

# Plug-in Hybrid Electric Vehicle Demonstration



One of ten Toyota Priuses converted to PHEV for testing in Manitoba

## Manitoba PHEV Demonstration

## Report of First Year Operations 2008/2009

### Overview

This report documents the outcomes and experience with ten Toyota Priuses converted to Plug-in Hybrid Electric Vehicles (PHEVs) within Manitoba. This is the first of three annual reports for the demonstration, covering the period from September 2008 to August 2009.

### Contents:

<b>Introduction</b>	1
Hybrids and PHEVs	1
Manitoba Demonstration	2
Project Objectives	2
Project Timeframe	2
<b>Demonstration Results</b>	3
Major Activities	3
Vehicle Use Characteristics	5
Fuel Economy	11
GHG Reductions	13
Temperature Impacts	15
Maintenance Impacts	17
Electricity Use	17
Additional Activities	17
<b>Next Steps</b>	17
<b>Partner Profiles</b>	18

### Introduction

#### Hybrids and PHEVs

“Hybrid vehicles” are defined most broadly as incorporating more than one source of power. Usually this means gasoline-electric hybrids. A conventional hybrid electric vehicle (HEV) incorporates an internal combustion engine with batteries for energy storage and at least one electric drive motor.

Hybrid electric operation can be implemented in various complex formats. Vehicles can be simply classified as either parallel hybrids, with a direct connection between the conventional engine and the drive wheels, with the electric motor only assisting; or series hybrids, with the conventional engine used solely to generate electricity, having no direct connection to the drive wheels. The Toyota Prius can permit all-electric operation under certain conditions,

and as such is considered as a mixed series-parallel system.

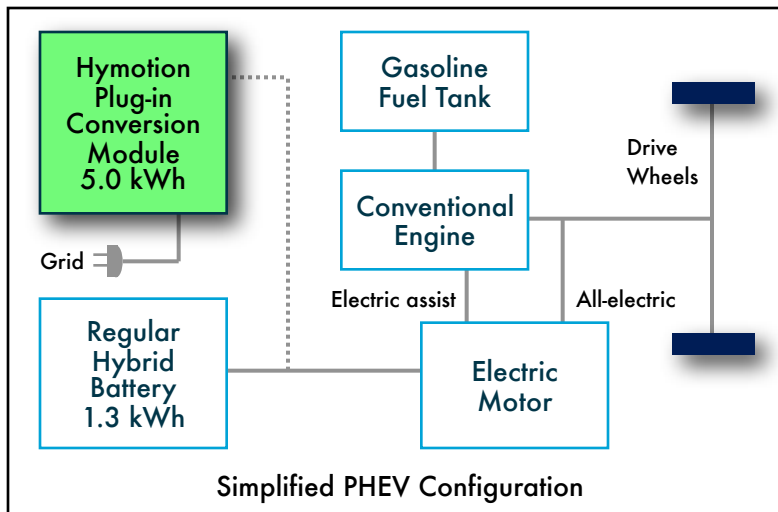
Although factory-built plug-in hybrid electric vehicles (PHEVs), like the Chevrolet Volt, are anticipated to be available by late 2010, PHEV technology so far has involved the modification of conventional HEVs by the installation of additional “energy” batteries. A PHEV plugs into the electrical grid to charge its additional batteries, and during operation uses energy from these batteries to help move the vehicle, whether all-electric or electric-assist.

What distinguishes the PHEV from the HEV is its ability to use grid-based electricity, with associated fuel cost and emissions reductions, but without the constraints and risks associated with being solely electric. With this technology people still drive normally, whether for work or pleasure, but do not consume as much fossil fuel.

Prepared by the Hydrogen Centre of  
Expertise Inc. in cooperation with



**RED RIVER  
COLLEGE**  
OF APPLIED ARTS, SCIENCE AND TECHNOLOGY



## Manitoba Demonstration

This demonstration involves ten Toyota Priuses in Manitoba converted to operate as PHEVs, using Hymotion Plug-in Conversion Modules (PCMs) from [A123Systems Inc.](#) The demonstration is being coordinated and administered by the [Hydrogen Centre of Expertise Inc.](#), a non-profit organization created in 2006. Conversions were performed by qualified automotive instructional staff at [Red River College](#). The College is now an authorized vehicle conversion centre for A123Systems.

Otto-Link data-loggers, manufactured by Manitoba-based [Persentech](#), are installed in each car to monitor driving data. Additional monitoring technology will be installed in 2010 in each vehicle to interactively monitor electricity consumption while plugged into the grid. This technology, called the IPLC-PHEV, is manufactured by Manitoba-based [Vantera Inc.](#), and adapted from Vantera's existing Intelligent Parking Lot Controller (IPLC), already in common use in Manitoba and elsewhere.

(See [Partner Profiles](#) later in this document for more information about these organizations)

Five different public-sector agencies provided Toyota Priuses for conversion to PHEVs, as follows:

- Province of Manitoba, Vehicle and Equipment Management Agency (VEMA) (4);
- Manitoba Hydro (2);
- Manitoba Public Insurance (2);
- City of Winnipeg Fleet Management Agency (1); and
- Red River College (RRC) (1), with this unit leased through VEMA.

These vehicles are all currently operating within respective public-sector fleets in the vicinity of Winnipeg. By agreement with the owners, vehicles are not specifically identified in this report. These ten new PHEVs, combined with two earlier beta-test PHEVs, converted previously for Manitoba Hydro and the University of Manitoba, means that Manitoba currently has the highest concentration of such vehicles in Canada.

## Project Objectives

The demonstration has multiple objectives, outlined as follows:

- Gain experience with PHEV technology under real-world conditions within Manitoba;
- Understand the benefits and limitations of the technology;

- Develop skills working with the technology;
- Understand and address cold-weather issues that are of importance in Manitoba;
- Understand the potential market for further PHEV conversions versus factory-built vehicles; and
- Develop new business opportunities.

## Project Timeframe

The first vehicle was converted in late August 2008; the remaining nine vehicles were converted in mid-April 2009. Performance monitoring is for a period of three years from the first conversion. This report covers the the period from September 2008 to August 2009. Subsequent reports will cover each of the remaining two years.

## Technical Details

Each converted Toyota Prius incorporates a Plug-in Conversion Module (PCM) from A123Systems, with capacity to store 5 kWh of energy from the electrical grid. A123Systems develops and manufactures advanced lithium-ion batteries and battery systems for the transportation, electric grid services, and portable power markets. (For more information visit the site [www.a123systems.com](http://www.a123systems.com)).

The PCM is installed in the spare-tire wheel well in the rear cabin area of the Toyota Prius (see photograph on page 3) and supplements the existing 1.3 kWh nickel metal hydride battery which is part of the original equipment hybrid system and left in the car as part of the conversion process. The PCM makes additional electricity available for use by the Prius, permitting extended electrical operation beyond what would normally be possible.



