All-Electric

Mitsubishi iMiEV in Manitoba



Summary of Operational Experience: Third (Final) Year Report

Prepared by the Electric Vehicle Technology & Education Centre,
Red River College, in cooperation with the Energy Division,
Manitoba Department of Municipal Government

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ELECTRIC VEHICLE TECHNOLOGY & EDUCATION CENTRE

RED RIVER COLLEGE
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Objectives and Reporting

In 2011 the Government of Manitoba began testing of commercially-available electric vehicles. The overall objectives for testing have been to understand the practicality and public perception of using electric vehicles in our climate conditions, and to publicize and demonstrate the benefits of these vehicles. The primary intent of this and other reports prepared on electric vehicles is to be able to address a variety of practical questions that potential users may have in considering the purchase of such vehicles. As such, this report is deliberately organized according to a series of questions clustered into four areas, regarding: operation; maintenance; economics; and overall suitability. Information in this and other reports is also being shared with respective automobile manufacturers to hopefully help them make their vehicles better in the future.

Introduction

MOU on Electric Vehicles

The Government of Manitoba signed a Memorandum of Understanding (MOU) with Mitsubishi Motor Sales of Canada (MMSCan) in April 2011 regarding electric vehicles, with a key part of this collaboration being the testing of two all-electric iMiEVs for a three-year period.[1] Annual reports on experience with the two vehicles have been prepared at the end of each of the three years. Testing was started using two European-version iMiEVs in April 2011. A report on their first year operation from April 2011 to April 2012 was published in September 2012. A report on their second-year operation from April 2012 to May 2013, when they were both returned to MMSCan, was published in December 2013. This final report covers the final 11 months from June 2013 through April 2014, involving two North American versions of the iMiEV.

iMiEV Vehicle Specifications

The iMiEV was originally based on the platform of a small gasoline-powered vehicle in Japan, called the "i". It was adapted to operate all-electrically and then slightly renamed, adding "Mitsubishi innovative Electric Vehicle" to its descriptor.

In late 2011 a slightly modified North American version of the iMiEV was commercially released in Canada. The first North American iMiEV in Canada was sold to a customer in Winnipeg, and this event was highlighted in local media.[2]

iMiEV (North American) Technical Specifications	
Dimensions	3.7 m long x 1.6 m wide x 1.6 m high
Curb Weight	1.2 tonnes (2,600 lb)
Turning Radius	4.7 metres
Motor	Permanent magnet synchronous; 49 kW max output; 196 Nm torque
Battery	Lithium ion chemistry (lithium titanate); capacity of 16 kWh; 330 V (direct current)
Speed	130 km per hour maximum
Range	155 km (single charge, under optimal conditions)
Energy Consumption	16.9 kWh per 100 km for city driving conditions (Natural Resources Canada – see page 6)

[1] http://news.gov.mb.ca/news/index.html?archive=2011-4-01&item=11325

[2] http://autos.winnipegfreepress.com/news-article/id-4226/

North American iMiEV

The North American version of the iMiEV, shown at the right, was commercially released in Canada in the fall of 2011. The North American version is slightly different from the European. Most noticeably it is slightly longer and slightly wider, and has two windshield wipers rather than one. The driving mode settings are also a bit different. More information about the iMiEV is available from the manufacturer: www.mitsubishi-motors.ca/en/i-miev

The iMiEV is intended as an urban commuting vehicle, with the capacity to carry up to four passengers. The vehicle has some stowage space, but is not intended for any significant hauling. The iMiEV is fully electric. It has no internal combustion engine and requires no gasoline or other liquid fuel. It is recharged using grid-based electricity. This means within Manitoba it uses renewable energy and generates almost no emissions of any kind.

The two North American iMiEVs provided by MMSCan for the final period of testing were 2012 model year. Both vehicles had already been used for approximately 18 months in other jurisdictions, and both had cumulative mileage of about 4,000 km at the start of operation here in Manitoba. Specifications of the North American version of the iMiEV are provided in the table on page 1.

Vehicle Designations

The two iMiEVs tested were each given a unique designation name for reporting purposes (based on their different colours), specifically:

- Blue iMiEV, which involved a premium package; and
- White iMiEV

The vehicles and specific drivers were not otherwise identifiable. The premium package in the Blue iMiEV included a number of features. Of these, the most relevant in terms of this report was the navigation system, which included a screen display. As noted earlier, both vehicles started operation with approximately 4,000 km already on the odometer.

Licensing and Insurance

The two replacement iMiEVs were registered for operation in Manitoba with Manitoba Public Insurance (MPI), and were each covered under standard automobile insurance policies. In both cases, the plates from the returned European iMiEVs were simply transferred to the newer vehicles, and in both cases a safety inspection was required by MPI, which is normal for all pre-owned vehicles. As noted in earlier reporting, since the second year, one of the vehicles has been registered and operated by Red River College. There was nothing special required in the registration process or insurance for these electric vehicles. They were not practically different from conventional vehicles in this regard.

Data-logging Devices

For the European version vehicles, OTTO-Link data-logging systems, as manufactured by Manitoba-based Persentech, were implemented on both. The primary intent of these devices was to better understand vehicle-use characteristics, in

Otto-Driving-Companion on dashboard

IPLC PM2 Meter for electricity consumption

particular two parameters: trips per day and daily travel distance.

These data-logging systems were not reinstalled on the two North American vehicles. Logs of daily travel distance were manually recorded, but not consistently. As such, some data on daily travel distance was available but not rigorously.

A second monitoring device was used more frequently, but in this case, not actually mounted on either of the vehicles. The IPLC-PM2 meter, manufactured by Manitoba-based Vantera Inc., provides the capability for interactive monitoring of electricity consumption of vehicles when plugged into the grid. These devices, as shown in the photographs above, were carried with the iMiEVs, and externally plugged in between the vehicle's cord set and Level 1 plug-point (i.e., 110 V, 15 A) where a vehicle was being recharged.

Although vehicle range is ultimately most important for drivers to understand in the operation of an electric vehicle, range estimates can often be vague. In order to assist in objectively addressing vehicle range, precise measurements of vehicle electricity consumption were taken at the wall plug under different conditions using the IPLC-PM2 device. The range of any all-electric vehicle depends directly on the available battery capacity, and on electricity consumption under the conditions of operation. As such, expected range is in general inversely related to any change in energy consumption, i.e., higher energy consumption means lower expected range.

Operation

What is it like to drive this vehicle?

The iMiEV is small, and is obviously oriented primarily to urban driving, but this makes sense given its intended market as a "second car" for users. During the third year of operation, the two North American versions, like the earlier iMiEVs, were used essentially as commuting vehicles. The iMiEV was found to be well-suited to this role, being small but nimble.

How is this vehicle typically used?

