.gc.ca*

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16. Résumé

Transports Canada, Environnement Canada et Postes Canada ont collaboré à une étude comparative du comportement dynamique et du niveau d'émissions de deux mini-fourgonnettes de distribution postale Grumman à longue durée de vie (LLV, pour *long-life vehicle*), avec conduite à droite.

Un des véhicules était propulsé par un moteur à combustion interne classique et l'autre, converti à l'électricité par Solectria Corporation, était équipé d'une batterie de traction au plomb.

Les deux véhicules ont été soumis à des essais dynamométriques simulant un circuit de distribution postale type, à 20 °C et à -20 °C. Ces essais visaient à évaluer l'autonomie du fourgon électrique ainsi que le rendement énergétique, l'accélération, le rendement en côte, la performance en freinage et la vitesse maximale des véhicules. Les essais dynamiques du véhicule électrique ont été réalisés suivant les protocoles de EV America.

L'étude a révélé que la fourgonnette électrique représente une option viable et plus écologique que le véhicule à essence pour la distribution postale. Il est recommandé d'améliorer le véhicule électrique aux chapitres de la vitesse maximale, de l'accélération et de l'autonomie.

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SUMMARY

Environment Canada (Transportation Systems Branch and the Emissions Research and Measurement Division (ERMD)) collaborated with Transport Canada's Transportation Development Centre and Canada Post to evaluate a Mini-Grumman long-life vehicle (LLV) right-hand drive postal delivery truck converted to electric propulsion by the Solectria Corporation. This experimental vehicle assessment is part of Canada Post's ongoing new vehicle technology evaluation for fleet renewal. In addition to the evaluation discussed in this report, the electric vehicle will also be evaluated in operational service by Canada Post.

Testing was conducted at Environment Canada's ERMD and PMG Technologies Ltd.'s motor vehicle test facility. The testing indicated that on the postal route driving cycle simulated by the chassis dynamometer, the vehicle could travel 29.58 km when the ambient temperature was 20°C. Further testing at -20°C indicated that the range was reduced to 27.4 km over the same cycle.

With respect to exhaust emissions, the fuel fired auxiliary heater used for cabin heat showed no measurable level of particulate emissions, and low emission rates of CO, CO_2, NO_x, and THC. The heater also exhibited low fuel consumption. The internal combustion engine (ICE) vehicle counterpart showed a significant increase in emissions at low temperature and higher fuel consumption to heat the passenger cabin while idling, despite the fact that it could only reach a cabin temperature of 5°C while the auxiliary heater in the electric vehicle brought the cabin to 15°C.

It is estimated that the 24-hour, 30 km duty cycle for the ICE vehicle in an environment of 20°C and idling time of 1 hour, required 51.5 kWh of energy, equivalent to a consumption of 4.92 L of gasoline. The vehicle produced emissions of 266.1 g CO, 14 g CO_2, 22.6 g NO_x, and 40.8 g THC. The electric counterpart for the same 24-hour duty cycle used *one quarter the energy* at 14 AC kWh, and emitted no CO, CO_2, or NO_x, and only a few grams of THC, from the evaporative emissions of the heater fuel.

In an environment of -20°C, with an idling time of 2 hours, the ICE vehicle would require 85.5 kWh of energy, equivalent to a consumption of 8.57 L of gasoline plus the use of 11 kWh of electricity by the engine block heater. It produced emissions of 649 g CO, 17.7 g CO_2, 35.1 g NO_x, and 122 g THC. The electric counterpart for the same 24-hour duty cycle would use *one third the energy* at 28.4 kWh, which is characterized by 22 kWh of electrical energy and 0.74 L of diesel for the fuel-fired heater. It produced 4.14 g CO, 6.4 g CO_2, 1.2 g $NO_{x,}$ and 1.2 g THC.

At the PMG test centre, the vehicles achieved a maximum speed of 120 and 81 km/h for the ICE and electric versions respectively. On simulated road grades of 3 and 6 percent, the ICE vehicle achieved a maximum speed of 102.8 and 94.8 km/h and the electric vehicle 65.3 and 53.5 km/h. The ICE vehicle's maximum grade climbing ability was calculated at 35.5 percent

and that of the electric vehicle at 20.2 percent. The ICE vehicle had a 0 to 80 km/h acceleration of 14.5 seconds vs. 47 seconds for the electric vehicle.

The emergency and 75 km/h wet pavement braking test indicated similar responses for both vehicles. The 75 km/h dry pavement braking showed that the electric vehicle required 6.2 m more than the ICE to come to a complete stop.

It was concluded that the electric truck is a viable and more environmentally sustainable mail delivery vehicle for Canada Post. It is recommended that the EV's maximum speed, acceleration, and range performance be improved.

SOMMAIRE

Environnement Canada (Direction des systèmes de transport et Division de la recherche et de la mesure des émissions) s'est joint au Centre de développement des transports de Transports Canada et à Postes Canada pour évaluer une mini-fourgonnette de distribution postale Grumman à longue durée de vie (LLV, pour *long-life vehicle*), avec conduite à droite, convertie à la propulsion électrique par Solectria Corporation. Cette étude expérimentale s'intégrait à l'évaluation continue de nouveaux véhicules menée par Postes Canada en marge du renouvellement de sa flotte. Outre les essais présentés dans ce rapport, le véhicule électrique sera aussi l'objet d'une évaluation en service par Postes Canada.

Les essais ont eu lieu au Laboratoire sur les émissions des véhicules d'Environnement Canada et aux installations d'essai de véhicules motorisés de PMG Technologies Ltd. Au cours du cycle de service simulé par le dynamomètre, le véhicule électrique pouvait parcourir 29,58 km à une température ambiante de 20 °C, comparativement à 27,4 km, lorsque la température était abaissée à -20 °C.

Pour ce qui est des émissions polluantes, la chaufferette au diesel utilisée pour chauffer l'habitacle du VÉ n'a rejeté aucune quantité mesurable de particules et de faibles quantités de CO, de $CO_{2,}$ de NO_x et de THC. Elle affichait en outre une faible consommation de combustible. Quant au véhicule équipé d'un moteur à combustion interne (MCI), le niveau de ses émissions augmentait de façon significative par temps froid, et il consommait davantage d'essence, au ralenti, pour le chauffage de l'habitacle, dont la température, malgré tout, atteignait à peine 5 °C. En comparaison, la chaufferette auxiliaire du VÉ portait la température de l'habitacle à 15 °C.

On estime que pour effectuer un cycle de service de 24 heures (30 km), y compris une heure de marche au ralenti, à une température de 20 °C, le véhicule MCI consommait 51,5 kWh d'énergie, soit l'équivalent de 4,92 L d'essence, et rejetait 266,1 g de CO, 14 g de CO_2, 22,6 g de NO_x et 40,8 g de THC. Le même véhicule propulsé à l'électricité consommait, dans les mêmes conditions, *quatre fois moins d'énergie*, soit 14 kWh d'électricité, et ses émissions de CO, de CO_2 et de NO_x étaient nulles, tandis que l'évaporation du combustible de la chaufferette ne produisait que quelques grammes de THC.

À -20 °C, avec un temps de marche au ralenti de 2 heures, le véhicule MCI consommait 85,5 kWh d'énergie, soit l'équivalent de 8,57 L d'essence, et 11 kWh d'électricité consommée par le chauffe-bloc. Il rejetait 649 g de CO, 17,7 g de CO_2, 35,1 g de NO_x et 122 g de THC. Le véhicule électrique exploité dans les mêmes conditions consommait *trois fois moins d'énergie*, soit 28,4 kWh, dont 22 kWh d'énergie électrique et 0,74 L de combustible pour la chaufferette au diesel. Il rejetait 4,14 g de CO, 6,4 g de CO_2, 1,2 g de NO_x et 1,2 g de THC.

Au centre d'essai de PMG Technologies, les versions MCI et électrique du véhicule ont atteint des vitesses maximales de 120 et de 81 km/h, respectivement. Sur des côtes simulées de 3 et de 6 p. 100, le véhicule MCI a atteint des vitesses de pointe respectives de 102,8 et de 94,8 km/h, et le VÉ, de 65,3 et de 53,5 km/h. La pente gravissable par le véhicule MCI et par le VÉ a été établi à 35,5 p. 100 et à 20,2 p. 100, respectivement. Le véhicule MCI passait de 0 à 80 km/h en 14,5 secondes, par rapport à 47 secondes dans le cas du VÉ.

L'essai de freinage sur chaussée mouillée à 75 km/h a révélé des comportements similaires de la part des deux véhicules. À l'essai de freinage sur chaussée sèche, toujours à 75 km/h, il a fallu 6,2 m de plus au VÉ qu'au véhicule MCI pour s'immobiliser complètement.

Il a été établi, en conclusion, que la fourgonnette électrique représente une option viable et plus écologique que le véhicule à essence pour la distribution du courrier de Postes Canada. Il est recommandé d'améliorer le VÉ aux chapitres de la vitesse maximale, de l'accélération et de l'autonomie.

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GLOSSARY

Ah	Ampere hour
AH	Auxiliary Heater
AHP	Actual Horsepower at 50 mph
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CVS	Constant Velocity Sampling
EPA	Environmental Protection Agency
EV	Electric Vehicle
FE	Fuel Economy
FID	Flame Ionization Detector
HWFCT	Highway Fuel Consumption Test
ICE	Internal Combustion Engine
IW	Inertia Weight
kWh	Kilowatt-hour
NDIR	Non-dispersive Infrared Analyser
NIST	National Institute of Standards and Technology
NO_x	Oxides of Nitrogen
THCs	Total Hydrocarbons
UDDS	Urban Dynamometer Driving Schedule

Canada Post Solectria-Grumman LLV Electric Postal Delivery Truck

1 BACKGROUND

Canada Post Corporation operates a fleet of approximately 6,000 vehicles, of which about 2,200 are small, right-hand drive urban mail delivery trucks. They generally operate eight hours per day and accumulate on average less than 100 km a day. The trucks are parked together in an outside compound and, during winter months, plugged into an electrical outlet system to ensure problem-free starting and quick warm-up.