A123Systems Plug-in Conversion Module installed in the rear compartment area of Toyota Prius, behind nickel metal hydride stock hybrid battery

## Demonstration Results

### Major Activities

Ten major activities were completed for the demonstration by the end of August 2009, and are summarized in the following points:

1. **Arrangements with user-organizations for vehicles.** Five agencies provided vehicles to be converted as part of the project. This activity included the negotiation and signing of user agreements with participating vehicle owners. Details of the vehicles are summarized in the Table on page 4.
2. **Insurance confirmation.** Discussions were held with Manitoba Public Insurance (MPI) regarding the project. It was confirmed that all of the converted Priuses would be covered under standard MPI vehicle policies, in particular that the capital value of the vehicle, including battery pack, would be still less than \$50,000, which is standard in MPI policies.
3. **Safety equipment.** Standard basic safety equipment was arranged for all vehicles (see photographs on page 4 and 5).

This included for each vehicle: 5 lb ABC fire extinguisher, if not already standard equipment; thumb-release tie-down straps to secure the spare-tire, jack and associated equipment displaced from normal location below the rear deck; driver safety information and safety card in each vehicle; and standard identification decal, or similar, installed on all vehicles on the rear driver-side window. Although useful for profile, a primary purpose of the decal is to provide a common and recognizable identification to fire and emergency services workers in the event one of the vehicles might be involved in an accident. The City of Winnipeg Fire and Paramedic Services are aware of the decal and its significance. The two earlier Beta-test vehicles also had the same or similar decal installed.

4. **Plug-in Conversion Modules.** A signed agreement was earlier secured with A123Systems for purchase and installation of ten conversion modules.
5. **First vehicle conversion.** One of the vehicles (Unit #1982) was converted to PHEV by personnel from A123Systems in late August

2008. This conversion was completed at the garage facilities of Manitoba Hydro. Staff from RRC were also present to observe the conversion. This permitted preliminary operation of at least one vehicle, in particular through a winter season, prior to the remaining conversions.

6. **Cold weather modifications.** The vehicle converted in August experienced cold-weather issues during the winter of 2008-2009. Details are described later under the section on **Temperature Impacts**. Important cold-weather solutions were developed by Red River College, with assistance from A123Systems Inc.
7. **Certification of Red River College by A123Systems.** A major success of the project was certification by A123Systems of RRC as a conversion centre. This permits the College to undertake additional conversions using A123Systems technology. The College's involvement also gives staff and students unique exposure to leading edge PHEV technologies. Five instructors from the College's Transportation program were trained by A123Systems and undertook the remaining nine conversions. Staff from the College's Applied Research group were involved in managing conversion records, as well as implementing cold-weather upgrades, and managing specialized equipment unique to this demonstration.
8. **Completion of installations.** The nine remaining vehicles were converted at Red River College in mid-April 2009. Cold-weather upgrades and data-logging equipment were installed at the same time.

# Summary of Toyota Priuses Converted in Demonstration

Identifier	Year	Odometer	Identifier	Year	Odometer
#1981	2008	11,509 km	#1986	2009	131 km
#1982	2008	6,542 km	#1987	2009	35 km
#1983	2008	2,497 km	#1988	2008	9,649 km
#1984	2004	134,599 km	#1989	2007	42,496 km
#1985	2008	14,203 km	#1990	2004 †	27,005 km

Notes: Identifier numbers are unique to this project; odometer readings are at time of conversion; † rebuilt unit



PHEV conversions of Toyota Priuses underway at Red River College in April 2009



Quick-release tie-down straps used to secure spare-tire and jack equipment, as installed in unit #1989 (left) and unit #1982 (right)

9. **On-board vehicle data-loggers.**

Two data-loggers from Manitoba-based Persentech were installed in all the vehicles (see photographs on pages 6 and 8). The Otto-Link unit plugs into the CAN-Bus and logs all vehicle data signals, while the Otto Driving Companion uses GPS data to log individual vehicle trips and the nature of driver habits. Only selected data from these data loggers are reported, but records are all being maintained to provide a data-mine for subsequent analyses.

10. **Electricity data-loggers.**

Ten Power Quality Logger (PQL) units were acquired to track battery energy consumption and power-quality parameters on each vehicle (see photograph on page 6). However, a key limitation was discovered. These units must remain at a single recharging

location, and cannot move with the vehicle without losing data. Their capabilities for monitoring power-quality still have been utilized, but restricted to a smaller number of vehicles. Accelerated monitoring, using higher resolution has been undertaken, with multiple PQL loggers rotated on selected vehicles having more dedicated and protected charging locations. Given the lack of an appropriate low-cost on-board device for monitoring and logging of electricity-use, discussions were initiated with Vantera Inc. to adapt their existing Intelligent Parking Lot Controller (IPLC) product for this purpose. The development of a prototype was begun, but not yet ready to implement by the end of August 2009.

## Vehicle Use Characteristics

Although fuel economy improvement is the key desired outcome of the project (described next under **Fuel Economy**), it is well recognized that fuel-use depends not just on the vehicle technology employed, but also significantly on the nature of vehicle-use characteristics (e.g. driver habits and duty cycle), as well as weather conditions (discussed later under **Temperature Impacts**).

In the Table on page 6, the ten vehicles are categorized, based on their vehicle-use characteristics:

- Nature of the driver, particularly whether this involved primarily (a) single driver, or (b) multiple drivers; and

## Safety Equipment on Demonstration Vehicles

Each of the converted Toyota Priuses in the demonstration is equipped with tie-down straps for relocated spare tire and other equipment, decal for recognition, 5 lb ABC fire extinguisher, and vehicle-safety card for driver.



Plug-in Hybrid  
Electric Test Vehicle

Manitoba 

Li battery  
below in trunk



5 lb ABC Fire Extinguisher (left) and common recognition decal (right)

# Transport-related Characteristics of Vehicles

Identifier	Nature of Driver	Nature of Operating Cycle
#1981	Pool with Occasional Regular Driver	Some Commute, Some Irregular
#1982	Primarily Single Regular Driver	Primarily Commute
#1983	Single Regular Driver with some Pool	Commute and Irregular Daily Use
#1984	Primarily Single Regular Driver	Regular Daily Work Route
#1985	Primarily Single Regular Driver	Commute and Irregular Daily Use
#1986	Pool Vehicle	Irregular Use
#1987	Pool Vehicle	Irregular Use
#1988	Rotating Single Regular Driver	Commute and Irregular Daily Use
#1989	Rotating Single Regular Driver	Primarily Commute
#1990	Pool Vehicle	Irregular Use



PQL electricity data-logger (left) and Otto Driving Companion logger and Otto-Link CAN-Bus logger (right)

- Nature of the operating cycle of the vehicle, particularly whether
  - (a) primarily regular commute,
  - (b) regular work route,
  - (c) irregular daily operation, or
  - (d) combination of commute and irregular daily operation.

