Plug-In Hybrid Electric Vehicle (PHEV) technology:
Experiments and measurements at Université Laval.

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24th April 2009,
Montreal.

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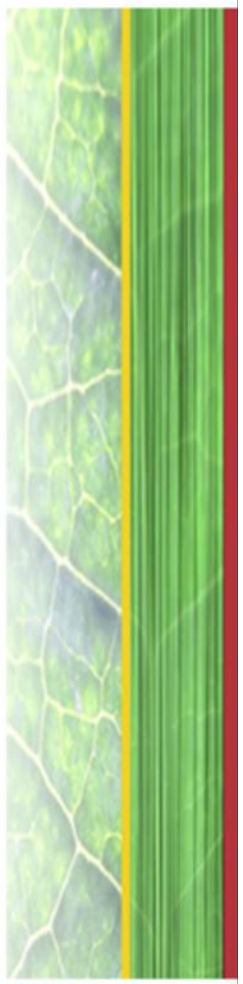

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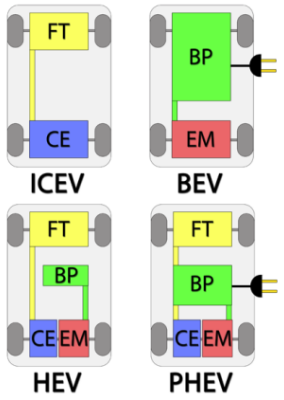
1.1: PHEVs, a promising alternative to gasoline powered-vehicles.

- Plug-In Hybrid Electric Vehicle (PHEV) = a “grid-able” HEV with a larger battery-pack.
- PHEVs: low-emissions vehicles
  - *EPRI & NRDC [(1)] : PHEVs greenhouse gas emissions are 40 % - 65 % less than those of ICEVs and 7 % - 46 % than those of HEVs.*
- PHEVs: low-fuel consumption vehicles
  - *PHEV-Québec test vehicle fuel economy numbers measured in summer 08: 1.6 L/100 km – 3.5 L/100 km.*



FT: Fuel Tank
CE: Combustion Engine
EM: Electric Motor
BP: Battery Pack
ICEV: Internal Combustion Engine
BEV: Battery Electric Vehicle
HEV: Hybrid Electric Vehicle
PHEV: Plug-In Hybrid Electric Vehicle

Trip length [km]	Mean speed [km/h]	Fuel cons. [L/100 km]
22	15	**1.6**
25	48	**2.6**
41	75	**2.8**
45	73	**1.9**
47	94	**3.5**
47	71	**2.5**

[(1)] : “Environmental Assessment of PHEVs. Vol 1: Nationwide Greenhouse Gas Emissions”, Electric Power Research Institute (EPRI) & US Natural Resources Defense Council (NRDC) report, 2007.