In an effort to reduce fleet operating costs and environmental impact, and responding to Bill S-7, which requires a gradual conversion of the federal fleet to alternative fuels, Canada Post has been looking at electric vehicles (EVs) as an option for some time.

Last year in the U.S., a number of original equipment manufacturers (OEMs) started to offer production type EVs for sale specifically to fleet operators. The U.S. Postal Service initiated an EV program involving 500 electric delivery vans, with a plan to increase that number to 6,000 units in the near future.

In November 1998, Canada Post contracted Solectria, a Boston EV company, to undertake the conversion of two Mini-Grumman LLV right-hand drive mail delivery trucks to electric propulsion. The vehicles were delivered to Canada Post in February 1999. Canada Post will explore the suitability of these trucks for mail service, through in-service experimentation at a postal delivery centre in Laval, Quebec. A more formal comparative evaluation was conducted with the collaboration of Transport Canada's Transportation Development Centre (TDC) and Environment Canada's Emissions Research and Measurement Division (ERMD), who have developed unique expertise in Canadian EV performance evaluation.

1.1 Objectives

The project's objectives were:

- to characterize the performance of a Canada Post urban mail delivery truck converted to electric propulsion; and
- to compare its energy, emissions, and dynamic performance with the original internal combustion engine (ICE) model.

1.2 Scope

Both conventional and electric drive trucks were tested on a dynamometer at Environment Canada's Vehicle Emissions Measurement Laboratory in Ottawa, using a typical delivery route duty cycle at both +20°C and -20°C to measure the energy and emissions performance benefits of the electric truck.

Vehicle acceleration, hill climbing, braking, maximum speed, and handling performance were measured at Transport Canada's test facilities (operated by PMG Ltd.) in Blainville, Quebec. Dynamic testing of the EV was carried out using the EV America testing protocols.

2 INTRODUCTION

The two vehicles – one EV and one ICE, fully serviced, inspected, and representative of the Canada Post vehicle fleet – were delivered for testing to the ERMD laboratory in Ottawa and later to the PMG test facilities in Blainville, Quebec.

At ERMD, the test program determined the comparative performance of both vehicles in terms of range, energy consumption, and emissions resulting from the operation of the vehicles over simulated postal, urban, and highway driving cycles on a chassis dynamometer. The testing also involved the measurement of the auxiliary fuel-fired heater emissions and cabin temperature of both vehicles in cold ambient temperatures in a cold room. To investigate the performance of a vehicle of this nature in Canadian conditions, the testing was conducted at both 20°C and -20°C. The results were used to estimate the relative energy, $CO_{2,}$ and pollutants emission performances of both vehicles in a typical 24-hour service duty cycle in both summer (20°C) and winter
(-20°C) conditions.

At the PMG test facilities, the vehicles were tested for acceleration, maximum range at constant speed, maximum speed on a level road and 3 percent and 6 percent grade road, and maximum slope climbing ability. Braking was evaluated on dry and wet pavement and emergency braking on wet pavement. The odometer accuracy was also verified. The results are documented in two PMG reports (1,2). The main results of these tests are described in this report, which also discusses the procedures that were undertaken at the ERMD laboratory.

2.1 Vehicle descriptions

Table 1 – Vehicle # 1: ICE

Year, make, and model	1989 Grumman LLV
Body style and colour	step van, red and white
Identification no.	1GBCS10EXK2310379
GVWR **– front GAWR** **– rear GAWR**	4450 lb. – 2200 lb. – 2800 lb.
Recommended tire size (F/R)	LT195/75R14
Recommended tire pressure (F/R)	50 psi/50 psi
Traction motor type and rating	4 cylinder, 2.5 L, 92 hp at 4000 rpm
Transmission type **Shift lever location**	automatic dashboard
Designated seating – front **– rear** **– front seat type**	2 0 bucket

Table 2 – Vehicle # 2: EV

Note: This vehicle was converted to electric propulsion in February 1999. The original engine and transmission were removed from the vehicle and replaced with Solectria's electric conversion design, resulting in a 4,500 lb. test inertia weight and 25.3 hp at 50 mph.

Year, make, and model	1991 Solectria-Grumman LLV (EV)
Body style and colour	MPV, red and white
Identification no.	1GBCS10A6M2925130
GVWR – **front GAWR** – **rear GAWR**	4450 lb. (same as OEM intended) – 2200 lb. – 2800 lb.
Recommended tire size (F/R)	LT195/75R14
Recommended tire pressure (F/R)	50 psi/50 psi
Traction motor type and rating	AC induction: model no. – AC50, 50 kW peak, 20 kW continuous
Transmission type **Overall drive train ratio** **Shift lever location**	N/A 4.56:1 dashboard
Designated seating – front **– rear** **– front seat type**	2 0 bucket
Traction battery	
Type and capacity	lead-acid, sealed gel-type, 12 kWh
Battery manufacturer	East Penn Manufacturing Co.
Battery model	8G24
Nominal pack voltage	216
Maximum pack voltage	270
Minimum pack voltage	190
Number of modules	18
Connection scheme	X Series Parallel, Series-Parallel
Auxiliary battery	N/A
State of charge indicator	amp-hour only
Battery voltage indicator	N/A
Kilowatt-hour indicator	N/A
Vehicle range	30 km (19 mi) in poor conditions
Auxiliary heater	diesel 5 kW
Regenerative braking	• regenerative braking is normally activated but with a de-activate switch and indicator clearly showing "REGEN OFF" • vehicle brake lights not activated by regenerative braking • regenerative braking is pre-set at a medium setting and not adjustable by the operator

Other specifications	- automatic battery thermal management system on 120 V AC

2.2 Fuel

Summer and winter grade fuels were used for the ICE vehicle and winter grade diesel for the EV's auxiliary heater.

3 INSTRUMENTATION

Dynamics

- On-road coast-downs using fifth wheel with ERMD data acquisition system.
- The acceleration test and speedometer calibration were done using a non-contact speed detector.

Dynamometer

- Twin rolls 8.65 in diameter DC electric or water brake. The dynamometer frictional and loading calibration is performed on a daily basis.

Emissions

- The analysis system used to measure the ICE and the auxiliary heater's emissions is the same as that used for the compliance program, composed of a constant volume sampler, non-dispersive infrared analyser (NDIR), flame ionization detector (FID), and chemiluminescent analysers. The test bench is capable of modal analysis. The analysers are calibrated two points (0 and span) before and during each test with gas standards of the National Institute of Standards and Technology (NIST). The analysers get a full response verification (10 points) with NIST traceable gas standards and new curve coefficients every four weeks. The constant velocity sampling (CVS) system is verified using the propane injection method. The overall system is verified using a repeat car, correlating with the other test cells of ERMD, the Environmental Protection Agency (EPA), and auto manufacturers' labs.

DC electric power meter

- Two systems were used to measure DC power consumption and DC power applied to recharge the battery. The first one is permanently mounted in the vehicle and gives total kWh, Ah. It totals the power used by the electric motor and subtracts the power regenerated by the regenerative braking. It also displays power added to the battery by the charger.

AC power meter

- The AC power applied to the charger is measured by an external power meter, using the hall effect technique and voltage measurement, adding AC Ah and AC kWh.

4 METHODOLOGY

Since this type of vehicle is designed for specific use, a typical postal route test cycle was established for a more representative testing. A speed vs. time trace was developed based on one of the city's postal routes (see Figure 1). Results obtained during this cycle are the focus of this report's discussion. For reference to more standardized cycles, tests were also conducted on the highway and urban cycles (see Figures 2 and 3). The SAE 1634 test standard is the recognized method for assessing the range and energy efficiency of EVs. However, in this case, the electric drive truck did not have sufficient range to go beyond the two consecutive urban test cycles required by the SAE 1634
test protocol.

Prior to the EV evaluation, a conventional gasoline Grumman postal van was tested under the same conditions as those planned for the EV. The purpose was to determine the potential environmental benefits and driveability of the electric configuration as compared to existing ICE powered vehicles.

Before testing the EV on the dynamometer, it was necessary to determine its road load horsepower to establish the three-point coefficient curve for the dynamometer loading by conducting on-road coast-downs using a fifth wheel. The times determined from the on-road measurements were duplicated on the laboratory dynamometer to determine the vehicle's road load horsepower.

The EV was then tested on the dynamometer in the electric mode to determine the range and energy consumption at 20°C and -20°C. The range was measured by driving the EV over repeat cycles of postal sequence until it could no longer perform the acceleration and speed requirements of the cycle. Urban and highway test cycles as per SAE J1634 were also driven.

The electrical power required to recharge the batteries represented the energy consumption. For the -20°C portion of the testing, the battery was recharged at -20°C; the vehicle was then soaked at least 12 hours at -20°C. The charger was left plugged in during the soak. The DC kWh, DC Ah, battery voltage, battery temperature, and vehicle speed were recorded during the driving period. While charging, the DC kWh, DC Ah, battery voltage, battery temperature, and AC kWh were also recorded.

The ICE vehicle's performance and exhaust emission tests were conducted by driving it over the same cold-start postal, urban, and highway cycles as for the EV. In the -20°C environment, the engine block heater was plugged in overnight before testing.

The cabin temperature of both vehicles was monitored during the -20°C testing; the temperature sensor was positioned on the passenger seat.

The dynamic performance tests were performed according to the Electric Transportation Applications EV America test procedures no. ETA-A-AC006, ETA-TP002, ETA-TP004, ETA-TP006, and ETA-TP011.

5 RESULTS AND DISCUSSIONS

The results and discussions found in this section deal with testing performed in laboratory conditions at ERMD. Results and discussions from the dynamic testing at PMG are presented in section 6.

