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VECTRIX MAXI-SCOOTER PERSONAL ELECTRIC VEHICLE

TEST RESULTS REPORT

Prepared by eTV
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Abstract

The Vectrix Personal Electric Vehicle is one of the world's first highway capable (maximum speed – 100 km/h) electric motorcycles. It is a fully electric, zero-emission and CMVSS-compliant open motorcycle. The ecoTECHNOLOGY for Vehicles (eTV) program selected the Vectrix for testing to determine if electric motorcycles are a viable mode of clean transportation in Canada. More specifically, eTV evaluated the Vectrix's energy consumption, daily charging efficiencies and performance at various states of charge.

Summary of results

Criteria	Results
Acceleration	•Reached maximum achievable speed (100 km/h) throughout all levels of battery charge except 20% state of charge (SOC) •At 20% SOC, not able to accelerate above 2.1 m/s^2 •At 20% SOC, not able to reach a speed higher than 30 km/h without losing power and retreating to power-save mode
Range at constant speed	•Able to travel about 70 kilometres at 60-70 km/h •Energy capacity is rapidly depleted at higher speeds
Braking	•Compliant with all aspects of the CMVSS 122 standard
Energy consumption	•Consumed an average of 4.8 kWh of electricity per charge
Charging efficiency	•In the city, in stop-and-go traffic, with an average speed of 24.3 km/h, the charging efficiency was between 6.6 and 6.9 km/kWh •On the highway, with an average speed of 68.7 km/h, charging efficiency was between 6.5 and 7.1 km/kWh
Electricity life cycle CO_2 emissions	•Averages about 33 g/km of CO_2 equivalent emissions for both the urban and highway driving cycles
Cost of electricity	•Consumed an average of 4.8 kWh of electricity per charge, for a cost of 1.5 cents per kilometre (based on an average of 10 cents per kilowatt-hour)
Gasoline equivalency	•Calculated gasoline equivalency is 1.66 L/100 km for city and 1.65 L/100 km on the highway.

1. INTRODUCTION

As witnessed by the visitors to the ecoTECHNOLOGY for Vehicles (eTV) booth, electric vehicles are becoming more prevalent in the minds of Canadians as an alternative to gasoline-fuelled vehicles. Due to the zero tailpipe and low life cycle CO_2 emissions associated with electric vehicles, they are an attractive technology for achieving eTV's goal of helping achieve a clean transportation system in Canada. As a result, electric cars and motorcycles are given full consideration for inclusion in the eTV program for testing and evaluation.

The Vectrix Personal Electric Vehicle (PEV) was selected for testing because it is a fully electric open motorcycle that is compliant with the Canada Motor Vehicle Safety Standards (CMVSS). In available documentation, the Vectrix is described as being capable of reaching a top speed of 100 km/h (62 mph) and a total range of 55 to 90 km (35 to 55 miles). Given the program's mandate to test new and emerging technologies, including electric vehicles, the Vectrix was evaluated using extensive testing procedures that are in keeping with established practice for testing electric battery-powered motorcycles certified for operation on Canadian public roads. This document provides information on the results of standard tests for determining energy consumption and range over a number of speeds and states of charge. Evaluations are based on the performance of the motorcycle's overall systems, rather than on its subsystems and components.

2. TESTING PROGRAM

The testing program was designed to provide an overall assessment of the electrically powered Vectrix PEV. The suggested tests were based on practices used by the Electric Vehicle Association of America, the International Standards Organization and the Society of Automotive Engineers (see Vectrix Test Plan for details).

The range, vehicle charging efficiency, energy consumption over separate driving cycles and acceleration and deceleration characteristics at varying payloads were tested.

3. TESTING LOCATION

All testing was performed at Transport Canada's test track facility in Blainville, Québec. The controlled environment was necessary to ensure that testing was performed on a gradability of ± 1%.

The test track is equipped with over 25 kilometres of road, including both a high-speed and low-speed circuit, to allow for a variety of tests.