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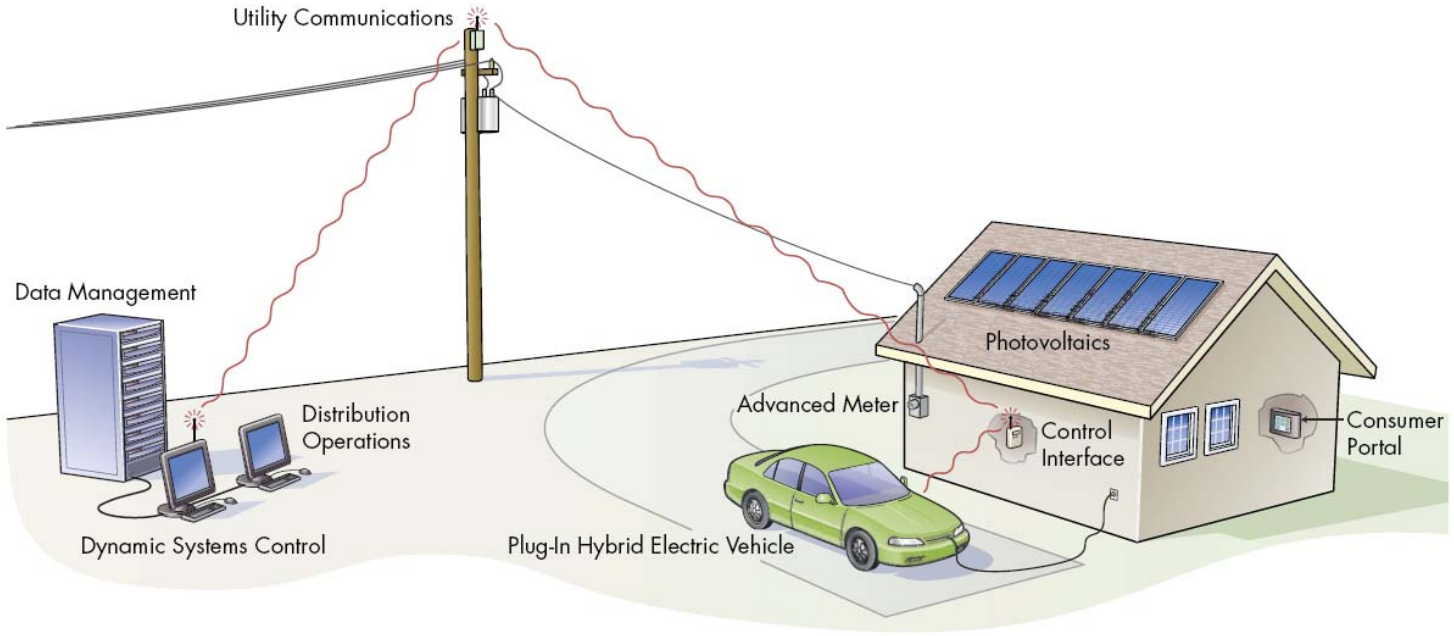
1.1: PHEVs, a promising alternative to gasoline powered-vehicles.

- PHEV vehicle-to-grid (V2G) capability: new opportunities for transport and power generation sectors.
  - ➢ PHEVs = distributed energy storage units in future intelligent networks.



Source: Electric Power Research Institute (EPRI) Journal, spring 08

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1.2: PHEVs, foreseen successors of HEVs ?

- F3DM from the chinese automaker BYD: the first commercial PHEV model on sale (China), since Dec. 2008.
- Several major car manufacturers have announced plans to introduce PHEVs (Toyota, GM, Ford, ...)
- Commercial PHEV upgrades from existing HEV platforms (Hymotion, Hybrid Plus, OEMTek, ...)

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1.3: PHEV market potential and viability: a need for more real-world, large-scale field studies.

- PHEV cost-benefit equation is strongly affected by a range of factors that cannot easily be taken into account in models or laboratory tests. Examples:
  - Driving habits affect PHEV fuel economy and price,
  - Climate affects PHEV performances and costs,
  - Consumer behaviour in charging situations,
  - Real impact on the utility grid,...
  - **A need for more real-world, large-scale studies.**

    ➡ **PHEV Québec test program contribution.**

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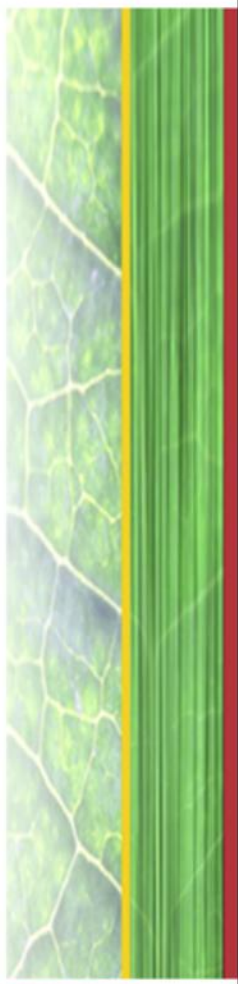

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2.1: PHEV Québec project overview.

- PHEV Québec test program aim:

  Examine PHEV market potential viability accounting for engineering, V2G, environmental and economical concerns, by conducting real-world field tests only.

- How?

  Experimental studies on a PHEV fleet owned by real consumers.