During the third year of operation (actually 11 months), approximate total travel distances were as follows:

- 6,000 km for the Blue iMiEV; and
- 3,000 km for the White iMiEV.

Ongoing data from Statistics Canada's annual Canadian Vehicle Survey shows that vehicles within Manitoba tend to be consistently driven an average of 16,000 km annually. Annual travel distances were much lower for both iMiEVs during the last year. Consistent with the two years of operation with the European iMiEVs, the vehicles achieved at most 35% to 40% of average distance. Indeed, of the different electric vehicles currently under testing within Manitoba, the iMiEVs have consistently had the lowest annual mileages.

The annual mileages for the two North American iMiEVs correspond to commuting travel consisting of 12 or 24 km per day travel respectively, five days per week, for 50 weeks per year. In terms of highway travel, the two iMiEVs were driven occasionally on Winnipeg's perimeter highway, but never for long periods or long distances. Due to temporary speed restrictions, the two iMiEVs were not driven at greater than 80 km per hour.

Lastly in terms of driving characteristics, the North American iMiEV has three selectable forward driving modes, summarized as follows:

- D-mode, which is normal driving model, and maximizes power;

Comparison of Available Driving Modes Between European iMiEV and North American iMiEV

Mode Setting Function	European iMiEV	North American iMiEV
Main driving mode	D-mode	D-mode
Enhanced regenerative braking	B-mode	Eco-mode
Strong regenerative braking		B-mode
Reduced regenerative braking	C-mode	

• Eco-mode, which reduces battery consumption to maximize energy-economy and travel distance; and

• B-mode, which increases the regenerative braking bias to maximize energy recycling, but with the same power as D-mode.

These driving mode settings are slightly different from those for the European version, with an approximate comparison provided in the table on page 3.

Through the course of the operating period, the two vehicles were almost never used in B-mode. A comparison of energy-consumption for D-mode versus Eco-mode is provided in the later section on electricity use by the vehicles. Eco-mode also has utility for winter driving, which is discussed later in the section on winter operation.

How does recharging work on this vehicle, how long does it take, and how frequently do I need to charge?

Like the European versions before, the two North American iMiEVs are each equipped with two separate charging ports:

• SAE J1772-compliant port at the rear passenger-side for charging at Level 1 (i.e., 110 V; 15 A), or at Level 2 (i.e., 220 V, 20 A); and

• CHAdeMO protocol compliant port on the rear driver side to allow for Level 3 charging (i.e., direct DC, rapid charging).

Overall, in terms of charge level preference, the iMiEV located at Red River College was charged predominantly using Level 2, specifically at the public Level 2 station located at the College. The iMiEV used by Government of Manitoba personnel was charged primarily using Level 1 at a variety of different locations, typically at homes. This made Level 2 impractical for the second vehicle.

Unlike the European versions, the two vehicles come with only one cord-set, this for Level 1 charging and compliant with SAE J1772. For the 2012 models, the Level 1 cord-set only permits an 8 A current during charging, which significantly extended out the time required. This represented a significant constraint for the iMiEV in order to achieve a practical charging time at Level 1, particularly at home. Fortunately, for the subsequent 2013 version of the iMiEV, this was corrected; still a single cord-set provided, but with adjustable current setting of either 8 A or 12 A, selected by the user.

Over the 11-month period, a total of 49 charging activities were logged for the two iMiEVs at Level 1 using the IPLC-PM2, with the monitored-iMiEV in all cases being charged outside. Data tracked by the logger permitted calculation of average power level during each main recharging event. Results differentiated into two groups: firstly, recharging events during the summer and fall period, up until weather became much colder; and secondly, recharging events in colder weather, also differentiated by the occurrence of battery-heating in addition to the main recharge. The mean and standard deviation values for both groups are provided in the table below. The two mean values were confirmed using a statistical two-sample t-test to be significantly different. Cold conditions were shown to reduce the power level by about 12% on average. Even under normal conditions, the power level for the 2012 iMiEV was 30% to 35% lower than the level found for the European iMiEV.

A current curve for normal (non-winter) recharging is presented in the figure on page 5. The shape of the curve is very similar to that of the European iMiEV, as illustrated in earlier reports, with two major exceptions. Firstly, the current level during the main charge event is lower overall, as described above. Secondly, a series of regularly occurring spikes appear after the main charging event. In longer tracked events, as many as four spikes were observed, always occurring at regular intervals in the range of six to seven hours. These spikes

Average Power Level for 2012 iMiEV Main Recharging Events			
	Mean (W)	Standard Deviation (W)	Sample Count
Normal conditions	992	± 14	35
Colder conditions	869	± 62	14

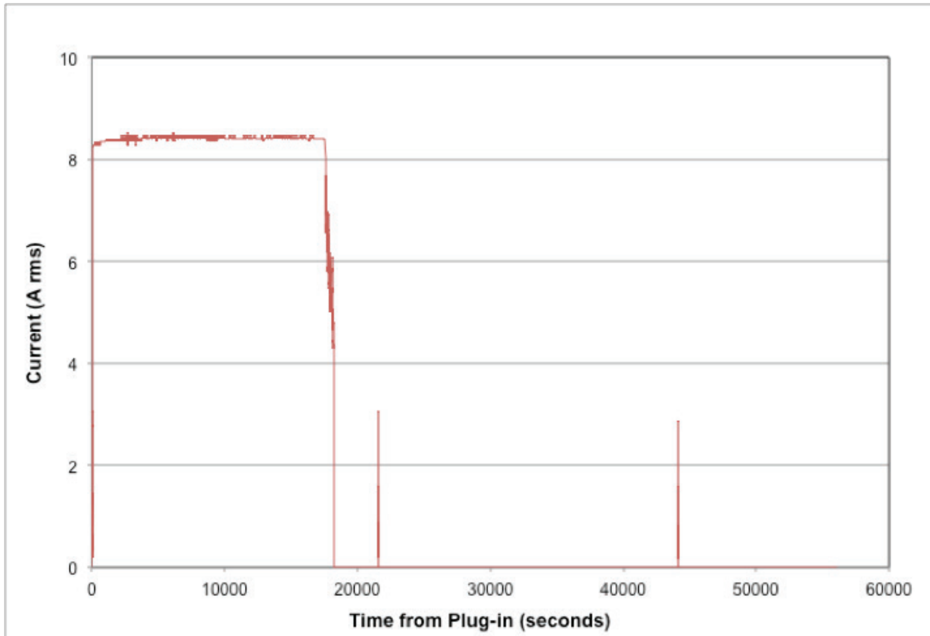
appear entirely normal, and correspond to the battery system self-checking to ensure satisfactory temperature conditions. The same regular intervals were observed for battery self-heating events described later in the section on winter operation.