Figure 1 – Transport Canada Test Track Facility, Blainville QC

Testing was performed between October 8 and November 13, 2008. Tests were carried out only in weather conditions that were favourable to evaluation and testing standards.

4. VEHICLE OVERVIEW

The Vectrix personal electric vehicle is one of the world's first high-speed electric motorcycles capable of achieving a maximum speed of 100 km/h (see Figure 2).

Figure 2 – Vectrix Personal Electric Vehicle

The vehicle is equipped with a 30 amp-hour (3.7 kWh) nickel metal hydride (NiMH) battery.

The two battery packs are located under the driver's seat and near the driver's feet, to provide a low centre of gravity. The weight of the battery packs is approximately 90 kg (200 lb), comprising almost 40% of the vehicle's total mass without the driver.

The vehicle is also equipped with regenerative braking, using a unique bi-directional throttle. To accelerate, as with a conventional motorcycle, the user simply rolls the

throttle towards them. To engage regenerative braking, the user rolls the throttle in the opposite direction, past neutral, to progressively engage the regenerative braking (see Figure 3).

Figure 3 – Throttle System

5. ACCELERATION

The acceleration of the Vectrix was evaluated at separate states of battery charge (SOC). A fully charged battery is at a 100% SOC. This approach was used in order to evaluate the performance of the Vectrix through various levels of battery depletion. Evaluations were performed at 100%, 60%, 40% and 20% SOC.

The maximum acceleration was determined by accelerating the vehicle from a standing start to its maximum attainable acceleration rate until either the vehicle's peak speed was reached or until a safely operable speed was attained.

5.1 Results

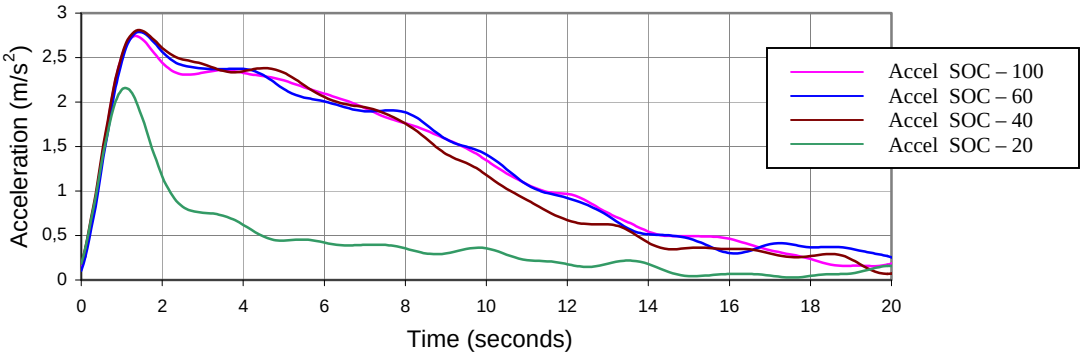

Figure 4 - Acceleration Versus Time (SAE J 1666)

The Vectrix has the ability to reach its maximum achievable speed (100 km/h) throughout most battery levels of charge (*see Figure 5*).

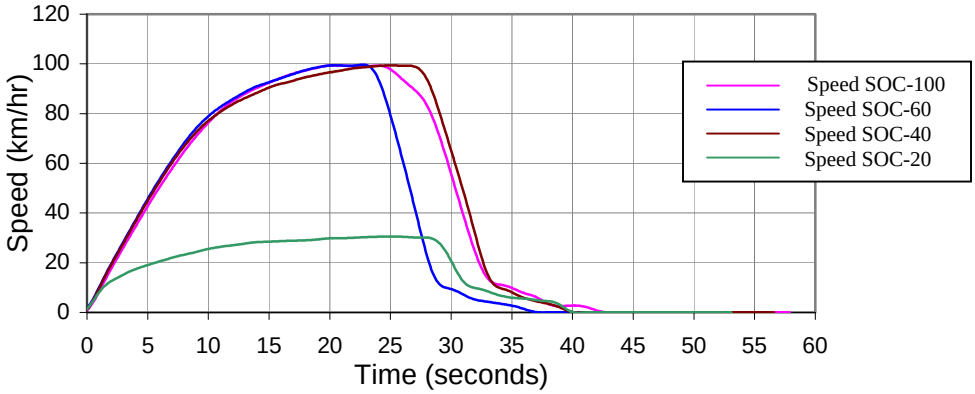

Figure 5 - Speed Versus Time (SAE J 1666)

