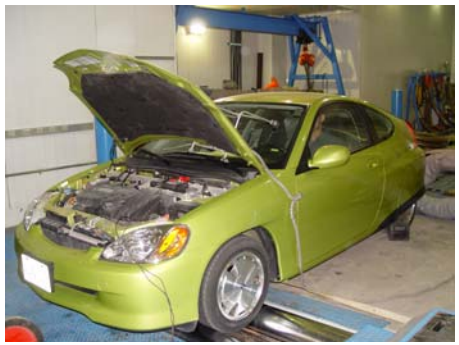
Exhaust Emissions from Light Duty Gasoline-Electric Hybrid Vehicles



Canadian Pollution Prevention Roundtable, 2006

M. Christenson[1], L. Graham[2], D. Karman[1]

[1]Department of Civil and Environmental Engineering, Carleton University

[2]Science and Technology Branch, Emissions Research and Measurement
Environment Canada

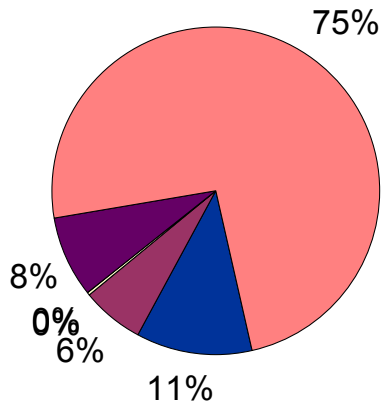
Environment Canada Environnement Canada

Carleton UNIVERSITY

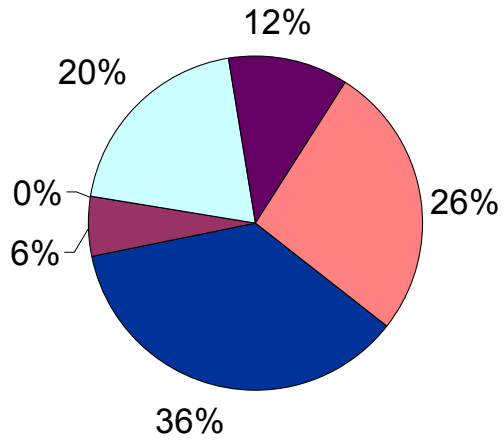
Department of Civil and Environmental Engineering

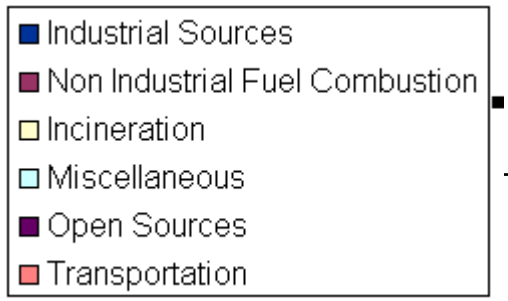
Transportation and the Environment

CO (tonnes)

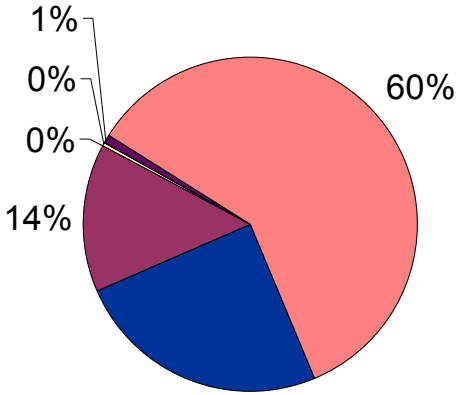


VOC (tonnes)

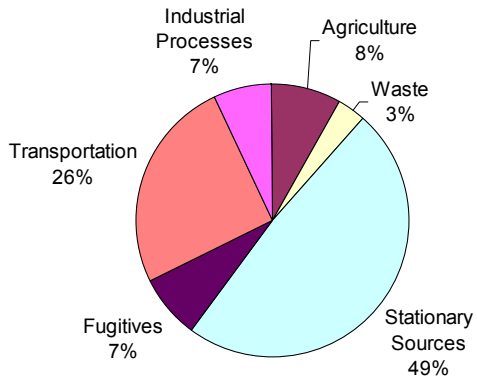




Nox (tonnes)



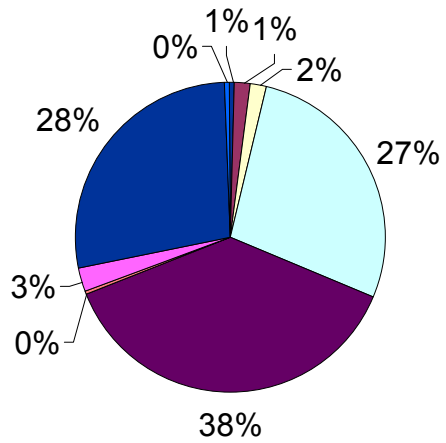
GHG (kt CO2 eq)



