

PHEV Laboratory Test Results: Energy Consumption and Emissions in Cold Climate

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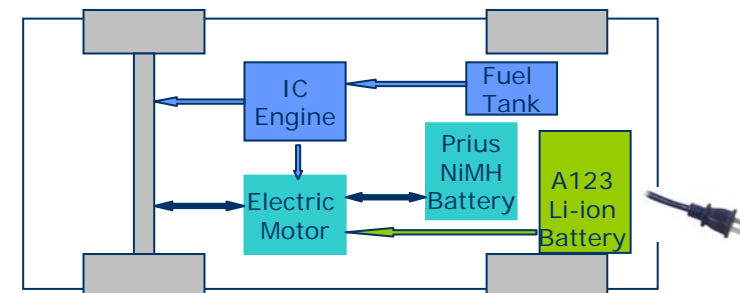
Overview



- Laboratory evaluation of PHEV emissions, fuel consumption and electrical consumption at cold temperatures
 - Test temperatures of 22°C, -7°C, -18°C
 - Drive cycles simulating urban, highway, aggressive, congested driving
 - (LA4, HWFET, US06, NYCC)
 - Lifecycle results using GHGenius
 - NRCAN model including Canadian specific data

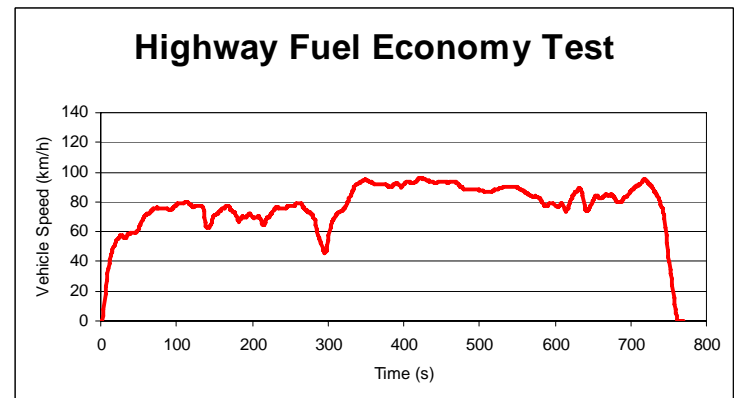
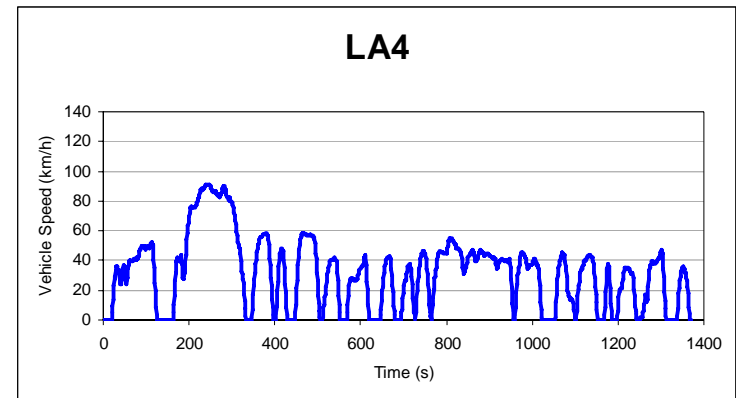
Test Vehicles

- Hymotion PHEV (2 vehicles)
 - Based on production Toyota Prius powertrain, with added 5 kWh A123Systems Li-ion pack
 - Two operating modes:
 - Blended charge depleting mode using IC engine, Li-ion pack, and production NiMH pack
 - Charge sustaining mode with same operation as production Prius
- Conventional Toyota Corolla