MMSCan indicated for the 2012 iMiEV that Level 1 requires approximately 22 hours to recharge from completely empty to full, and that Level 2 requires approximately seven hours to recharge from completely empty to full. As described later, a series of drive-to-depletion tests were undertaken using the two iMiEVs to directly assess maximum travel distances under different temperature and operating conditions. For most of these tests, the Level 2 system at Red River College was employed but in three cases charging was done using Level 1.

For the cases using Level 1, mean recharging time from completely empty to full was found to be 19.5 hours ± 1.6 hours (n = 3). This translates to about 12% faster than suggested by MMSCan, and did not appear to be affected by ambient temperature. For the cases using Level 2, mean recharging time from completely empty to full was found to be 6.1 hours ± 1.1 hours (n = 8). This translates to about 13% faster than suggested by MMSCan.

During warmer months the iMiEVs certainly did not need to be recharged every night. During colder months it was found to be prudent to recharge the vehicles every night. This was to ensure that maximum possible energy was available on-board, if required.

The iMiEV also incorporates a port for Level 3 charging as a standard feature, as noted earlier. This was never used on either vehicle. Level 3 charging stations based on CHAdeMO protocol are still relatively rare, with



Current curve for normal recharging of North American iMiEV at Level 1 (White iMiEV on Saturday, July 20, 2013, event PM1_0135)

none currently within Manitoba, and are expensive to implement.

What happens if the vehicle runs out of battery energy while driving?

The iMiEV has a state of charge (SOC) meter on the left side of the driver display, consisting of 16 blocks, essentially one for each kWh of battery charge. On the inside of this meter is a gasoline-like fuel-pump symbol with an electric plug. As battery energy nears full depletion, the vehicle display of the iMiEV proceeds through a series of progressive warning stages.

The first occurs when the SOC meter drops to two blocks. At this point, the electric fuel-pump symbol begins to regularly flash. When the SOC meter drops to a single block remaining, the last block of charge and the electric fuel-pump symbol flash alternately. Flashing continues even after all blocks disappear, and the vehicle reaches zero energy.

Importantly, when the iMiEV reaches zero blocks/zero energy, the main climate systems, whether heating or air conditioning, automatically cease operation. Acceleration capability also declines. Both measures are obviously to conserve remaining energy. At the same time, however, the iMiEV at this point does not yet stop operating.

Drive-to-depletion tests were directly undertaken with the two iMiEVs, as described later. The average distance that was traveled after reaching the zero energy indication was 3.3 ± 0.5 km (n = 12). As such, the North American iMiEV still retains some reserve available to ensure a driver would not be stranded.

Also important, the 12-volt systems of the vehicles appear to continue operating throughout. All instrument displays and even the heated driver seat continue to work. This is even after the main battery was depleted to zero.

[3] http://www.tc.gc.ca/media/documents/programs/i-MiEV_testplan_ENG.pdf

Baseline Energy Consumption for Electric Vehicles in Summer Operation with No Heating or Air Conditioning Involved

Vehicle Model	Vehicle Energy Consumption (kWh per 100 km)	
	Winnipeg Test Results	Natural Resources Canada 2012 City-based Official Result*
2012 Mitsubishi iMiEV	16.3 ± 0.9 (n = 10)	16.9
2012 Nissan Leaf	20.2 ± 1.6 (n = 5)	19.6
2012 Chevrolet Volt	19.9 ± 2.1 (n = 5)	22.3

* Natural Resources Canada. Fuel Consumption Guide 2012. Available at: http://oee.nrcan.gc.ca/transportation/tools/fuelratings/fuel-consumption-guide-2012.pdf

Conversion equation: Electricity use = L equiv per 100 km x 8.9 kWh per L equiv

How much electricity does this vehicle use?

Electricity use was measured for the two North American iMiEVs using the IPLC-PM2 meter for Level 1 charging, as described earlier. Combined with odometer changes over logged periods, this permitted calculating vehicle energy consumption in units of kWh per 100 km. This calculation method is consistent with that employed by Transport Canada as part of the ecoTechnology for Vehicles (ETV) program in evaluation of electric vehicle performance.[4]

Three different types of commercially available electric vehicles, all 2012 model year, have been evaluated for energy consumption in the same way during summer operation in the vicinity of Winnipeg, with no AC or heating employed. In addition to the iMiEV, these include the Nissan Leaf and the Chevrolet Volt. Baseline energy consumption data for all three vehicles are provided in the table above, with mean and standard deviation shown. These results are based on actual monitor data, with the numbers of replicate tests for each vehicle as indicated.

Official baseline energy consumption results for these same three vehicles also have been determined by Natural Resources Canada under conditions for city-based driving with no AC or heating employed, albeit in this case based on specific dynamometer cycle operation.[5] These results are also included in the same table above.

Baseline energy consumption during the summer period of 2013 was determined for the North American iMiEV to be 16.3 ± 0.9 kWh per 100 km (n = 10, five for each vehicle). This value is identical to the mean energy consumption found earlier for the European iMiEV under similar conditions, albeit in this case based on a larger number of replicate tests. This value for the iMiEV is also significantly lower than both the Leaf and Volt, which makes sense given the much smaller size and mass of the iMiEV.

Summer-based testing with AC turned fully on was undertaken for the two North American iMiEVs, and showed energy consumption of 22.6 ± 1.7 kWh per 100 km (n = 10, five for each vehicle). This value is 39% higher than the baseline energy consumption for the North American iMiEV, and also roughly 12% higher than for the European iMiEV. Theoretically this should translate to a 39% reduction in travel distance compared to summer-baseline. Maximum travel distance was also assessed for AC turned fully on as part of drive-to-depletion tests, described later. These tests showed a travel distance reduction of 32% compared to baseline operation. Although the reduction was not quite as high as predicted from energy consumption, it was nevertheless much higher than experienced with the European iMiEV. The reasons behind the significant difference were briefly investigated, but there was no obvious explanation.