EV test sequence

The vehicle's battery was fully charged, the vehicle was pre-soaked for 12 hours at the appropriate temperature, and then driven over consecutive postal cycles until the battery was depleted and could no longer perform with adequate acceleration and speed. This was repeated three times in both -20°C and +20°C environments. The same tests were performed for urban and highway cycles. The diesel-fired auxiliary heater emissions, CO, CO_2, NO_x, and THC, were also measured.

ICE test sequence

The vehicle was driven over a preconditioned cycle and then soaked at the appropriate temperature for a minimum of 12 hours. It was then tested as a cold engine start and driven over the postal cycle, while measuring CO, CO_2, NO_x, and THC emissions, as well as fuel consumption. The same tests were performed for urban and highway cycles.

5.1 EV power consumption and range

Tables 3 and 3A outline the energy used to drive the EV over the postal route and the energy used to recharge its battery at + and -20°C. Each table indicates the average of the individual test day results in the form test type (postal, highway, urban, or charging), the distance travelled, the average speed, and total Ah and kWh used. The total Ah and kWh are the sum of the actual drain from the battery, in addition to what is regenerated during the test. The last column represents Wh per kilometre.

Table 3 – Average power consumption and range (all energy is DC)

Temp. (°C)	Test	Distance (km)	Average speed (km/h)	Total (Ah)	Total (kWh)	Drain (Ah)	Regen. (Ah)	Drain (Wh)	Regen. (Wh)	Total (Wh/km)
-20	postal	27.39	18.09	-38.65	-5.35	-43.46	4.81	-6359.26	984.65	-197.40
20	postal	29.58	22.85	-35.33	-4.76	-41.58	6.25	-5927.20	1162.77	-160.40
-20	highway	28.29	44.23	-42.03	-5.80	-42.82	0.79	-5954.71	157.74	-204.90
20	highway	27.16	45.29	-38.40	-4.89	-39.48	1.08	-5094.88	209.30	-179.90
-20	urban	See table 3A								
20	urban	34.58	22.81	-38.00	-4.58	-45.50	7.50	-6106.30	1523.83	-132.50

Table 3A – Average power consumption and range (urban cycle at -20°C)

Date	Temp. (°C)	Test	Distance (km)	Average speed (km/h)	Total (Ah)	Total (kWh)	Drain (Ah)	Regen. (Ah)	Drain (Wh)	Regen. (Wh)	Total (Wh/km)
30/3/99	-20	urban	23.19	28.70	-32.62	-4.02	-36.74	4.13	-4903.87	880.40	173.50
31/3/99	-20	urban	16.40	18.98	-23.06	-2.91	-26.17	3.11	-3461.27	547.66	177.66
1/4/99	-20	urban	4.00	34.94	-6.34	-0.67	-6.75	0.41	-751.95	85.54	166.60

Table 3A demonstrates the need for the battery pre-heat thermal management system. Since battery recharging was carried out at 220 V, the battery thermal management system was not operational and the battery temperature gradually dropped from 40°C to -5°C during the three-day test sequence, resulting in a significant battery capacity loss.

Actual range will most likely be slightly lower because of differences in air density and the presence of slush, snow, and ice, which cannot be simulated on the dynamometer.

Tables 4 and 4A indicate the charging voltage, Ah and DC kWh put into the battery, AC kWh (what was used to charge and maintain battery temperature), and the charging duration.

Table 4 – Average AC power used to recharge battery and maintain battery temperature

Temp. (°C)/ cycle	Test	Voltage	Total (Ah)	Total (DC kWh)	DC charge time (h)	Total (AC kWh)	AC plugged-in time (h)
-20/postal	charging	110	51.73	12.59	13.57	24.00	25.21
20/postal	charging	220	52.53	12.27	5.13	14.00	17.95
-20/highway	charging	110	N/A	N/A	N/A	20.00	N/A
20/highway	charging	220	48.23	11.24	N/A	13.50	13.50
-20/urban	charging	See table 4A – insufficient testing data					
20/urban	charging	220	50.34	12.46		14.50	17.28

Table 4A – AC power used to recharge battery and maintain battery temperature (urban cycle at -20°C)

Date	Temp. (°C)	Test	Voltage	Total (Ah)	Total (DC kWh)	Total (AC kWh)	AC plugged-in time (h)
3/30/99 – 3/31/99	-20	charging	220	41.44	10.800	13	19.46
3/31/99 – 4/1/99	-20	charging	220	29.48	7.800	9	21.52
4/1/99	-20	charging	220	22.15	5.960	6.5	4.00
4/6/99 – 4/7/99	-20	charging	110	54.06	12.910	21.00	23.00

5.2 Charger

The charger efficiency was approximately 87 percent, which was calculated using the average of the DC kWh on recharge divided by the average of all AC kWh on recharge at +20°C. This was performed with the 208/220 V charge, at +20°C, a mode at which the battery heating elements are not activated. The charge time on

208/220 V was 5 hours, extending to 13.62 hours using 120 V. For testing at both voltages, the starting battery temperature was above 30°C.

When charging at 208/220 V with the charger current reduced to 1 to 0.5 amp, the battery voltage rose to 290 V for 5 hours, then dropped abruptly to 233 V when the desired current was reached (i.e. 0.15 amps). When charging at 120 V, with the charge current reducing to 0 amps, the battery voltage rose to 317 V for a period of 1.5 hours, then dropped to 254 V when the current reached 0.2 amp. The battery voltage increased because it was fully charged and the charger was still supplying some power to the battery. The charger stops when the voltage starts to increase, because the overcharging causes the battery to release explosive gases. This is demonstrated in Figures 10 and 11.

5.3 Battery temperature

The battery temperature was measured at five different points inside the battery compartment. In the -20°C environment, each point had a different temperature depending on its location; readings taken closer to the exterior gave lower temperatures than those taken at the centre. The difference between the highest and lowest points varied between 8 and 14°C and they all varied synchronously with each other. The temperature chart in Figures 4 and 5 is an average of all the measured temperature points.

Table 5 shows the battery temperature at the beginning and the end of the driving cycle or charge period in an environment of -20°C. The temperature varied between 15 and 40°C, which is within normal lead-acid battery operating temperatures.

Table 5 – Battery temperature while driving (postal cycle at -20°C)

Date	Test	Start temperature (°C)	End temperature (°C)
4/7/99	drive	19.8	34.4
4/7/99 – 4/8/99	charge	31.2	25.0
4/8/99	drive	25.0	40.3
4/8/99 – 4/9/99	charge	36.3	16.3

For the -20°C urban test cycle (see Table 3A), the vehicle was recharged on 208/220 V. Since the battery thermal management system operates only when recharging on 120 V, the vehicle's range was reduced as follows: the first day, the range was reduced to 23.19 km, the second day 16.4 km, and the third day 4 km. Over the three-day period, the battery temperature dropped from 40°C to -5°C.

When driving the vehicle, the battery temperature rose rapidly at the beginning of the test in the first 10 minutes, then stabilized for the next 28 minutes, rising rapidly at the end of the test cycle (see Figures 4 and 5). The higher speed caused a faster rate of discharge, which rapidly raised the battery temperature.

5.4 Battery heater

The battery compartment is equipped with a cold temperature, thermal management system, which consists of electric heating blankets that are activated when the battery temperature reaches approximately 10°C. On this vehicle, the heater operated only on 120 V. It performed well and easily maintained the temperature above 10°C.

During recharge on 120 V, the temperature gradually dropped over a period of time depending on the initial battery temperature. This period varied from 6.5 hours to 9.5 hours. When the temperature reached around 10°C, the battery heater engaged and brought the temperature up to around 22°C. It then disengaged and let the battery cool down. The cooling from 22°C to 10°C took 5 hours, at which point the heating cycle would start over again. This cycle is demonstrated in Figure 9.

5.5 Cabin temperature

The vehicle's cabin is not thermally insulated; its large glass area requires continuous defrosting. During the tests, the vehicle's parcel door was closed.

The EV relies on a diesel fuel auxiliary heater to heat the passenger cabin. It has neither on-board nor off-board cabin electric heating capabilities. The heater output control mounted in the dashboard has minimum, medium, and maximum settings. The diesel fuel heater heats up conventional antifreeze, circulating it through the original vehicle's heater core. In this study, the heater control was set at maximum for all tests and the second defrost fan was also activated. The testing done at -20°C indicated that it takes approximately 13 minutes to raise the cabin temperature to +5°C and, from that point on, the temperature increased almost linearly to its maximum over a period of 23 minutes. The maximum temperature reached was between 12 and 15°C. The heat output was unaffected by engine load, remaining constant throughout the cycle.

Figures 6 and 7 show the cabin temperature vs. time for the postal cycle. Figure 7 shows the cabin temperature drop during the 12-minute soak after the first test cycle and the temperature increase after the soak when the heater was turned back on. Since the antifreeze did not cool off too much, it only took 4 minutes to reach 5°C. The auxiliary heater used 0.23 L of fuel per hour. Table 6 indicates the heater's emissions in grams per hour. They are quite low compared to those produced by the ICE when idling.

Table 6 – Auxiliary heater emissions and fuel consumption

Date	Temp. (°C)	Test	CO (g/h)	CO_2 (g/h)	NO_x (g/h)	THC (g/h)	Fuel cons. (L/h)
4/16/99	-20	heater	1.26	607	0.36	0.36	0.23

The ICE relies on the main engine for heat. The testing done at -20°C indicated that the maximum temperature reached during the first portion of the test before the

10-minute soak varied between 3.5 and 5°C. Figure 8 shows that the heat output depends on engine load. The temperature increased at the beginning of the test because of higher vehicle speed. It then decreased during the middle portion because the route was more of a low-speed, stop-and-go type of cycle. It then rose at the end because of higher speeds. After the 10-minute soak period during the second postal route cycle, the cabin temperature rose constantly to reach a maximum of 8 to 10°C, mainly because the engine block had reached the maximum temperature in these conditions. In real on-road conditions, these temperature variations will be reduced as a result of increased air infiltration and a greater heat transfer effect caused by the increased airflow around the vehicle brought about by increased speed.

