Medium- and Heavy-Duty Electric Drive Vehicle Simulation and Analysis

DOE VTP Annual Merit Review

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Project ID: VSS043

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Project Overview

Timeline

- Project started in FY09
- Project is 75% complete

Budget

- Total DOE project funding
  - FY09: $150k
  - FY10: $150k
  - FY11: $250k
- Total project partner funding:
  - FY10: $37k
- In-kind support received from FedEx Express®, Azure Dynamics®

Barriers Addressed

1. Risk Aversion
2. Cost
3. Computational models, design and simulation methods

Project Partners

- FedEx Express
- Azure Dynamics
- Calstart®, South Coast Air Quality Management District (AQMD)

Project Relevance

Medium Duty (Classes 3-6) Vehicle Segment

- Consumes over 8 billion gallons of fuel per year (U.S.)
- Emits on average 13 tons CO_2 per vehicle per year
- Growing fast: +35% and +49% growth (class 3 and 4) from 1997 to 2002
- Includes short haul delivery → largest segment group
  - 28% of 16.3M vehicles in 2009

Parcel Delivery is Well-Matched to Electric Drive

1) Transient-intensive drive cycles
2) Fleet vehicles return to base (overnight charging)
3) Operate in densely populated areas
4) Significant potential for per-vehicle emission reductions

Project Relevance

OEMs Need to Know

1. What medium-duty vehicle segments should be targeted?
2. What usage profiles should be designed to?
3. What are the warranty implications?

End Users Need to Know

1. What are the best electric drive options?
2. Which routes are best (distance and intensity)?
3. What is the total cost of ownership?
4. How much petroleum and greenhouse gases (GHG) can be avoided?

Project Objective

Help answer industry and end-user questions, accelerate deployment, magnify impact of plug-in electric vehicles (PEVs), and reduce petroleum consumption.

Project Milestones

Month-Year	Milestone
September 2010	Conference paper: "Model-Based Analysis of Electric Drive Options for Medium-Duty Parcel Delivery Vehicles," Presented at the 25th World Battery, Hybrid and Fuel Cell Electric Vehicle Symposium and Exposition, November 5–9, 2010, Shenzhen, China
September 2011	Technical report and/or conference paper summarizing analysis.

Project Approach

1. **Drive Cycle Data Collection & Analysis**
   - Real-world driving (distance, intensity)
   - Match and bound usage profiles

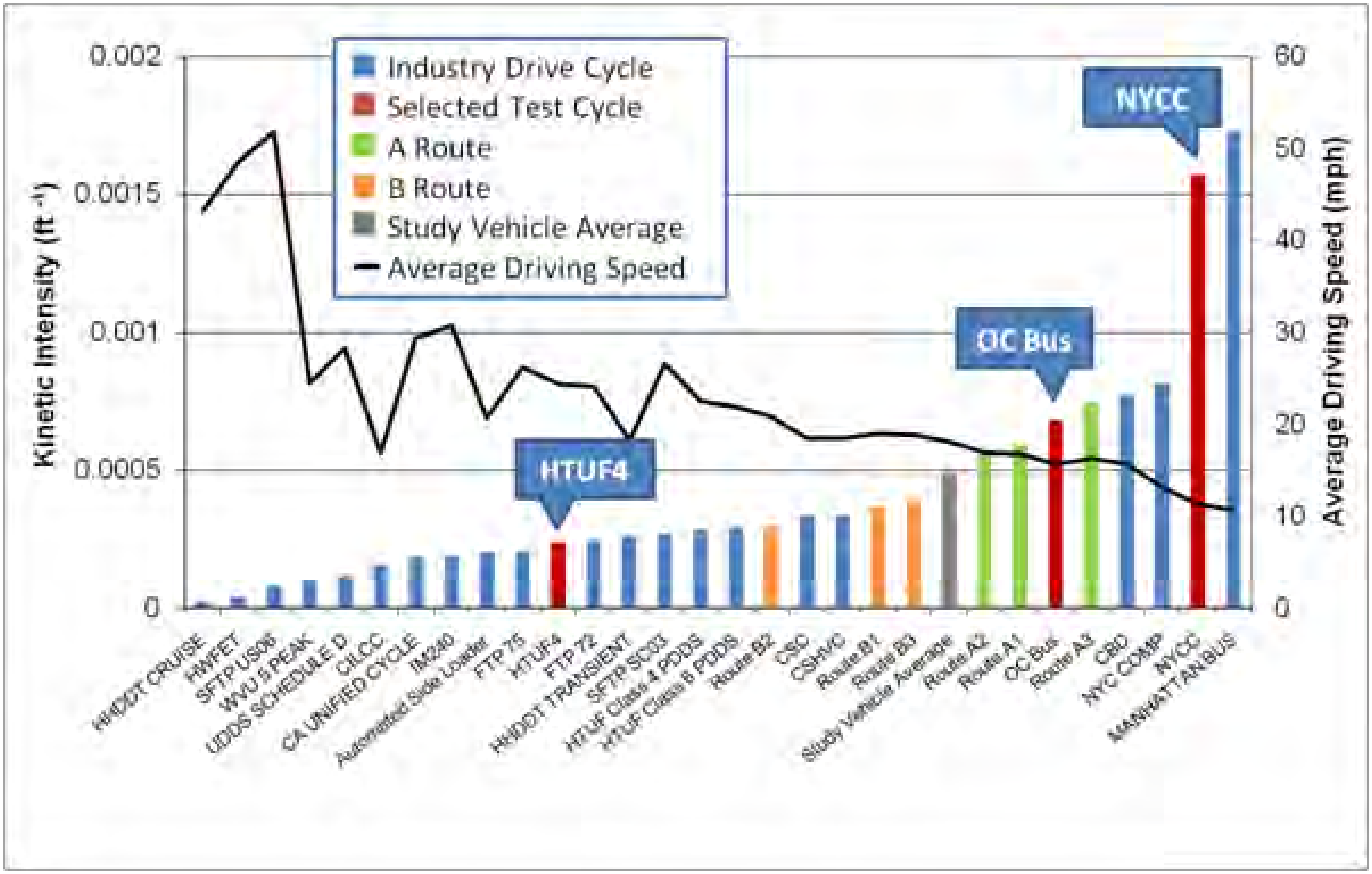
2. **Measure Fuel Consumption**
   - NREL ReFUEL Laboratory Chassis Dynamometer