As noted earlier, the North American version of the iMiEV has three forward drive settings. To evaluate impacts on energy consumption of driving in Eco-mode versus normal D-mode, the Blue iMiEV was driven during the summer a total of five additional days. Using Eco-mode, energy consumption was found to be 15.9 ± 0.3 kWh per 100 km (n = 5). Although notionally lower than the baseline energy consumption by close to 4%, comparison using a statistical two-sample t-test showed

[4] http://www.tc.gc.ca/media/documents/programs/i-MiEV_testplan_ENG.pdf

[5] Natural Resources Canada, Fuel Consumption Guide 2012. Available at: http://oee.nrcan.gc.ca/transportation/tools/fuelratings/fuel-consumption-guide-2012.pdf

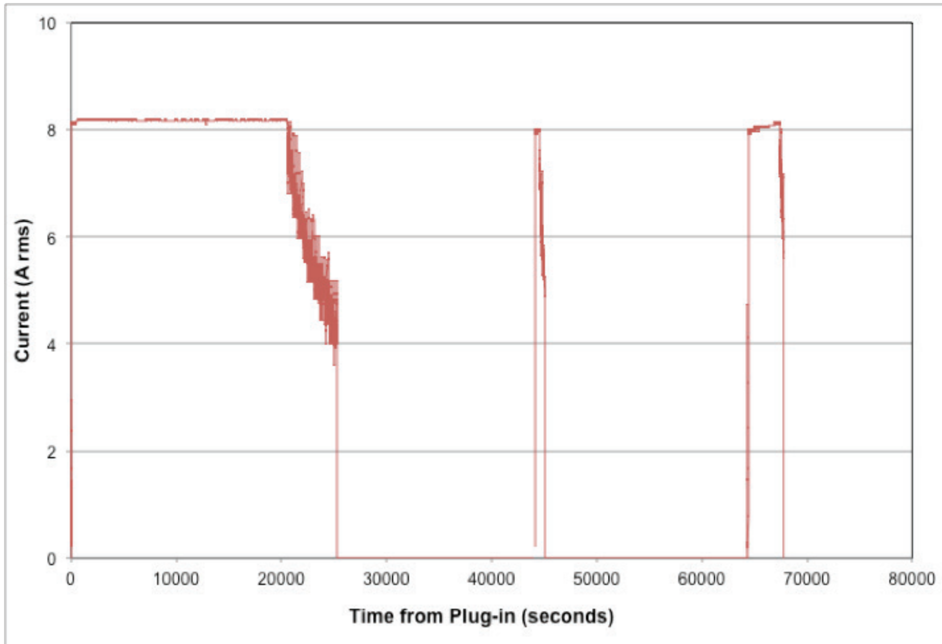
the two values were not significantly different. Just as in the case of the European iMiEV (using B-mode operation), energy consumption using Eco-mode for the North American iMiEV did not result in any significant reduction in energy-use. Drive-to-depletion tests were not undertaken using Eco-mode to directly assess impacts on travel distance.

How well does this vehicle operate in the winter?

Operation in Manitoba's winter conditions is a challenge for all vehicles, including those that are electric. The first two years of operation with the European iMiEV showed both much higher energy consumption and much shorter travel range during winter. As such, these impacts were not a surprise to drivers with the North American iMiEV during the final test year.

A current curve for winter-based recharging of the North American iMiEV is presented in the figure above. This curve shows sequentially three different types of events that can occur during winter. First is a main charge event, very similar to that illustrated earlier for summer operation. Second is a battery self-heating event while plugged in. Lastly is a cabin-preheating event, whereby the climate controls of the vehicle were turned on in advance of startup using the iMiEV remote fob.

The battery-heating events were found to be unique to winter operation. An important difference between the North American vs. European iMiEV is that a battery conditioning system was implemented in order to better maintain the battery within a desired temperature range. Such battery-heating events were identified in two-thirds of logged winter plug-in activities. Over longer tracked



Current curve for winter recharging of North American iMiEV at Level 1, showing three sequential events: main recharge; followed by battery-heating; followed by cabin preheating (Blue iMiEV on Thursday January 30, 2014, event PM1_0230)

periods, as many as four such events were detected, with relatively regular time intervals in the range of six to seven hours, closely matching the time intervals of current spikes noted during summer recharging, as noted earlier.

The characteristics of these battery-heating events are summarized in the table at the top of page 8, based on a sample of 15 monitored. These events were typically quite short, and involved relatively low energy input to the vehicle compared to main recharging events. In reviewing data, the duration and the input energy per event were highly variable, while the power level and time interval between events were much less so.

Energy consumption was not monitored rigorously, but was tracked in the period from early December 2013 to late January 2014, in particular for 11 different occasions when the ambient temperature was below -15°C. As noted in the next section, such data correspond to the suggested flat minimum range plateau describing vehicle travel range behaviour at low temperatures. A summary of these energy consumption data is presented in the table at the bottom of page 8. Energy consumption was high, particularly when additional energy inputs for battery self-heating were included. Energy consumption values also showed no correlation in this case with the ambient temperature, as would be expected for a flat range-plateau. Adding in battery self-heating not only increased the absolute value of energy consumption, but also its variability. Mean energy consumption translated to 71.7 kWh per 100 km, or roughly 4.4x the summer baseline. Importantly, this did not include any energy inputs associated with deliberate cabin preheating.

In order to fully test the limits of the vehicles, both iMiEVs were driven continuously to full-depletion on different occasions, as described in more detail in the next section. As noted later, these tests include a range of winter conditions. The lowest

Winter Battery-Heating Event Characteristics, Based on 15 Monitored Events		
Parameter	**Mean Value**	**Standard Deviation**
Time interval (h)	6.8 h	± 1.3 h (18%)
Time duration (h)	0.73 h	± 0.86 h (117%)
Energy (kWh)	0.56 kWh	± 0.69 kWh (123%)
Power (kW)	0.74 kW	± 0.08 (10%)

temperatures were for ambient conditions of -25°C to -26°C. The average travel distance for these was 44 km, or roughly a 3x reduction from summer baseline. As discussed below, this travel distance was based on achieving an average net vehicle speed in the range of 35 to 40 km per hour, including all stops, etc.

The cold conditions tested were also similar to those undertaken in the previous year, for which the European iMiEVs averaged about 40 km, as reported in the second-year operational report. As such, the North American iMiEV appeared to be a little better, travelling roughly 10% further during winter. A higher travel distance was also found for somewhat higher temperatures compared to the European iMiEV.

At cold temperatures, energy consumption and maximum travel distance for the European iMiEV appeared to be well correlated. For the North American iMiEV, however, energy consumption and travel distance appeared to be more decoupled during the winter. Using energy consumption data, as noted above for the North American iMiEV, the corresponding reduction of travel distance in winter should have been higher.

The maximum travel distances achieved during winter by the North American iMiEV, as noted above, also reflected steady operation at 35 to 40 km per hour net. Energy consumption and available travel range during cold weather are significantly affected by net travel speed. If traffic speed is very slow, the vehicle could end up using a very high amount of energy and have travel distance dramatically reduced. A specific incident of this type occurred on Nov. 28, 2013. Although not terribly cold, there was significant fresh snow that drastically slowed both in-bound and out-bound commuter traffic. The iMiEV driver on the homeward commuting leg was in traffic for more than 1.5 hours, and reached home with less than two blocks remaining. This was achieved by deliberately turning off the heater system. A slow net travel speed during winter represents a highly vulnerable situation for all electric vehicles. This remains an area for further investigation.