- Where?

  Université Laval, Québec city, Canada. Central position, 35 000 pers., independent electrical grid, large temp. gradients climate.

- Who?

  A team of engineers and financial analysts with industrial (ModEnergy, Bell Canada) and financial partners (Desjardins).

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2.2: Engineering concerns:

Goal: conduct field tests to determine optimal PHEV systems patterns.

- Build a PHEV fleet (50 PHEVs over 5 years) from existing HEV platforms. Ex: Toyota Prius.
- Consider different battery techno. & various battery pack sizes.
  ➡ **Identify optimal trade-offs.**
- Evaluate the impact of the climate on PHEV performances.
  ➡ **Québec's climate = large temperature gradients.**
- Study driver – PHEV interactions.
  ➡ **Identify driving trends & optimal PHEV systems.**

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2.3: V2G concerns:

Goal: Achieve real bi-directiona university's electrical grid.

- Université Laval's campus infrastructure:

  - 22 MW electrical grid capacity;
  - Isolated from the public grid;
  - Installed wind turbines ;
  - 6 MW controllable load resistor (boiler) ;
  - Many parking lots ;

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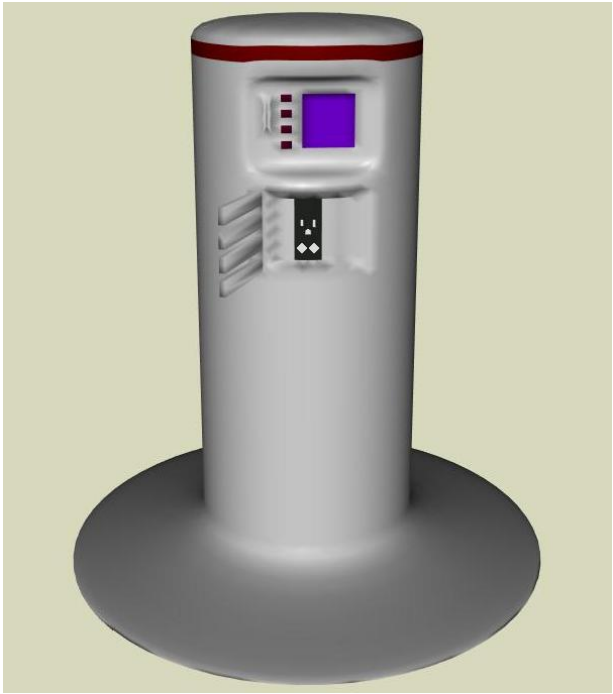
2.3: V2G concerns (2):

- Charging stations allowing for slow- & bi-directional fast-charging rates.
  - ➡ **Experience real energy flows.**
  - ➡ **Experiment grid support.**

- Charging stations will be equipped with energy management and billing systems.
  - ➡ **Evaluate customer charging behaviours.**
  - ➡ **V2G technologies testing.**



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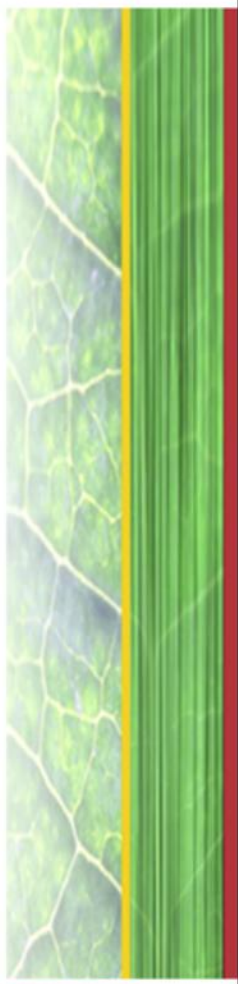