5.6 ICE emissions and fuel consumption

Table 7 indicates the vehicle's CO, CO_2, NO_x, and THC emissions in g/km and fuel consumption in L/100 km and litres required to drive one postal route at both temperatures. The vehicle travels two postal routes per day. Therefore, the number of litres of fuel used per day in summer conditions is 5.08 L. In winter conditions, 6.61 L of fuel are used, an increase of 30 percent in addition to fuel used for idling. Winter condition emissions are increased significantly: CO – 156 percent, NO_x – 52 percent, THC – 860 percent, and CO_2 – 20 percent. These results can be explained by the higher friction of the drive train and engine, which in turn means that the engine requires a richer air-fuel ratio. The catalytic converter takes longer to warm up and might not have been working as efficiently as it should have been at these low temperatures.

Table 7 – Average emissions and fuel consumption of the ICE truck

Temp. (°C)	Test	Distance (km)	CO (g/km)	CO_2 (g/km)	NO_x (g/km)	THC (g/km)	Fuel cons. (L/100 km)	Fuel used per cycle (L)
-20	postal	15.13	17.32	479.57	1.05	1.72	21.90	3.31
20	postal	15.46	6.75	399.12	0.69	0.20	16.41	2.54
-20	highway	15.59	16.88	609.24	2.18	0.64	17.03	N/A
20	highway	16.43	16.84	554.24	1.27	0.38	15.34	N/A
-20	urban	17.83	17.26	530.97	1.11	0.35	19.58	N/A
20	urban	17.55	35.76	671.08	2.22	2.12	14.85	N/A

5.6.1 Idling

Table 8 presents: the ICE vehicle's emissions in grams per hour and fuel consumption in L/h during idling time; at -20°C, emissions in grams and fuel consumption in litres for a cold start and warm-up period of 8.5 minutes; and emissions in grams per hour and fuel consumption in L/h after the warm-up period. At 20°C, only the after warm-up was recorded in g/h and L/h.

Table 8 – Canada Post Grumman delivery van: ICE truck emissions and fuel consumption in idling operation mode

	Temp. (°C)			CO (g/h)	CO_2 (g/h)	NO_x (g/h)	THC (g/h)	Fuel cons. (g/h)	Fuel cons. (L/h)
3	20	idling	after warm-up	60.27	2133.63	1.56	34.75	740.63	1.00
1	-20	idling	after warm-up	60.27	2133.63	1.56	34.75	740.63	1.00
				grams produced during warm-up period of 8.5 min at -20°C					
1	-20	idling	first 8.5 min	45.05	417.86	0.51	2.38	157	0.02
Note: add the first 8.5 min values to the idling values after warm-up									

At -20°C, the engine and catalytic converter took longer to warm up and the emissions from that warm-up period are added to the after warm-up idling values. Once the vehicle's engine is warmed up, the fuel consumption and emissions are the same at both ±20°C. The ICE's fuel consumption at idle is 1 L/h, which is four times more than for the auxiliary heater or the EV. As in the case of the EV, the on-road emissions and fuel consumption will vary because of air density and extra drag caused by snow, ice, and slush. The extra load will affect both postal truck versions.

5.7 Estimated 24-hour energy cycle

A 24-hour energy cycle is defined as the total energy requirements of the vehicle for a 24-hour period. A 24-hour period accounts for a full day's usage along with any overnight charging or temperature soaking. The 24-hour cycle is estimated by converting the fossil fuel energy used to a kWh equivalent to obtain a standardized reference. The conversion ratio used is 8.69 kWh/L of gasoline or diesel fuel. It reflects the energy used, either electric or fossil fuel, to cover the 30 km distance travelled per day, plus the power to energize an 800 W block heater plugged in overnight for an estimated 13.75 hours, plus the energy consumed by the battery warmer active time, based on the battery cool-down time and the heating time overnight. This cycle would also include an extrapolation of typical idling periods that the vehicle undergoes. In this study, the winter condition power source was 120 V, while the power source for summer conditions was 208/220 V.

5.7.1 Winter conditions

In the winter, the EV's auxiliary heater must ensure adequate heat for the passenger cabin and the ICE engine block heater is activated to ensure engine startability in cold conditions. The vehicle's idling time during the day would be two hours. Because of the cold weather conditions, the engine is allowed to idle longer for various reasons, ranging from safety issues to cabin temperature and starting. The total energy for 24 hours is the sum of the energy for traction (driving and idling) and either the block heater for the ICE vehicle or the auxiliary heater for the EV's energy consumption. It is possible to estimate that the ICE energy consumption of 85.5 kWh is at least three times that of the EV at 28.4 kWh.

5.7.2 Summer conditions

In the summer, the block heater and auxiliary heater are not used. The total energy is only that required for traction plus idling time. The idling time for summer conditions is approximately 1 hour. The shorter idling time and warmer temperature reduce the ICE energy consumption to 51.5 kWh. The EV cabin heater and battery warmer are not used in summer; therefore, the only energy consumption is that used by the traction motor, i.e. 14 kWh, four times less than for the ICE version.

5.7.3 Average 24-hour duty cycle energy balance

Combining summer and winter energy consumption into a typical average 24-hour duty cycle for those mail delivery vehicles (approximating the average year of eight summer months and four winter months), the EV is more than three times more energy efficient than the ICE version at 18.8 vs. 62.8 kWh/day. (See Figure 12.)

5.8 Greenhouse gas emissions

The 24-hour energy cycle described in Section 5.7 was estimated on an energy consumption basis. CO_2 production can also be estimated over 24 hours in a similar manner. As energy is being consumed, CO_2 gas is being produced, at a rate dependent on the kind of energy being consumed. CO_2 gas is the transport industry's major greenhouse gas. It is produced by internal combustion engines burning fossil fuels or fossil fuel-fired thermo-electric power plants. While the electricity produced by hydro power is clean, the coal-fired power plant production emits the highest emissions per kWh and contributes to 15.5 percent of the total Canadian electricity production. These coal-fired plants are known as "base production plants" and any excess demand would be met by other, cleaner fuels, such as oil or natural gas.

A 1995 NRCan study (3) shows that the Canadian electricity production mix consisting of fossil fuels, nuclear and hydro-electric, produced 192 grams of CO_2 per kWh at the power plant. The efficiency of electricity transportation is estimated at 93 percent. When the energy is 100 percent hydro-electric, the EV truck's CO_2 emissions are significantly reduced.

5.8.1 Winter conditions

At -20°C, the ICE 24-hour CO_2 production is 20 kg. This includes the amount produced while driving the daily postal route in addition to the amount generated while the engine is idling and the amount required to energize the block heater. The driving portion of the cycle produced 13.45 kg of CO_2. The two-hour idling portion produced 4.27 kg. The block heater used 11 kWh at 93 percent efficiency and 192 g/kWh produced 2.26 kg. Extrapolated to a four-month period (4/12*52 weeks * 5 days = 88.6 days), this amounts to (13.45+4.27+2.26) *88.6 = 1,731 kg.

The EV CO_2 production when using the Canadian mix electricity power production for a 24-hour period is 6.43 kg. This includes the amount produced by the diesel-fired cabin heater while driving and idling and the amount produced by generating the electricity to recharge the vehicle and maintain the battery pack heat. The driving portion produced 0.78 kg and the idling portion produced 1.21 kg. The recharge and battery pack heating portion required 21.6 kWh at 93 percent efficiency and 192 g/kWh, producing 4.44 kg of CO_2. Extrapolated to a four-month period (88.6 days), this amounts to (0.78+1.21+4.44) * 88.6 days = 557.6 kg.

When comparing the ICE and the EV, we see that the EV produces *three times* less CO_2 than the ICE. As an example, four months of operation of one vehicle would reduce CO_2 emissions by 1,173 kg.

If the energy is hydro-electric, the CO_2 production is attributable only to the diesel-fired cabin heater while driving and during idling. The driving portion produced 0.782 kg and the idling portion produced 1.21 kg, for a total of 2 kg. Extrapolated to a four-month period, it amounts to 173 kg. The EV would produce *nine times* less (1,535 kg/173 kg) CO_2 than the ICE.

5.8.2 Summer conditions

In summer conditions, the idling time is 1 hour for the ICE version with no diesel heater CO_2 emissions for the EV version since it is not being used. While driving the daily postal route, the ICE produced 11.87 kg, plus 2.13 kg generated while the engine was idling, for a total of 14 kg. The EV's CO_2 production when using the Canadian mix electricity power production for a 24-hour period was 2.69 kg, five times less than with the ICE vehicle. This includes the energy used to recharge the vehicle, 14 kWh at 93 percent efficiency and 192 g of CO_2 per kWh. If we extrapolate to eight months (8/12 * 52 weeks * 5 days = 173.3 days) of summer type use, the ICE will produce (14 kg * 173 days) 2,427 kg of CO_2 and the EV 466 kg. If the electricity is hydro-electric, the ICE would produce 2,427 kg more than the EV.

5.8.3 Average 24-hour duty cycle CO_2 emissions balance

Combining summer and winter CO_2 emissions into a typical average year of operation for these mail delivery vehicles (approximating the average year at eight months of summer and four months of winter), the electric version emits four times less CO_2 than the ICE version at 1,023 vs. 4,158 kg. If the electricity is hydro-electric, the EV emits 20 times less CO_2 than the ICE version. (See Figure 13.)

5.9 Estimated 24-hour duty cycle local area criteria pollutant emissions

Using the same calculation methodology used for the energy and CO_2 24-hour duty cycle, it is estimated that the EV provides an annual emissions reduction of 102 kg of CO, 7 kg of NO_x, and 17 kg of THC over the ICE vehicle, almost a 100 percent reduction.

6 DYNAMIC TESTING AT PMG

The vehicles were tested at the PMG test centre for braking, acceleration, maximum speed, and for the EV maximum range at 80 km/h (45 mph) (see Figure 1). All tests were done on an exterior test track. The brake tests consisted of driving the vehicle at 75 km/h and then applying the brakes (hard braking). The two vehicles exhibited similar performances except for the dry pad, where the EV required an extra 6.2 m to stop, probably because of its extra weight.