Given individual characteristics, as outlined in the Table on page 6, the vehicles cluster overall into five distinct groups expected to have similar performance:

**Group 1:** Single Driver with Commute Use (2 vehicles);

**Group 2:** Single Driver with Regular Daily Work Use (1 vehicle);

**Group 3:** Single Driver with combined Commute and Irregular Daily Work Use (3 vehicles);

**Group 4:** Pool Vehicle with Multiple Drivers and Irregular Daily Work Use (3 vehicles); and

**Group 5:** Combined Single/Multiple Driver and Regular/Irregular Use (1 vehicle).

This categorization is employed for further analysis of transportation-related vehicle evaluations.

Prior to the start of the PHEV demonstration, a separate on-going project was already underway by researchers at the University of Winnipeg. This involves the same Otto Driving Companion data-loggers, but assessing a much larger sample of regular vehicles, i.e. 79 vehicles operated by volunteers over a one year period. Summary statistics from their work are presented in the side-bar on page 10 for relevant parameters.

The Otto data-loggers permit the tabulation of diverse parameters. Based on discussions with the researchers at the University of Winnipeg, two key parameters were selected for presentation and further analysis as part of this report:

- **Trips per day;** and
- **Daily travel distance.**

A summary of the PHEV data is presented in the Tables on page 8 through page 10:

- Table on page 8 summarizes data on the **trips per day** for each vehicle including mean, median, standard deviation, and number of data points (i.e. number of days).
- Table on page 9 summarizes data on the **daily travel distance** for each vehicle including mean, median, standard deviation and number of data points.
- Table on page 10 summarizes linear correlations of the **daily travel distance** (treated as dependent variable) as a function of the **trips per day** (treated as independent variable) for each vehicle.

Additional explanations of analyses are provided on pages 9 and 10. There are several key observations:

- Data were missed for two vehicles; in one case logged data were not recorded during the appropriate period, and in the other case the logger was damaged.
- The number of data points (i.e. days) for each vehicle are included in the tables and tend to be less than would be expected. This was due to limitations in the storage capacity of the data loggers.
- Data for **trips per day** for different vehicles show different patterns. In some cases the data are essentially single-modal in nature, but in most cases are multi-modal (i.e. number of significant peaks).

- Data for **daily travel distance** for each vehicle appear to be multi-modal in all cases, and quite positively skewed in some cases. This makes sense given that only a few long trips will strongly distort the data distribution.

- Data for **daily travel distance** for all vehicles were quite different from regular vehicles (i.e. see University of Winnipeg data on page 10).
- Data for **daily travel distance** also could be compared to “average” vehicle travel in Manitoba. As outlined in the side-bar on page 8, the average annual travel distance for a passenger vehicle in Manitoba is just under 16,000 km, based on data from Statistics Canada. For 365 days per year, an average daily travel distance of about 43 km would be anticipated. Values greater or less than this benchmark show whether an individual vehicle is driven more or less than the overall average value for Manitoba. Only two vehicles were above average. All the others had much lower values, likely due to the nature of fleet-based operation in all cases.
- Although potentially counter-intuitive, there was relatively little direct correlation between **trips per day** and **daily travel distance** for each vehicle. This confirmed the desirability to consider these parameters separately.
- The highest correlation between **trips per day** and **daily travel distance** ( $r^2 = 0.72$ ) was for unit #1984, which makes sense as this was the only one with a single, regular driver and a regular work-related driving cycle (i.e. **Group 2**).

# Measured Trips per Day Data for Test Vehicles

Identifier	Mean	Median	Standard Deviation	Data Points
#1981	2.1 trips per day	0.0 trips per day	3.1 trips per day	68 days
#1982	4.3 trips per day	4.0 trips per day	2.8 trips per day	201 days
#1983	4.1 trips per day	4.0 trips per day	2.6 trips per day	56 days
#1984	2.3 trips per day	0.0 trips per day	3.9 trips per day	103 days
#1985	2.3 trips per day	2.0 trips per day	2.4 trips per day	131 days
#1986	Log data not available			
#1987	Log data not available			
#1988	2.2 trips per day	2.0 trips per day	2.4 trips per day	128 days
#1989	3.4 trips per day	3.0 trips per day	2.2 trips per day	57 days
#1990	3.1 trips per day	2.0 trips per day	3.6 trips per day	110 days



Otto Driving Companion logger mounted on vehicle dash-board

## Average Travel Distance

Statistics Canada regularly publishes the "Canadian Vehicle Survey" (Catalogue no. 53-223-XIE) with recent summary annual data for Manitoba as follows:

Year	Number Vehicles <sup>†</sup>	Travel Distance (km/year)	Average (km/year)
2000	583721	9334200000	15,991
2001	592212	9669300000	16,327
2002	601943	8691100000	14,438
2003	605115	11044200000	18,251
2004	616015	8840500000	14,351
2005	623383	9314400000	14,942
2006	631517	10256500000	16,241
2007	643582	11845400000	18,405
2008	659493	9705000000	14,716

<sup>†</sup> Vehicles less than 4.5 tonne

Mean annual travel 15,872 ± 1,601 km/year  
 Aggregate average travel 15,962 km/year  
 Resulting daily travel is about 43 km per day



## Measured Daily Travel Distance Data for Test Vehicles

Identifier	Mean	Median	Standard Deviation	Data Points
#1981	25.6 km per day	0.0 km per day	73.2 km per day	68 days
#1982	44.0 km per day	24.3 km per day	82.4 km per day	201 days
#1983	67.1 km per day	21.1 km per day	150.6 km per day	56 days
#1984	16.4 km per day	0.0 km per day	35.9 km per day	103 days
#1985	18.2 km per day	14.4 km per day	36.3 km per day	131 days
#1986	Log data not available			
#1987	Log data not available			
#1988	16.7 km per day	5.8 km per day	20.8 km per day	128 days
#1989	21.0 km per day	21.3 km per day	13.7 km per day	57 days
#1990	25.8 km per day	5.0 km per day	53.1 km per day	110 days

### What do the data on vehicle-use characteristics mean?

#### Data on "trips per day":

In the Table on page 8, summary statistical data are presented for each vehicle, including mean, median and standard deviation. The vehicles can be divided into two categories:

- Units #1982 and #1983 show results that are statistically similar to the overall pattern exhibited by the study group of vehicles evaluated by the University of Winnipeg. Unit #1982 in particular was deliberately operated as more of a regular "commuter vehicle" so this result can be explained.
- All other units show results that are distinctly different, suggesting very different "fleet" driving patterns when compared to the larger study group of vehicles.

#### Data on "daily travel distance":

In the Table on page 9, summary statistical data are presented for each vehicle, including mean, median and standard deviation. In this case none of the vehicles are similar statistically to the average vehicle performance as determined for the larger study group of vehicles by the University of Winnipeg. Again, the vehicles can be divided into two groups, in this case comparing to average daily travel for vehicles in Manitoba:

- Units #1982 and #1983 showed daily travel above the expected average daily travel distance in Manitoba (i.e. 43 km per day);
- All other vehicles show results that are significantly lower than average daily travel distance in Manitoba, suggesting very different "fleet" driving patterns. Several vehicles even show 0 km per day as a median value. This is not an error but results from these vehicles being idle on weekends and additional days.