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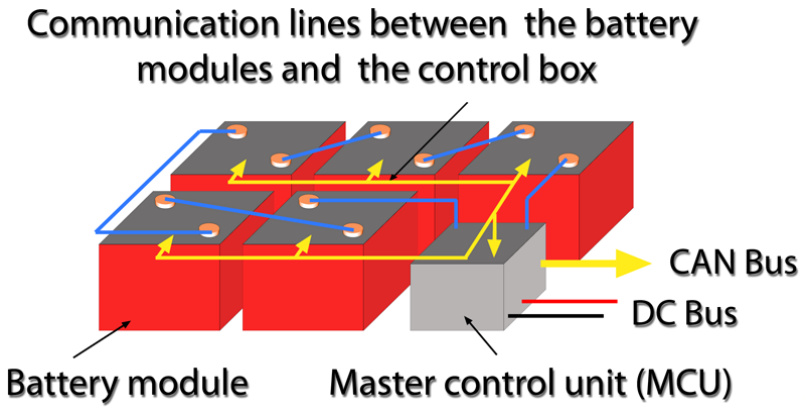
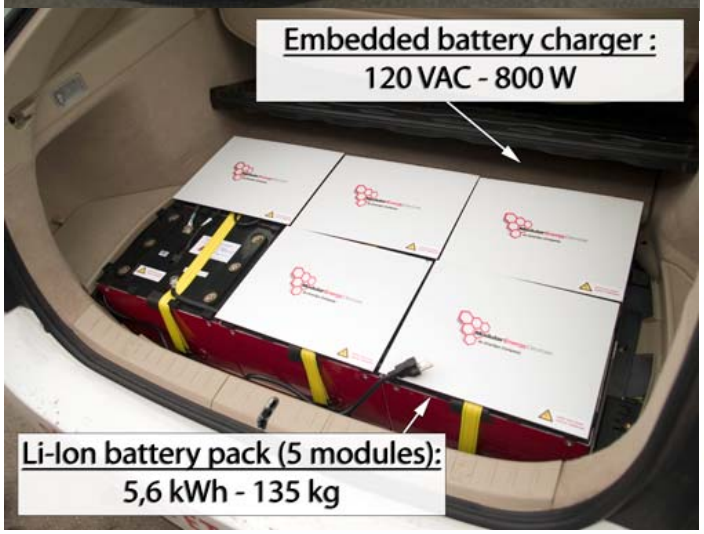
3.1: PHEVα characteristics.

- PHEVα is equipped with a Li-Ion battery pack:

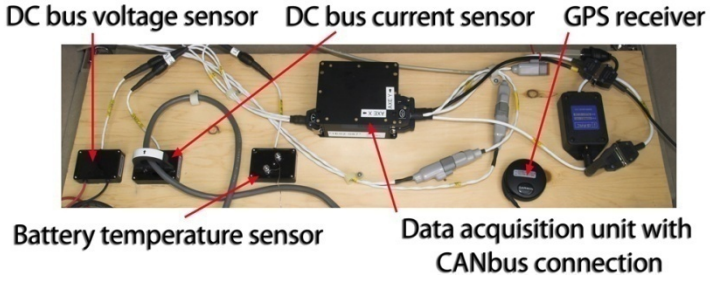
  - 5.6 kWh Li-Ion Manganese,
  - 5 48V/24Ah battery modules,
  - A master control unit manages energy flows & broadcast data,
  - Onboard 120V/800W charger.





3.2: Field test procedure.

- Performance comparison involving PHEVα and a non-converted Toyota Prius 2005.
- Datalogging system in both cars (CANBus, battery current/voltage, GPS, vehicle fuel cons.).
- Fuel cons. & battery energy use monitored for 3 driving profiles: urban, mixed, highway.
- Snowy conditions & temperature between -10 ºC & 0 ºC.