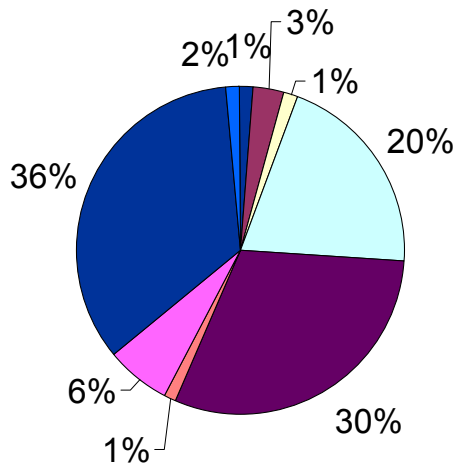
Source: Environment Canada

Transportation and the Environment

CO (tonnes)

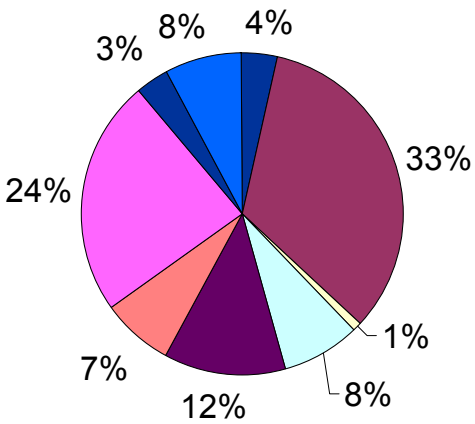


VOC (tonnes)

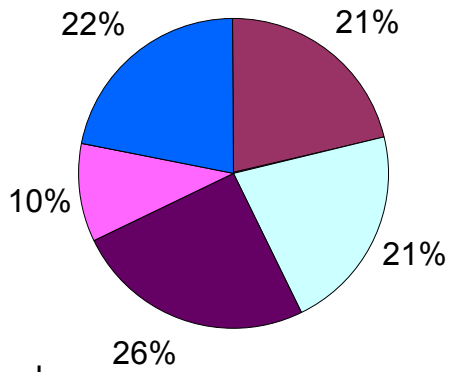


- Air Transportation
- Heavy-duty diesel vehicles
- Heavy-duty gasoline trucks
- Light-duty gasoline trucks
- Light-duty gasoline vehicles
- Marine Transportation
- Off-road use of diesel
- Off-road use of gasoline
- Other

NOx (tonnes)



GHG (kt CO2 eq)



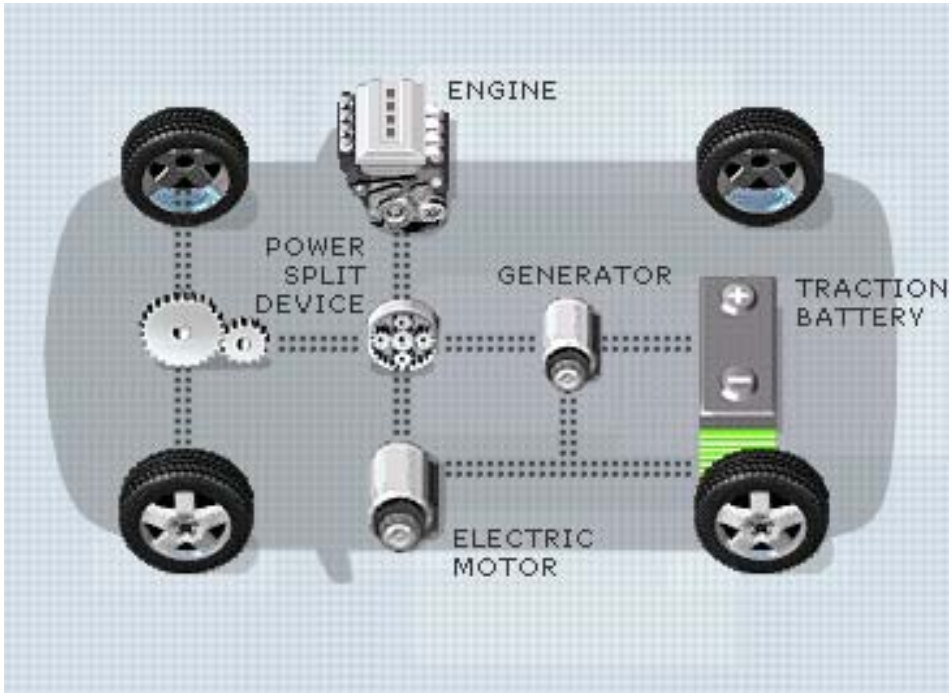
Source: Environment Canada

Reducing Vehicle Emissions

- Consume less fuel
  - Drive less
  - Drive smaller vehicles with small efficient engines
- Use alternative technologies such as
  - Hybrid vehicles
  - Fuel cell vehicles

