EVS 24
Towards Zero Emission

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Idaho National Laboratory

U.S. Department of Energy – Advanced Vehicle Testing Activity: Plug-in Hybrid Electric Vehicle Testing and Demonstration Activities

AVTA Background and Goals

- The Advanced Vehicle Testing Activity (AVTA) is part of DOE's Vehicle Technologies Program
- The Idaho National Laboratory (INL) and Electric Transportation Engineering Corporation (ETEC) conduct AVTA. Argonne National Laboratory performs dynamometer testing
- AVTA goals:
  - Document potential of new vehicle technology to reduce petroleum consumption
  - Provide benchmark data to technology modelers and target setters, research and development programs, and vehicle manufacturers
  - Assist fleet managers in making informed vehicle purchase, deployment and operating decisions

12 PHEVs Tested by AVTA

Aftermarket PHEV conversions

- Toyota Prius with A123Systems Hymotion L5 conversion pack (5 kWh lithium-ion [Li-ion])
- Toyota Prius with Hybrids Plus conversion (5 kWh Li-ion)
- Toyota Prius with EnergyCS conversion
  - Valence (9 kWh Li-ion)
  - Altairnano (9 kWh Li-ion)
- Toyota Prius with Manzanita Micro conversion
  - Hawker (5 kWh valve-regulated lead acid)
  - Thunder Sky (5 kWh Li-ion)
- Ford Escape Hybrid with A123Systems Hymotion conversion (8.5 kWh Li-ion)
- Ford Escape Hybrid with Hybrids Plus conversion
  - Hybrids Plus (12 kWh Li-ion)
  - K2 Energy Solutions (13.3 kWh Li-ion)
- Ford Escape Hybrid with Electrovaya conversion (12 kWh Li-ion)

OEM PHEVs

- Renault Kangoo with Saft battery (25 kWh nickel-cadmium)
- Ford Escape E85 PHEV with Johnson Controls/ Saft battery (12 kWh Li-ion)

PHEV Testing Methodology

Perform independent testing of PHEVs in three phases:

- Baseline performance testing
  - On closed track and dynamometer
- Accelerated testing
  - Dedicated drivers follow defined on-road loops
- Fleet evaluation
  - Vehicle performance monitored in undirected fleet using onboard data loggers

PHEV Baseline Performance Testing

ETEC conducts initial track testing near Phoenix, AZ

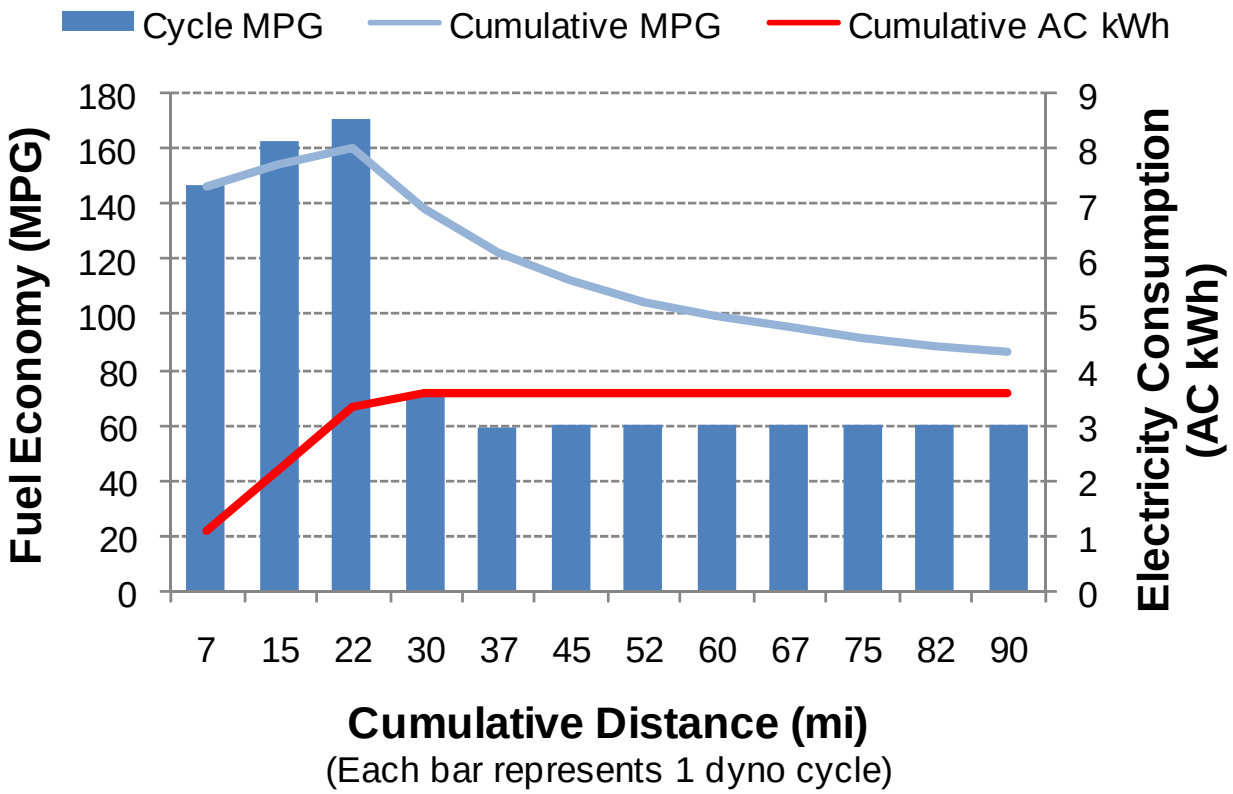
- Includes coastdowns to determine dynamometer coefficients, acceleration, top speed, braking, charging, and durability testing