3. **Vehicle Modeling**
   - Calibrate model using measured fuel consumption by drive cycle
   - Simulate fuel consumption

4. **Analysis**
   - Sweep range of designs, usage patterns, costs

Project Approach

- 11 FedEx vehicles, 4 depots, 82 route-days, 1 Hz speed-time



Project Approach

Photo credit: Robb Barnitt, NREL

Drive Cycle	HEV Fuel Consumption (liter / 100km)
HTUF4	22.5
OC Bus	27.3
NYCC	34.9

HEV = Hybrid Electric Vehicle

Project Approach

Parameter	FedEx HEV
C_d	0.7
Frontal area (m^2)	7.02
Vehicle mass (kg)	4,472
Engine power (kW)	182
Motor power (kW)	100
Battery power (kW)	60
Battery capacity (kWh)	2.45

Drive Cycle	Measured Fuel Consumption (L/100km)	Simulated Fuel Consumption (L/100km)	Error
HTUF 4	22.5	24.5	8.9%
OC Bus	27.3	27.4	0.4%
NYCC	34.9	35.2	0.9%

Project Approach

Energy and Power

- +20, 40, 60, 80 kWh
- 30, 60 kW

Daily Distance Driven

- 40 km (25 miles)
- 80 km (50 miles)
- 120 km (75 miles)
- 160 km (100 miles)