Hybrid Technology

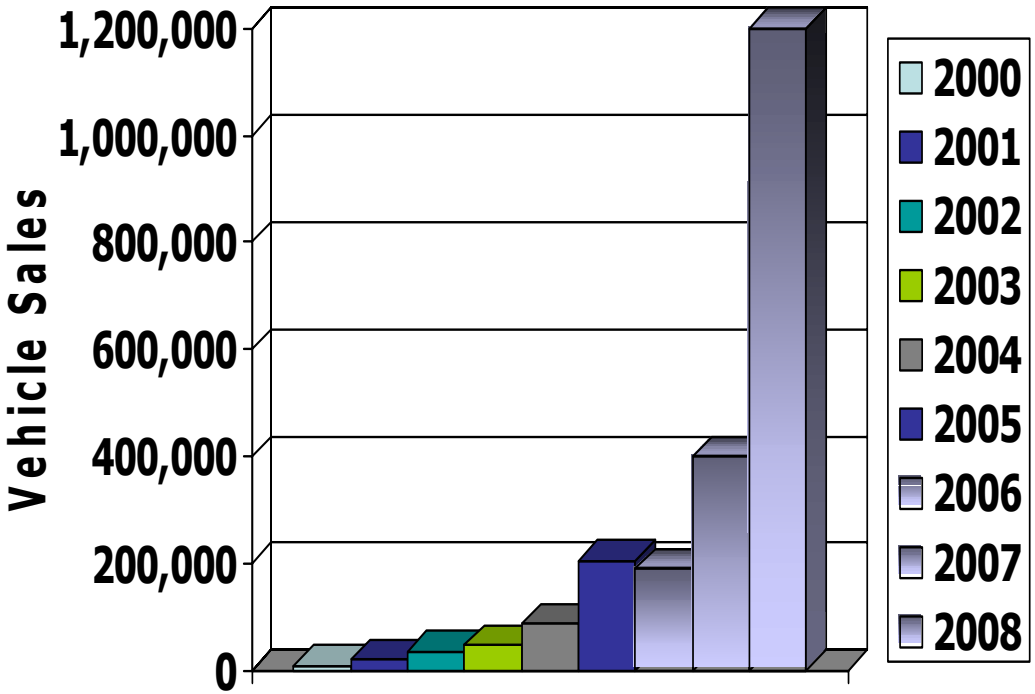
- **Conventional Vehicle**
  - Use maximum HP rating only 1% of the time
  - Large engine adds weight, is less efficient
- **Hybrid**
  - Small efficient engine
  - Electric motor can assist when needed or in some cases power the vehicle
  - Regenerative braking
  - Other emission control/energy saving features



Source: Toyota.com

Hybrid Sales

- Hybrid vehicles sales are on the rise
  - Hybrids accounted for 1.2% of vehicles sold in the US in 2005
  - By 2007, at least 20 new hybrid models will appear in America (CSM Worldwide)
  - By 2010, 5 - 6% of all cars sold in America will be hybrids, assuming current petrol prices persist (ABI Research)



Source: HybridCars.com

Objectives

- Quantify Vehicle Emissions
  - Fuel Economy, Criteria Pollutants, GHGs
- Represent available advanced technologies
- Represent realistic driving patterns
- Examine impact of winter temperatures