Argonne 5-day dynamometer testing regime includes:

- UDDS (Urban Dynamometer Driving Schedule)
- HWFEDS (Highway Fuel Economy Driving Schedule)
- US06
- Testing includes at least 26 cycle repetitions, including charge depleting (CD) and charge sustaining (CS) cycles, hot and cold starts, and repetition of cycles with and without air conditioning

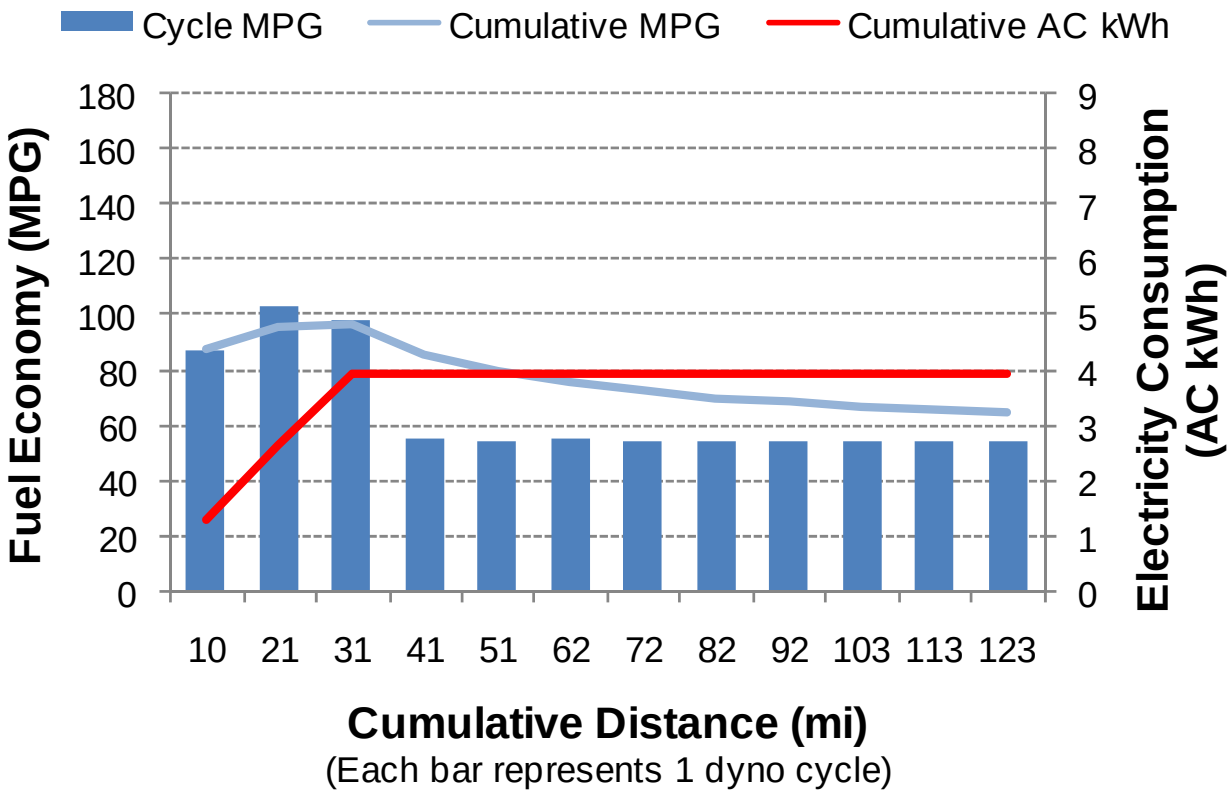
Hymotion Prius Gen 1 – UDDS Fuel Use

5 kWh Li-ion Supplemental Pack



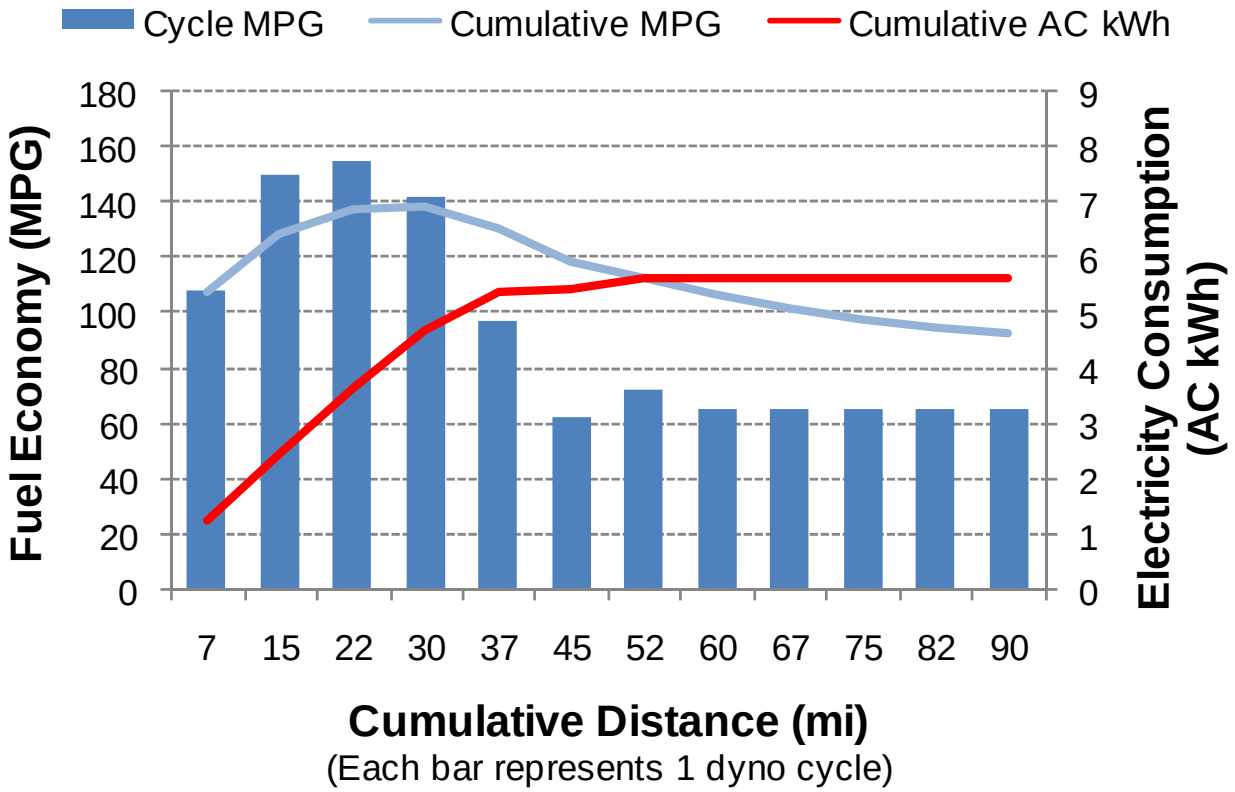
Hymotion Prius Gen 1 – HWFEDS Fuel Use