The lack of braking distance difference during wet conditions can be explained by the testing conditions themselves. Normally in braking tests, a specified value for pedal force is provided; however, in the EV America protocol, no pedal force is specified. Therefore, brake tests become more subjective, as it is left to the driver to control the pedal force at pending lock-up. Therefore, the performance of the vehicle on dry pavement is a better indication of the differences of braking performance of the two vehicles.

In terms of acceleration, better performance was achieved at 50 percent state of charge, then at 90 percent state of charge. This is counter intuitive, because batteries can normally supply higher power at higher states of charge. This difference is explained by examining the motor controller characteristices. At higher states of charge, battery voltage is higher. The controller has a safety feature that limits power (by managing current flow) in the controller at higher voltage, as a safety precaution. This, therefore, limits the vehicle performance at higher (90-100 percent) states of charge.

The acceleration test indicated that from 0 to 80.0 km/h, the ICE took an average of 14.5 seconds and the EV took 55 seconds. The reason the EV took so long to achieve this speed is that it is very close to the vehicle’s maximum speed, compared with 120 km/h for the ICE. The EV’s range at 72 km/h (45 mph) was 39.8 km. Its range at maximum speed was 53.7 km. This unexpected result can be explained by the fact that the EV America test procedure requires that the accelerator pedal be at the maximum position for the duration of the test and that at that pedal position the EV will run at approximately 81 km/h for three minutes, at which point the controller goes into a power-saving mode, which cuts the power to the traction motor and the maximum speed drops to 66 km/h for the remainder of the test. This is slower than the 72 km/h constant speed test requirement, which explains a greater range at maximum speed than at 72 km/h. These results are very specific to this vehicle and we would normally see the opposite in other EVs. The maximum speed obtained on 3 and 6 percent grades is substantially less for the EV than for the ICE, reflecting a weaker traction motor.

Table 9 shows a summary of the results obtained during dynamic testing at PMG.

Table 9 – Summary of comparative dynamic performances of the EV and ICE truck versions

Test	EV state of charge	Electric vehicle	Conventional vehicle	EV America specifications
Average range (in km) at 72 kph (45 mph)	100%	39.8	N/A	N/A
Average range (in km) at maximum speed	100%	53.7	N/A	N/A
Average acceleration (in sec) from 0 to 80 kph (50 mph)	90%	64.5	14.5	<=13.5 sec
Average acceleration (in sec) from 0 to 80 kph (50 mph)	50%	47.0	14.5	<=13.5 sec
Average maximum speed (in km/h) on level road	90%	81.8	119.8	>=113 km/h
Average maximum speed (in km/h) on level road	50%	80.8	120.1	>=113 km/h
Average maximum speed (in km/h) on a 3% slope	50%	65.3	102.8	>=86 km/h
Average maximum speed (in km/h) on a 6% slope	50%	53.5	94.8	>=72 km/h
Average maximum gradability (in %)	50%	20.2	35.5	>=25%
Average brake test (in m), dry pavement at 75 kph (46.8 mph)	<50%	41.6	35.4	N/A
Average brake test (in m), wet pavement at 75 kph (46.8 mph)	<50%	42.2	43.1	N/A
Average emergency braking (in m) from 75 kph (46.8 mph)	<50%	34.2	34.2	N/A
Maximum vehicle recharge time (h)	0-100%	6.6	N/A	<=12 h
Speedometer error (%)	N/A	10.0	-18.7	N/A

Compared to the ICE version, the EV's dynamic performance is marginal and does not meet EV America's minimum requirements, which have been set to help American electric utility companies evaluate and acquire acceptable EVs for their fleets. It might be argued that the current Solectria-Grumman electric truck's dynamic performance is not sufficient for the vehicle to operate well with typical urban traffic speed and acceleration requirements, particularly where expressway segments must be travelled.

7 CONCLUSION AND RECOMMENDATIONS

The comparative performance evaluation of the two Mini-Grumman LLV right-hand drive mail delivery trucks revealed the following.

- The EV, when used in a typical 24-hour postal delivery duty cycle, on an average day (eight months at 20°C and four months at -20°C):
  - is at least three times more energy efficient than the ICE version;
  - emits four times less CO_2 than the ICE version (based on average Canadian electric power generation mix);
  - emits on average 99 percent less criteria pollutants than the ICE version in the urban centre where it operates.

- On a typical postal delivery route, the electric drive version has a range of 29 km at 20°C and 3 km less at -20°C. (Note that these performances are estimated using dynamometer test results, which do not account for the reduced efficiency attributable to:
  - effect of increased air density on aerodynamics in -20°C conditions;
  - effect of snow and ice on traction losses.

- Because of its auxiliary fuel-fired heater, the EV has the potential to keep the cabin compartment warmer because of the available heat capacity and the fact that this heat is independent of the main engine (ICE) operating conditions.

- The EV exhibited only marginally acceptable dynamic performances.
  - it meets none of EV America's minimum performance requirements;
  - its top speed is 80 kph;
  - its acceleration from 0 to 80 kph takes approximately 55 seconds, more than three times the ICE version performance;
  - its stopping distance from 75 kph is 6.2 m farther than the ICE version.

It is recommended that the electric truck acceleration and speed performance be improved to permit a more harmonious phasing with typical urban traffic speeds.

The traction battery capacity should be improved by adding a few more battery modules or by switching to a higher capacity battery technology, such as nickel-metal-hydride or lithium-polymer advance systems. This would ensure the vehicle's ability to complete, with an appropriate capacity margin, the 24-hour postal duty cycle.

It is also recommended that the battery thermal management system be made to operate while charging at 220 V to preserve the already limited battery energy capacity at low ambient temperatures.

Overall, it is expected that with the recommended improvements, the electric drive vehicle can become a viable and more environmentally sustainable mail delivery vehicle option for Canada Post.