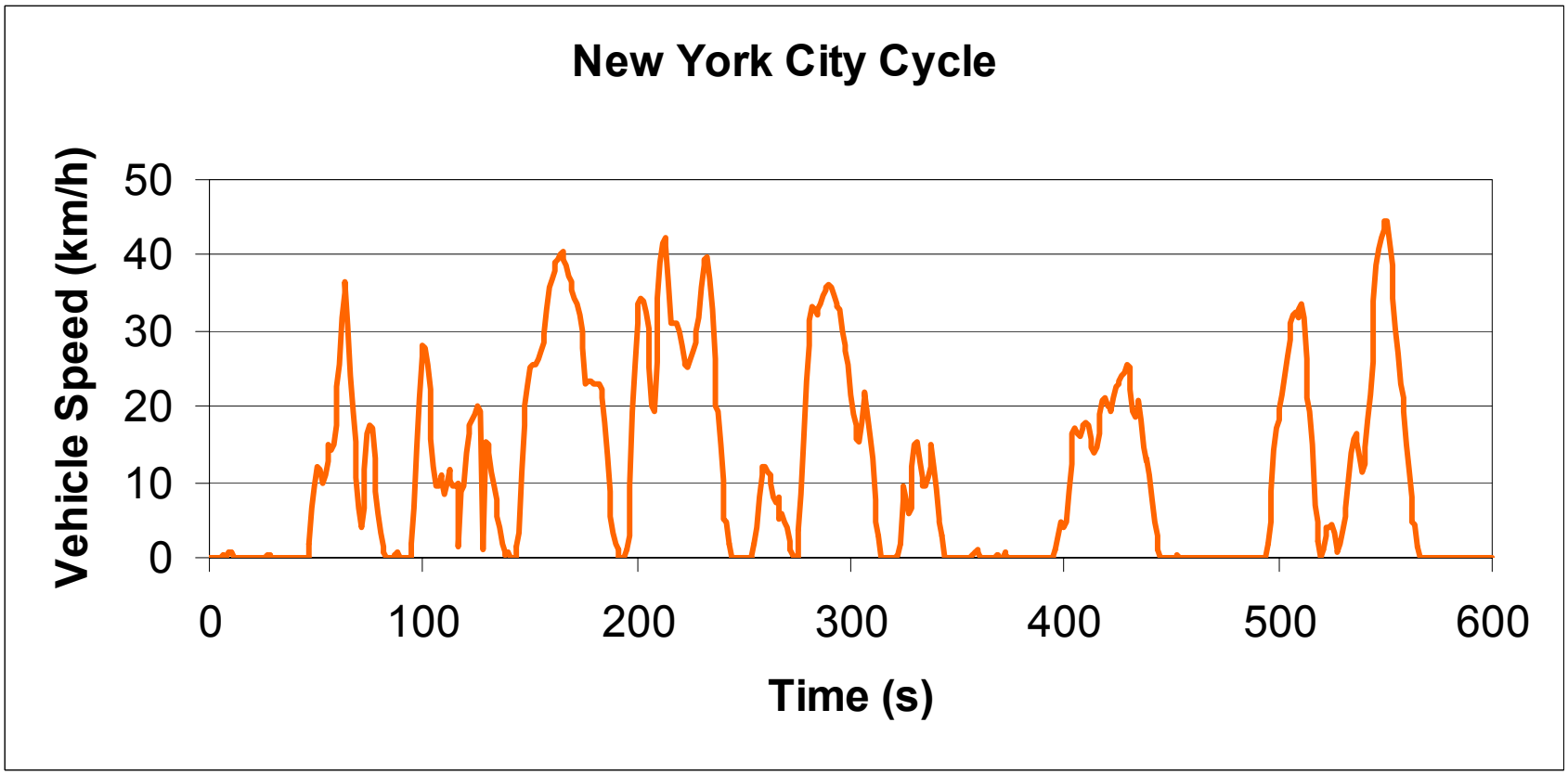
Project Overview

- 4 hybrid vehicles and a highly efficient conventional gasoline vehicle tested on a chassis dynamometer
- Ambient temperatures of 20^{o}C and -18^{o}C
- Driven over five cycles representing various driving conditions
- Sampling criteria pollutants, GHGs, particulate matter
- Monitoring battery state of charge or charging current

Vehicles

- **LD Gasoline Hybrids**
  - Ford Escape (2005)
  - Toyota Prius (2004)
  - Honda Civic (2003)
  - Honda Insight (2000)
- **Gasoline SmartCar (2002)**

