Plug-in Hybrid Electric Vehicle Demonstration

October 2011

Toyota Priuses converted to PHEV for testing in Manitoba

Manitoba PHEV Demonstration

Final Summary Report

Overview

This report summarizes the experience and outcomes with ten Toyota Priuses converted to Plug-in Hybrid Electric Vehicles (PHEVs) within Manitoba. The vehicles were converted in 2008/2009 and monitored for three years.

Project Objectives

The demonstration had 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 potential markets for further PHEV conversions versus factory-built vehicles; and
- Develop new business opportunities, as appropriate.

Introduction

Hybrids and PHEVs

"Hybrid vehicles" are defined 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.

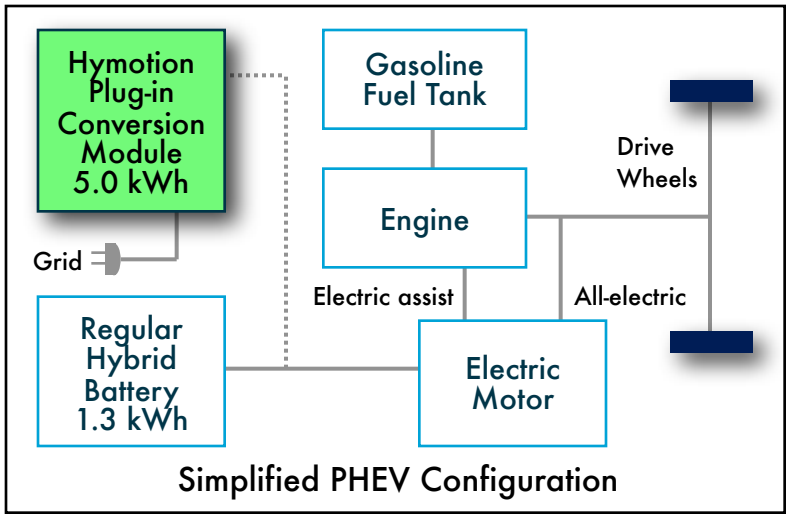
Hybrid electric operation can be implemented in various formats. Vehicles can be simply classified as either parallel hybrids, with a direct connection between the conventional engine and the drive wheels, with the electric motor only assisting; or series hybrids, with the conventional engine used solely to generate electricity, and 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), such as the Chevrolet Volt and Toyota Prius PHV, are becoming commercially available, PHEV technology to date primarily involved the modification of conventional HEVs by the installation of additional "energy" batteries. A PHEV plugs into the electrical grid to charge its added 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 electric-only. With PHEV technology people drive normally, whether for work or pleasure, but do not consume as much fossil fuel.

Prepared by the **Centre for Emerging Renewable Energy Inc.**, in cooperation with

Red River College
OF APPLIED ARTS, SCIENCE AND TECHNOLOGY



Simplified PHEV Configuration

Technical Details

Each converted Toyota Prius incorporated 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).

Manitoba Demonstration

This demonstration involved ten Toyota Priuses in Manitoba converted to operate as PHEVs, using Hymotion Plug-in Conversion Modules (PCMs) from A123Systems Inc. Coordination and financial administration were provided by the non-profit Centre for Emerging Renewable Energy Inc. Conversions were performed by automotive instructional staff at Red River College. Red River College is now a fully-authorized vehicle conversion centre for A123Systems.

Otto data-loggers, manufactured by Manitoba-based Persentech, were installed in each car to monitor characteristics of vehicle use. Selected interactive monitoring of electricity consumption of vehicles, while plugged into the grid, was done using an upgraded version of the IPLC-PHEV meter, the PM2. Manufactured by Manitoba-based Vantera Inc., this technology was adapted from their Intelligent Parking Lot Controller (IPLC), already in common use in Manitoba and elsewhere.

(See Partner Profiles later in this document for more information about participating 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.

All vehicles were operated in the vicinity of Winnipeg, Manitoba.