The North American iMiEV has a remote control fob that permits turning on the climate controls for the vehicle, whether AC or heating, prior to start-up. Preheating is obviously a more critical function here, given Manitoba's climate. The device was used on a number of occasions with both Level 1 and Level 2 charging. The current-track for a cabin-preheating event using Level 1 is illustrated as part of the figure on page 7. Given higher power level, preheating using Level 2 was obviously better. Unfortunately the remote device proved to be finicky. It involves sending a radio-wave signal, and only works within roughly 100 m of the vehicle. Achieving a positive confirmation of radio connection was difficult, and appeared to be negatively affected by temperature. Other vehicles employing a smartphone app for the same function were found to be much more convenient and more reliable. This is an area of suggested improvement for the iMiEV.

The significant impacts of cold weather on energy consumption for cabin heating raised the question regarding how extensive savings could be through the use of preheating. A test to help assess

Winter Energy Consumption by iMiEVs Using Level 1, Based on 11 Events from December 2013 Through January 2014 with Ambient Temperatures of -15°C or lower.		
Condition	**Mean Value (kWh per 100 km)**	**Standard Deviation (kWh per 100 km)**
Main recharging only	65.1	± 11.1 (17%)
Recharging plus any battery self-heating	71.7	± 20.5 (29%)

Comparison of Energy Consumption for Preheating Test		
Condition	**Energy Consumption (kWh per 100 km)**	**Log Event**
iMiEV maintained outside at ambient condition	52.3	PM1_0214
IiMiEV stored and charged indoors	43.7	PM4_0185

this was conducted on Jan. 2, 2014, when the ambient temperature was in the range of -24°C to -26°C. One of the iMiEVs was maintained outside throughout (including charging), while the second iMiEV was stored and charged inside at Red River College (i.e., +20°C), being taken outside only to be driven. Both vehicles were driven comparable distances, in the range of 20 km to 25 km at roughly the same outside temperature.

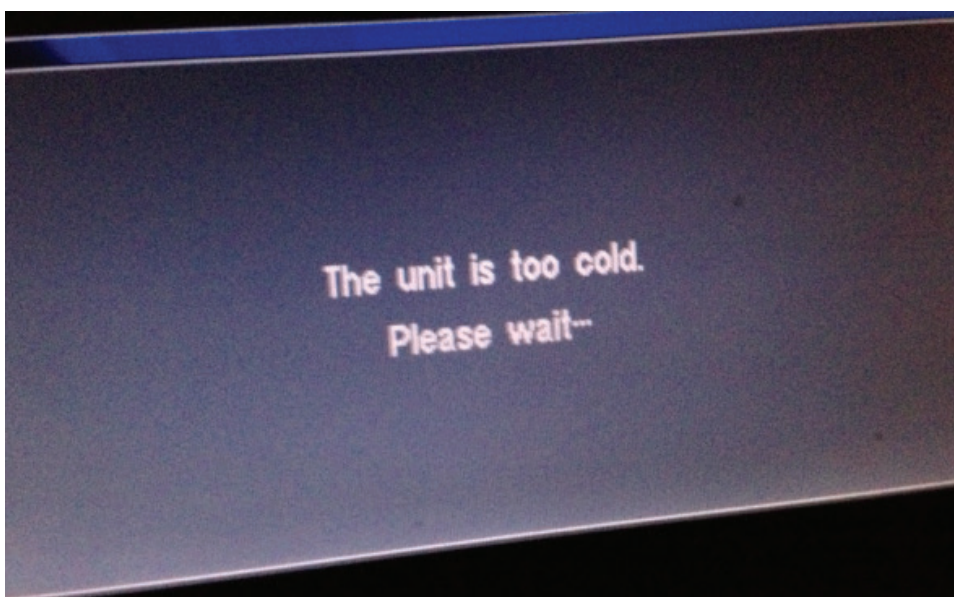
Recharging was logged to determine energy consumption per unit travel, with a summary of results presented in the table above. This showed the vehicle stored indoors had energy consumption close to 20% lower, which was significant. How to best approach vehicle preheating requires further investigation.

An additional minor winter vulnerability appeared with the Blue iMiEV when ambient temperatures became very cold, i.e., around -30°C or lower. The screen display on the vehicle's navigation system — part of the premium package on the car — would not function, as illustrated in the photograph at right. This was only a temporary situation, which was always rectified once the vehicle had been operated for five or so minutes. Also no important control was lost.

One surprising winter advantage for the iMiEV and other electric vehicles emerged during an extremely cold period, i.e., at ambient temperature around -35°C. Such cold weather is well known to be detrimental for the 12-volt batteries of conventional vehicles, causing very high numbers of start-failures that require battery boosting of some kind. And yet, under the same conditions, a series of electric vehicles, including the iMiEVs, were found to be highly robust in terms of being able to start up and quickly drive away. In an interesting paradox, on the day in question, the driver of the Blue iMiEV reported literally passing two disabled conventional vehicles, both with the front-hood characteristically open; one being boosted, the second waiting for a boost. This is a significant advantage.

The use of Eco-mode was described earlier in term of its impact on energy consumption, which was not directly found to be significant. Nevertheless, in driving the iMiEVs during winter it was found to be useful to engage Eco-mode in order to enhance stability of the car. Eco-mode reduces torque and acceleration, which was found to be beneficial when snow and possible ice were present. Switching to Eco-mode during the winter, thus, was identified as a useful driving tactic for the iMiEVs.

An additional and obvious tactic during winter for the iMiEV, and other electric vehicles, is making sure to plug in at different locations through the course of the day, particularly at work. Most work-related parking lots in Manitoba already have plug-in points available for block heaters, and these can be used for top-up charging at Level 1



Display screen on Premium-Package navigation system display inactivated temporarily by extremely cold weather.

for electric vehicles. Even given the lower rate of charge on the iMiEV at Level 1, over a typical parking period of about eight hours, it is possible to add back almost half of the battery capacity, if necessary. Plugging in helps to enhance the vehicle's available travel range, and also permits cabin preheating.