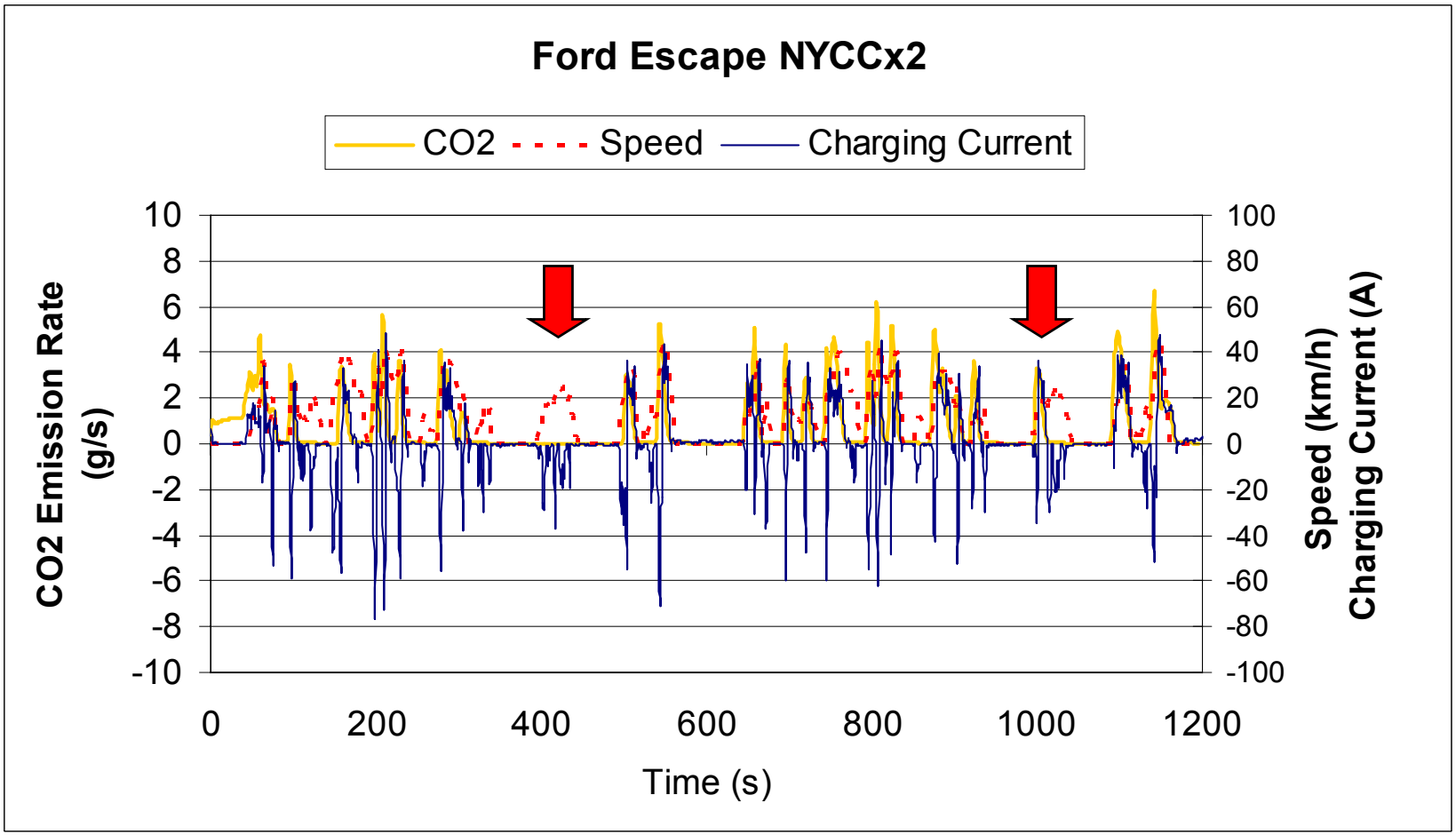
Driving Cycles



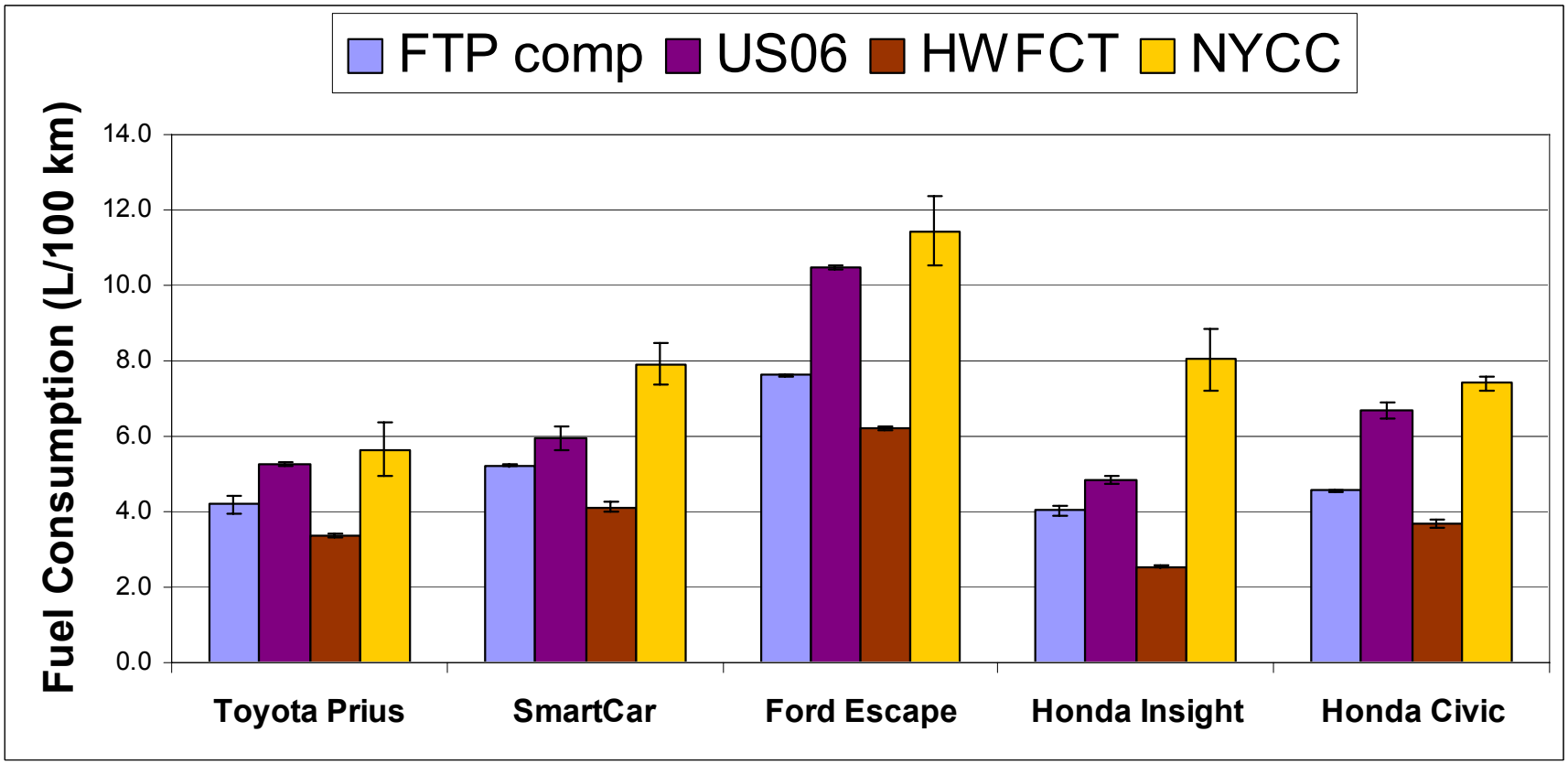
Sampling

- **Integrated**
  - CO, NO_x,THC, NMHC, NMOG
  - CO_2, N_2O, CH_4
  - $PM_{2.5}$ mass emissions
  - Organic and elemental carbon
- **Transient**
  - Particle # and size (ELPI, CPC)
  - CO_2, CO, NO_x, THC
  - Battery charge or charging current