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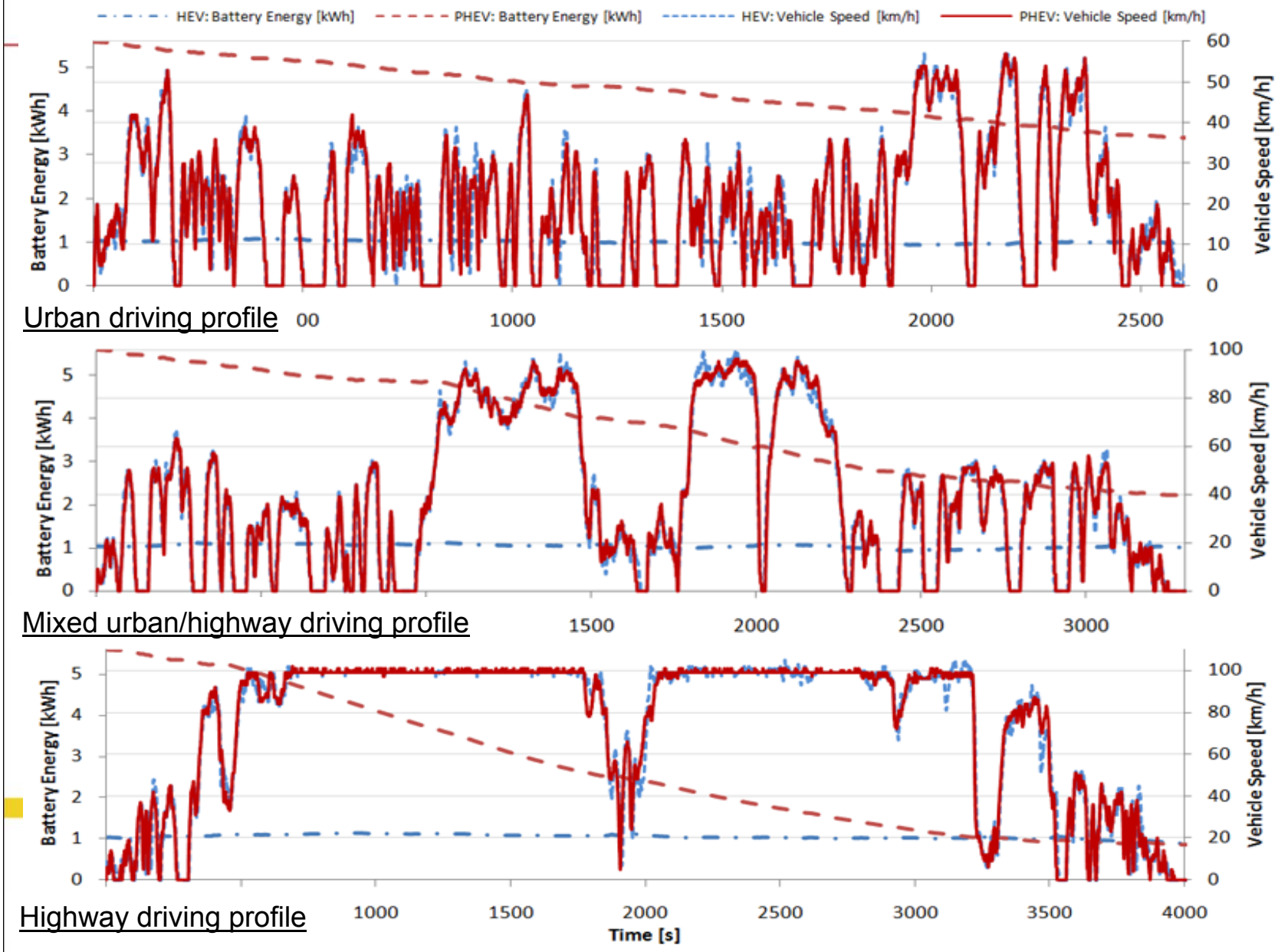
3.3: Comparison tests results: PHEV vs HEV



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3.3: Comparison tests results (2): PHEV vs HEV

		Urban Cycle (14.5 km)	Mixed Cycle (35.6 km)	Highway Cycle (84.3 km)
Mean fuel consumption	PHEV [L/100 km]	5.00	3.62	3.88
	HEV [L/100 km]	7.72	5.93	5.46
	Gain	35 %	39 %	29 %
Battery energy use	PHEV [kWh]	2.22	3.38	4.73
	PHEV DoD*	40 %	60 %	84 %
	PHEVα	**Highest cycle life**	**Best fuel efficiency**	

*DoD = Depth of Discharge

- Highest fuel cons. for shorter trips: cold start-sequences.
- Lower fuel cons. has been obtained in different test conditions.
- The size of the battery pack should be chosen based on driver's use to minimize fuel cons. & maximize battery cycle life.