Drive Cycles

- HTUF4
- OC Bus
- NYCC

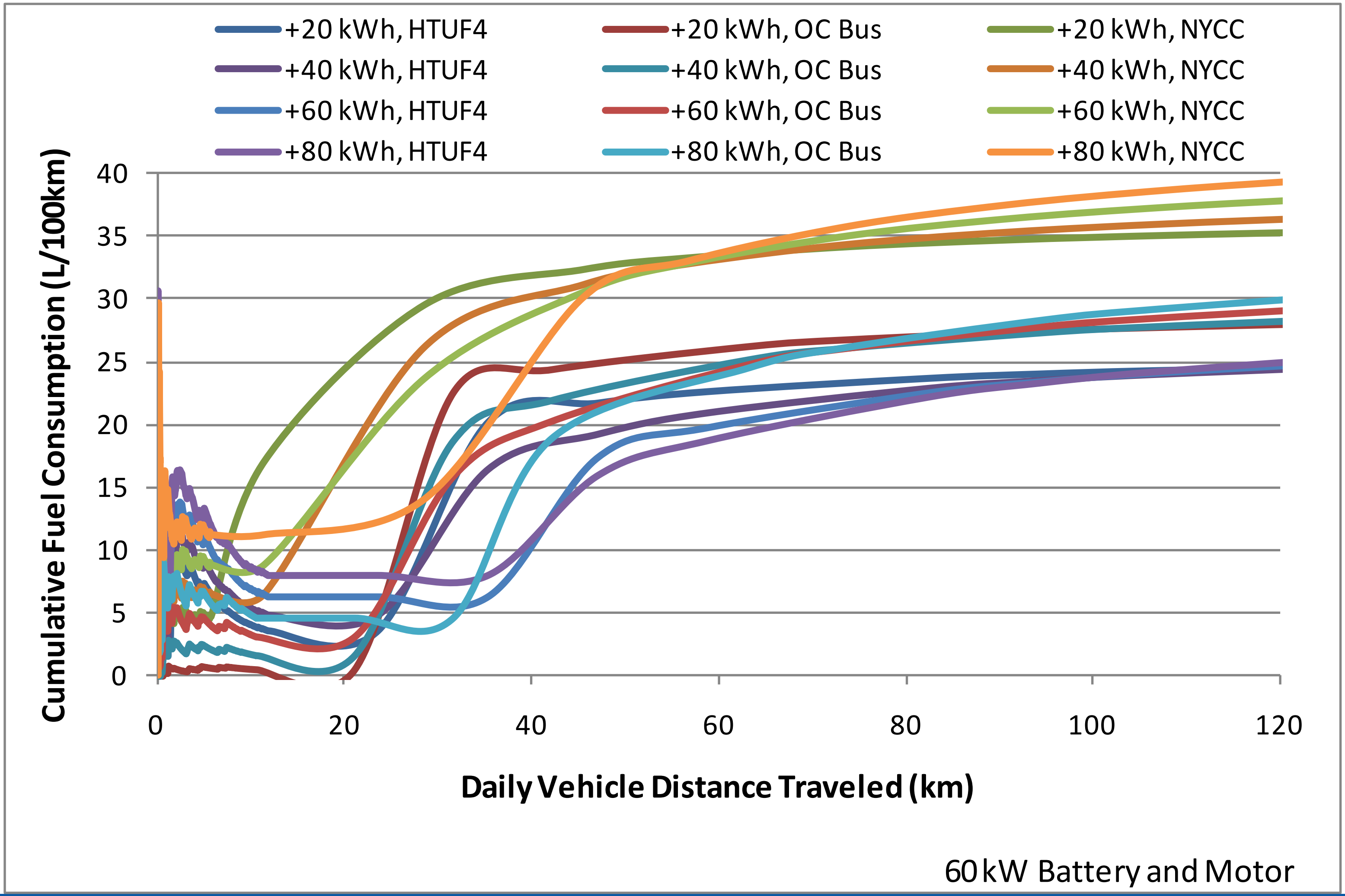
Fuel and ESS Cost

- Current → \$3/gallon fuel, \$700/kWh ESS
- Midterm → \$5/gallon fuel, \$300/kWh ESS
- Electricity cost = \$0.12/kWh