However, it should be noted that at 20% state of charge (SOC), the vehicle's acceleration could not exceed 80% of nominal. The vehicle was not able to accelerate above 2.1 m/s^2 or to reach a speed higher than 30 km/h without losing power and retreating to the power-save mode that is intended to provide enough power for the driver to find a charging station.

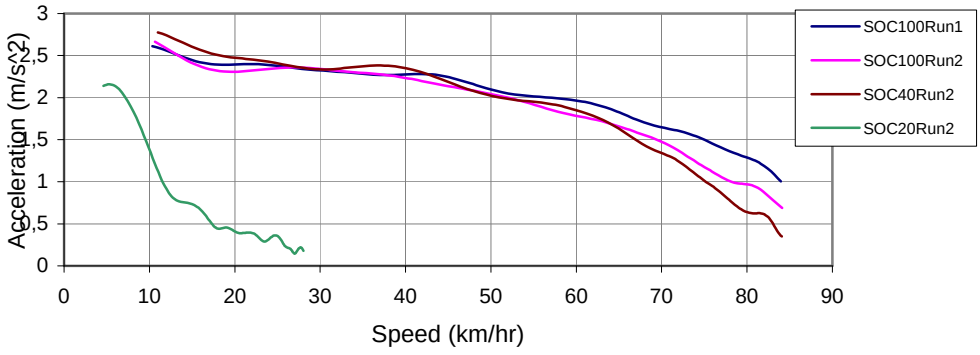

Figure 6 - Acceleration Versus Time (SAE J 1666)

6. RANGE AT CONSTANT SPEED

The range of the Vectrix was evaluated at several constant speeds. The purpose of the test was to determine the maximum distance that the vehicle could travel when the batteries are fully charged (100% SOC).

To perform the test, the vehicle was loaded to its wet curb weight plus driver (339.2 kg). From a standing start, the vehicle was accelerated to a constant speed and sustained until the vehicle could no longer maintain the required speed.

The range of speeds selected for testing were 40 km/h, 50 km/h, 65 km/h, 72 km/h, 96 km/h and the vehicle's maximum achievable speed of 100 km/h.

It is important to note that, due to the nature of the test, regenerative braking was not used. As such, the absolute range may differ when regenerative braking is used to increase the overall vehicle's range.

6.1 Results

In closed-track testing, the Vectrix was able to travel approximately 70 kilometres at a speed of 60 to 70 km/h (see Figure 7).

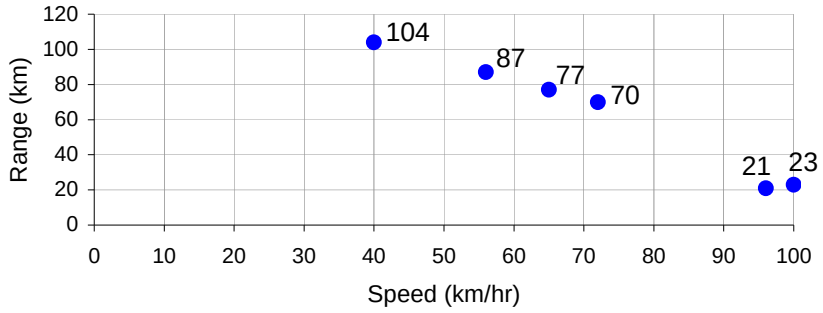

Figure 7 – Range Versus Speed

This means that the Vectrix may be an option for Canadians who want to drive an electric vehicle and who have a total daily commute of 40-60 kilometres, with no option of charging during the day.

However, at higher speeds, the energy capacity of the Vectrix's NiMH batteries is rapidly depleted (see Figure 8).