# Daily Travel Distance as a Function of Trips per Day

Identifier	Linear Regression Intercept	Linear Regression Slope	$r^2$
#1981	- 9.51 km per day	16.84 km per trip	0.50
#1982	- 9.66 km per day	12.54 km per trip	0.18
#1983	- 14.54 km per day	20.13 km per trip	0.12
#1984	- 1.84 km per day	7.88 km per trip	0.72
#1985	- 1.57 km per day	8.55 km per trip	0.32
#1986	Log data not available		
#1987	Log data not available		
#1988	1.78 km per day	6.87 km per trip	0.64
#1989	4.42 km per day	4.85 km per trip	0.60
#1990	- 0.04 km per day	8.35 km per trip	0.32

## Correlations of "daily travel distance" as a function of "trips per day":

In the Table on page 10, results are presented for each vehicle of the linear regression of **daily travel distance** as a function of **trips per day**. These assessments were undertaken to determine to what extent the two parameters are related to one another. For each vehicle, the resulting intercept, slope and coefficient of determination ( $r^2$ ) value are presented. The latter coefficient expresses the proportion of variation that can be explained by the linear relationship between the two variables.

Intuitively, it might be expected that a larger number of trips per day would translate to a longer daily travel distance. However, in all cases the  $r^2$  values are relatively poor (i.e. 0.10 to 0.70). A value over 0.80 is typical to show a strong association. Although not entirely independent, the two parameters are poorly related to one another.

## University of Winnipeg

### Summary of relevant vehicle statistics

#### Trips per day:

Mean:	4.5 trips per day
Median:	4.0 trips per day
Standard Deviation:	3.1 trips per day

#### Daily travel distance:

Mean:	35.8 km per day
Median:	26.0 km per day
Standard Deviation:	42.4 km per day

Blair, D., and R. Smith. University of Winnipeg. Unpublished results from analysis of Otto Driving Companion data. For more information visit the site: <http://auto21.uwinnipeg.ca>

## Fuel Economy

In order to be consistent with both current recommended practice for reporting fuel economy of PHEVs (see sidebar on page 16) and Canada's official status in employing the International System of Units (SI), the primary units for reporting of fuel (energy) economy in this demonstration are:

- Litres per 100 kilometre for gasoline consumption; and
- Kilowatt-hours (kWh) per 100 kilometre for electrical energy consumption as a separate value.

Given that the prototype IPLC-PHEV units are not yet installed, no electrical energy consumption has been reported for any vehicle (see [Electricity data-loggers](#) on page 5).

For gasoline consumption, reference periodically is made to "miles per U.S. gallon" (MPG), given this is an official unit in the U.S. and thus important for reference purposes. Units of "miles per Imperial gallon" (MPIG) are not employed directly, given this unit is no longer used officially anywhere, and also can cause significant confusion with MPG values from the U.S. when not properly identified. A table of equivalent values for gasoline fuel economy is provided to permit conversion to desired units (see side-bar Table on page 12).

In order to evaluate the improvement of fuel economy resulting from PHEV operation, as well as GHG reductions, it is important to obtain a good base-line for expected fuel consumption under relevant conditions with the regular Toyota Prius. This raises a number of concerns. An obvious bench-mark value that can be considered is the

official fuel economy rating by the Government of Canada. The rating for combined City/Highway travel for 2004-2009 model years of the Toyota Prius has been consistently about 4.1 Litres per 100 km. However, this value, which is based on specified dynamometer testing, is well known to be only applicable to relatively ideal conditions, and unlikely to be achieved under any real conditions in Canada. The problematic nature of this rating was exacerbated given that in 2006-2007 the U.S. Government revamped their fuel economy testing in an effort to provide "more realistic" values. Their revised rating for combined City/Highway travel is about 46 MPG for the same Prius model, translating to 5.1 Litres per 100 km, roughly 25% more fuel for the same distance. Further, given Canada's more harsh climate, gasoline consumption typically would be expected to be higher in Canada than the U.S. in general.

Using data and experience provide by VEMA, Manitoba Hydro, and the City of Winnipeg Fleet Management Agency for approximately twenty conventional Priuses, the expected Prius fuel economy is about 6.2 Litres per 100 km under Manitoba conditions. This is much higher than the official value, but is less than half the average Manitoba fuel consumption. (see side bar on page 12).

At the same time, A123Systems suggests a "desired" fuel economy for the PHEV, considering gasoline only, of about 100 MPG. This translates to about 2.4 Litres per 100 km as the desired bench-mark.

The calculated overall fuel economy achieved so far for each of the ten PHEVs in the demonstration is provided in the Table on page 12.

This involved operation from the time of conversion to the latest refueling stop prior to September 1, 2009. This represented a one year period for the first vehicle, but under six months for the others. In different cases, depending on refueling date this involved a somewhat shorter or longer period. Presented in the table are the total travel distance, the total fuel consumption, and the resulting overall fuel economy as calculated. As is the case for all fleet-based vehicles, the tracking of fuel consumption is very accurate in all cases. What is more problematic is obtaining precise odometer readings to correspond with fueling. As such, in some cases odometer readings are estimated as closely as possible, with fuel economy values in such cases being less accurate.

Overall, fuel economy values ranged from 3.7 to 5.6 Litres per 100 km. This reflects differences in not only the extent of electricity use, but also the nature of driving operations and temperature conditions. Overall aggregate fuel consumption for all vehicles was calculated to be 4.8 Litres per 100 km. Six vehicles had fuel economy better than this value and four vehicles worse. Only one vehicle's performance could be easily and consistently explained; this being Unit #1984, with the highest fuel consumption. This was the only vehicle classified into [Group 2](#) (regular work route), and was driven in a highly diligent manner. Yet, given its regular operation for a consistent and relatively steady daily-work route, it would use up the entire battery charge relatively quickly, without opportunities for recharging during the course of a day. As such, this vehicle ended up operating

# Measured Fuel Economy for Test Vehicles

Identifier	Travel Distance	Fuel Consumed	Fuel Economy
#1981	2,072 km	82 Litres	4.0 Litre / 100 km
#1982	12,155 km	597 Litres	4.9 Liter / 100 km
#1983	9,004 km	477 Litres	5.3 Litre / 100 km
#1984	5,171 km	289 Litres	5.6 Litre / 100 km
#1985	2,686 km	127 Litres	4.7 Litre / 100 km
#1986	3,789 km	179 Litres	4.7 Litre / 100 km
#1987	4,265 km	156 Litres	3.7 Litre / 100 km
#1988	2,096 km	89 Litres	4.2 Litre / 100 km
#1989	3,056 km	116 Litres	3.8 Litre / 100 km
#1990	2,979 km	155 Litres	5.2 Litre / 100 km

## Vehicle Emissions Profile Determination

### Average Vehicle Emissions

The report *Beyond Kyoto* by the Government of Manitoba includes data that shows:

- Average Manitoba vehicle travels approximately 16,000 km per year
- Average Manitoba vehicle gasoline fuel economy is 15 Litres per 100 km

Environment Canada indicates the emissions factor for gasoline combustion to be about 2.3 kg per Litre on a tank-to-wheels basis. Including Manitoba's current ethanol mandate of 8.5%, an average vehicle uses approximately 2,200 Litres of gasoline and 200 Litres of ethanol, generating about 5.05 tonnes per year of GHG emissions on a tank-to-wheel basis. On a tank-to-wheels basis both electricity and ethanol have zero emissions (i.e. emissions only in upstream processing).