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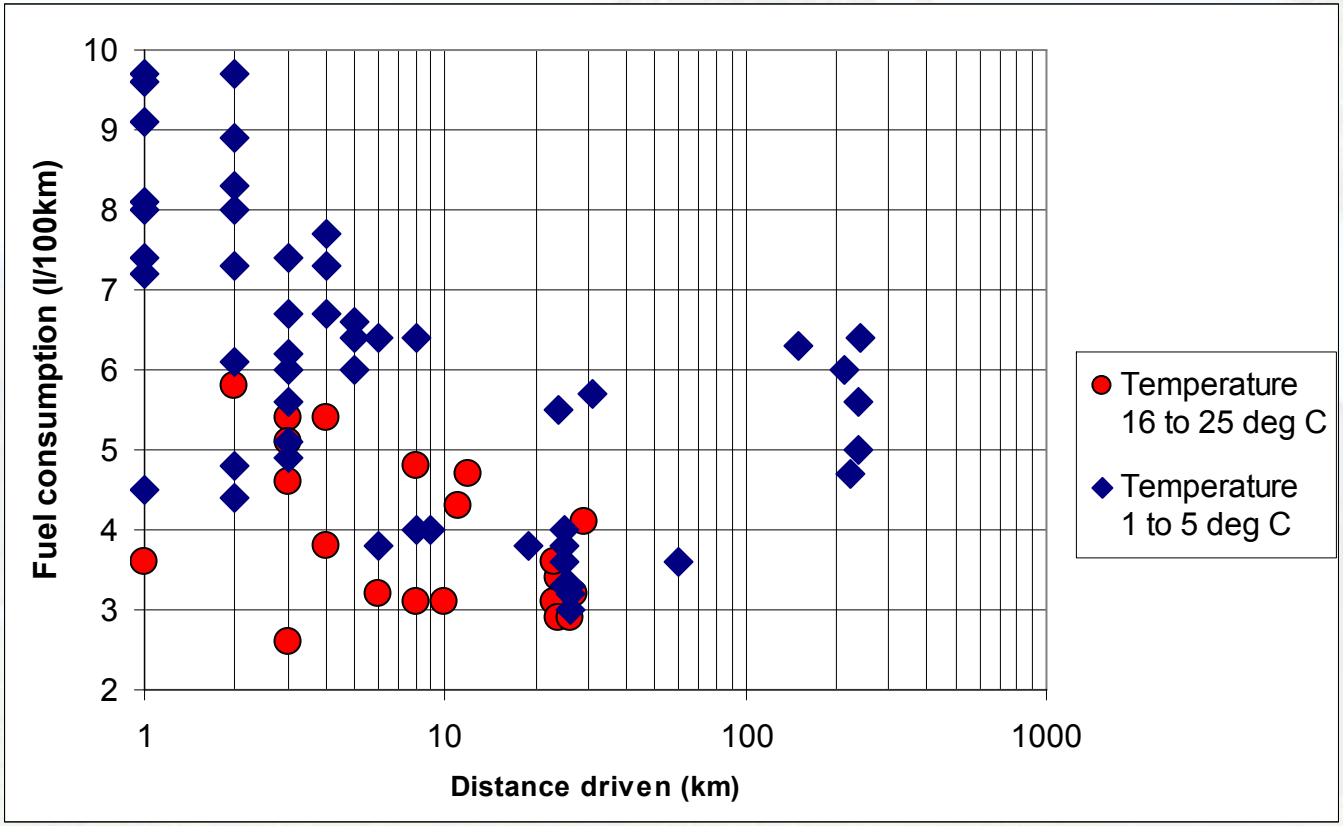
3.4: Test results : PHEV only