Unique Hybrid Emission Characteristics



Effect of Driving Cycle on Fuel Consumption



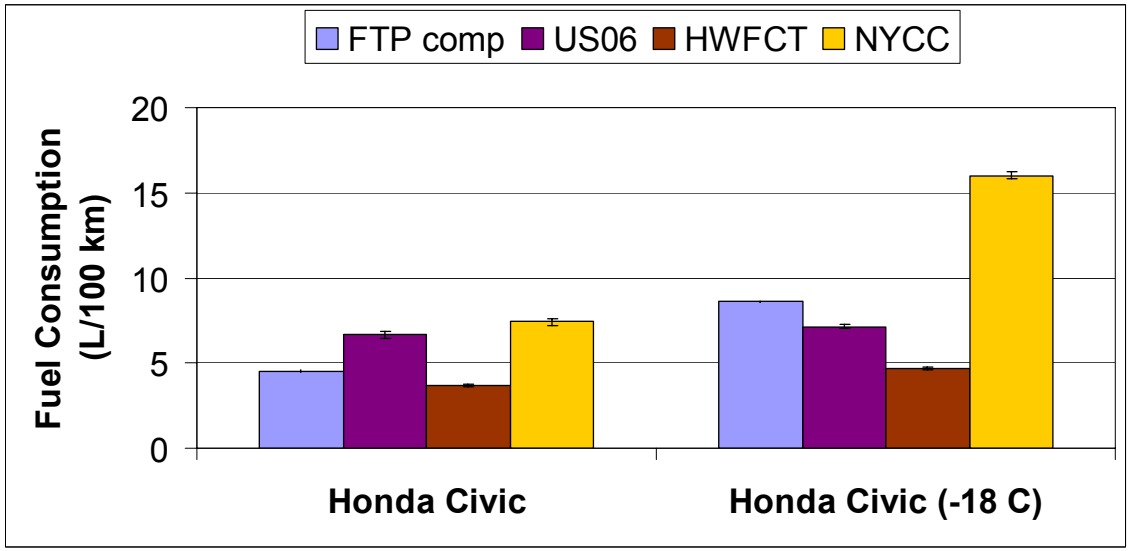
Effect of Driving Cycle on Fuel Consumption

- At 20°C, compared to FTP Composite:
  - Aggressive, high speed driving increases fuel consumption.
  - Free flow highway driving decreases fuel consumption.
  - Congested urban driving increases fuel consumption.

	Ratio US06 / FTP Comp	Ratio HWFCT / FTP Comp	Ratio NYCC / FTP Comp
SmartCar	1.14	0.79	1.51
Toyota Prius	1.25	0.80	1.34
Ford Escape	1.38	0.82	1.50
Honda Insight	1.21	0.63	1.99
Honda Civic	1.46	0.81	1.63

Cold Temperature Operation

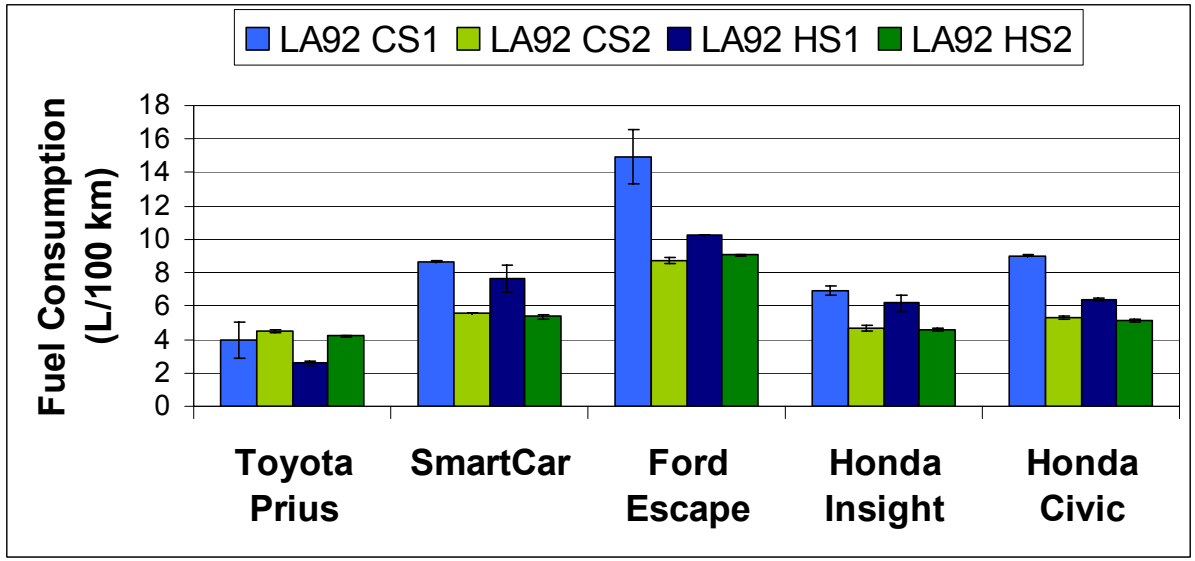
- Cold temperature increases fuel consumption
- Compared to the FTP Composite:
  - Higher speed driving cycles (both US06 and HWFET) decrease fuel consumption.
  - Lower speed driving cycle (NYCC) increases fuel consumption