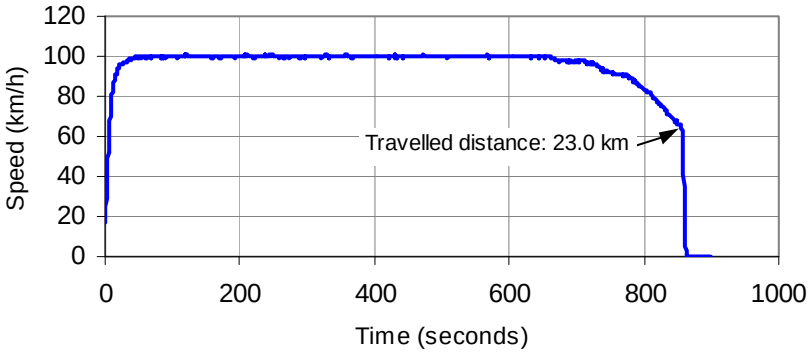

Figure 8 – Range at Maximum Speed

This is due to the large amounts of current necessary to provide sufficient power to the electric motor to continue to maintain a high level of speed. The effect is a range of less than 23 kilometres at a sustained speed of 100 km/h.

7. BRAKING

The Canada Motor Vehicle Safety Standards (CMVSS) 122 Motorcycle Brake Systems Test was performed. The vehicle was subjected to a burnishing of the brakes, which included over 200 individual stops. Repeated stops at speeds of 48.3 km/h (30 mph) and 96.6 km/h (60 mph) were performed in both dry and wet conditions.

Figure 9 – Vectrix brakes being soaked in water

7.1 Results

The Vectrix is compliant with all aspects of the CMVSS 122 standard. Figure 10 displays a sample of the stopping distances at both compliance speeds. It should be noted that it is typical for all vehicles to exceed the high-speed braking standard by a greater

relative amount than the low-speed braking standard. This is partially due to the difficulty in applying maximum braking pressure at the start of the brake test.

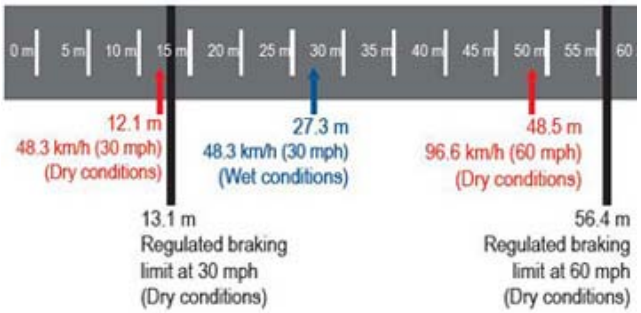

Figure 10 – Vectrix braking performance

8. ENERGY CONSUMPTION

Energy consumption is the energy used by a vehicle over a specific distance. In a vehicle using an electrically rechargeable battery, there is always a certain amount of the total AC energy supplied to the battery that is not available for vehicle propulsion, due to charger and battery inefficiencies or other vehicle maintenance requirements.

Energy consumption was measured in the following manner: the AC energy from the power outlet required to return the battery to full charge after testing was divided by the range of the vehicle on the particular test cycle, calculated in units of AC in Wh/km.

$$\textit{Vectrix AC energy consumption} = \frac{\textit{AC energy to charger for recharge}}{\textit{Distance travelled}}$$

Additionally, the vehicle's daily charging efficiency was also calculated, in units of km/kWh.

$$\textit{Vehicle charging efficiency} = \frac{\textit{Mileage travelled since last charge}}{\textit{Kilowatt-hours used}}$$

On-track AC energy consumption was evaluated by towing the vehicle back to the charging station after each test.

The preferred method of measuring energy consumption would have been to measure onboard direct current (DC) consumption and direct current regenerative braking and to compare these results to the AC energy consumption. However, this method proved to be problematic in that it required access to the manufacturer's battery management system

and schematics, which are proprietary and not available for testing. For this reason, only the AC energy consumption was measured.

8.1 Results

The following table illustrates a sample of the AC energy consumption recorded for the Vectrix.