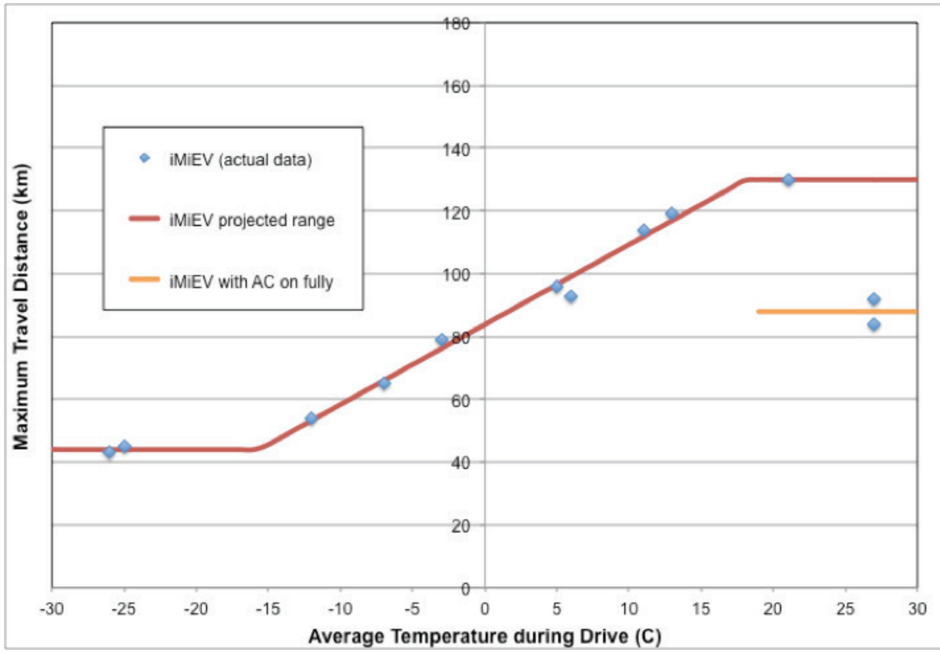
Lastly in terms of winter operations, specialized winter tires were installed on one of the iMiEVs (i.e., Blue iMiEV). This is not an issue specific to electric vehicles, but rather part of a more recent general trend. The winter tires generally appeared to improve winter handling, however opinion as to the extent of improvement was not universal. For example, the White iMiEV, without winter tires, was not found to be significantly more difficult to operate in winter.

How far will this vehicle travel (on a single charge), particularly in the winter (i.e., range by season)?

For an all-electric vehicle like the iMiEV, the most critical performance factor is the available travel distance. In the past, it was found that electricity consumption and all-electric travel range were directly linked. However, in the current year, as described in the last two sections, the relationship between these two parameters was disrupted during the winter. As such, although energy consumption at the wall-plug is important to know in order to understand operating costs, it turned out for the North American iMiEV that electricity consumption could not be used to reasonably estimate travel range.

During the last year, the two North American iMiEVs were driven to full depletion on a total of 12 occasions in the urban vicinity of Winnipeg under different temperature and operating conditions in order to better understand single-charge maximum travel capabilities. As noted earlier, this is an obvious approach, but one that is not extensively undertaken, given high costs to operate environmentally controlled chambers. Winnipeg was essentially used as a low-cost "live" test-bed, taking advantage of the broad range of temperature conditions that naturally occur here across seasons.

Unfortunately with electric vehicles, it has become relatively common for maximum travel estimates to combine actual distances with on-board indicators of remaining range. This is problematic given that the remaining-range indicators for electric vehicles in general have been found to be notoriously unreliable. This includes the remaining-range indicator for the iMiEV. On-going tracking of actual travel, compared to associated changes in the indicated remaining-range, showed projections were always in error, typically by a significant amount. Fortunately in the case of the iMiEV, the remaining-range indicator is not highly prominent, so this is less of a concern than on other vehicles



Drive-to-depletion Travel Results for the North American iMiEV under Varying Temperature and Operating Conditions

For all of the drive-to-depletion tests undertaken, the same driver was involved. Temperatures were referenced as the average temperature at the Winnipeg Richardson International Airport (WRIA) for the actual period covered by the drive. D-mode was used in all cases for consistency, even though during winter Eco-mode was preferable for driving conditions.

A similar driving route was employed, obviously not exactly the same given differences in distance. This involved city-based driving within Winnipeg in a combination of 50, 60, 70 and 80 km per hour speed zones, but also with actual measured net travel averaging at a rate in all cases in the range of about 35 to 40 km per hour including stoppage for traffic lights, etc. Cabin heater rates were adjusted to be comfortable for the driver.

The resulting maximum travel distance data are presented in the figure on page 10. These data form the shape of a logistical or "S" curve, which makes sense given this is essentially what would be expected for a conventional vehicle. At the same time, rather than attempting to use a highly sophisticated mathematical model, for simplicity, the curve is reasonably approximated using three distinct linear sections, which are outlined as follows:

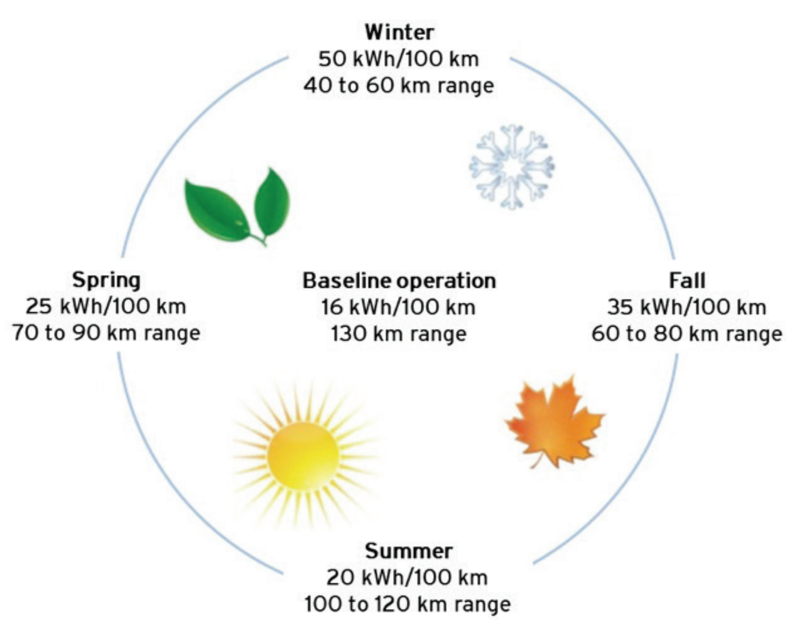
Maximum Range Section: At the upper right top end of the curve, under warm operating temperatures, without AC and using D-mode, the iMiEV reached a maximum travel distance of about 130 km, which is entirely consistent with the travel distance suggested by MMSCan. This maximum distance is determined primarily by on-board battery capacity and is not strongly influenced by temperature, as long as AC is not used. As such, this range is a flat plateau relative to temperature. This is what would be expected for a conventional vehicle. Driving normally without AC, a conventional vehicle will only go so far, limited by gasoline tank size and relative efficiency of the engine. At the same time, for driver comfort, under increasingly hot conditions the driver would require AC, which results in reduced travel distance, whether electric or conventional vehicle. A separate lower flat line is also indicated on the upper right of the curve, which is the maximum range with AC on fully. The use of AC on fully results in a reduction of more than 30%, but it was found that having AC on fully made the vehicle excessively cold, such that AC could be easily throttled back in most instances to a more comfortable level with reduced energy consumption.