5 kWh Li-ion Supplemental Pack



EnergyCS Prius Valence – UDDS Fuel Use

9 kWh Li-ion Replacement Pack



EnergyCS Prius Valence – HWFEDS Fuel Use

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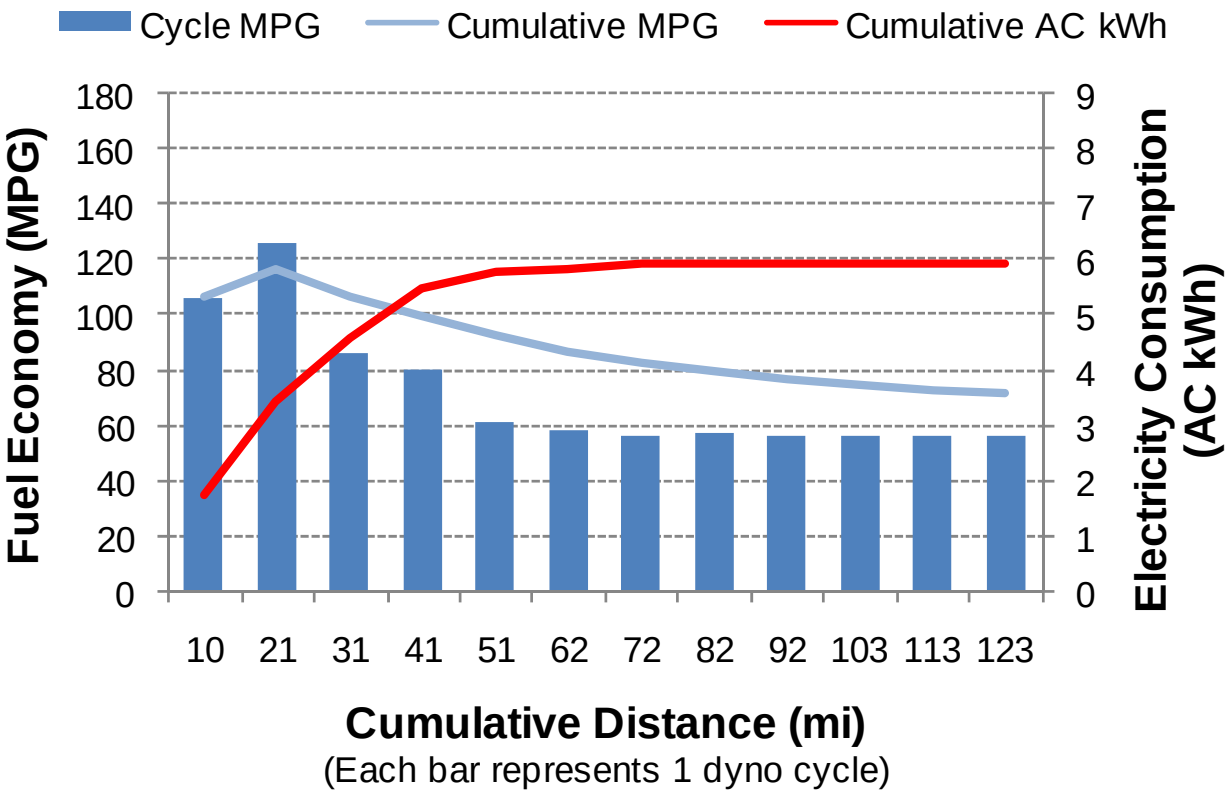
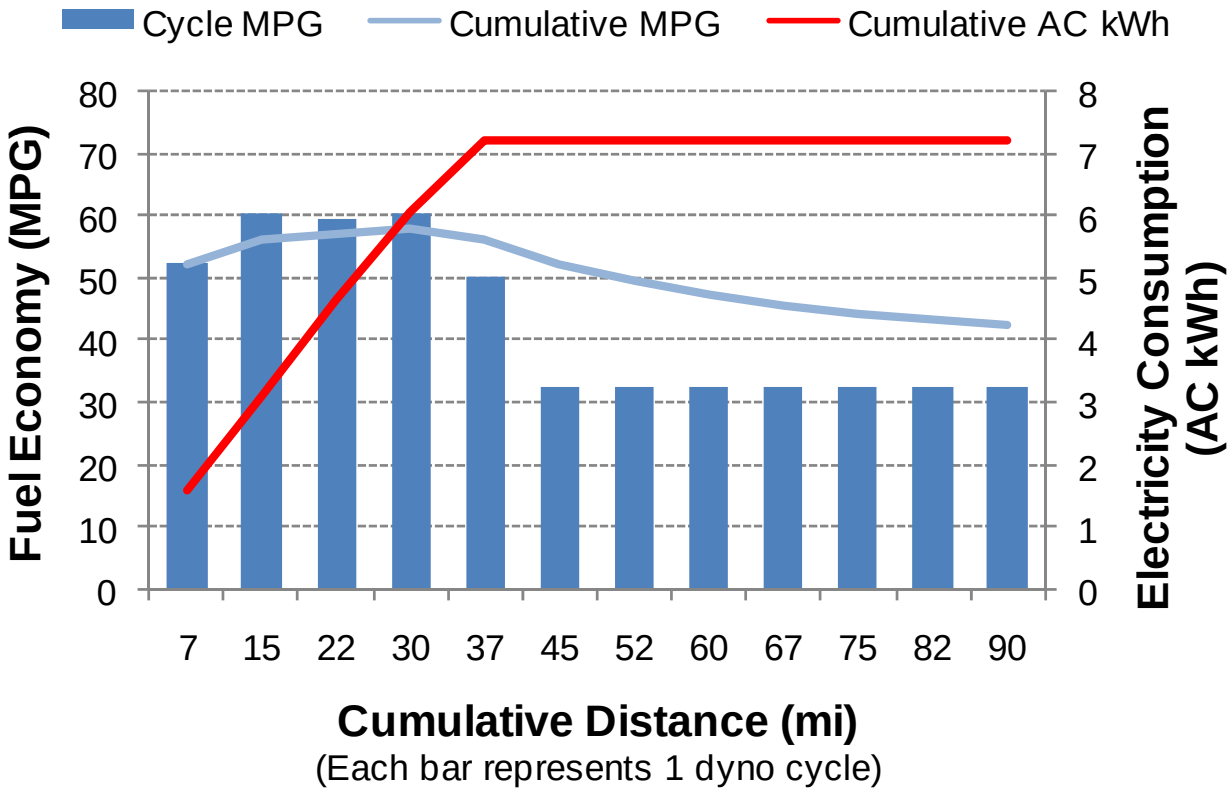