### Toyota Prius Emissions

Applying the same travel distance with a fuel economy of 6.2 Litre per 100 km, a regular Toyota Prius would consume 910 Litres of gasoline and 80 Litres of ethanol, translating to 2.09 tonnes per year of GHG emissions on a tank-to-wheel basis.

### PHEV Prius Emissions

Applying again the same travel distance with aggregate fuel economy of 4.8 Litres per 100 km (i.e. 2,267 Litres / 47,273 km), a PHEV Prius would consume 700 Litres of gasoline and 70 Litres of ethanol, translating to 1.62 tonnes per year of GHG emissions on a tank-to-wheels basis.

*Beyond Kyoto*: [http://www.gov.mb.ca/asset\\_library/en/beyond\\_kyoto/top10.pdf](http://www.gov.mb.ca/asset_library/en/beyond_kyoto/top10.pdf)

*Environment Canada*: [http://www.ec.gc.ca/pdb/ghg/inventory\\_report/2006\\_report/a12\\_eng.cfm#a12\\_1\\_4](http://www.ec.gc.ca/pdb/ghg/inventory_report/2006_report/a12_eng.cfm#a12_1_4)

## Unit Conversions

L/100 km	MPG	MPIG
2	118	142
3	79	95
4	59	71
5	47	57
6	39	47
8	29	35
10	24	28
15	16	19

proportionately more time as a conventional hybrid, with the benefits of PHEV operation thus less pronounced. Such a regular-use cycle appears less well suited to PHEV operation at this time. This is the same reason why taxi-use is well suited to a conventional HEV but not as well suited to be a PHEV (i.e. constant driving with little idle time for recharging). For all other vehicle Groups there was no consistent behaviour, with performance both above and below aggregate fuel economy.

Only one of the vehicles (Unit #1982) had a full-year of operation, and, as such, this unit provides the best information so far for full yearly operation within Manitoba. Its fuel consumption was 4.9 Litres per 100 km, just slightly higher than the aggregate value.

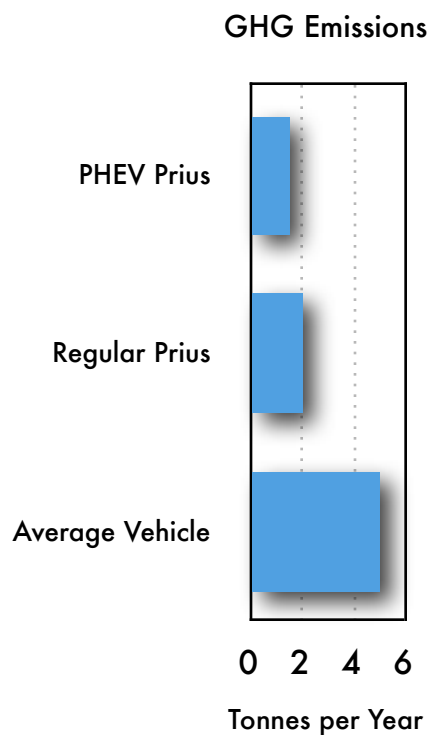
A time-track of calculated “fill-to-fill” fuel economy values for three selected vehicles is presented in the Graph on page 14. As illustrated, there is wide variation in data, obviously linked to differences in seasonal temperatures. It is also important to note that incremental fuel economy values approached or exceeded A123Systems expectations (i.e. 2.4 Litres per 100 km) on a number of limited intervals, all in warmer months. The best calculated fuel economy achieved was about 1.9 Litres per 100 km, this for unit #1981 in late-June, early-July while being driven on a more regular basis.

The aggregate fuel consumption for all vehicles of 4.8 L per 100 km was used for further analysis. Although twice the desired fuel consumption for the PHEV as outlined by A123Systems, this value is roughly 25% lower than that for a conventional Prius under similar

conditions in Manitoba, and is likely close to the best gasoline fuel economy achieved by any vehicle under Manitoba conditions. Based on this value, expected annual fuel savings of about 220 Litres could be anticipated for the PHEV Prius compared to a conventional Prius, but, at the same time, more than 1,600 Litres lower when compared to an average Manitoba vehicle.

## GHG Reductions

Preliminary data for annual greenhouse gas (GHG) emissions are presented in the following Plot for the PHEVs on a tank-to-wheels (TTW) basis:



Presentation on a TTW rather than well-to-wheels (WTW) basis is provided for two reasons. Firstly is the current use of a TTW reporting approach by Environment Canada for transportation applications, and secondly is the lack of electrical consumption data, which is needed to prepare a full-cycle emissions foot-

