Cold-Weather Modifications of Plug-in Hybrid Electric Vehicles (PHEV) for Manitoba Operation

Curtis Gregor, Associate Member, IEEE

Research Technologist, Red River College

Robert V. Parsons, MBA (Presenting Author)

Secretary/Treasurer, Centre for Emerging Renewable Energy Inc.

RED RIVER COLLEGE

OF APPLIED ARTS, SCIENCE AND TECHNOLOGY

Centre for Emerging Renewable Energy

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  - Province of Manitoba, who provided funding for the Manitoba PHEV Demonstration.

Overview

- Background:
  - Manitoba PHEV Demonstration
  - Cold-weather issues encountered
- Nature of upgrades undertaken:
  - Auxiliary 12-Volt battery related
  - Cabin-warmth related
- Subsequent experience

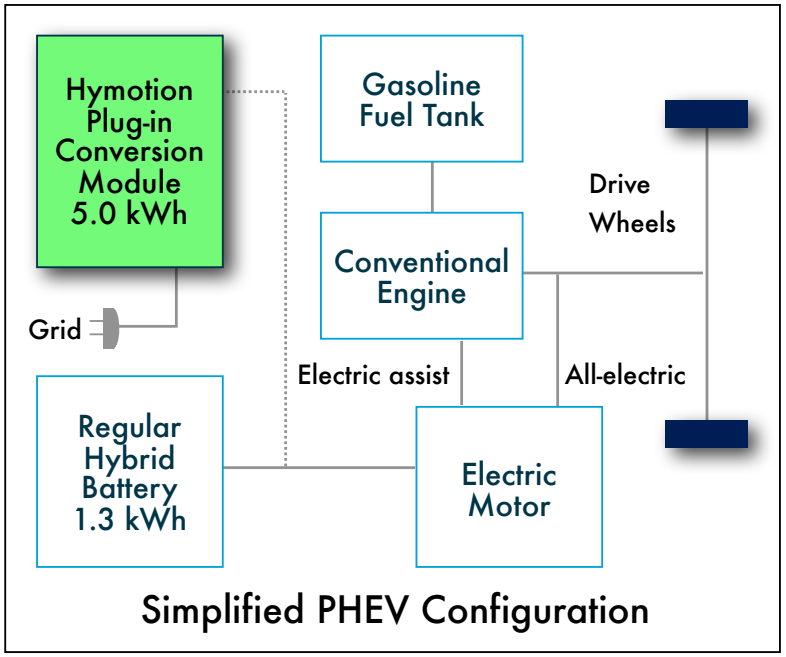
Manitoba PHEV Demonstration

Manitoba PHEV Demonstration

- Vehicles/Technology:
  - Ten Toyota Priuses involved
  - Model years 2004 through 2009
  - Conversion technology from A123Systems
- Operations:
  - Vehicles were from five public-sector agencies
  - All were used in the vicinity of Winnipeg
  - Monitoring for three years, with public reports

A123Systems Conversion

- 5 kWh Hymotion Plug-in Conversion Module (PCM) installed in each vehicle



Operational principle:

The PCM makes additional electricity available for use by the Prius, permitting extended electrical operation beyond what would be normally possible.