Hymotion Escape – UDDS Fuel Use

8.5 kWh Li-ion Supplemental Pack



Hymotion Escape – HWFEDS Fuel Use

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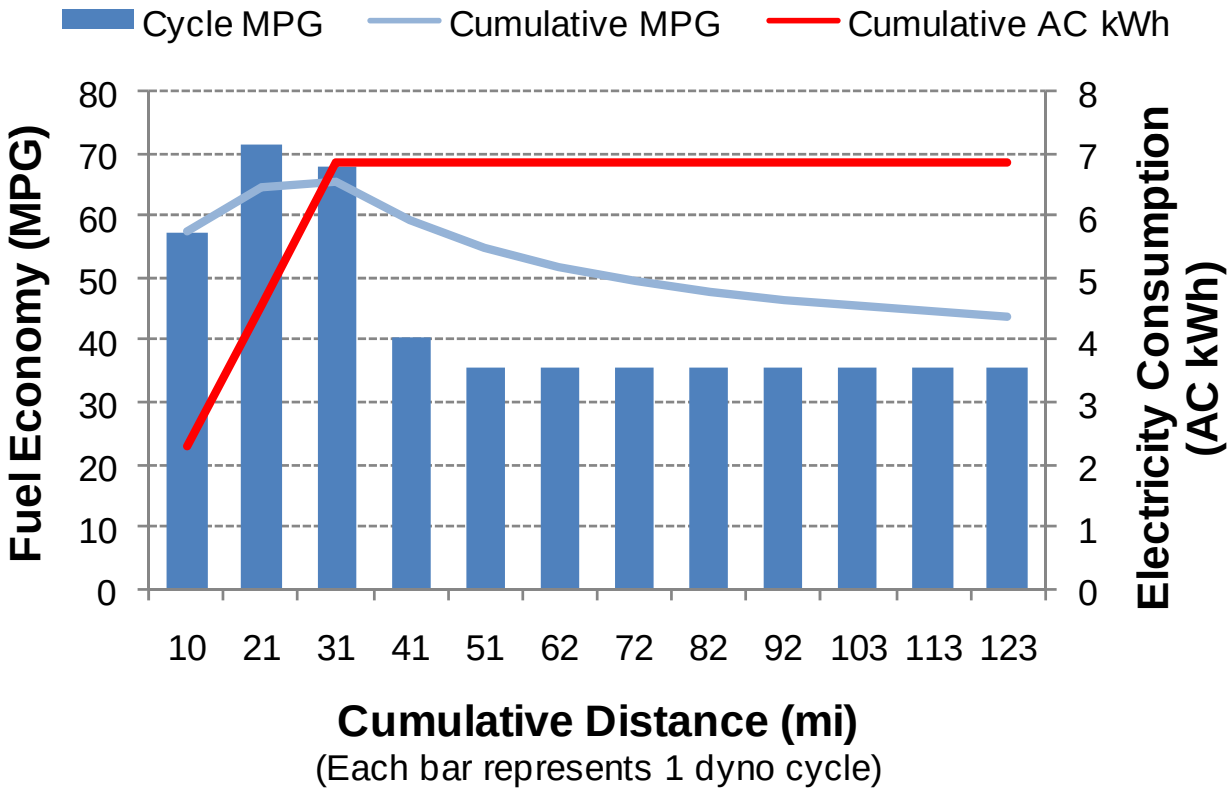
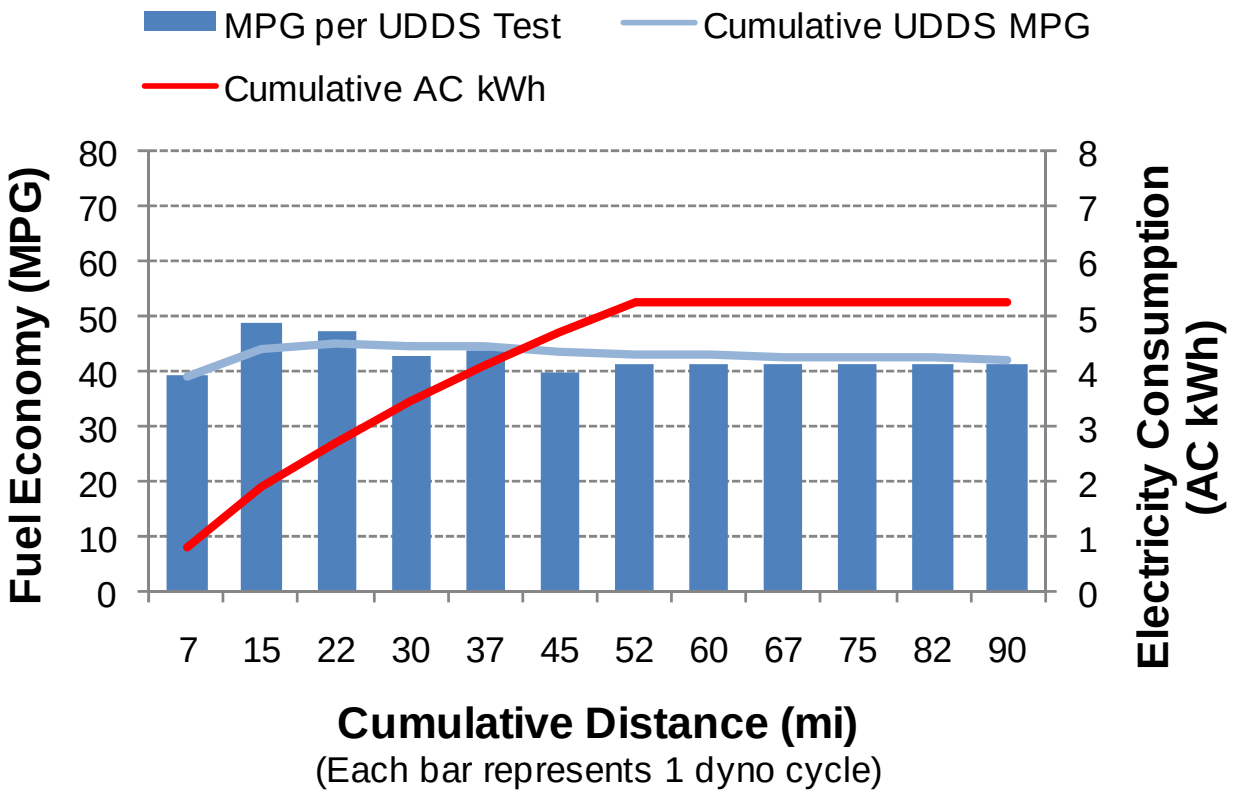