8 FIGURES

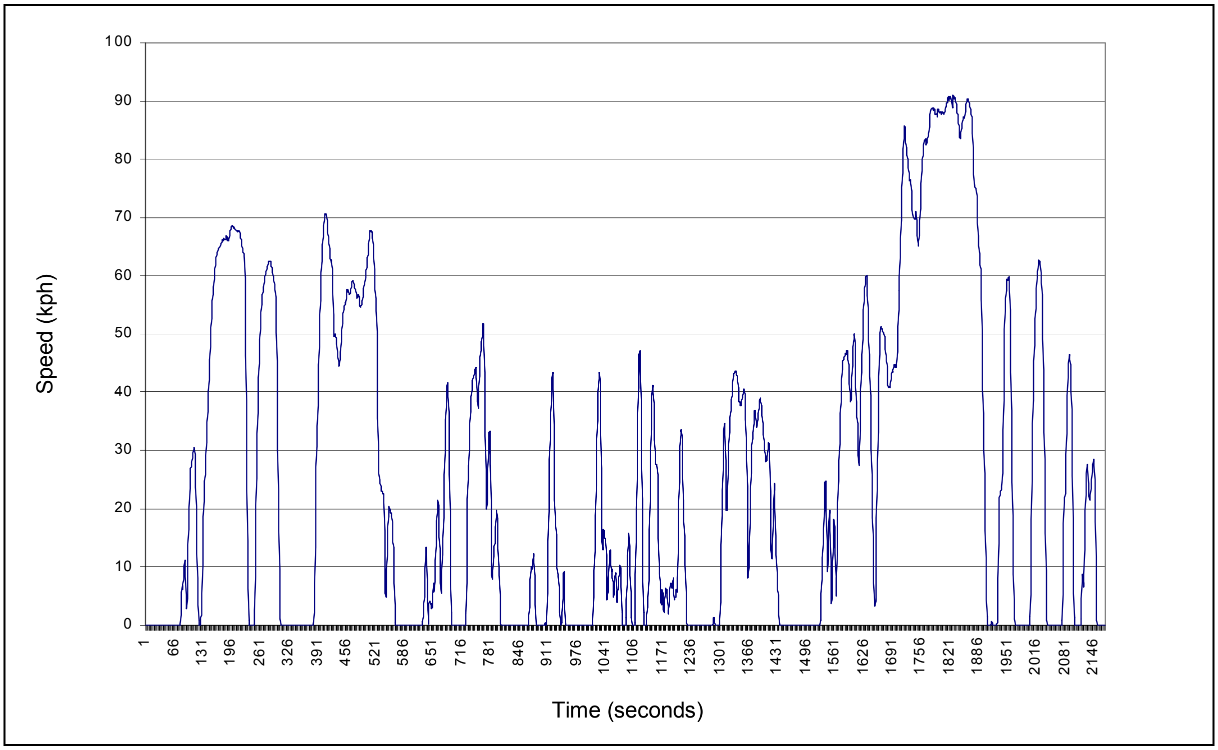


Figure 1 Typical postal delivery duty cycle

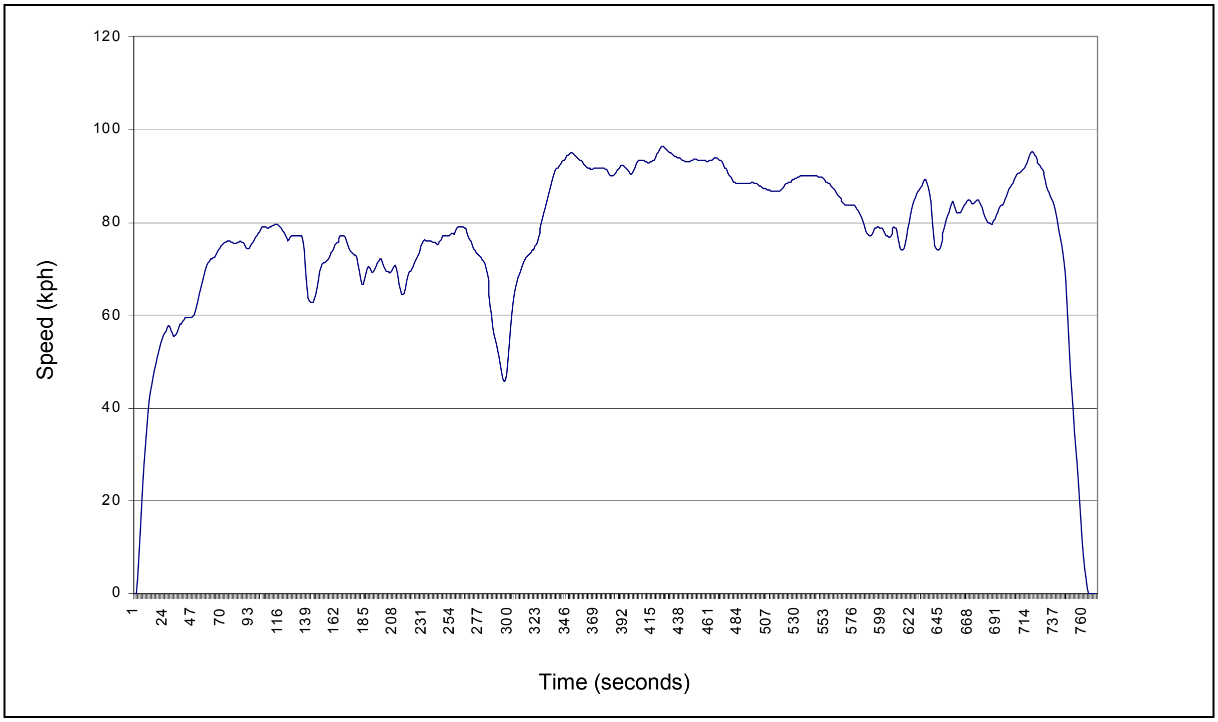


Figure 2 Highway fuel economy test cycle

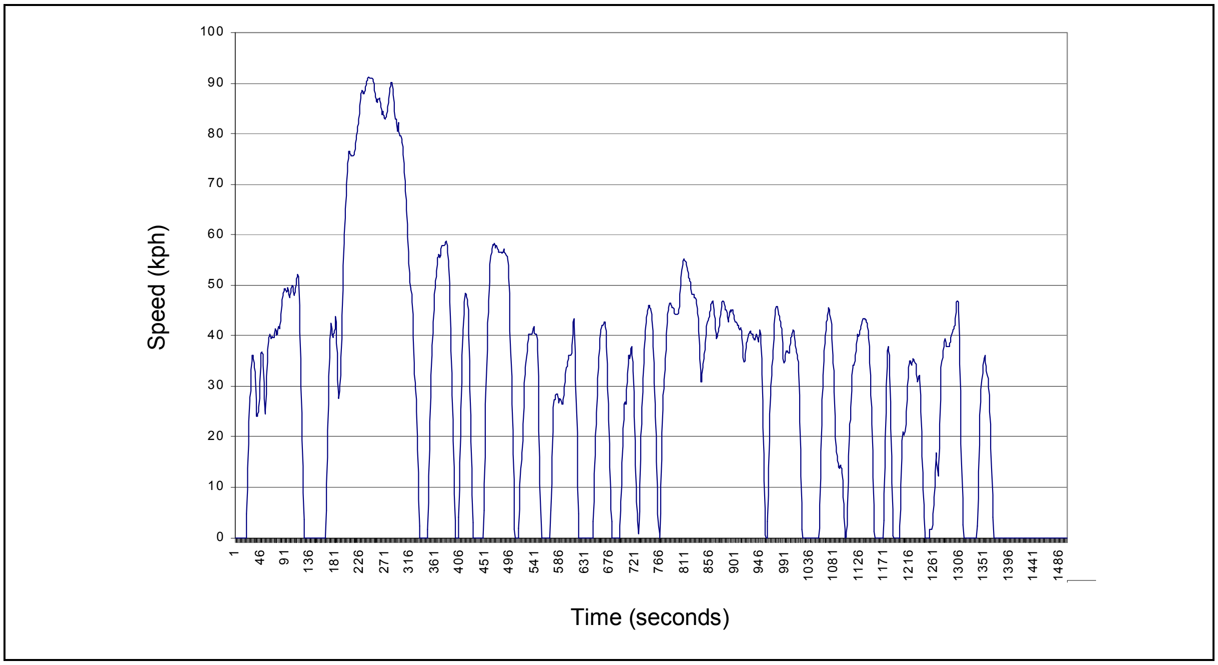


Figure 3 **Urban dynamometer driving test cycle**

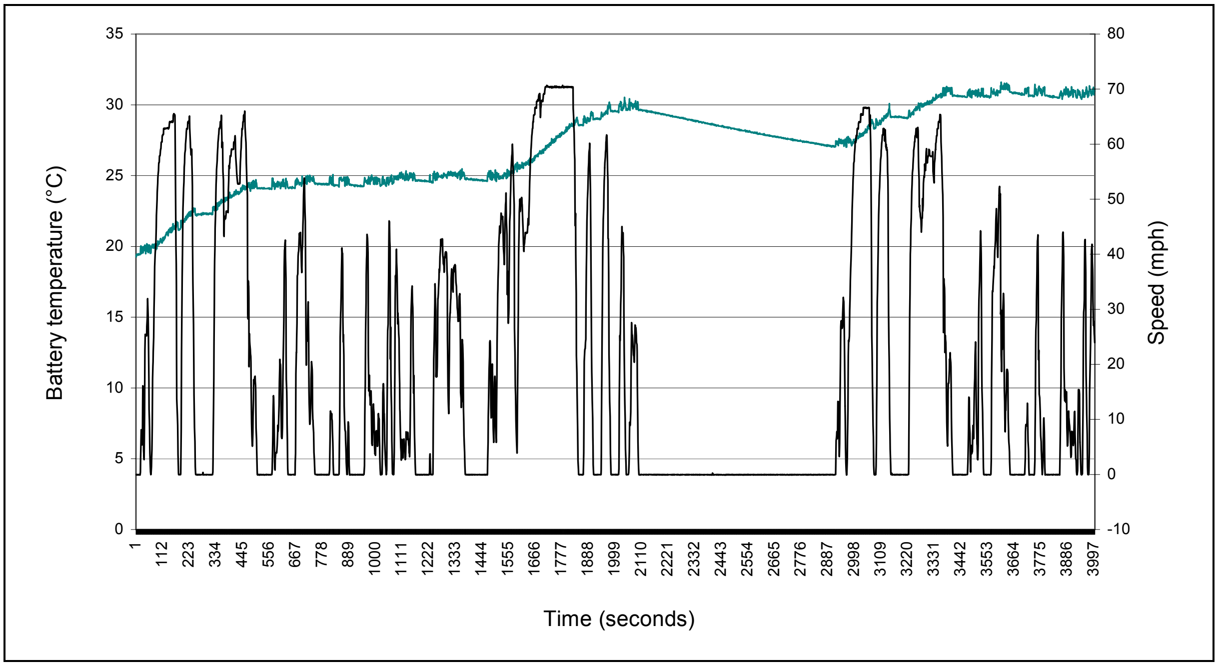


Figure 4 **EV battery temperature, postal cycle, at -20°C**
(13 April 1999)

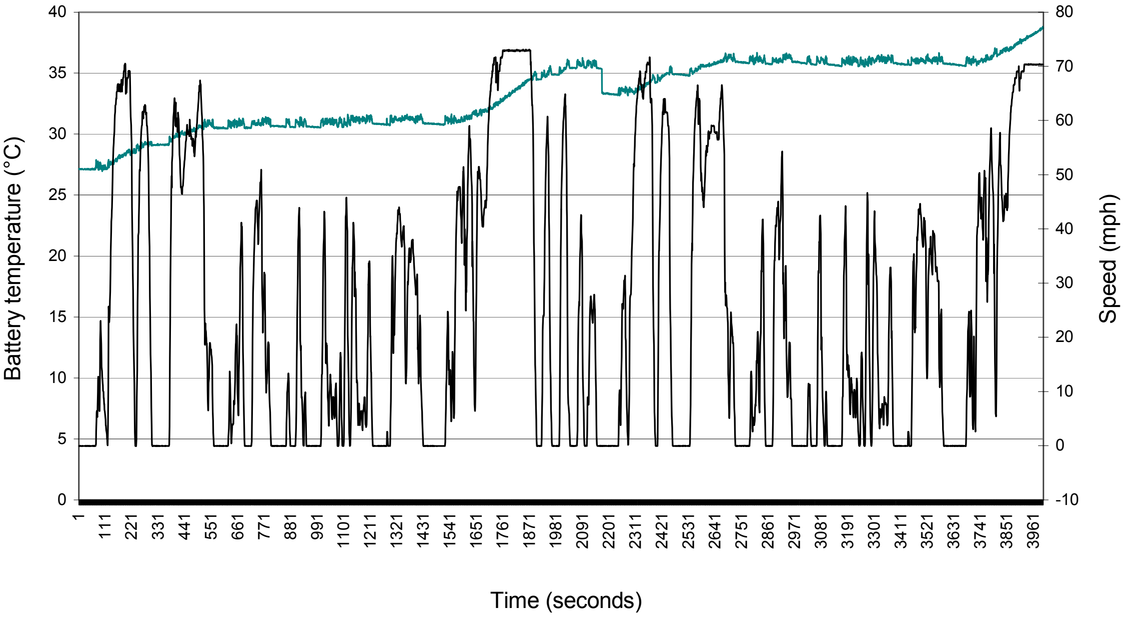


Figure 5 **EV battery temperature, postal cycle, at 20°C**
(16 April 1999)