ESS = Energy Storage System

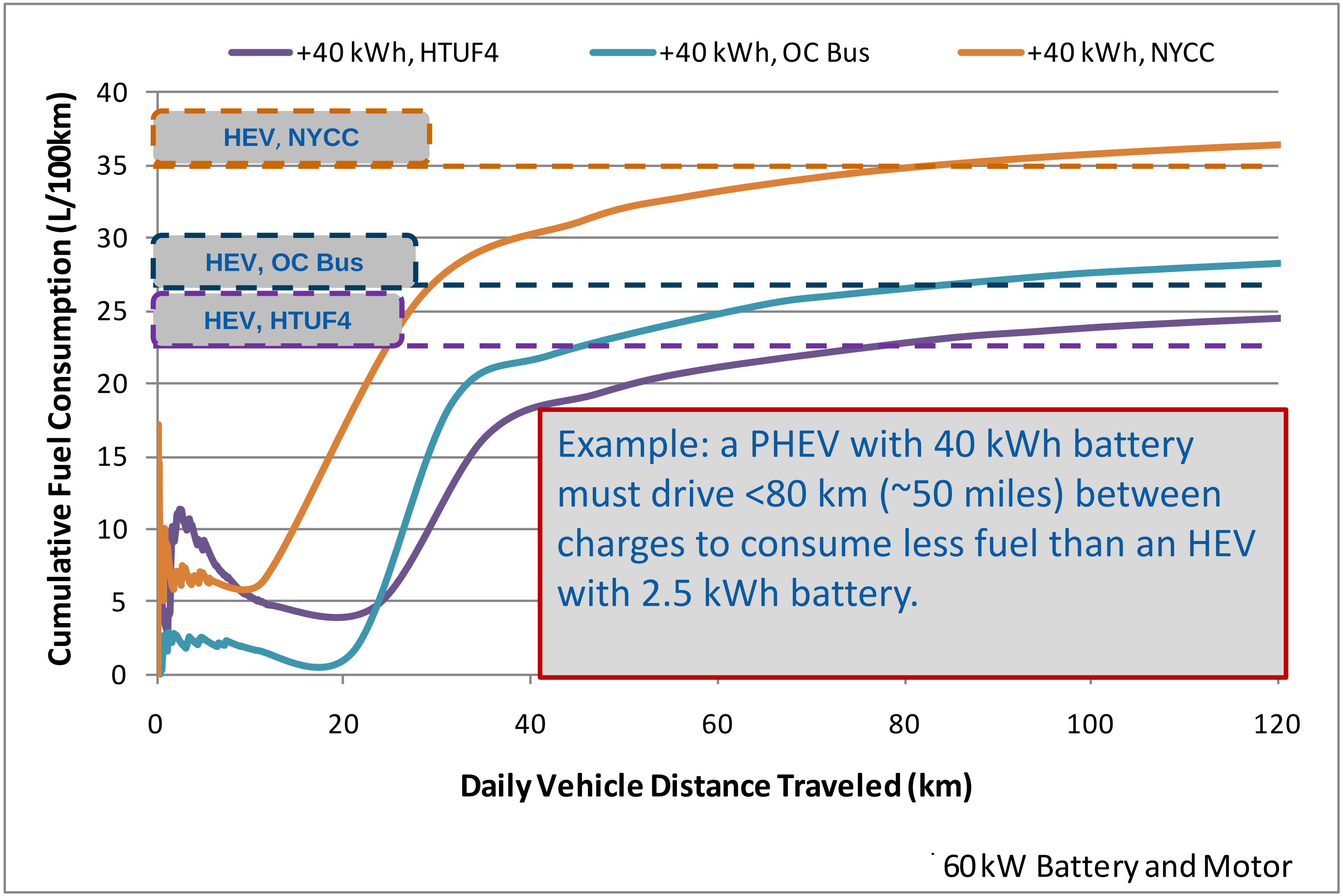
Technical Accomplishments

- Higher cumulative fuel consumption with increasing drive cycle intensity, battery capacity and mass