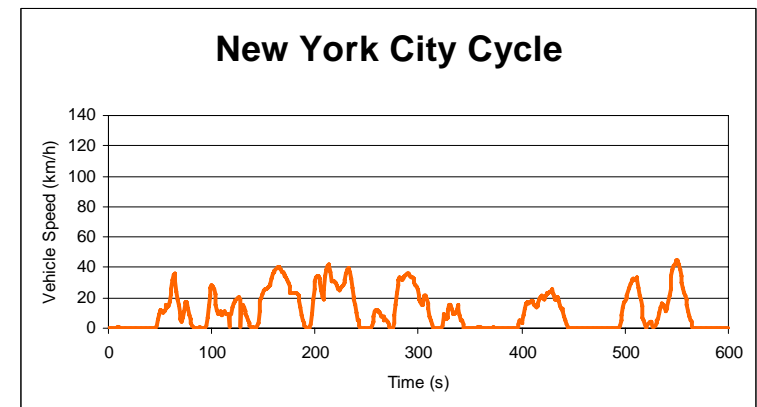
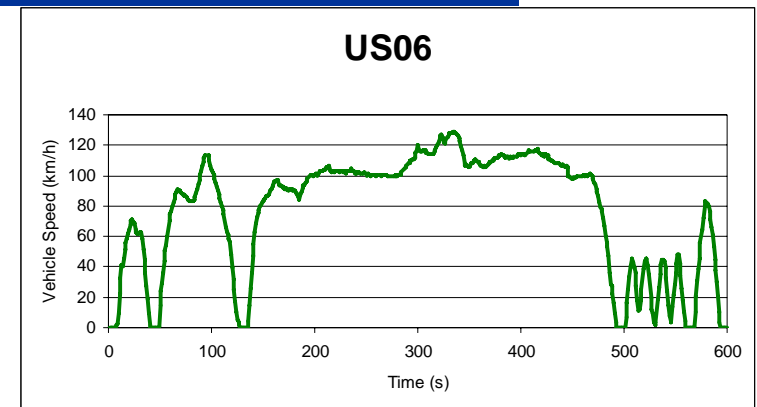
Driving Cycles – Round 1

- First round was a collaboration with Argonne National Laboratory – EVS24
- LA4
 - Average speed of 32 km/h;
 - Maximum speed of 91 km/h
 - Cold start
- HWFET
 - Average speed of 78 km/h;
 - Maximum speed of 96 km/h



Driving Cycles – Round 2

- US06
 - Average speed of 78 km/h;
Maximum speed of 129 km/h
 - Cold-start
- NYCC
 - Average speed of 11 km/h;
Maximum speed of 45 km/h
 - Cold-start
- 22°C, -7°C