	Temp Ratio -18/20	Ratio to FTPcomp (-18)
FTPcomp	1.88	1
US06	1.07	0.83
HWFCT	1.27	0.55
NYCC	2.16	1.86

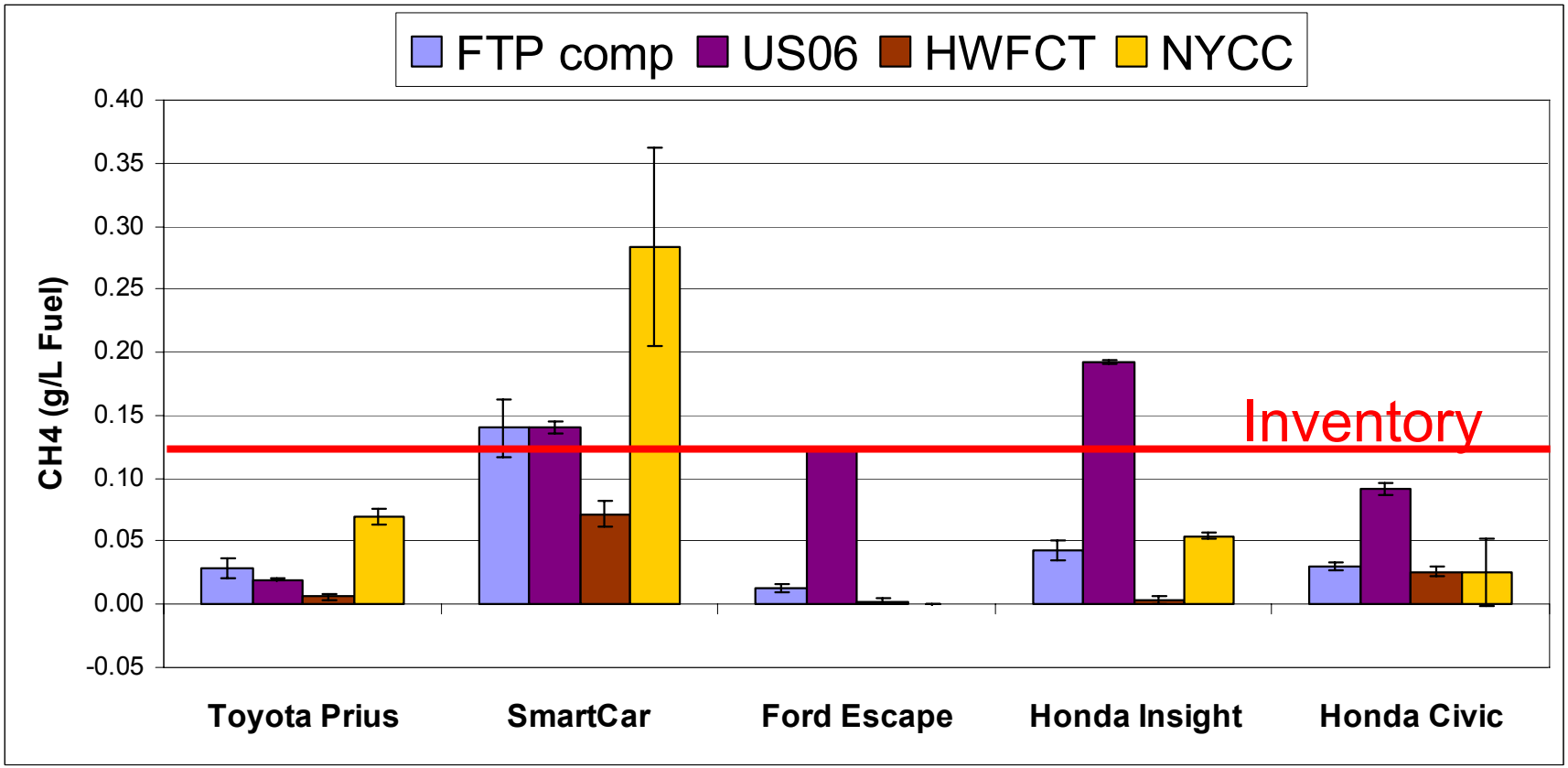
Effect of Cold Start Conditions

- **On cold engine start:**
  - Fuel consumption increases compared to warm engine start (Phase 1 vs. Phase 3).