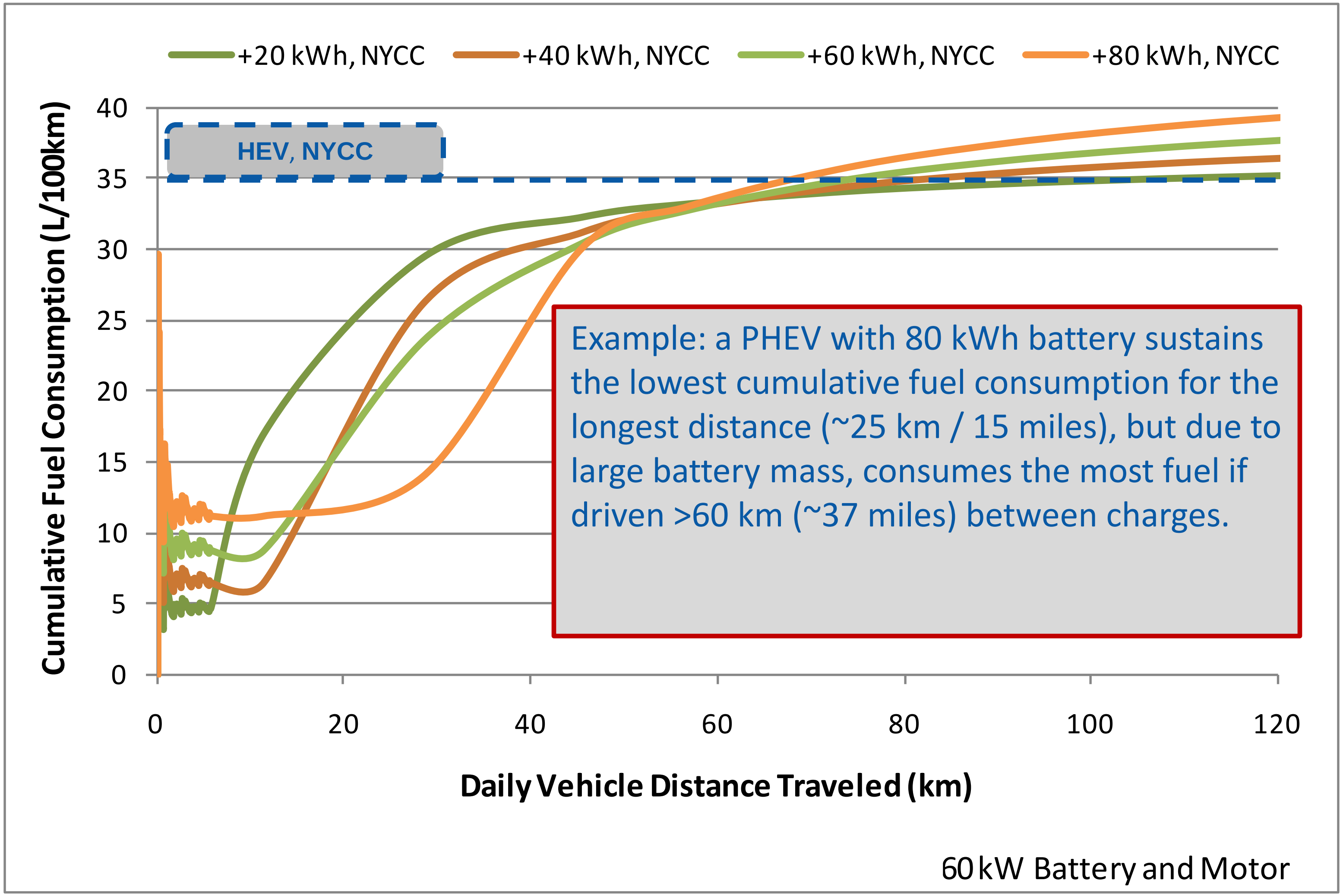
Technical Accomplishments

- Drive cycle intensity impacts CD range and cumulative fuel consumption



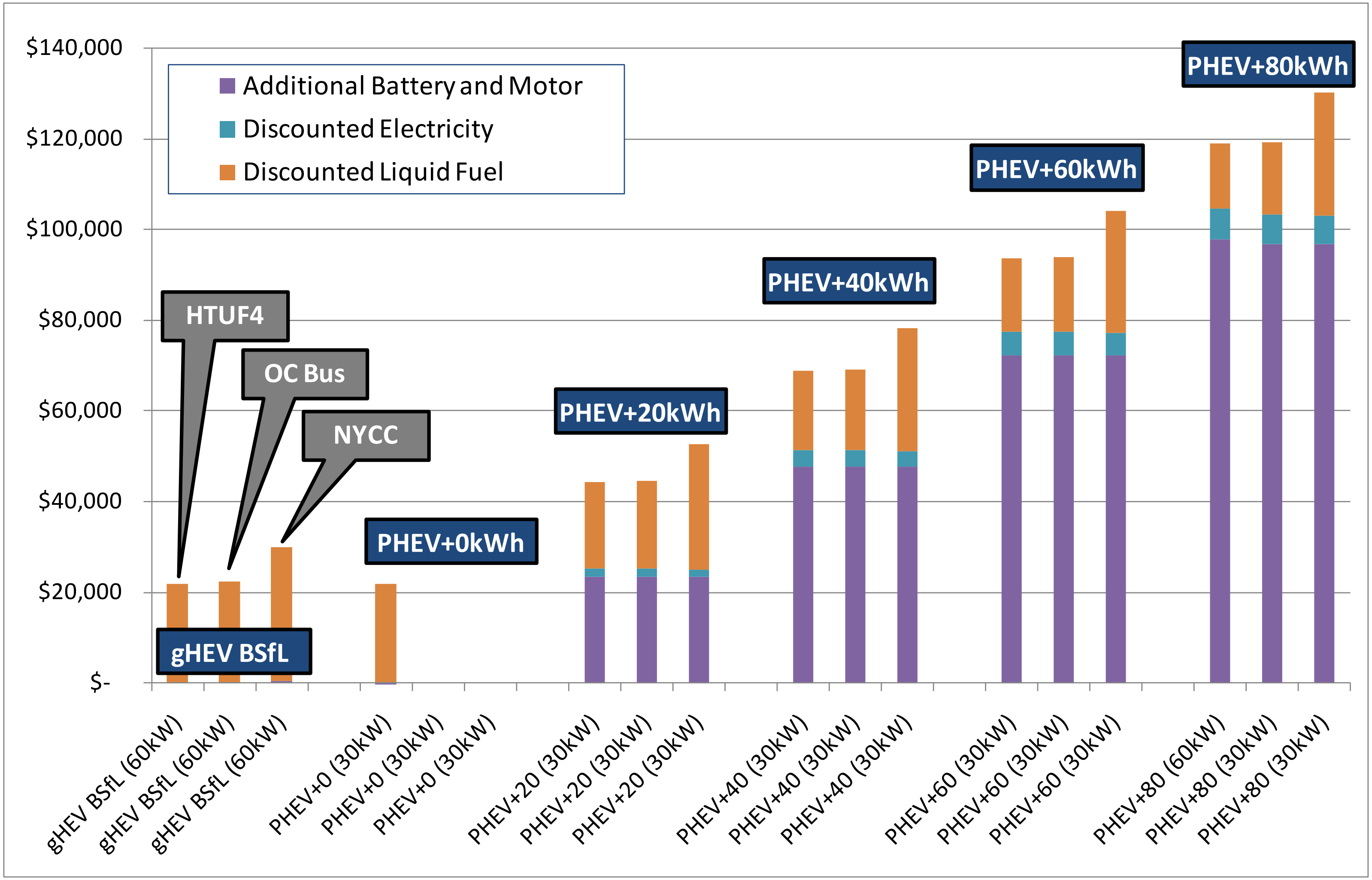
Technical Accomplishments

- Battery capacity and mass impact CD range and cumulative fuel consumption