Average Consumption (Watt) (1)	kWh Total (2)	kWh Cumulated	Charging Time (hours)	Actual Average Consumption (Watt) (3)	Actual Total kWh (4)	Standby kWh (5)
392.00	6.87	6.87	5.64	1103.40	6.22	0.65
167.00	2.85	9.72	3.01	699.30	2.10	0.74
103.00	9.75	19.47	4.71	1048.00	4.94	4.81
290.00	7.23	26.70	5.98	1035.60	6.19	1.03
332.60	5.83	32.53	4.79	1065.00	5.10	0.73
317.40	5.76	38.28	4.71	1057.40	4.98	0.78
695.00	2.81	41.09	3.41	811.10	2.77	0.04
93.00	6.29	47.38	3.35	803.10	2.69	3.60
915.00	3.10	50.47	3.38	915.20	3.09	0.00
312.00	5.63	56.11	4.66	1045.00	4.87	0.76
56.10	1.24	57.34	0.15	362.00	0.05	1.18
1667.70	1.88	59.23	1.13	1667.70	1.88	0.00

Table 1 – AC Energy Consumption

In Table 1, the average energy consumption (1) contains the total energy consumption from connection to an electrical outlet to disconnection, and includes all the different modes in which the vehicle's onboard charger operated. For energy consumption related to travelled distance (4), the actual energy consumption should be dissociated from the energy consumption when the onboard charger operates in standby mode (5).

Therefore, actual total consumption (4) is calculated from {total consumption (2) minus standby consumption (5)}, which corresponds to just-completed charge consumption (4).

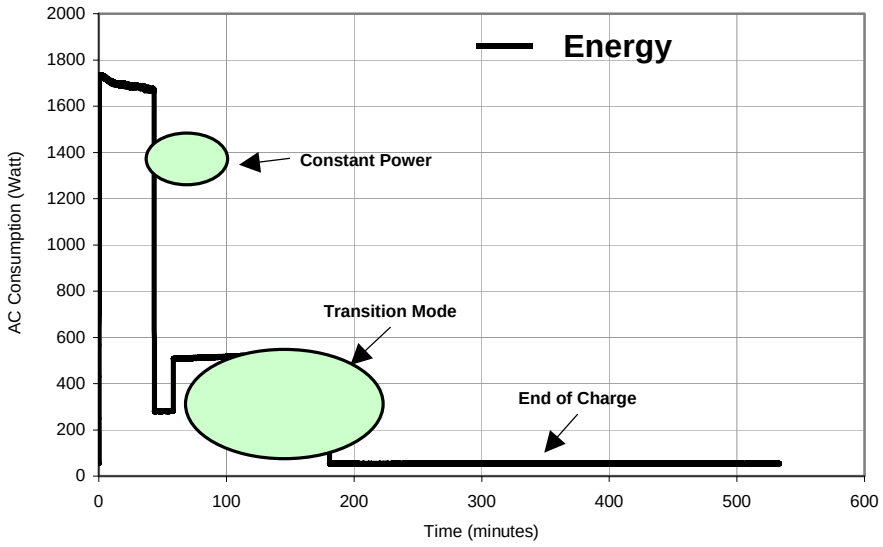

Figure 11 - AC Energy Consumption Charge Profile

Figure 11 shows the different charging modes during a single charge session. The charge modes are constant power, transition mode, constant current and end of charge.

By determining the total area beneath the curve (see Figure 11), the total energy consumption can be calculated for the Vectrix. The average consumption calculation does not include the standby period (indicated as the End of Charge in Figure 11). Taking into account all mileage accumulated during testing and fleet use, the Vectrix consumed an average of 4.8 kWh of electricity per charge.

9. URBAN AND HIGHWAY DRIVING CYCLE

To approximate the AC energy consumption and vehicle charging efficiency, various urban and highway cycles were selected.

The driving cycles were selected in accordance with the International Standards Organization Electric mopeds and motorcycles – Performance – Part 1: Reference energy consumption and range (ISO Standard 13064). Each cycle was performed over four consecutive trials, at both the vehicle's curb weight plus driver and at the gross vehicle weight rating.