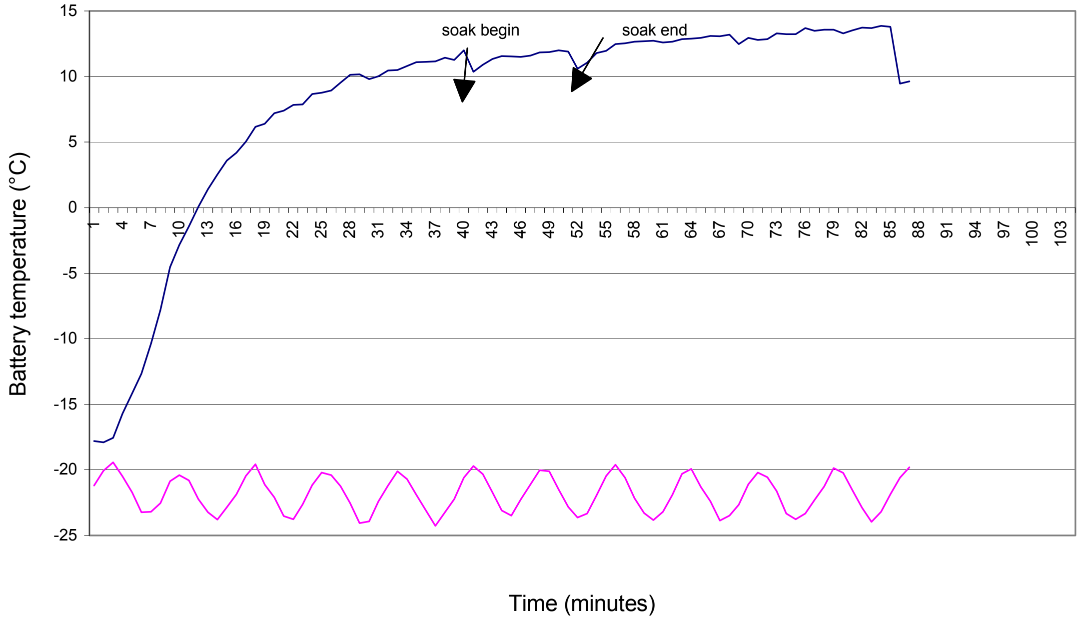


Figure 6 **EV cabin temperature at -20°C with heater on, between two postal cycles**
(13 February 1999)

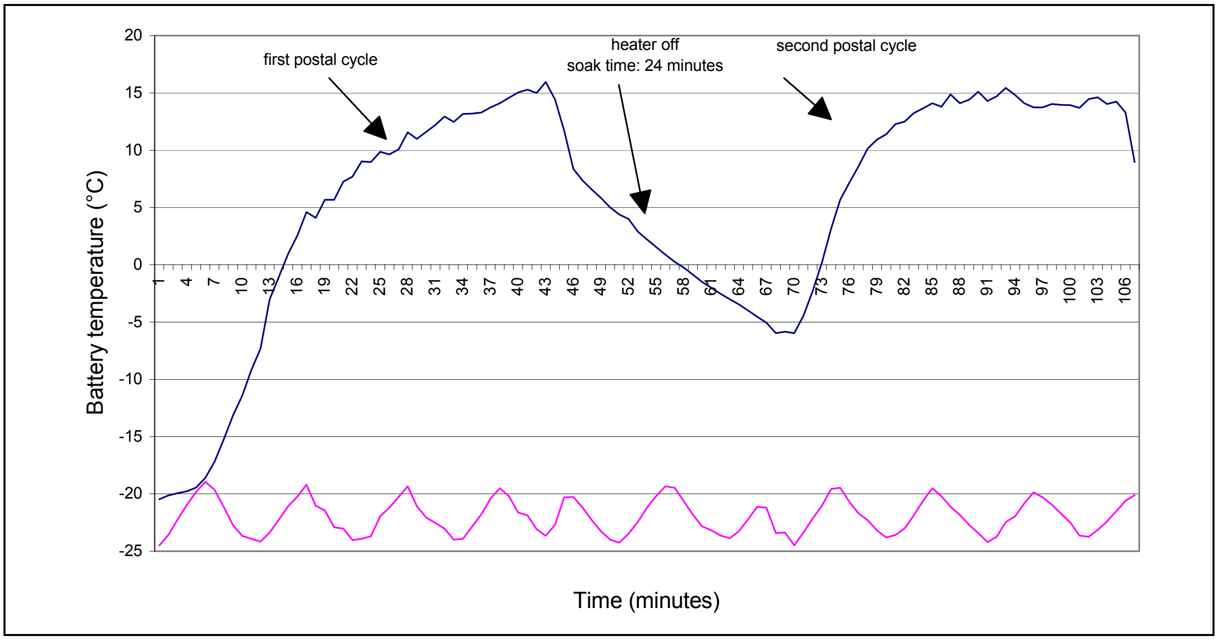


Figure 7 **EV cabin temperature at -20°C with heater off, between two postal cycles** (7 April 1999)

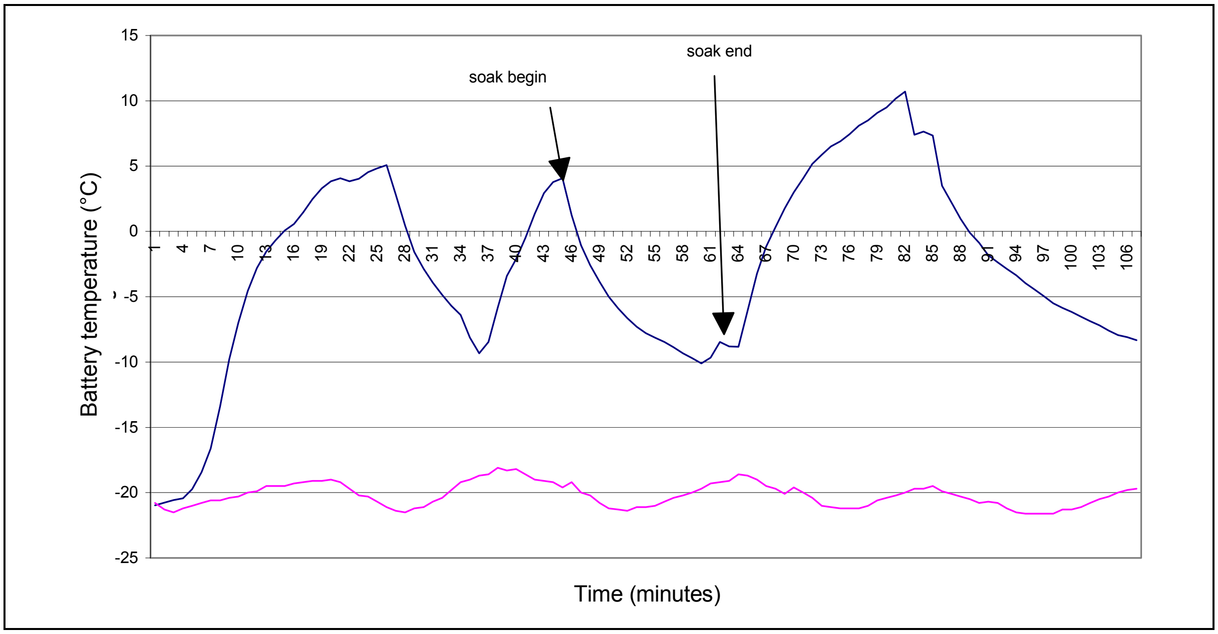


Figure 8 **ICE cabin temperature at -20°C, postal cycle** (22 February 1999)