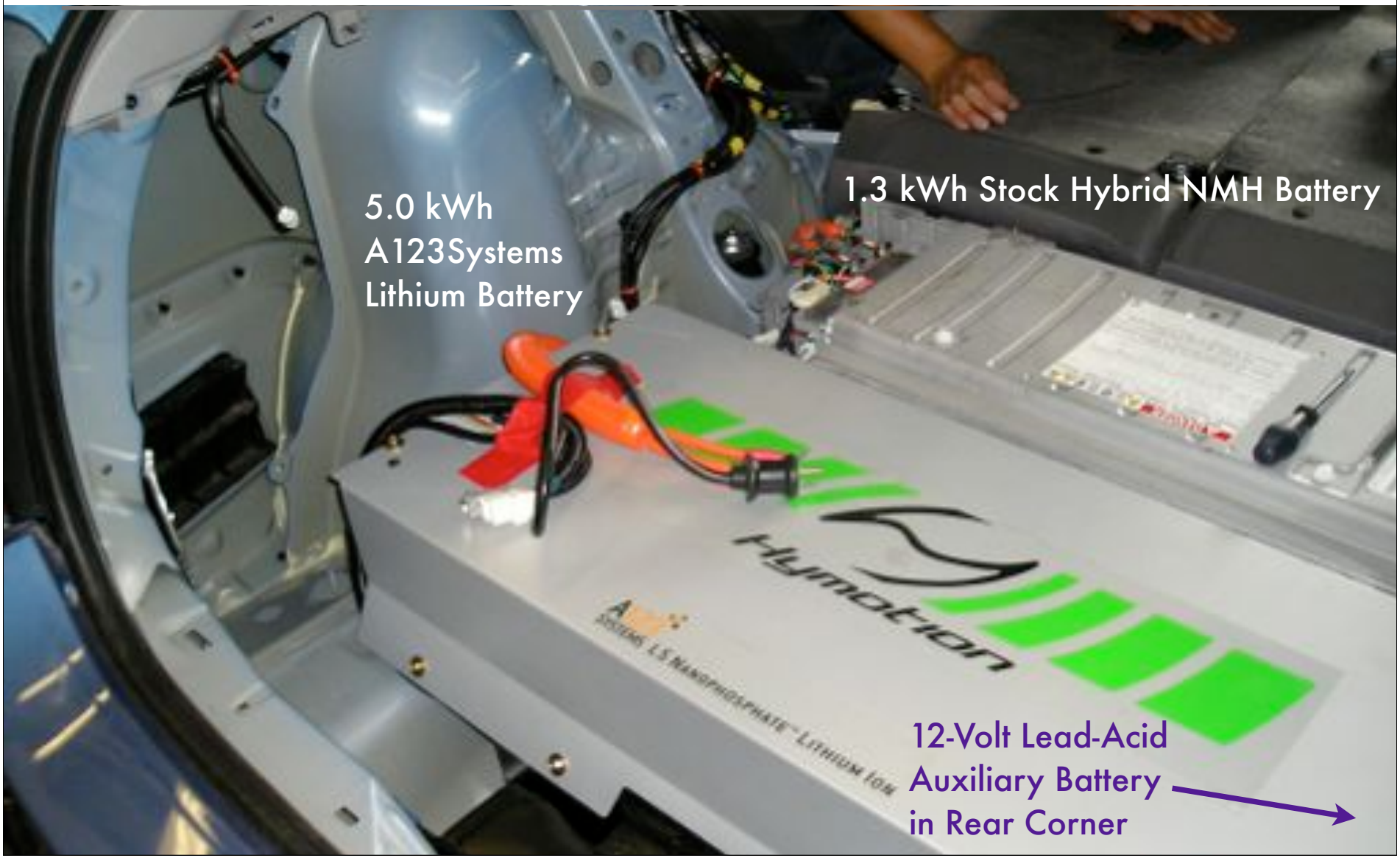
Cold Weather!

in Manitoba

Identified Winter Impacts

- Auxiliary 12-Volt battery was inadequate:
  - Two “dead” vehicles in early winter of 2008
  - Very uncomfortable, and potentially a safety concern, to have vehicle failure in winter
- Cabin was too cold for passengers:
  - Better efficiency of vehicle also meant less waste heat, which is used for cabin heating
  - PHEVs took “very long time” to warm up

Three Batteries in PHEV



Prius 12-Volt Auxiliary Battery

Prius 12-Volt Auxiliary Battery

Prius 12-Volt Auxiliary Battery

- Toyota provides amazingly very little information on Prius 12-Volt battery:
  - No Battery Council International (BCI) number
- Do confirm in owners documentation that:
  - It is a 28-Ah rated, 12-Volt battery;
  - It involves glass mat technology;
  - It is sensitive to high voltages; and
  - Trickle-charge current must be less than 3.5 A