9.1 Results

The urban driving cycle (see Figure 12) is a procedure used to simulate stop-and-go traffic with an average speed of 24.3 km/h and a maximum speed of 50 km/h.

Regenerative braking, although not directly measured, was implemented when slowing the vehicle down. The calculated vehicle charging efficiency for this cycle was determined to range between 6.6 to 6.9 km/kWh.

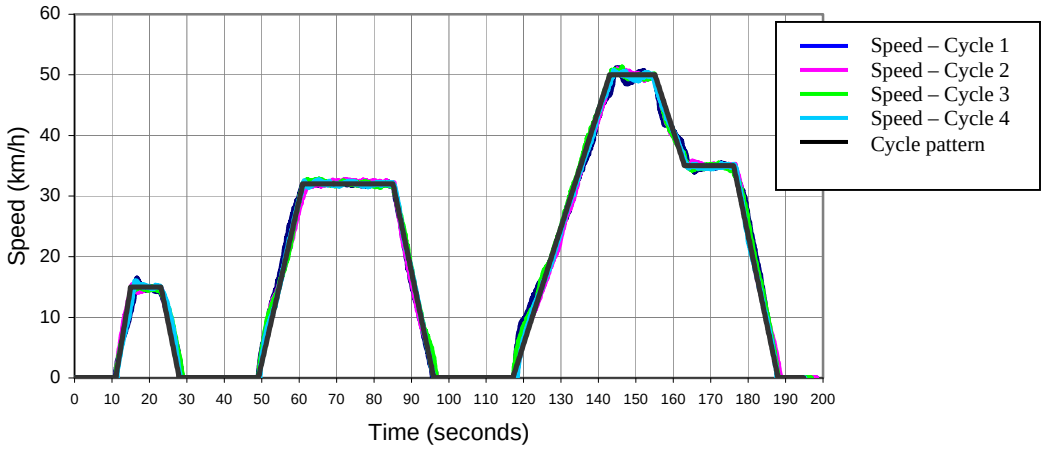

Figure 12 - Urban Driving Cycle (ISO 6460)

Similarly, a simulated highway driving cycle (see Figure 13) was also conducted. This cycle has an average speed of 68.7 km/h and a maximum speed of 100 km/h.

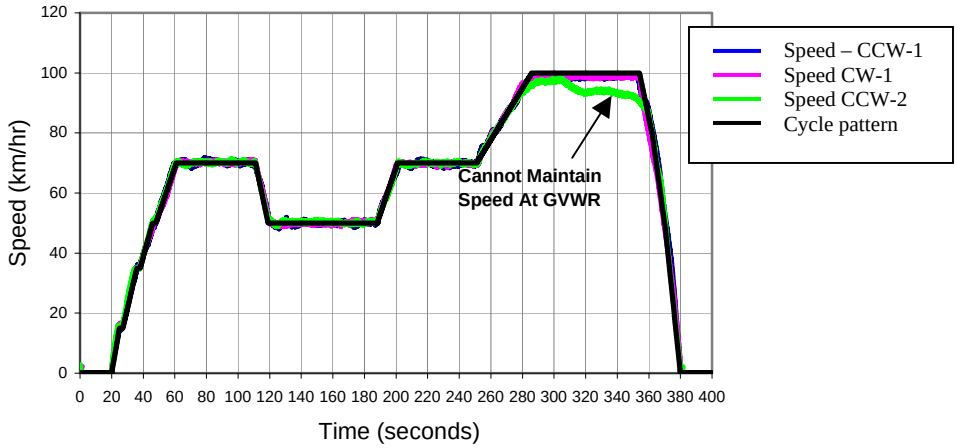

Figure 13 - Highway Driving Cycle (ISO 6460)

The calculated vehicle charging efficiency for this cycle was determined to be between 6.5 to 7.1 km/kWh. In high-speed trials with the vehicle loaded to its gross vehicle weight rating, the Vectrix was unable to maintain the required speed for the test procedure.