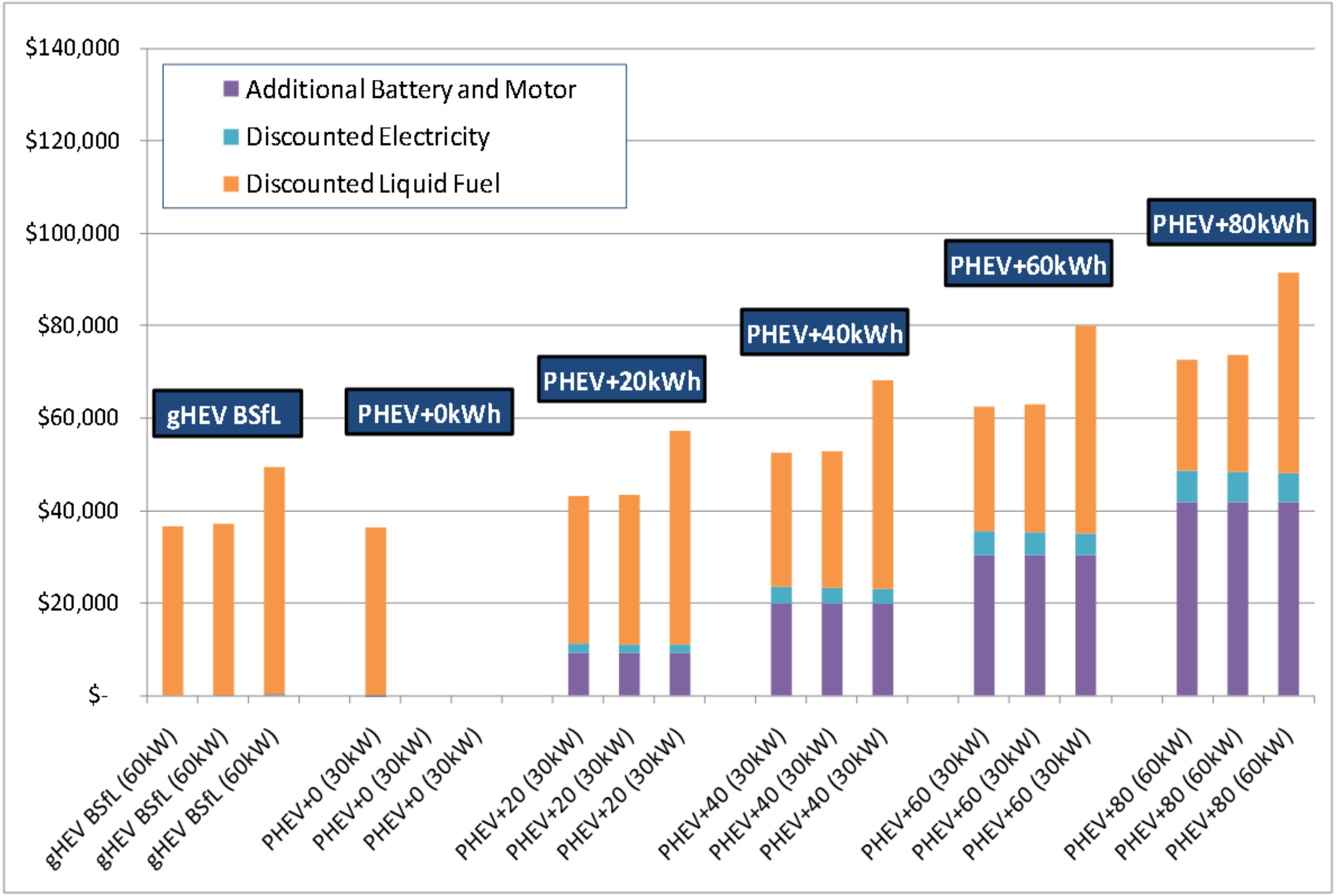
Technical Accomplishments

Incremental PHEV lifetime operating costs are not currently HEV-competitive ($3/gallon fuel, $700/kWh ESS; 40 km/day)



Technical Accomplishments

Incremental PHEV lifetime operating costs can be HEV-competitive ($5/gallon fuel, $300/kWh ESS; 40 km/day)