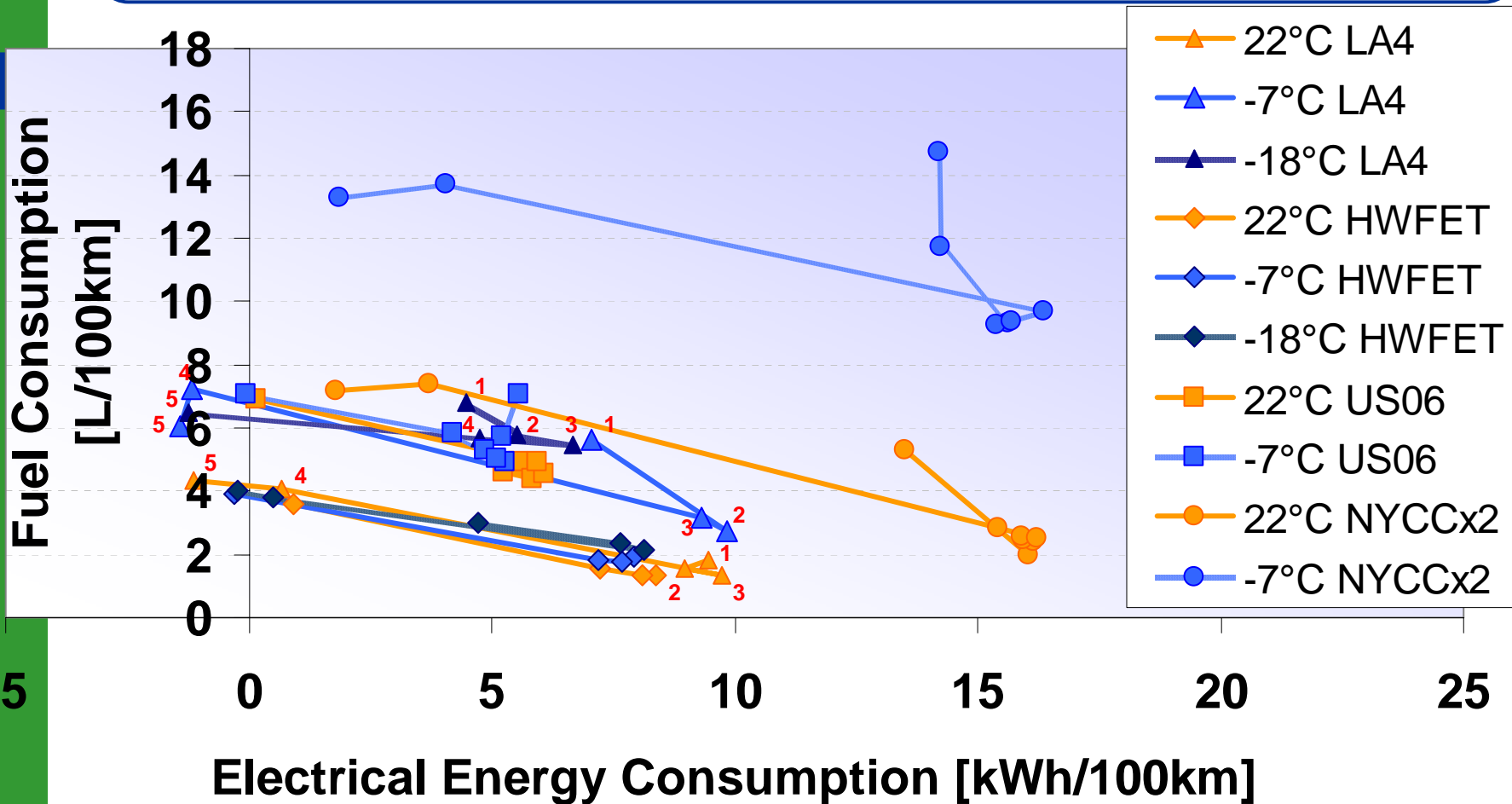


Analysis

- Measured data
 - All cycles:
 - CO₂, CO, THC, NO_x
 - Fuel consumption by carbon balance
 - Electrical consumption
 - Engine speed
 - Engine oil and catalyst temperatures
 - Select cycles:
 - Other GHGs: CH₄, N₂O
 - Light HC speciation, aldehydes, VOCs
 - PM_{2.5}, PM_{1.0}, particle number concentration and size distribution
- Lifecycle analysis
 - GHGenius used for estimation of upstream emissions from fuel and electrical use