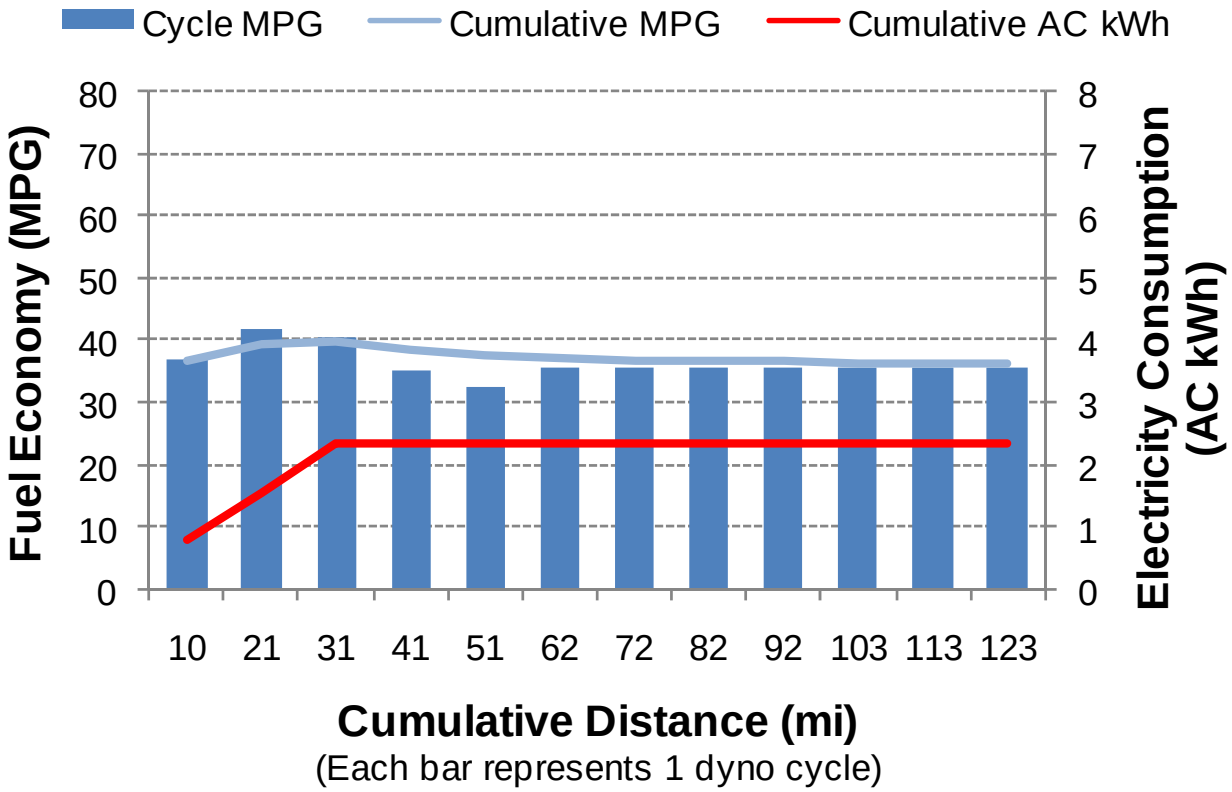
Electrovaya Escape – UDDS Fuel Use

12 kWh Li-ion Supplemental Pack



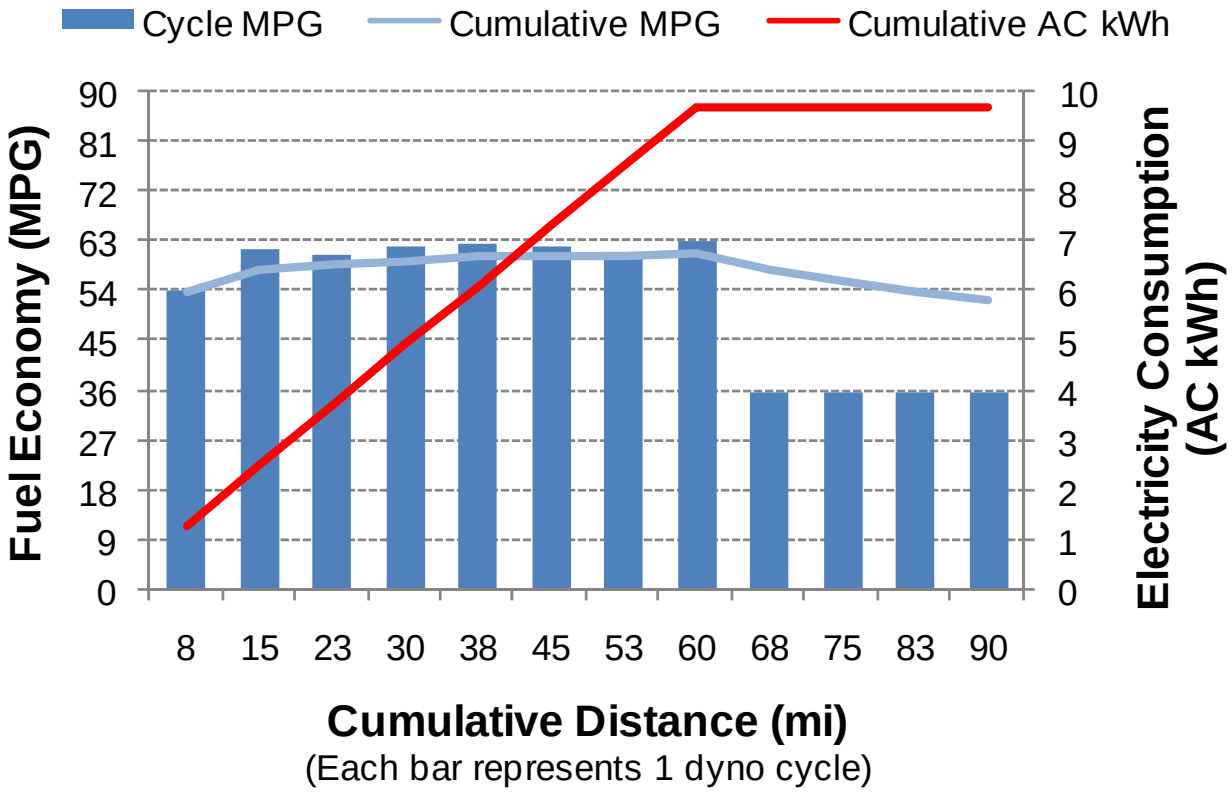
Electrovaya Escape – HWFEDS Fuel Use

12 kWh Li-ion Supplemental Pack



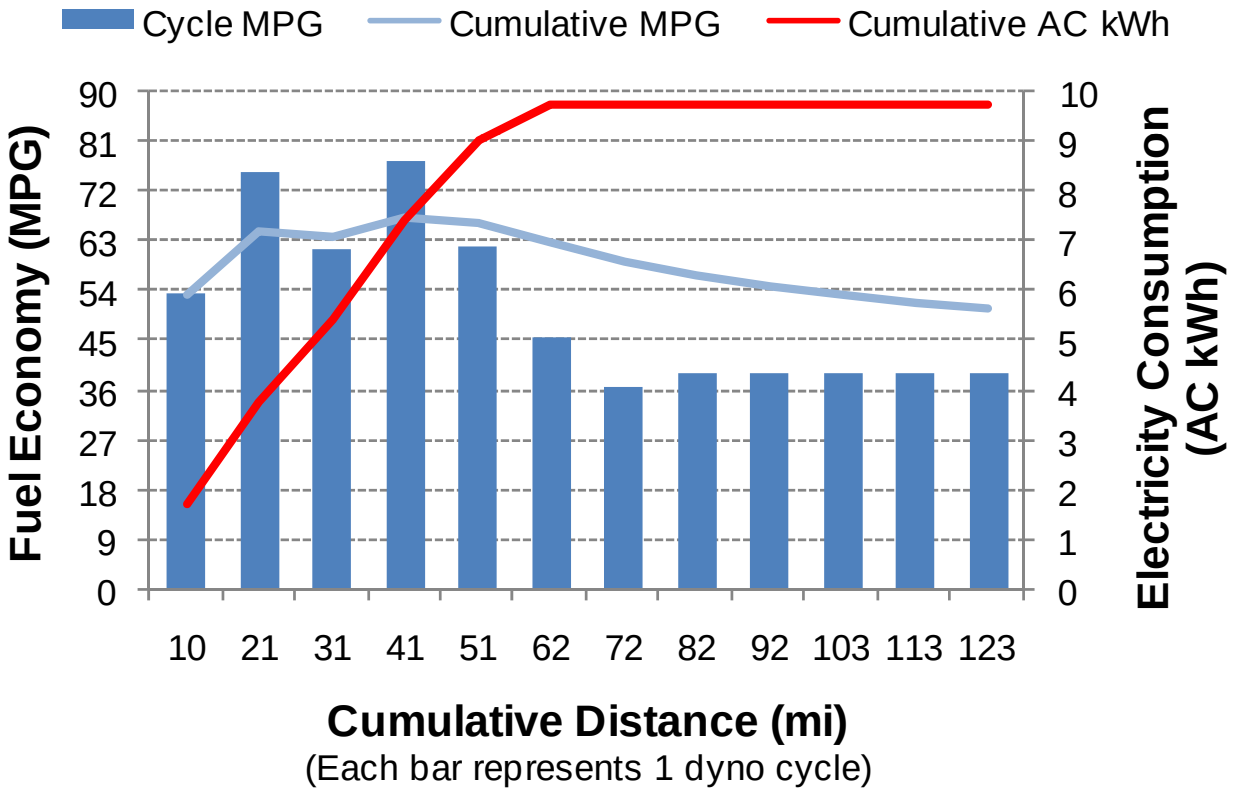
Hybrids Plus Escape – UDDS Fuel Use

12 kWh Li-ion Replacement Pack



Hybrids Plus Escape – HWFEDS Fuel Use

12 kWh Li-ion Replacement Pack



Renault Kangoo Dyno Test Results

- First OEM series PHEV – has 9.6 kWh (usable) Saft NiCad pack and 650cc gasoline engine

Test Cycle	AC kWh per Mile	Miles per Gallon