***PHEV** Fuel consumption for various distances and temperature conditions*



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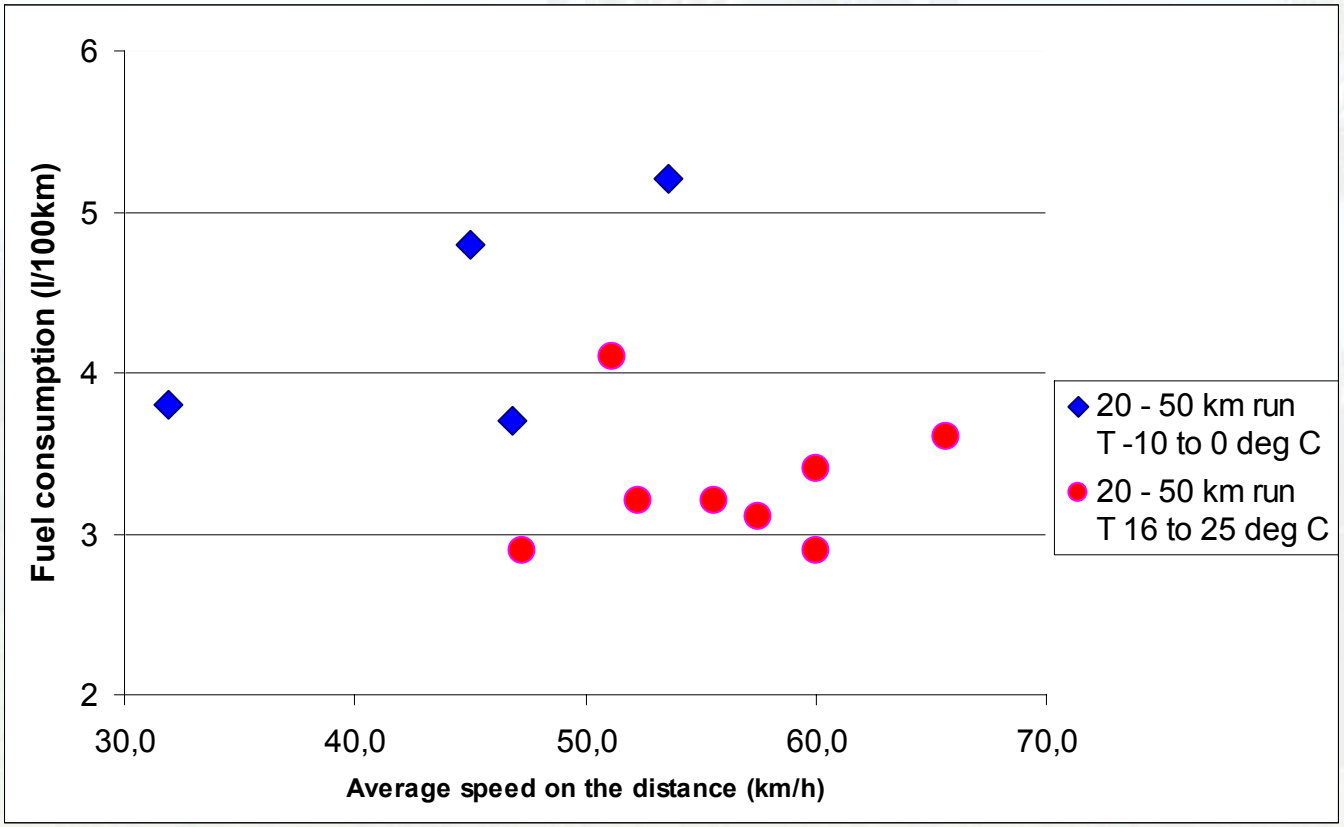
3.4: Test results : PHEV only

PHEV Fuel consumption for runs between 20 to 60 kms in various temperature conditions



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Conclusion:

- Current status: End of the pilot phase. A functional PHEV system has been built & performs as expected.

- Next steps:

  - Conversion of 3 other vehicles until June 2009.

  - PHEV fleet is expected to grow to 10 vehicles at the end of 2009.

  - Charging stations are under development: slow charging stations are going to be implemented soon on the university campus.

www.phevquebec.ulaval.ca

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