Middle Range Section: The middle portion of the curve covered from about +18°C down to -15°C. Over this range, the travel distance was highly linear with respect to changes in temperature. Indeed, the r2 value for travel distance as a function of temperature was 0.98. The slope value was about 2.5 km range per °C change in temperature, representing the rate of range reduction, with the intercept value, at 0°C, being about 84 km. This highly linear behaviour with respect to temperature change was also observed with other all-electric vehicles.

Minimum Range Section: At the lower left of the curve, under the coldest operating temperatures, the iMiEV reached its minimum single-charge travel distance, again represented as a flat plateau. Such behaviour may initially sound odd, but does make sense, and again is entirely consistent with the behaviour of conventional vehicles. The iMiEV has limited on-board heater capabilities. Once these are reached, with all systems fully on (i.e., main heater, seat heater and rear defogger), the vehicle cannot produce any additional heat itself. Driving at lower and lower temperatures begins to depend more on the tolerance of the driver and on the prioritizing of heating loads, usually with windscreen defogging/defrosting being the top priority. But this is no different than what is experienced with a conventional vehicle. Based on interpolation of curves, the iMiEV appeared to reach its maximum heating capacity at a temperature of about -15°C, at which point, the travel distance curve plateaus. The resulting travel distance was approximately 44 km based on actual experience.

The travel distance achieved for a single charge under cold conditions, even with reduced battery capacity is higher than the average daily travel distance for Manitoba cars (i.e., 43 km per day). This result suggests the iMiEV is adequate on a daily travel basis for Manitobans, even during winter, albeit with certain caveats. A key vulnerability, as identified in the last section, is when overall traffic travel speed is reduced.

Electricity consumption and resulting range for the North America iMiEV depend significantly on the season. Any combination of heating and/or cooling would have an impact. Based on experience with the vehicle so far, rough estimates of seasonal energy consumption and associated travel ranges were determined, as presented in the figure below. These values provide preliminary guidelines.



Travel range over the course of a typical year can also be envisioned in terms of the proportion of time operating within each of the three linear-segments modeled in the figure on page 10. Based on average daily temperatures in Winnipeg, an iMiEV would be expected to operate for roughly two to three months per year in the upper maximum range plateau, roughly two to three months per year in the lower minimum range plateau, and roughly six to eight months per year in the varying middle range segment.

Are there any important issues to be aware of in the operation of this vehicle?

The iMiEV in general has been the first commercial electric vehicle into the market. It became available in its European or Japanese format significantly before others. This speed-to-market was facilitated both by its small and basic nature, and by its being adapted from an already-existing gasoline vehicle. Also, compared to other vehicles, the overall priority of the vehicle systems appears oriented toward practical operation, rather than passenger comfort.

For some drivers, the iMiEV continues to represent a simple and fun vehicle to drive. On the other hand, for many other drivers, its more basic nature, especially compared to more well-appointed competitors such as the Nissan Leaf and Chevrolet Volt, has been viewed as its main drawback. When the iMiEV was the only electric vehicle available, it was a true novelty. But, now, newer and better equipped electric vehicles are being released that are more comparable to conventional vehicles in the North American market.

Maintenance

What maintenance is required for this vehicle?

The extent of maintenance required for electric vehicles tends to be much lower than for conventional internal combustion engine (ICE) vehicles, but appropriate maintenance is still required, i.e., they are not completely maintenance-free. This represents a saving both in terms of convenience and economics.

At the start of the final year, each of the two vehicles underwent safety certification. The vehicles were found to be in good working order, and during the subsequent term no significant issues appeared with vehicle operation. For the Blue iMiEV, which had a set of winter tires, a tire-swap was undertaken in the late fall to change to winter tires.

Although several drivers noted a distinct pleasure in being able to drive past gasoline refueling stations, the iMiEVs were still occasionally taken to such stations, notably for windshield washer fluid purchases and carwashes.

Aside from an annual checkup review, there was no warranty-driven maintenance required for either of the two iMiEVs.

What battery degradation would be expected, both seasonal and long-term?

Over the final year of operation, there was no noted degradation of the main battery for either of the North American iMiEVs. These two vehicles, however, were still relatively new, having been in service elsewhere for only about 1.5 years when operation was begun. MMSCan has indicated that after five years, the battery is expected to degrade to about 80% of its original capacity, and that after 10 years, the battery is expected to degrade to about 70% of its original capacity.

How long will the batteries last, and will replacement be required?

The practical longevity of batteries is a key aspect for electric vehicle operation that still remains uncertain. Insufficient long-term experience exists yet to be able to predict battery life. This uncertainty has been reflected in the economic evaluation (next section) by including differences in the assumed

Comparative Current Operating Costs

Vehicle	Fuel Consumption per 100 km	Operating Cost per 100 km	Annual Operating Cost
iMiEV (all-electric)	32.5 kWh	$2.30	$280
Average conventional car	15 L	$18.00	$2,160
Efficient conventional car	8 L	$9.60	$1,150
Assumptions: gasoline price of $1.20 per L; electricity price of 7¢ per kWh; and annual travel of 12,000 km			

[6] http://www.rrc.mb.ca/files/file/appliedresearch/preliminaryeconomicreport.pdf

resale value of an electric versus conventional vehicle.

Economics

What does it cost to purchase an electric vehicle?

From earlier economic assessment of electric vehicles it is known that their economics depend most sensitively on the purchase price.[6] The North American version of the iMiEV became available starting in late 2011. When initially released, the North American iMiEV was relatively expensive, around $33,000 (more for the premium package). At the same time, in response to changing market conditions, reductions in purchase price have occurred. More recent model-year versions of the iMiEV have become available for a price of around $28,000.

What does it cost to operate an electric vehicle?

The use of electricity as the "fuel" for the iMiEV results in a dramatically lower operating cost compared to a conventional vehicle. Representative operating costs are presented in the table on page 12, comparing the iMiEV to both an average conventional vehicle and an efficient vehicle, like a conventional hybrid. Values are presented both in terms of "per 100 km" basis and "annual" basis, the latter assuming 12,000 km travel per year (noting that an average Manitoba vehicle travels roughly 16,000 km, which includes a portion of longer distance trips).

The electricity consumption value of 32.5 kWh per 100 km was calculated as the average of seasonal values. Based on actual experience so far, overall energy consumption was increased from the values in the last report by about 25%. The current cost of electricity is about 7¢ per kWh, versus about $1.20 per L of liquid fuel used in conventional vehicles.

Even with relatively high annual electricity consumption, the iMiEV's operating cost is only about 1/8th that of an average Manitoba vehicle, and 1/4th that of an efficient vehicle. Recharging the iMiEV from a fully-depleted condition to completely full works out to cost about $1.40. In contrast, one individual visit to a gasoline refuelling station today for a conventional vehicle typically costs more than $25. These price advantages make a compelling case for electric vehicles within Manitoba.