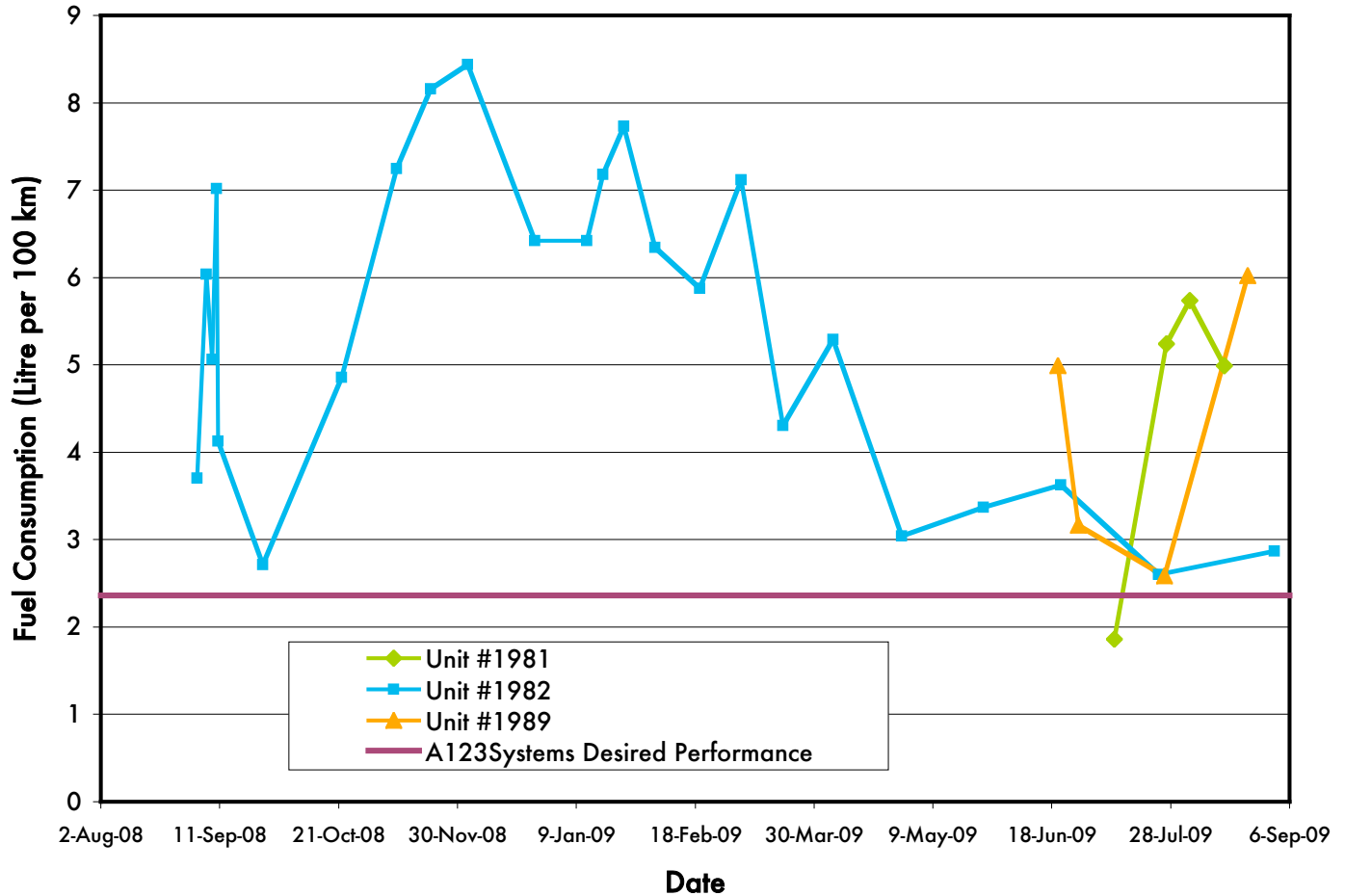
print. Reporting of GHG emissions in Environment Canada’s National Inventory Report considers only a TTW basis, with all upstream emissions for production and processing of fuel of all types reported under industrial processing. In this case the emissions associated with electricity as a fuel are zero irrespective of source on a TTW basis, given this method of accounting.

In the TTW emissions plot, benchmark data for non-PHEVs are also included for comparison (for average vehicle calculations see Emissions Profile on page 12). As illustrated, the PHEV reduces annual vehicle TTW emissions by roughly 25% compared to a regular Prius. At the same time, the reduction is roughly 70% compared to an average vehicle in Manitoba.

The resulting incremental reductions achieved by PHEV technology may appear proportionally small, especially compared to the significant reductions achieved by simply moving to an efficient vehicle, like the conventional Prius. However, moving to progressively lower emission thresholds becomes progressively more difficult and costly, and must be viewed in that context, i.e. easier to reduce from 5 to 2 tonnes, than below 2 tonnes.

Developing a full emissions footprint profile for the PHEVs requires electricity consumption data, which is not yet available. On a full (WTW) basis, the total extent of emission reductions for the PHEVs will be proportionately larger, in particular given the extremely low emissions associated with Manitoba’s electrical grid mix.

# Interval Fuel Economy Values for Selected Test Vehicles



**What do these data mean?:** Data points in the above figure represent calculated incremental fill-to-fill fuel consumption values for each vehicle, with the date in each case being the average date between the two sequential refueling dates.



Upgrade Optima "Yellow-Top" 12-volt battery (left) and 12-volt trickle charge (right) implemented to address cold weather problems

## Temperature Impacts

Manitoba's cold winter-weather presents a challenge to many new technologies, including PHEVs. Having one of the vehicles converted early and operating through the winter of 2008-2009 provided valuable experience to identify and address cold-weather problems. As well, this experience was compared with the cold weather experience of the earlier Manitoba Hydro beta-test vehicle.

The chief concern that arose was with the performance of the Prius' factory-installed 12-volt battery when temperatures dropped. Concerns regarding this battery were not unexpected, given that Prius taxi fleets in Manitoba are known to commonly upgrade the 12-volt battery.

The extent of problems was worse than anticipated. By mid-December 2008, which had been particularly cold, vehicle failures had been experienced with unit #1982 and the Manitoba Hydro beta-test vehicle. The nature of the problem was identified, and staff from RRC, working in conjunction with A123Systems, developed appropriate solutions.

**Nature of problem:** In order for the Prius to start-up, the 12-volt battery needs to maintain a minimum voltage-level of at least 10.6 volts. The stock Prius 12-volt battery is relatively small, and can have difficulty maintaining this level as the temperature drops to lower levels. As such, the voltage could slip below the minimum threshold, and the vehicle would not start. This situation was made worse as the Otto-Link data-logger plugs into the CAN-bus and draws power from that source, essentially off the 12-volt

system, putting additional stress on the battery.

**Solutions:** As illustrated in the schematic below on this page, two solution approaches were incorporated simultaneously to resolve the cold-weather problem with the 12-volt battery:

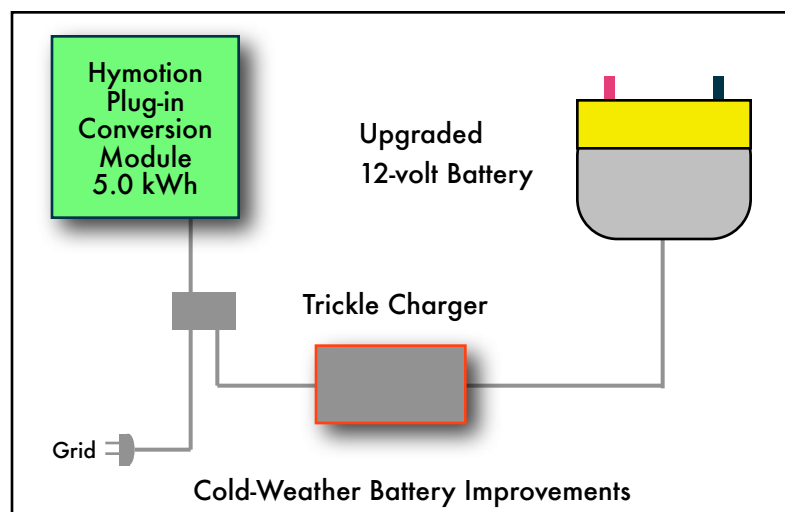
- Replacing the stock Prius 12-volt battery with a more robust, deep-cycle battery, specifically an Optima Yellow-Top battery (see photograph on page 14); and
- Installing an automatically activated trickle charger off the main charging line for the PCM that would charge the 12-volt battery whenever the main battery was plugged in (see photograph on page 14).