Demonstration Results

Liquid Fuel Consumption

The converted PHEVs achieved fuel savings, but these were more incremental than dramatic. In aggregate, the ten vehicles travelled 233,000 km, consuming 13,100 Litres of fuel over the three years. This translated to overall fuel economy of 5.6 Litres per 100 km. This was roughly 10% better overall compared to the conventional Prius, at about 6.2 Litres per 100 km under Manitoba conditions (based on fleet experience), and more than 60% better than the average Manitoba vehicle at approximately 15 Litres per 100 km.

The nature of vehicle operation and Manitoba's cold-climate conditions were significant factors affecting fuel economy. The best performance was achieved by vehicles operating as "commuters." This corresponded to characteristics of: highly regular daily travel, in the range of about 20 to 30 km per day, which was the vehicle's effective electric-only distance; intermittent rather than steady daily use, with ample idle time for recharging; lower emphasis on highway travel; and continuous operation while in use, with vehicle not turned on and off repeatedly.

One unit operated consistently in this manner, but other units also appeared to approximate the same pattern on occasions. For these units the aggregate average fuel economy was 4.8 Litres per 100 km, which is among the very best fuel economy performance of any vehicle of any kind within Manitoba.

Electricity Consumption

The electricity used by one of the units was closely monitored during one summer. The vehicle was operated as fully-electrically as

possible, both for the cases of air conditioning (AC) off and fully-on.

With AC off, electricity-use averaged 16.3 kWh per 100 km, and with AC fully-on it averaged 20.1 kWh per 100 km, roughly 25% higher. A mid-range value of 18.2 kWh per 100 km (i.e., 50% AC) was used for further analyses. Liquid fuel displacement thus required in the range of 2 to 4 kWh per Litre.

It was also found that electricity-use was not significantly different from a factory-prototype Toyota Prius Plug-in Hybrid Vehicle (PHV) under testing at the same time.

Electricity-use was monitored during the winter, although not as thoroughly, and in general was found to drop when colder. This was a very different behaviour from all-electric vehicles. Their electricity use increases in winter due to heating.

It was not possible to correlate electricity-use to temperature, nor to fully correlate liquid fuel-use versus electricity-use. All vehicles were satisfactorily recharged using standard 110 volt, 15 amp circuits, which are commonly available for vehicles in Manitoba.

Maintenance Impacts

The PHEVs showed maintenance saving may be possible in terms of reduced oil-changes. Oil samples showed oil quality to be very satisfactory, even for intervals as high as 12,000 km. Further investigations of maintenance savings are warranted.

Over the three year period, one battery problem was encountered on one of vehicles that required replacement of its pack. Based on this experience, expected battery-life was simply estimated to be approximately eight years. This value closely matched warrantee periods now being offered by vehicle manufacturers.

Temperature Impacts

Manitoba's cold winter-weather presents a challenge to many new technologies, and this included the PHEVs. During the first year of the demonstration, the most critical cold-weather problem was with regard to the 12-volt battery on the Priuses. Two solutions were developed to address this concern on all vehicles: (1) installing a more robust replacement 12-volt battery; and (2) installing a trickle charger to automatically recharge the 12-volt battery whenever the main PCM unit was being charged. During the second year, custom front covers were installed on eight of the vehicles and electric in-car warmers on six of the vehicles, both these measures to address cabin warmth. These two sets of measures were successful, but the ongoing challenges of winter operation still required constant vigilance. Vehicle manufacturers have also been working to address winter operation.

The tracking of liquid fuel consumption showed a recurring cyclic pattern, obviously linked to changes in seasonal temperatures. Fuel consumption rose during colder months and dropped during warmer months. Incremental fuel economy did periodically approach or achieve the desired expectations as outlined by A123Systems, which was 2.4 Litres per 100 km. However, this only occurred during warm months.

During the second winter, two of the vehicles were assessed in a parallel test, with their PHEV systems alternately turned off and on. This test confirmed PHEV operation to be of benefit even in the cold, but with the extent of the benefit diminishing as the temperature dropped.