Winter Vulnerabilities

- Battery required to maintain minimum voltage of 10.6 V to initiate start-up
  - In cold weather, it hovered dangerously low
  - Worsened by data logger installed on vehicle
  - Drop below threshold - and vehicle dead!
- Not really different from regular vehicles
  - That's why the CAA offers roadside battery charging services across Canada

Winter Vulnerabilities

- Prius 12-Volt battery a known problem
  - Conventional Prius hybrid vehicles dominate taxi market in Winnipeg
  - For all taxis, the 12-Volt battery is stripped and replaced with more robust unit
- This weakness is anecdotal and not well documented in academic literature

12-Volt Upgrades Undertaken

- Two simultaneous upgrades undertake
  - Undertaken on all vehicles converted
  - Acted as redundant systems

1. Replacing **12-Volt battery** with more robust unit

2. Installing an automated **trickle charger**
   - Top-up when the main battery recharged

Selection Criteria - 12-Volt Battery

Criterion	Description
Dimensions	Fit in available space, with contact terminals in same locations
Capacity	Have sufficient amp-hour capacity
Performance	Perform well under expected cold weather conditions

Led to Selection of Optima Unit

- Criteria led to the selection of the **Optima "Yellow Top" D51** battery:
  - Lead-acid spiral cell technology
  - 38-Ah capacity (much larger than existing Prius battery)