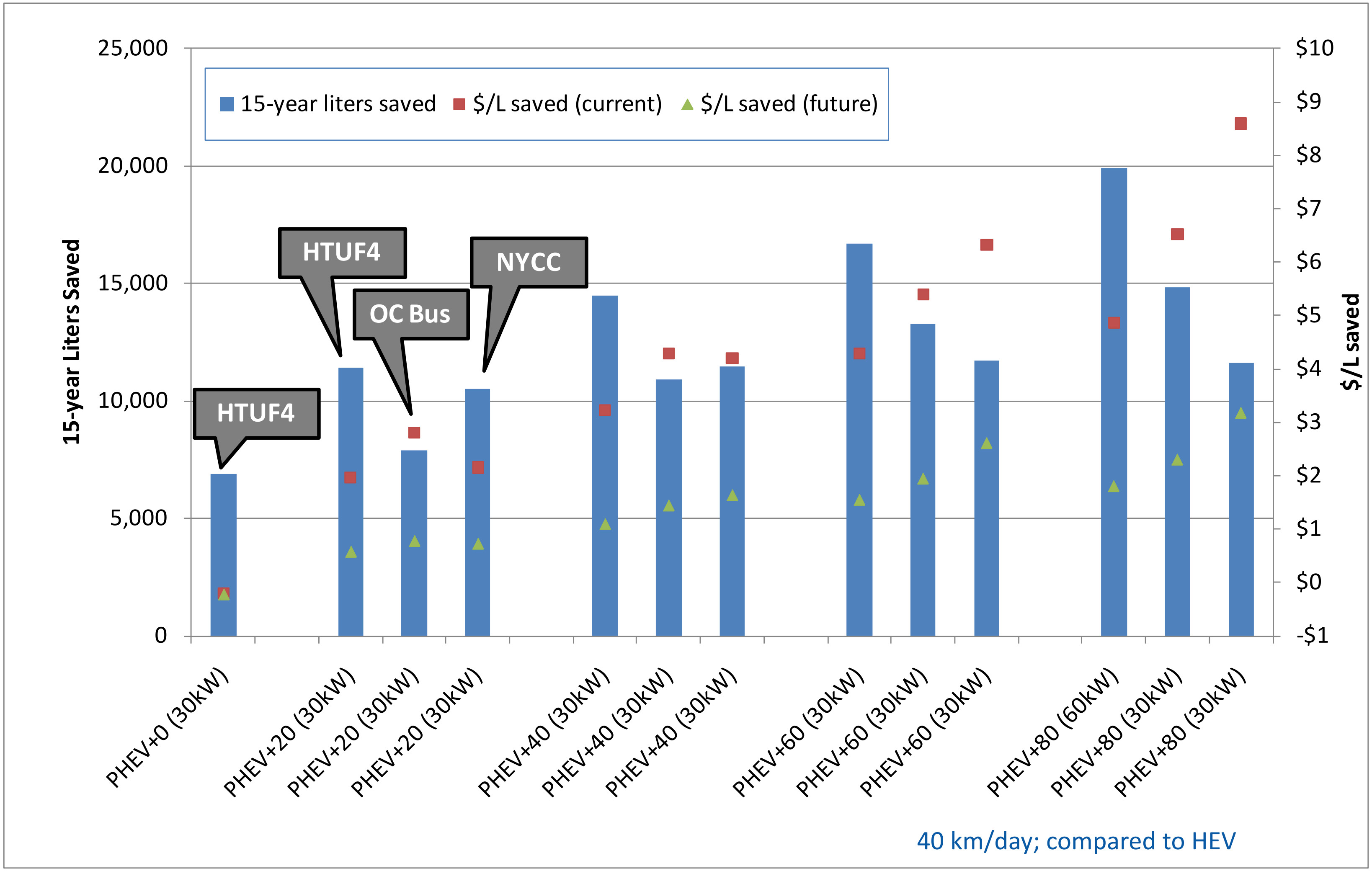
Technical Accomplishments

- Incremental lifetime operating costs ($5/gallon fuel, $300/kWh battery) for most cost-effective configuration compared to HEV baseline
- Drive cycle intensity and daily distance important factors
- Fleets could balance incremental cost against purchase incentives

Vehicle	Drive Cycle	40 km/day	80 km/day	120 km/day	160 km/day
PHEV+20 (30kW)	HTUF4	$6,568	$7,525	$9,018	$10,473
PHEV+20 (60kW)	HTUF4	$7,944	$9,247	$11,150	$13,029
PHEV+20 (30kW)	OC Bus	$6,154	$7,600	$9,200	$10,854
PHEV+20 (60kW)	OC Bus	$7,661	$9,719	$11,880	$14,149
PHEV+20 (30kW)	NYCC	$7,620	$9,678	$11,838	$14,049
PHEV+20 (60kW)	NYCC	$9,311	$12,040	$14,924	$17,927