Vehicle Economics

The capital cost of the Prius conversion, in the range of $10,000 to $15,000 per vehicle, obviously could not provide a realistic payback compared to a regular Prius. The demonstration's focus, however, was to understand vehicle performance. The conversions involved relatively early-stage technology that was known would be relatively expensive, especially when compared to full-production vehicles. At the same time, the cost premium to achieve very high fuel economy performance was not excessive.

An economic analysis was undertaken using assumptions from the experience of the demonstration, based on "commuter" operation. For average Manitoba travel of 16,000 km annually, a commuter PHEV would use 630 Litres of gasoline, 60 Litres of ethanol, and 900 kWh of electricity. A regular Prius would use 910 Litres of gasoline and 80 Litres of ethanol, and an average Manitoba vehicle would use 2,200 Litres of gasoline and 200 Litres of ethanol. The PHEV was also assumed to require half the number of oil changes.

The present value of operating savings was calculated using a 6% cost of money and eight year period (assumed battery life) for the PHEV. The price per Litre of gasoline is a key variable affecting the extent of savings. Using a reasonable range of fuel prices into the future (i.e., $1.10 to $1.60 per Litre), suggested a PHEV likely would save $11,000

to $16,000 over eight years compared to an average Manitoba vehicle, and $1,200 to $2,100 compared to a conventional Prius.

The economic payback for new, commercial PHEVs will be different, likely to be better. Their economic viability will need to be evaluated. In general, the incremental capital costs for PHEVs and other electric vehicles are anticipated to continue to decline, as increased numbers of commercial models come into the market, and as performance and production levels continue to rise.

GHG Reductions

Greenhouse gas (GHG) emissions for the PHEVs, and associated reductions were calculated. Assumptions were based on the performance of the "commuter" vehicles in the demonstration. The results showed that the accounting methodology used to compare GHG emissions had a very important impact on the extent of calculated reductions. Using a "well-to-wheel" basis, which is arguably the most legitimate approach, showed dramatic reductions for the "commuter" PHEV. Compared to a conventional Prius, the PHEV achieved a net reduction of over one tonne annually. The reduction was closer to six tonnes compared to an average Manitoba vehicle. Lower reductions were shown when a "tank-to-wheel" basis was employed. The lowest reductions were for the methodology used by Environment Canada in its annual National Inventory Report.

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).

Centre for Emerging Renewable Energy Inc. is a Manitoba-based non-profit organization; and provided funding administration and project management for the demonstration.

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/).

Manitoba Hydro is a Manitoba crown corporation and integrated electrical and natural gas utility; and provided two vehicles for conversion (www.hydro.mb.ca).

Manitoba Innovation, Energy and Mines IEM), through its Energy Division, is responsible for energy and energy efficiency policy, facilitating renewable energy development, and business development for energy product manufacturing; and provided funding and staff-time support for the project (www.manitoba.ca/iem/energy/index.html).

Manitoba Public Insurance is a Manitoba crown corporation and public vehicle-insurance agency; and provided two vehicles for conversion (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).

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 provided support to the demonstration as it proceeded, and also made a vehicle (leased through VEMA) available for conversion (www.rrc.mb.ca).

University of Manitoba Transport Institute is based within the Department of Supply Chain Management as part of the I.H. Asper School of Business. The Institute's mission is to facilitate economic prosperity, environmental sustainability, and social advancement. It has been a Canadian leader in research on many complex transportation issues. The Institute undertook a survey on consumer attitudes to electric vehicles as part of the demonstration (http://umanitoba.ca/asper/ti/).

Vantera Inc. is a Manitoba-based manufacturer of intelligent electrical-load management technologies; and provided IPLC-PHEV PM2 units for comprehensive electricity consumption monitoring on selected vehicles (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 (four in Government Departments plus one at RRC) for conversions (www.vema.gov.mb.ca).

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