Optima Battery Installed

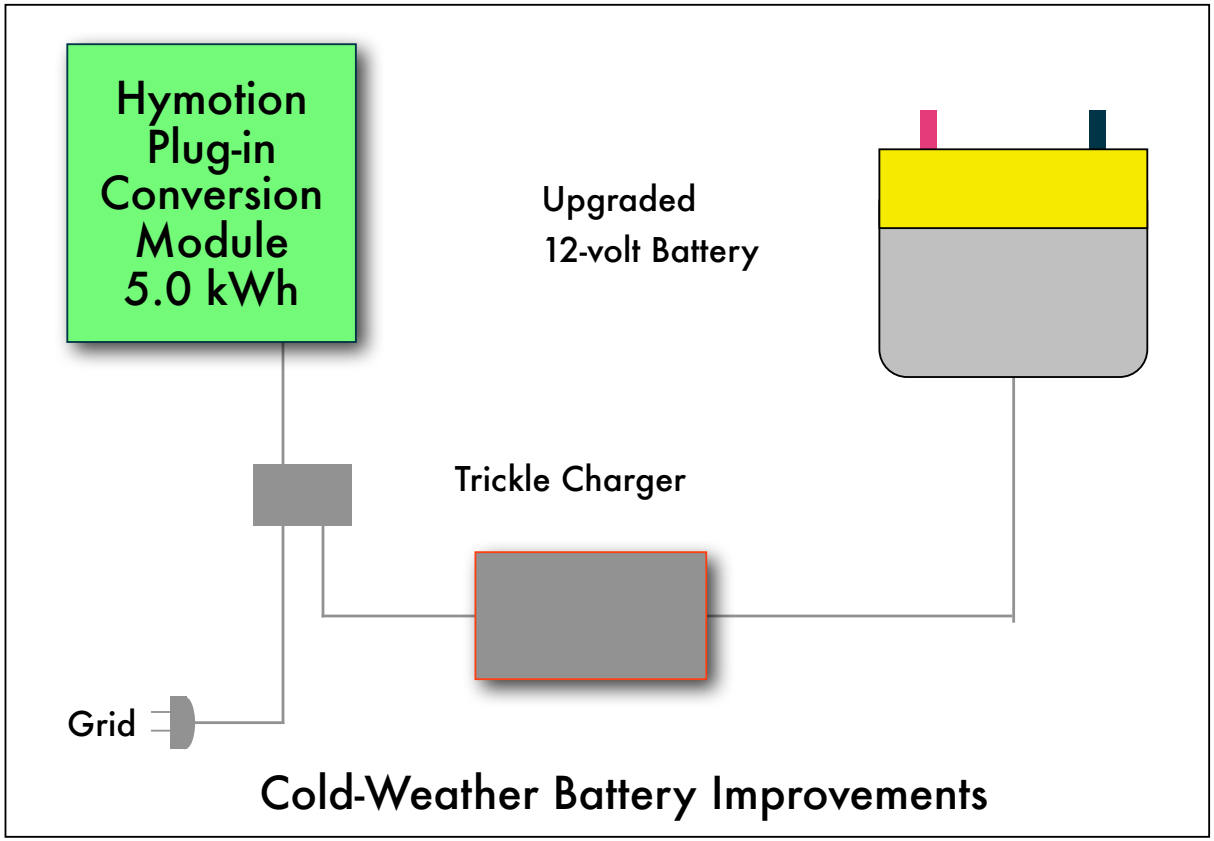
Selection Criteria - Trickle Charger

Criterion	Description
Size	Sufficiently compact and able to fit into the available space in the Prius rear cabin
Adequate Temperature Limit	Able to operate at sufficiently low temperatures as would be encountered during a Manitoba winter
Suitable Connectors	Able to be hard-wired to the 12-Volt battery, not just connected via “grip clamps”
Current Maximum	Maximum charging current of 3.5 A
Automatic Operation	Able to activate “automatically” without any general need for operator initiation