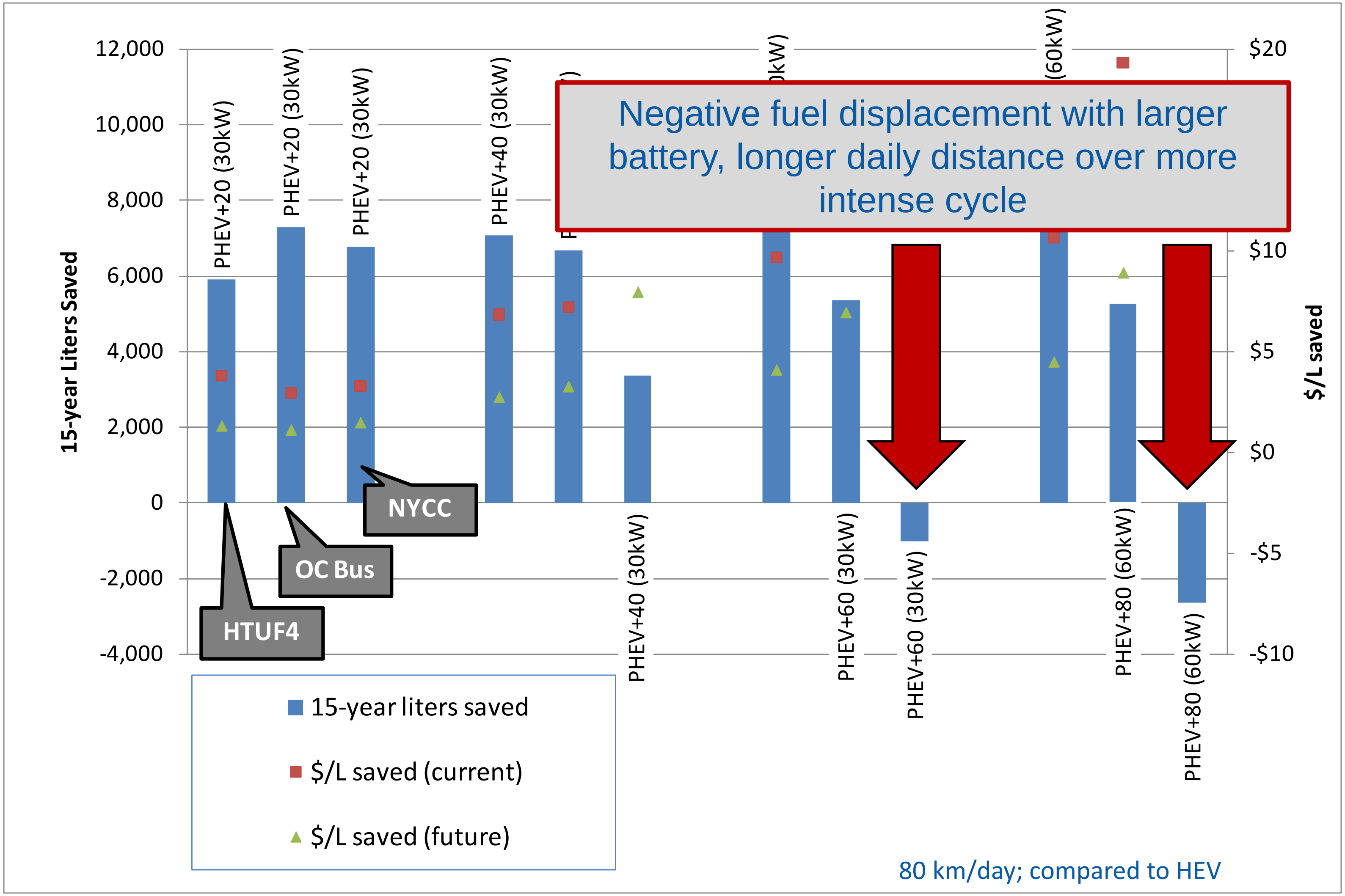
Technical Accomplishments

PHEV configurations have significant fuel displacement potential



Technical Accomplishments

PHEV fuel displacement advantage depends upon route selection



Collaborations

AZD
AZURE DYNAMICS

CALSTART

AQMD

<u>FedEx Express</u>

- Industry partner, outside VTP
- Supplied drive cycle data and a test vehicle

<u>Azure Dynamics</u>

- Industry partner, outside VTP
- Supplied vehicle model inputs and data acquisition support

<u>Calstart and South Coast AQMD</u>

- Industry, regulatory partners outside VTP
- Provided added financial support

Summary

Medium duty vehicles are excellent candidates for electric drive application by virtue of usage profiles, fleet logistics, and fleet-specific value proposition.

***BUT*, battery and fuel costs dominate economics**

- As we know, lowering battery costs is critical to electric drive penetration.
- $5/gallon fuel and $300/kWh battery still not lifetime operating cost-competitive with HEV.

***SO*, targeted design and strategic deployment are critical**

- Maximizing petroleum reduction, minimizing cost are best achieved by careful route (intensity and distance) selection.
- Shorter, less intense routes are best suited to lower power motor/battery and less battery capacity (and mass).

Proposed Future Work

1. Develop additional models of Class 4 parcel delivery vehicles
   - Conventional vehicle (diesel)
   - Diesel HEV (EPA 2007 and 2010)
   - Diesel PHEV (EPA 2007 and 2010)
   - EV
2. Simulate performance using matrix of designs and usage patterns
   - Use real drive cycles
   - Battery sized for 0–2 replacements over life of vehicle
   - Apply battery life model
   - Ambient temperature variation
   - Overnight and opportunity charging
   - Charging profiles (Level 2 and Level 3)
3. Analysis
   - Total Cost of Ownership
     - Range of liquid fuel and battery costs
     - Impact of battery replacements
   - Lifetime petroleum reduction
   - Lifetime GHG reduction

Acknowledgments

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Questions?