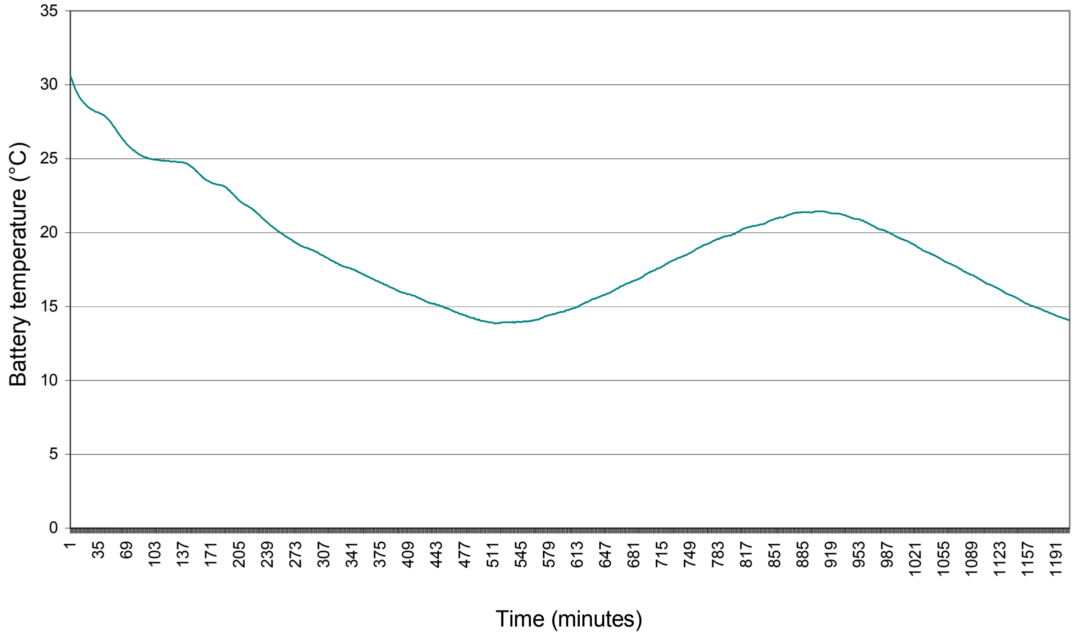
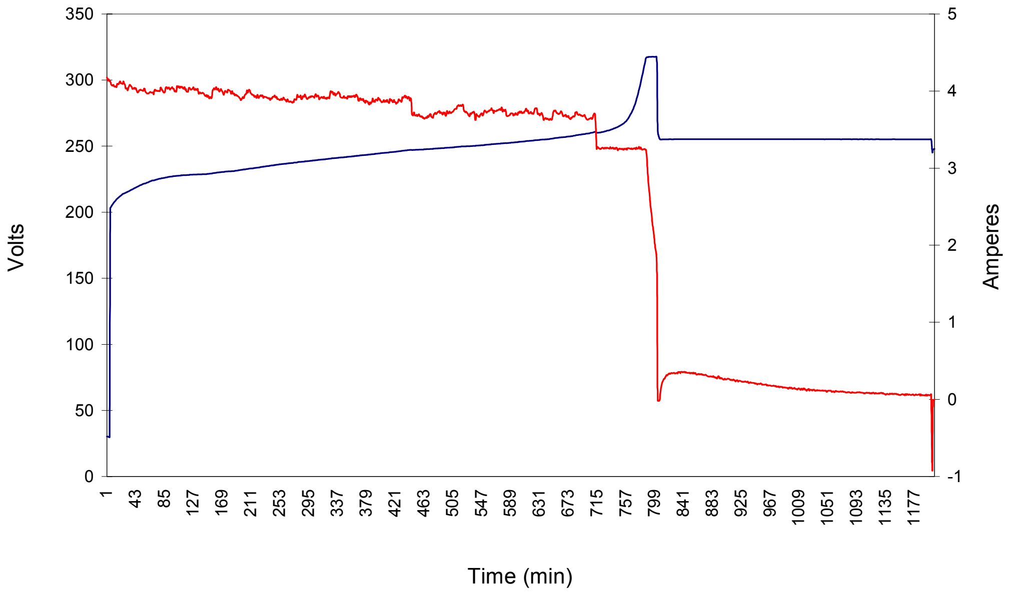
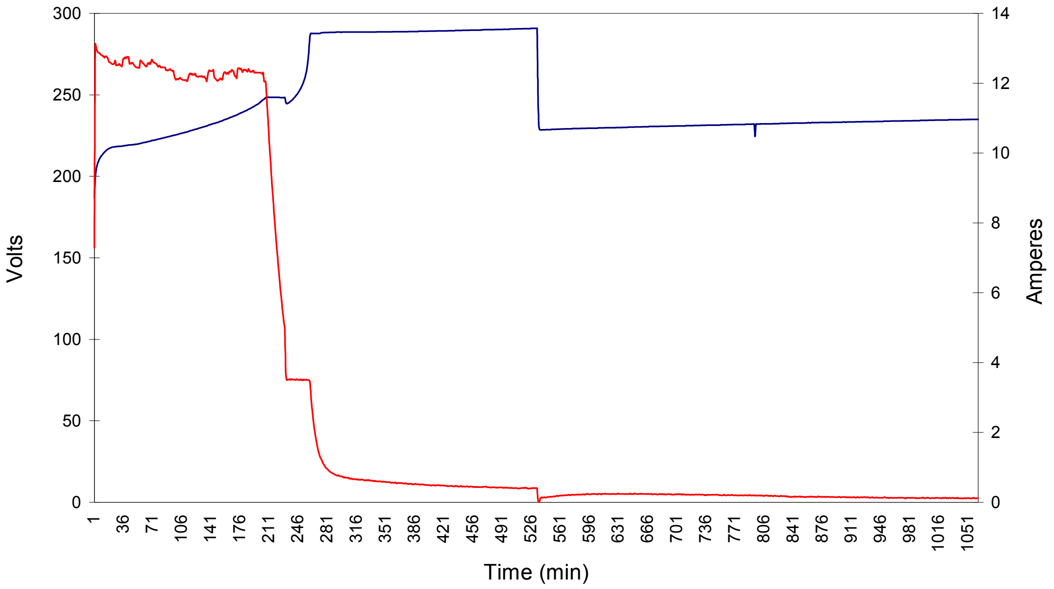


Figure 9 **EV battery temperature while charging (120 V) at -20°C**
(13-14 April 1999)



Voltage:	120 V	Time plugged in:	25:21 h	AC kWh:	24
DC Ah:	51.73	DC charge time:	13:42 h	DC kWh:	12.60

Figure 10 **EV battery charging (120 V) at -20°C**
(13-14 April 1999)



Voltage: 220 V
DC Ah: 51

Time plugged in: 17:43 h
DC charge time: 5:25 h

AC kWh: 14
DC kWh: 12.06

Figure 11 EV battery charging (220 V) at 20°C
(25-26 March 1999)

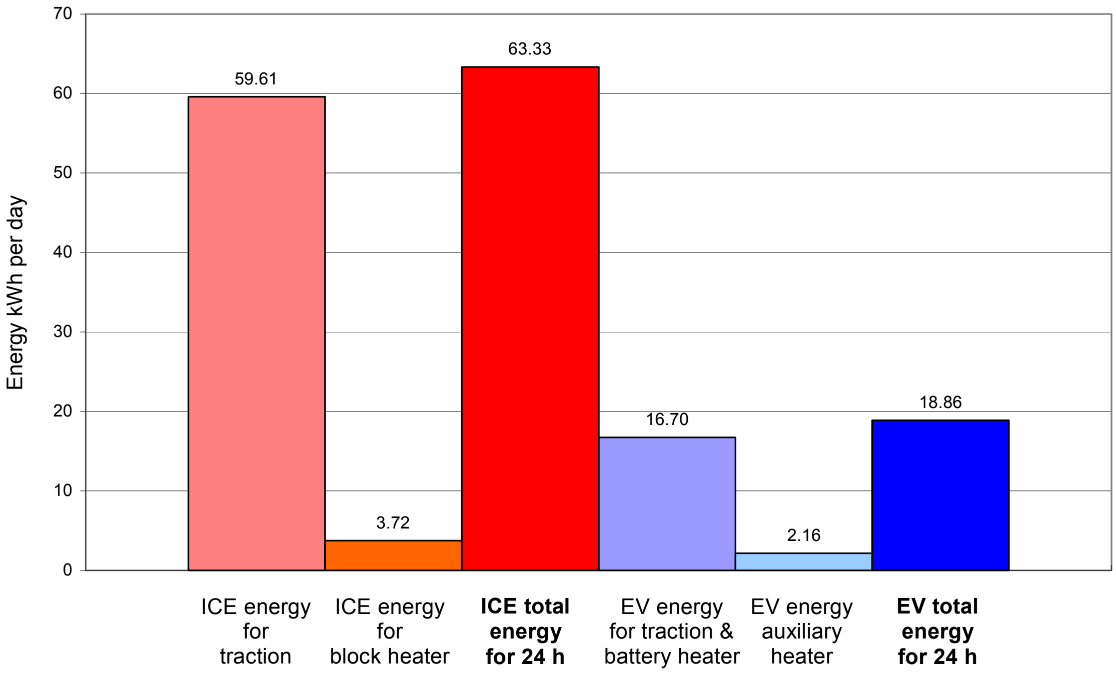


Figure 12 Average 24-hour energy consumption, ICE vs. EV postal truck

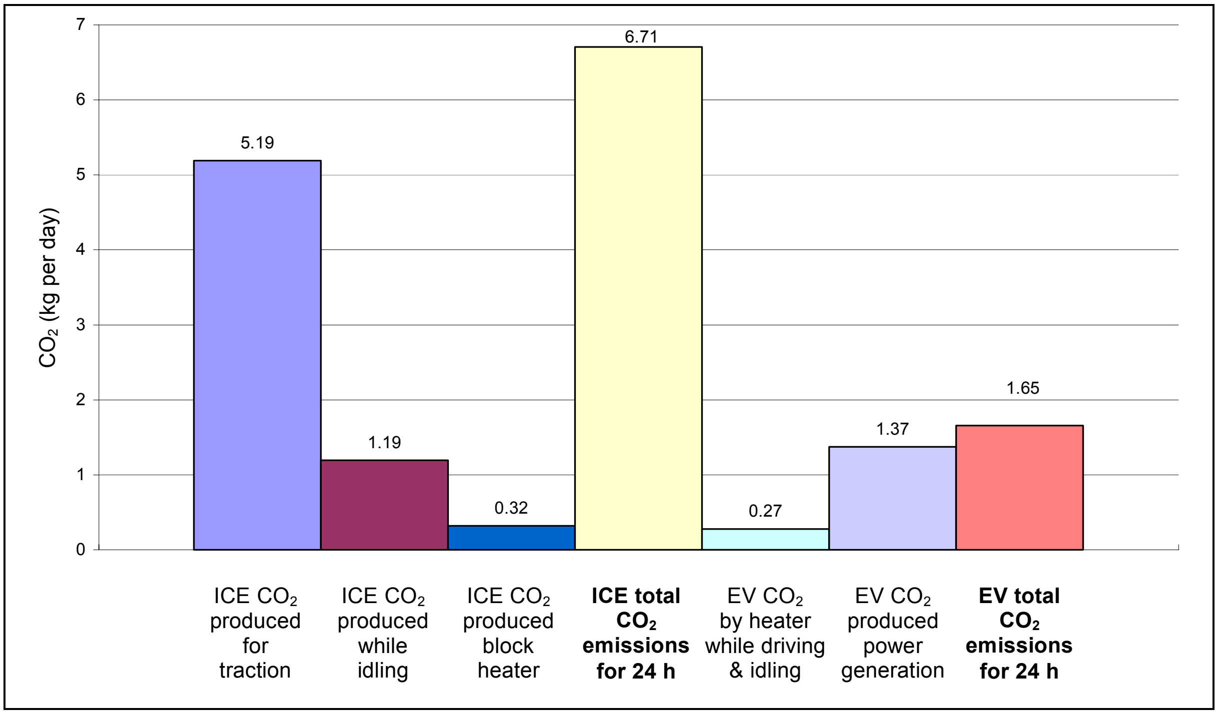


Figure 13 **Average 24-hour CO$_2$ emissions, ICE vs. EV postal truck**

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1. *Gasoline Mail Delivery Truck*, Test Report, No. RR00-036, 21 July 1999

2. *Electric Mail Delivery Truck*, No. RR00-34, 21 July 1999

3. *Trends in Canada Greenhouse Gas Emissions*, 1990-1995, Cat. No. EN49-5/5-8E