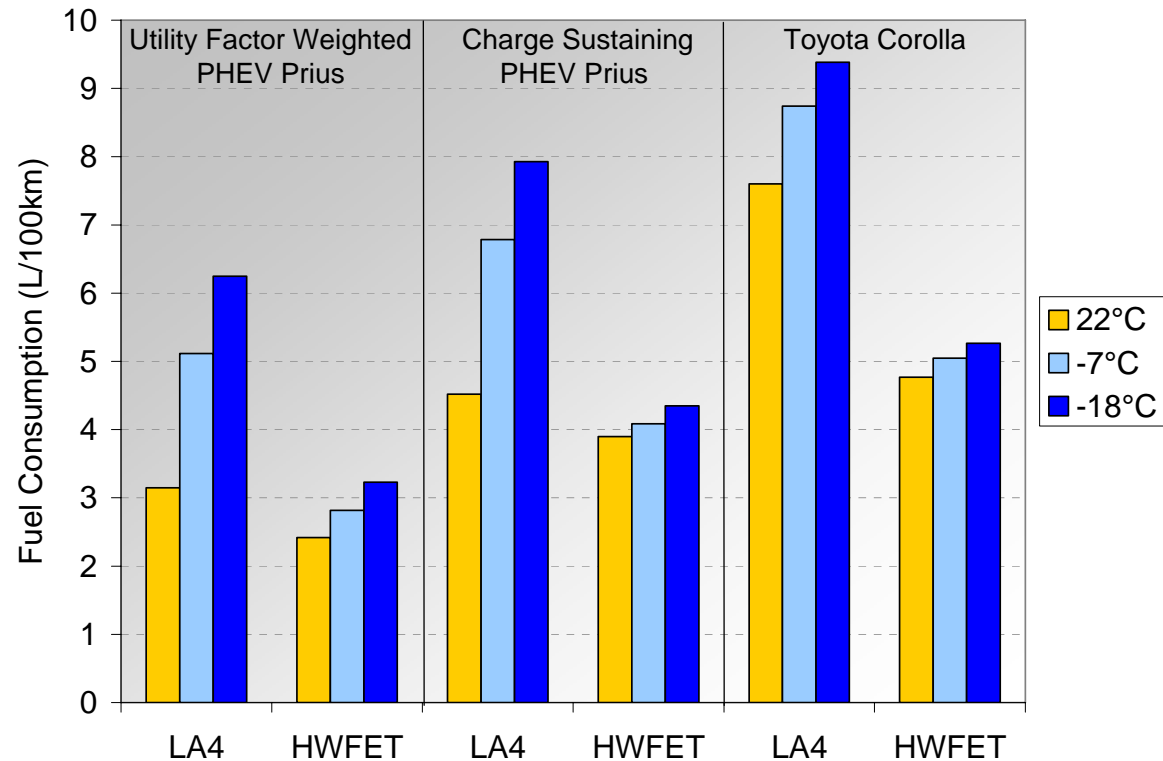


Energy Consumption



Fuel Consumption Summary

- City fuel consumption increases at -7°C and -18°C
 - PHEV: 63%, 99%
 - HEV: 50%, 75%
 - Conv: 15%, 23%
- Highway fuel consumption increases at -7°C and -18°C
 - PHEV: 16%, 34%
 - HEV: 5%, 12%
 - Conv: 6%, 10%



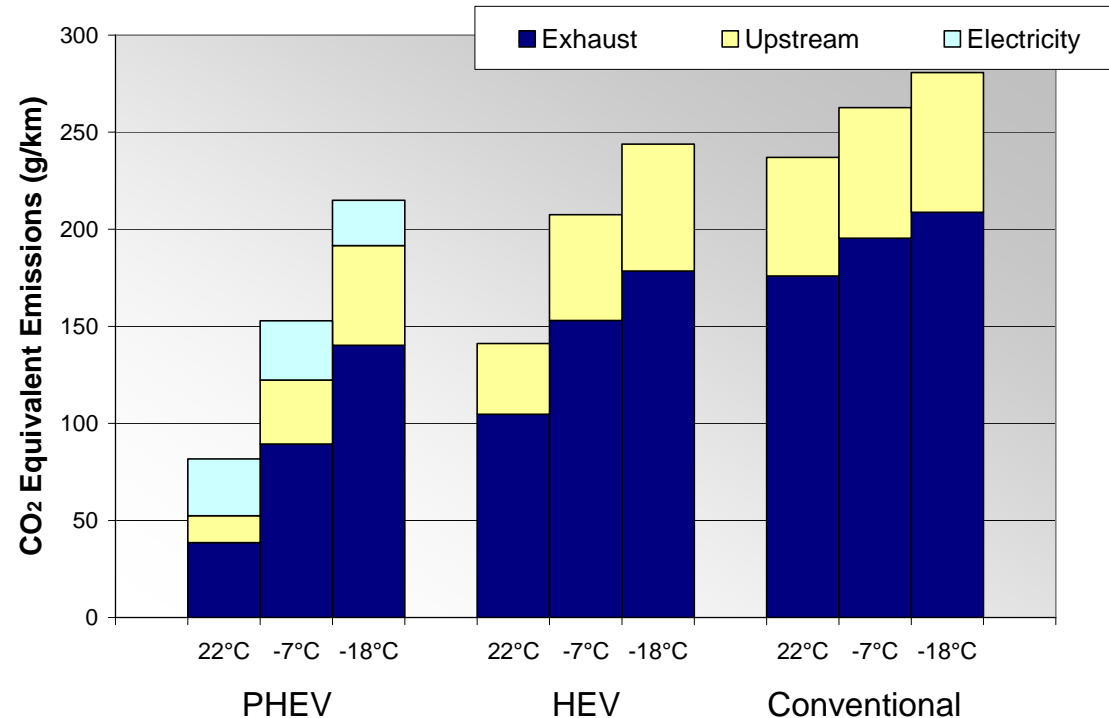
Electrical Summary

- With decreasing ambient temperature
 - All-electric range decreases
 - Battery usable capacity decreases
 - Electrical round trip efficiency decreases

Ambient Temperature (°C)	UDDS			HWFET			US06		NYCC	
	22	-7	-18	22	-7	-18	22	-7	22	-7
Charge Depletion Distance (km)	38	36	45	49	48	50	64	75	27	23
Electric Range Fraction (%)	49	37	19	61	53	35	32	18	67	19
Equivalent All-Electric Range (km)	24	13	9	30	26	23	21	14	18	4
Hymotion Electrical Energy Use (DCkWh)	4.1	3.8	3.5	4.0	3.8	3.3	3.8	3.7	3.9	3.8
Charging Energy (ACkWh)	5.2	5.1	5.3	5.1	5.2	4.7	4.8	4.9	4.9	5.0
Round Trip Efficiency (%)	79	75	67	78	73	71	81	76	80	76
Charging Time (Hours)	5.2	5	6.3	5.1	5.4	6	4.5	4.8	4.6	4.7