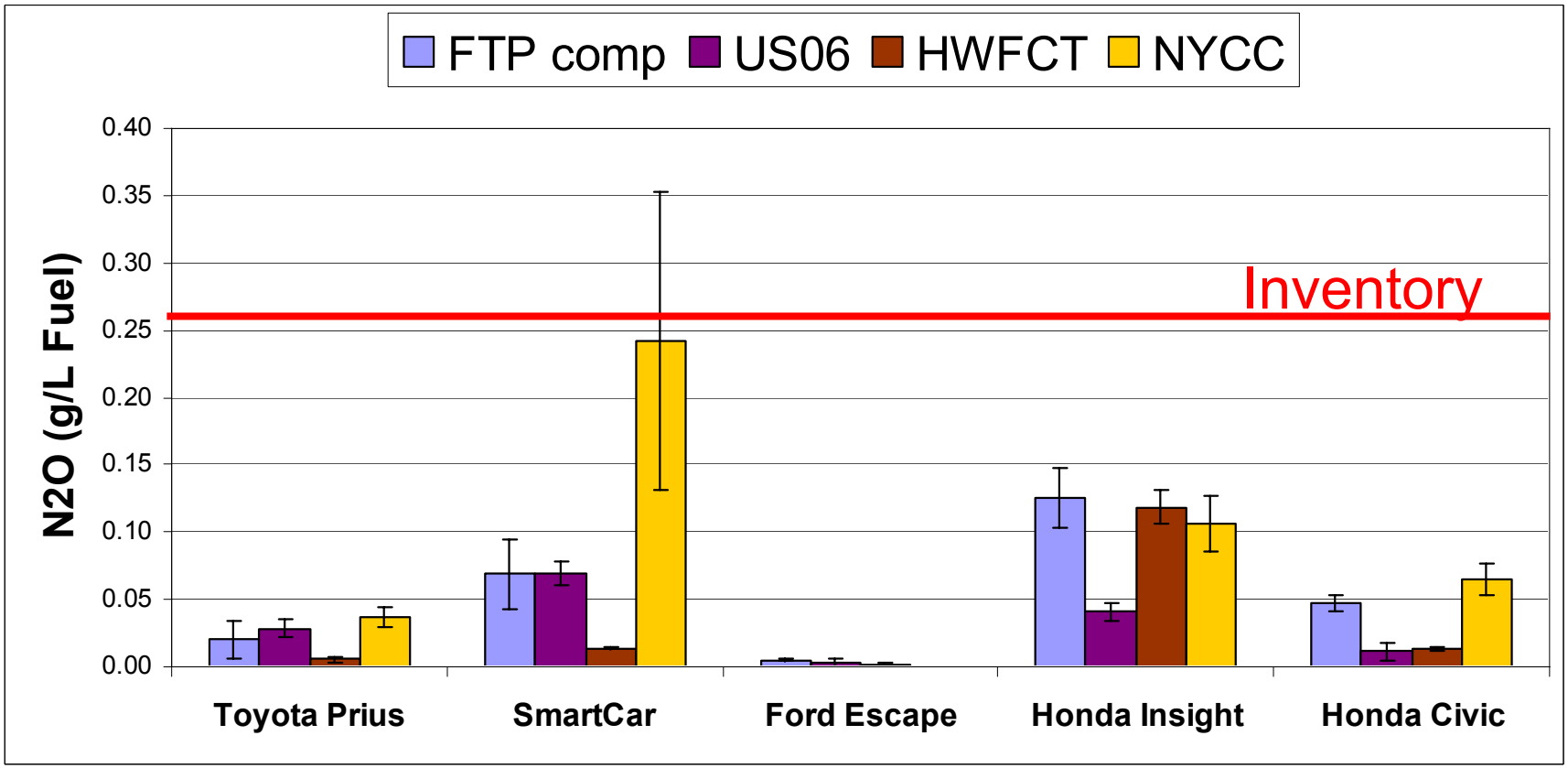


	Ratio FTP1/FTP3	Ratio LA92CS1/LA92HS1
SmartCar	1.13	1.13
Toyota Prius	1.22	1.53
Ford Escape	1.13	1.46
Honda Insight	1.14	1.12
Honda Civic	1.14	1.40

GHG Emission Factors: CH_4



GHG Emission Factors: N_2O



Summary

- Hybrid transient emission patterns are different from those of conventional vehicles and can vary from one repeat of a test to another
- Hybrid fuel consumption
  - 30-40% lower under city driving conditions
  - 5-20% lower under highway driving conditions
  - Aggressive driving and congested urban conditions negatively affect fuel consumption
  - Cold temperature operation increases fuel consumption
    - Factor of 2 for Honda Civic

Implications

- Government interventions can increase benefits
  - OEE Auto$mart, SmartDriver, FleetSmart
- Results will be used to update emission factors for national emission inventory
- Results can also be used in emission estimation models
  - MOBILE 6.2C
  - MOVES

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