10. Electricity Life Cycle CO_2 Emissions

Electric vehicles offer zero emissions from a 'tailpipe' perspective. However, electricity – a portion of which is non-renewable energy – is required to charge the vehicle's batteries and to provide energy to the electric DC motor.

The following formula can be used to calculate the amount of CO_2 emitted into the atmosphere for the electricity generation for the vehicle, expressed in terms of grams per kilometre (g/km) of CO_2.

Vehicle CO_2 = Energy generation (g /kWh) x Vehicle kWh/km

Electricity generation is based on estimated values received by Department of Natural Resources on the CO_2 life cycle assessment of the Canadian electrical grid. The approximate national average for all of Canada is 228.4 kilograms of CO_2 per megawatt-hour of generated electricity.

10.1 Results

Applying the above formula to the results for both the urban and highway driving cycles, the Vectrix averages approximately 33 g/km of CO_2-equivalent emissions. It is important to note that CO_2 emissions will decrease even further in certain provinces where non-carbon polluting renewable resources – such as hydroelectric power – are used.

Conversely, the average American unit of electricity produces slightly more than three times the amount of CO_2 emissions as compared to Canada.

11. Cost of Electricity

The Vectrix charges from a standard 110V/15 amp household outlet. Charging is 80% complete after two hours and 100% complete after three hours. The Vectrix was driven in excess of 600 km, with each charge being recorded.

11.1 Results

As noted above, the Vectrix consumed an average of 4.8 kWh of electricity per charge. For Canadians, this means the Vectrix can be driven for about 1.5 cents per kilometre[1].

12. Gasoline Equivalency

To better understand the energy required to operate the Vectrix, a gasoline equivalency is provided to compare one fuel source (electricity) to a more common fuel source (gasoline).

[1] Based on an average of 10 cents per kilowatt-hour

12.1 Results

Taking the calculated vehicle charging efficiency for each cycle and using published U.S. Department of Energy data , the energy density for gasoline ($U_{gasoline}$) can be expressed as 115,000 Btu/gal or 8.903 kW/L. The calculated gasoline equivalency is 1.66 L/100 kilometres for the urban cycle and 1.65 L/100 kilometres for the highway cycle.

13. On-Road Evaluation

The eTV engineering team and staff also had the opportunity to test the Vectrix on the streets of the City of Ottawa.

Most users were impressed with the vehicle's acceleration in city traffic and with its balanced behaviour while driving. Other positives included knowing that they were enjoying a new form of transportation without producing harmful emissions.

At no time did users experience range anxiety, where they would not push the limits of the vehicle's energy storage capacity. Most users reported that they were able to enjoy their ride with some battery energy remaining. In some instances, when the limits were pushed, the vehicle went into a power-save mode with approximately 20% of battery charge remaining. However, users reported that they were warned by an indicator on the vehicle's instrument panel to charge the vehicle. Although acceleration was limited while in power-save mode, users were able to drive 10 to 15 kilometres while looking for

a charging station. Another positive note is that after only 90 minutes of charging, the Vectrix was able to travel a further 40 kilometres.

Lastly, users noted that the vehicle often became the focus of conversation at stoplights and rest stations. Other motorcyclists were often intrigued by the design and did not readily identify the vehicle as all-electric. Observers were extremely impressed that the vehicle was 100% electric and required less maintenance than a conventional gasoline-powered motorcycle.

14. Conclusions

For Canadians, the Vectrix offers an affordable alternative mode of transportation with an operating cost of less than two cents per kilometre and approximately 30-40 grams of life cycle CO_2 produced per 100 kilometres travelled.

As well, for Canadians with a daily commute of 40 to 60 km on roads with a posted speed limit of 60 km/h or less, range anxiety should not be an issue. Should it be necessary, recharging is possible at any standard household outlet, with an 80% charge achieved in less than two hours. Additionally, battery life should not be a concern as the

battery pack is rated to maintain 80% of its capacity after 10 years. In conclusion, the Vectrix offers a way for motorcycle commuting Canadians to reduce their transportation related CO_2 emissions.