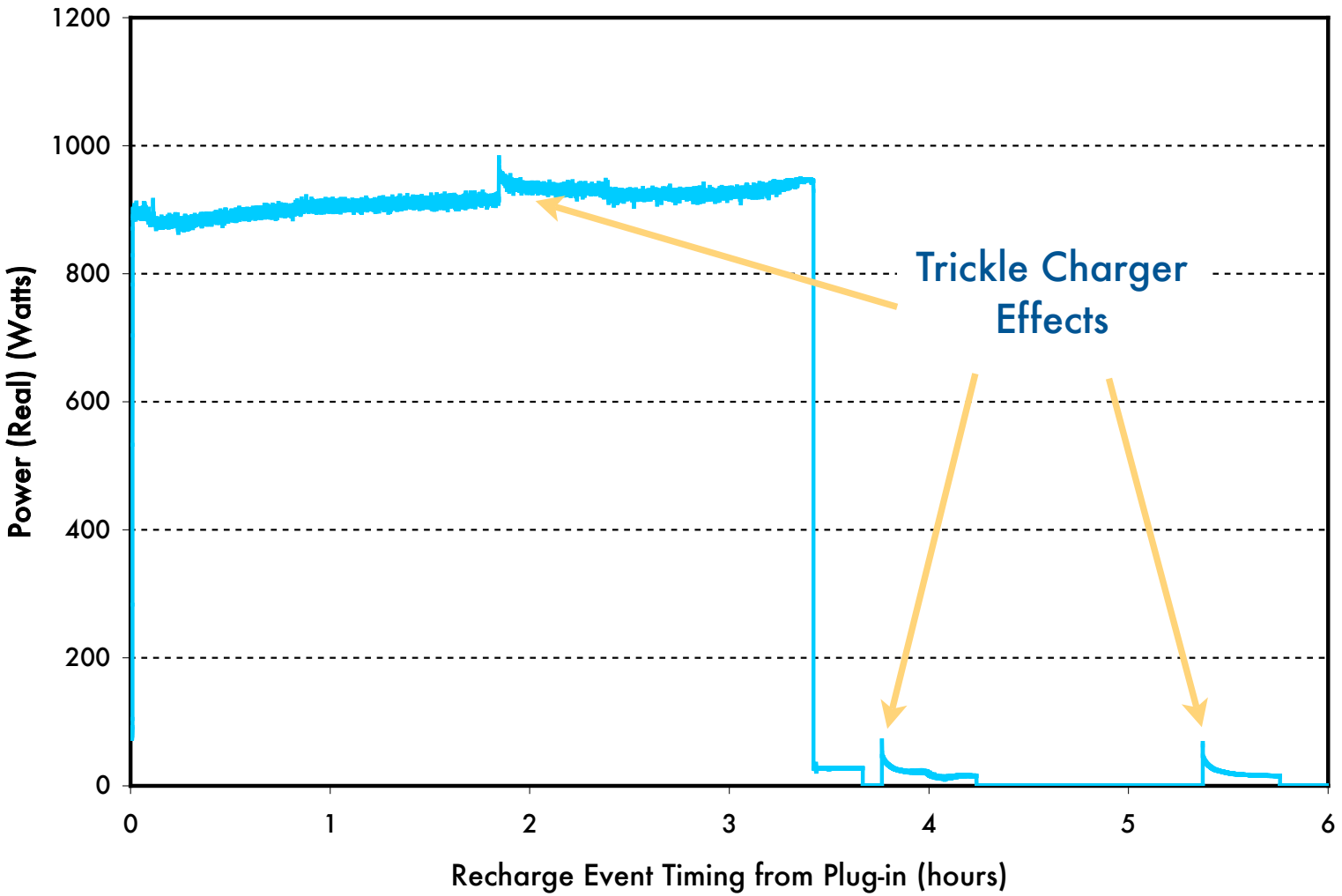
Led to Selection of CTEX Unit

- Criteria led to the selection of the **CTEX 3300** trickle charger:
  - Charging at 3.3 A
  - Automatic activation
  - Suitable for lower temperatures

Trickle Charger Installation



Impacts on Load Curve



Cabin Warmth Upgrades

- Two separate approaches evaluated
  - Note: changing thermostat was not possible

1. Custom **winter cover** on front of vehicle
   - Undertaken for eight of ten vehicles

2. Electric **in-car warmer**
   - Undertaken on six of ten vehicles

Custom Winter Covers

- Intended to reduce air-flow to permit coolant system to operate at higher temperatures:
  - Provided some benefit
  - But, not as successful as second measure

Electric In-Car Warmers

- Tied in with block heater and plugged into separate circuit from battery when vehicle stopped:
  - Resulted in significant and immediate improvement
  - Prompted a lot of highly positive comments

Cold-Weather Upgrade Impacts

- Upgrades addressed the major problems
  - There were no major further 12-Volt issues
  - Vehicle cabins were significantly warmer
- Were still some minor winter problems
  - Winter operation requires constant vigilance
- Importantly, the successful solutions were primarily electrical in nature

Implications

- Cold-weather upgrades were critical to the Manitoba PHEV Demonstration
  - Without them the project would have failed
- Important unique comparison was also possible due to a separate demonstration underway at the same time:
  - Toyota Plug-in Partnership demonstration in Manitoba of 2011 Prius Plug-in Hybrid Vehicle

Units Compared

2008 PHEV Conversion

2011 Toyota Prius PHV

Seasonal Results

Fall

Winter

Spring

- Could compare gasoline consumption at pump over course of different seasons
- This led to some important insights

Seasonal Results

Fall

Winter

Spring

- During fall and spring shoulder-seasons, the factory-built Prius PHV had better gasoline consumption
- This was likely due to the much better integration of the vehicle systems

Seasonal Results

Fall

Winter

Spring

- During winter, PHEV had better gasoline consumption
- May be other factors, but major difference was the cold-weather upgrades for the PHEV, but no changes for the factory-built PHV compared to test units used elsewhere
- Emphasized importance of cold-weather upgrades

Conclusions

- Cold-weather upgrades to the PHEVs resolved major winter operating problems
- Cold-weather upgrades to the PHEVs were essentially electrical in nature
- Cold-weather vulnerabilities are important to address but unique to each vehicle
  - Suggests need for individual vehicle evaluation and upgrade development

Thank You

Any Questions?

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http://www.manitoba.ca/iem/energy/transportation/index.html