What is the payback compared to a conventional vehicle?

The overall economic feasibility of the iMiEV was considered based on a series of assumptions, compared to two alternatives: an average conventional vehicle powered by an internal combustion engine (ICE), and an efficient conventional vehicle (i.e., a smaller more efficient vehicle). Assumptions are presented in the table on page 13. The results are presented in the figure at right, in terms of the present value of total vehicle costs (i.e., purchase and operating) over an eight-year period.

Economic Feasibility Assessment Assumptions

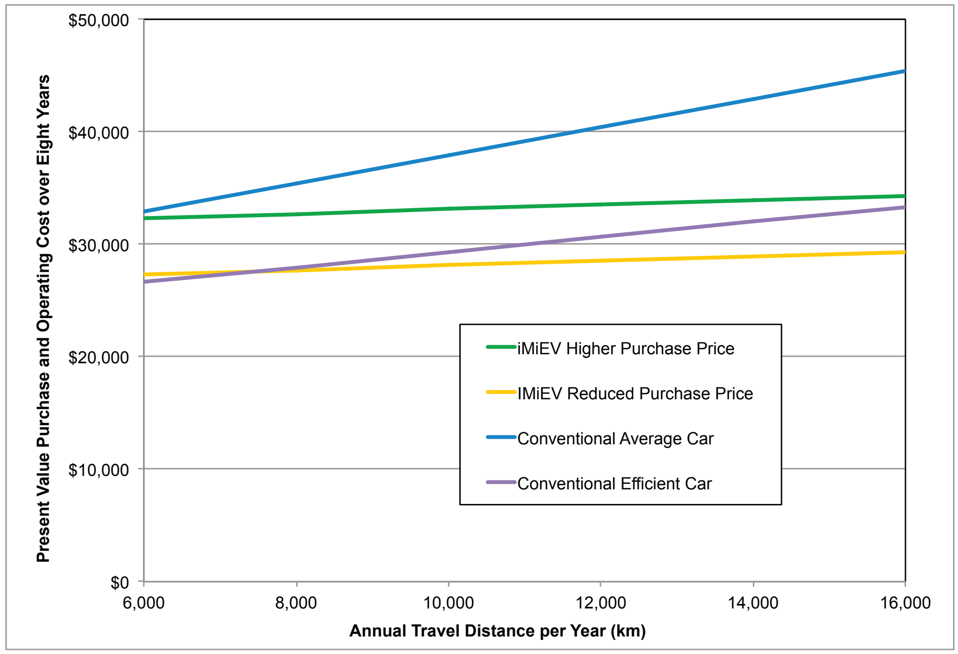
Mitsubishi iMiEV (North American)	Conventional Cars
Higher purchase price: $33,000 Reduced purchase price: $28,000	Conventional average car price: $26,000 Conventional efficient car price: $22,000
Annual maintenance cost: $200	Annual maintenance cost: $400
Energy consumption: 32.5 kWh per 100 km	Conventional average car: 15 Litre per 100 km Conventional efficient car: 8 Litre per 100 km
Longer term electricity price: 10¢ per kWh	Longer term liquid fuel price: $1.35 per Litre
Resale value after eight years: $5,000	Resale value after eight years: Conventional average car: $5,000 Conventional efficient car: $3,000
Cost of money of 6%, and assumed vehicle life of 8 years. Annual travel distance treated as independent variable as presented.	

The iMiEV could be expected to operate much longer, but eight years was selected for analysis given it corresponds to the typical battery warranty period, including that provided by MMSCan.

There is still some uncertainty as to the life and costs of batteries for electric vehicles. For this analysis, the resale value for the iMiEV was assumed to be no better than an average conventional vehicle, even though the iMiEV has a high initial purchase price. This is a highly conservative assumption.

It is known that the economic feasibility of electric vehicles is most sensitive to purchase price. Two cases are included: "higher purchase price" of $33,000, which reflects the initial cost of the iMiEV as announced by MMSCan; and "reduced purchase price" of $28,000, which reflects price reductions.

In earlier economic analysis on electric vehicles, the price of gasoline was used as the major independent variable. Although the economics of electric vehicles are known to be much more sensitive to changes in gasoline price versus electricity price, gasoline price has continued to increase more or less steadily, and a single average future price of $1.35 per litre was assumed in this case covering the eight-year period. The corresponding future average price of electricity was assumed as 10¢ per kWh. For analysis of the iMiEV, the major independent variable was assumed as the annual travel distance by the vehicle, ranging from 6,000 km annually, reflecting basic commuting only, to 16,000 km annually, which is the average travel distance for all cars within Manitoba.



Comparison of Present Value Total Costs (Purchase plus Operation) over Eight-year Period

Suitable User Characteristics for the iMiEV All-Electric Vehicle
Need to carry up to only four passengers at a time.
Limited luggage or cargo hauling requirements.
Drive roughly 150 km or more per week on a regular basis throughout the year, including daily commuting and additional use.
Little highway travel (vehicle can travel on highway but not extensively).
Available dedicated driveway, garage, carport or parking spot with at least Level 1 plug-in point available.

As illustrated in the figure on page 14, the iMiEV (with higher purchase price) has a lower total cost over eight years than a conventional average vehicle at any of the travel distances considered. More relevant, however, is the comparison to a lower cost, more efficient conventional vehicle. As illustrated, the iMiEV (with higher purchase price) is overall more costly for any travel distance, but this changes dramatically when the reduced purchase price is considered. The iMiEV (with lower purchase price) has a lower overall present value cost based on eight years life compared to a conventional efficient vehicle when the annual travel distance is greater than approximately 7,400 km per year. As such, for many prospective vehicle purchasers today, depending on user characteristics, the iMiEV represents a good choice economically, not even considering any of its environmental benefits. For users with very low annual travel distances, other options, such as the use of a car-share approach, are likely more attractive.

Overall Suitability

What are the most suitable users for this type of vehicle?

The iMiEV is essentially an urban commuting vehicle. The suitable annual travel distance would involve urban driving in the range of 8,000 km to 12,000 km, sufficient to economically attractive, but not to push the limits of the vehicle.

How does one determine if a particular operation or style of use is suitable for an electric vehicle?

In order to help evaluate suitability of the iMiEV, a series of relevant user characteristics are provided as a guideline in the table to the bottom right of page 14.

Electric Vehicle Technology & Education Centre (EVTEC)

EVTEC at Red River College is responsible for applied research and innovation projects concerning ground transportation electric and hybrid vehicles that utilize renewable fuels. EVTEC has a mission to: support electric vehicle (EV) innovation amongst Manitoba's transportation sector; enhance electric vehicle education at the College and in the region; and increase public awareness and understanding of electric vehicle technology.

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