During continued testing with unit #1982 over the remainder of the winter of 2008-2009, no further problems were encountered. RRC staff formalized the procedures for the 12-volt battery upgrades, and the same modifications were made to all nine remaining vehicles at the same time as the PCM installations. The performance of the 12-volt battery upgrades will be monitored through the course of the second

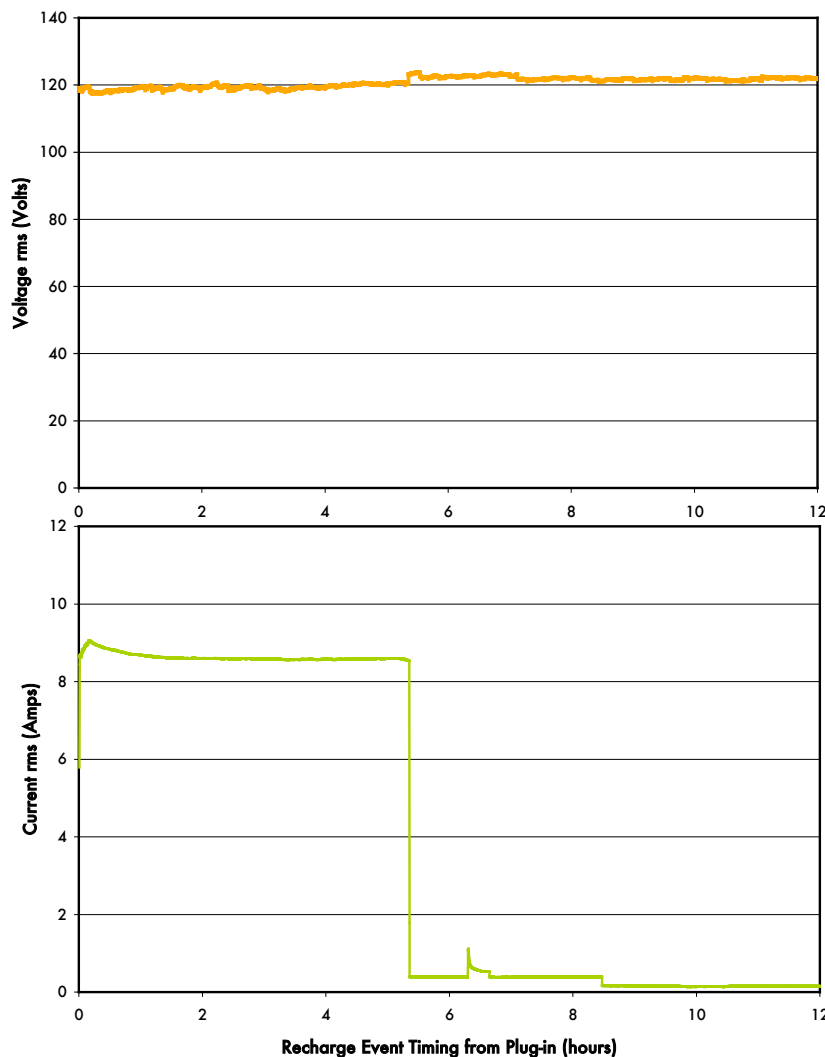
winter season to confirm resolution of the identified problems.

One additional potential cold-weather issue identified with the PHEV Prius, but not yet directly addressed, is cabin heat. Internal combustion engine vehicles rely on waste engine heat to provide warmth for the cabin, essentially operating as "co-generation" systems. But, increasing electrical operation of the vehicle inherently reduces the amount of waste heat available for cabin warming. Unit #1982, which was converted earlier and operated during the winter of 2008-2009, was noted to be "slow" to warm up during cold weather.

Requesting cabin heat also calls on the gasoline engine to engage more frequently, subsequently reducing fuel economy. This is further exasperated when the dedicated windshield defrost setting is activated. The dedicated windshield defrost setting demands the warmest possible temperature output from the vehicle heater, and will thus run the engine even more frequently than some of the other heat settings. For the second winter, a variety of possible solutions to enhance cabin warmth will be investigated.



# Electrical Data Plots for Representative PHEV Recharging Event (Unit #1981, June 24, 2009)



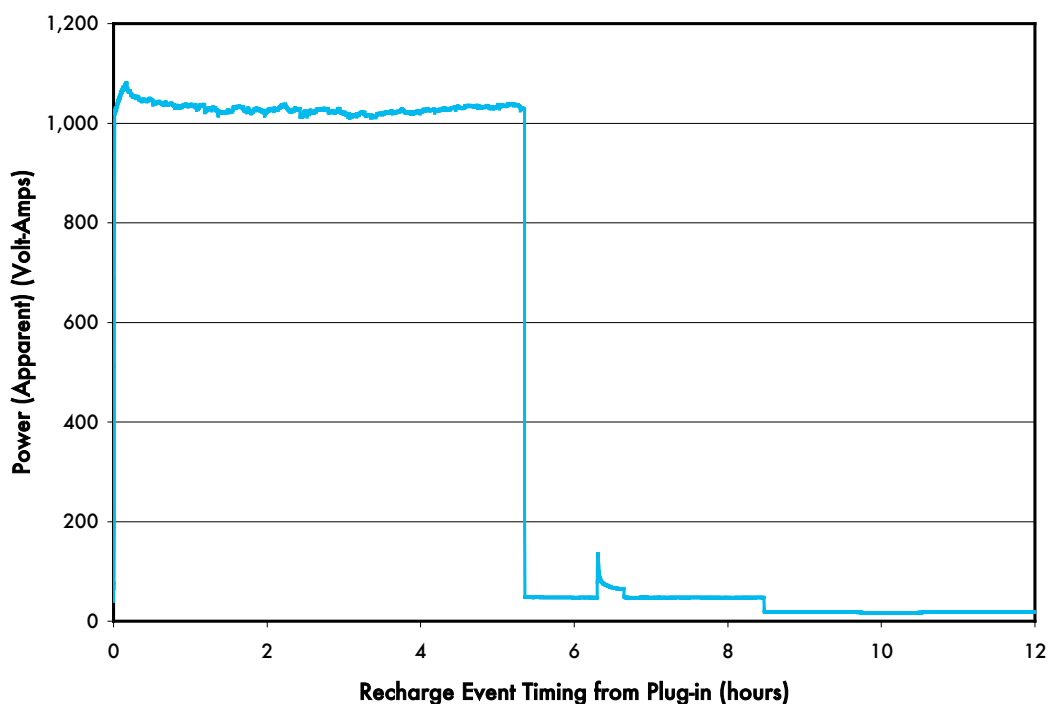
## PHEV Fuel Economy Reporting

The PHEV presents a complex case for the reporting of fuel economy, given that two completely separate energy sources (gasoline and grid electricity) are combined to operate the vehicle. This is analogous to the classic "joint-process" problem often encountered in accounting.