GHG Emissions

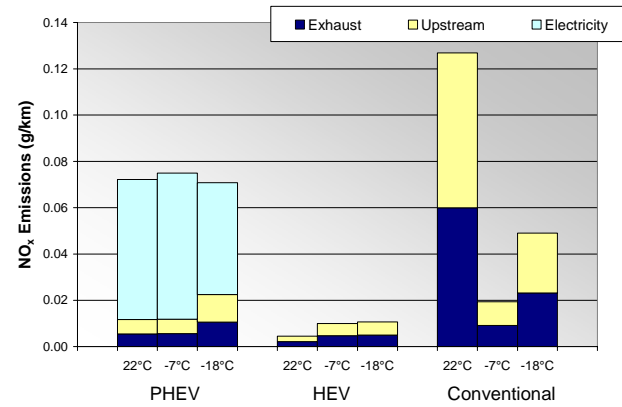
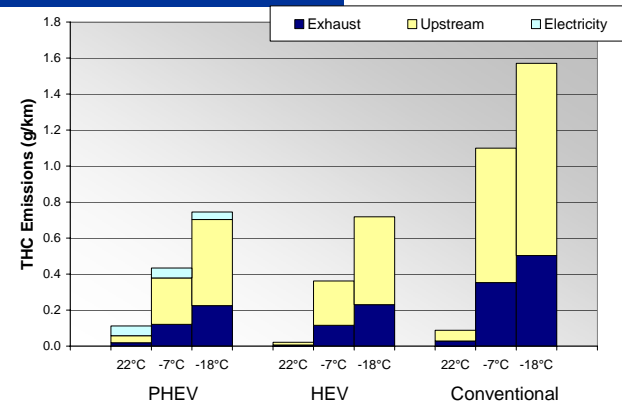
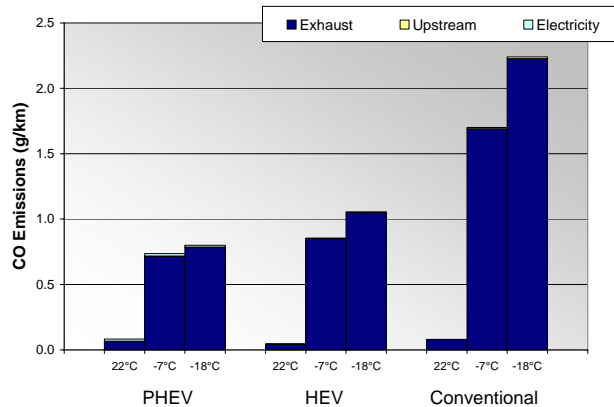
- CO₂, CH₄, N₂O
- Composite LA4
- GHGenius 3.16 used for lifecycle emissions
- Lifecycle GHG emissions increase at -7°C and -18°C
 - PHEV: 87%, 163%
 - HEV: 47%, 73%
 - Conventional: 11%, 18%



Lifecycle CO, THC, NO_x Emissions

- CO
 - almost entirely from tailpipe, PHEV offers benefits even at cold temperatures
- THC
 - significant upstream emissions from electricity generation
 - PHEV exhaust emissions slightly higher than HEV at cold temperature due to less frequent engine operation and cooler catalyst temperatures
- NO_x
 - PHEV benefits cancelled by upstream emissions from electricity generation

LA4 composite
(combined urban cold start and hot start)



Summary

- Fuel consumption increases at cold temperatures
 - Due to low engine temperatures and reduced electrical capabilities, the relative impact was greatest for the PHEV, and under congested urban driving conditions (up to 5 times increase)
 - Due to quicker engine warm-up, the Corolla had a maximum fuel consumption increase of only 33% on the cold start urban cycle at -18°C .
 - Overall fuel consumption is still lowest for the PHEV at all temperatures

Summary

- Lifecycle GHG emissions increase at cold ambient temperatures
 - Relative increase is greater for the PHEV
 - Absolute emission rates are lower for the PHEV at all temperatures
- Lifecycle emissions of CO and THC are significantly higher at cold temperatures for all vehicles
 - PHEV has lower CO emissions compared to the HEV, but THC and NOx emissions are higher due to upstream emissions

Acknowledgements

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Backup – Canadian Power Sources