Although reporting gasoline consumption alone is intrinsically simple, it inherently misses differences in the electricity use of vehicles, which is particularly important for full-cycle emissions.

In 2006, Gonder and Simpson of NREL recommended that both should be reported separately, with electricity in units of Wh per mile (for the U.S.). Their report is available at the following internet site:

<http://www.nrel.gov/vehiclesandfuels/vsa/pdfs/40377.pdf>





## Maintenance Impacts

During the first year no important maintenance impacts, whether positive or negative, were identified with the PHEVs.

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## Electricity Use

As was noted earlier, the PQL data-loggers were found to be inappropriate for on-going mobile monitoring of electricity use. These units had to remain at a single charging location and also had to be kept sufficiently warm. As such, for electricity-use monitoring the decision was made to switch to IPLC-based units, which will be installed later. However, the ten PQL data-loggers are being applied to more intensive monitoring at selected locations for units #1981, #1982 and #1989, in particular for harmonic and power quality impacts.

So far, for the selected locations monitored, no significant impacts on power quality or harmonics have been identified for single-charging of vehicles, whether at a residential or commercial/institutional site.

Presented on page 16 are time traces of data for a representative recharging event for unit #1981 on June 24, 2009. This event covered a full 12-hour period, with the PCM having been fully drained prior to charging.

Three data plots are presented on page 16 for electricity “at the wall plug” going to the vehicle, each consisting of more than 8,000 data points, with logging at 5 second intervals:

- **Voltage** (i.e. root mean squared or  $V_{rms}$ ) in volts;
- **Current** (i.e.  $I_{rms}$ ) in amps; and

- **Power** in volt-amps, in this case “apparent” power (calculated from  $V_{rms} \times I_{rms}$ )

Several important observations can be made from the data in these plots. Firstly, the voltage to the vehicle remains relatively constant, around 120 volts, with only small variations, as would be expected. The small downward step change at the beginning reflects the start of the main charging cycle for the PCM, while the small upward step change at around 5.4 hours corresponds to its end. Secondly, the current going to the vehicle rises rapidly at plug-in but then falls back, leveling at about 8.6 amps during the main charging. The initial peak likely reflects the combined load of the PCM and trickle charger. Once the main charging cycle for the PCM is completed, however, the current does not drop to zero. Rather it drops first to an intermediate level, and then to a low level, but never completely off. This characteristic likely reflects the trickle charger and on-board fan and computer associated with the PCM. Thirdly, the shape of the power curve over the course of recharging cycle is not quite the same as that observed by others, such as Manitoba Hydro for their beta-test vehicle. Further, by summing all instantaneous power (apparent) values for each 5-second interval, electrical energy over the 12-hour period totaled approximately 5.7 kilo-volt-amps. Assuming a power factor of about 95% for typical residences means this translates to about 5.4 kWh, about 8% higher than the anticipated energy for recharging (i.e. 5 kWh). The difference in charge curves and the somewhat higher than expected electrical energy use reflect both the added

trickle charger and other on-board loads accompanying the PCM.

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## Additional Activities

### Manitoba Hydro Multiple-Vehicle Recharging Test.

In the later part of July 2009, Manitoba Hydro coordinated an important charging test at one of their facilities. This involved the simultaneous charging of eight PHEVs at one time at a single site on eight ordinary winter engine-block heater circuits (see photograph on page 18). This activity involved six vehicles from the demonstration, plus beta-test vehicles from Manitoba Hydro and the University of Manitoba. It represents the largest number of PHEVs in the world so-far to be simultaneously recharged off a single circuit breaker panel.

The intent of this exercise was to simulate recharging at an ordinary commercial site and to assess potential impacts, particularly with regard to power quality and harmonics. Staff from Manitoba Hydro’s internal power quality group monitored the dedicated circuit using highly sophisticated equipment. In general they found there were few additive impacts, and the overall impact was much like normal block heater use except for consuming about 30% to 40% more electrical power. The nature of impacts was not unexpected, and easily manageable.

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## Next Steps

Over the remaining two years of the demonstration, a series of activities will be pursued:

- Confirming effectiveness of cold weather battery adaptation over next winter period.
- Addressing cabin warmth issues with vehicles for the next winter.
- Completing prototype development and implementing the IPLC-PHEV units in all vehicles, together with [Vantera](#).
- Continuing to track data, and enhance the quality of data as much as possible.
- Undertaking a survey of user and public attitudes toward PHEVs in the third year.
- Developing conclusions from the demonstration and preparing recommendations for follow-up actions, based on the real-world experience gained.

## Partner Profiles

[A123Systems Inc.](#) develops and manufactures advanced lithium-ion batteries and battery systems for the transportation, electric grid services, and portable power markets, and supplied Hymotion Plug-in

Conversion Modules for the project ([www.a123systems.com](http://www.a123systems.com)).

[City of Winnipeg Fleet Management Agency](#) is an Agency of the City of Winnipeg that delivers fleet management services to City Departments, and provided one vehicle for conversion ([www.winnipeg.ca/fleet/](http://www.winnipeg.ca/fleet/)).

[Hydrogen Centre of Expertise Inc.](#) is a Manitoba-based non-profit organization providing funding administration and project management for the demonstration.

[Manitoba Hydro](#) is a Manitoba crown corporation and integrated electrical and natural gas utility, and provided two vehicles for conversion ([www.hydro.mb.ca](http://www.hydro.mb.ca)).

[Manitoba Public Insurance](#) is a Manitoba crown corporation and public vehicle-insurance agency, and provided two vehicles for conversion ([www.mpi.mb.ca](http://www.mpi.mb.ca)).

[Persentech Inc.](#) is a Manitoba-based manufacturer of personal sensor devices and solutions for location-based services, and supplied Otto-

Link data-logging equipment for the project ([www.persentech.com](http://www.persentech.com)).

[Red River College](#) is a Winnipeg-based post-secondary institution, specializing in technology and trades education, and applied research. The College is certified as a Hymotion conversion centre, and staff undertook conversion of vehicles to PHEV. The College is providing additional support as the demonstration proceeds, and also made a vehicle (leased through VEMA) available for conversion ([www.rrc.mb.ca](http://www.rrc.mb.ca)).

[Vantera Inc.](#) is a Manitoba-based manufacturer of intelligent electrical-load management technologies, and is providing IPLC-PHEV units to be used for comprehensive electricity consumption monitoring for all vehicles ([www.iplc.com](http://www.iplc.com)).

[Vehicle and Equipment Management Agency](#) is a special operating agency (SOA) of the Government of Manitoba for fleet management services, and provided five vehicles (4 in Departments plus 1 at RRC) for conversions ([www.vema.mb.ca](http://www.vema.mb.ca)).

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Multiple PHEV recharging test by Manitoba Hydro