Battery Only – UDDS	0.268	--
Battery Only - HWFEDS	0.155	--
Battery Only @ Constant 45 mpg	0.271	--
Battery and Gas Cold UDDS	0.144	42.3
Battery and Gas Hot UDDS	0.110	39.4
Battery and Gas Hot HWFEDS	0.042	40.9

PHEV On-road Accelerated Testing

On-road vehicle testing with dedicated drivers following pre-determined routes on public roads

Cycle (mi)	Urban (10 mi)	Highway (10 mi)	Charge (hr)	Reps (N)	Total (mi)	Reps (%)	Miles (%)
10	1	0	4	60	600	37%	11%
20	1	1	8	30	600	19%	11%
40	4	0	12	15	600	9%	11%
40	2	2	12	15	600	9%	11%
40	0	4	12	15	600	9%	11%
60	2	4	12	10	600	6%	11%
80	2	6	12	8	640	5%	12%
100	2	8	12	6	600	4%	11%
200	2	18	12	3	600	2%	11%
Total	2,340	3,100	1,344	162	5,440		
Average	43%	57%	8.3	18			

Hymotion Prius Gen 1

Cycle	Urban	Highway	Charge	Reps	Total	Electricity	Gasoline	
(mi)	(10 mi)	(10 mi)	(hr)	(N)	(mi)	AC kWh	Gals	MPG
10	1	0	4	60	600	136.33	4.81	127.2
20	1	1	8	30	600	122.02	5.37	115.9
40	4	0	12	15	600	84.10	6.05	101.1
40	2	2	12	15	600	87.22	5.78	106.9
40	0	4	12	15	600	79.82	8.54	73.1
60	2	4	12	10	600	55.33	8.98	68.9
80	2	6	12	8	640	43.99	11.36	58.3
100	2	8	12	6	600	35.98	8.43	73.2
200	2	18	12	3	600	15.0	11.02	54.8
Total	2340	3100	1404	167	5,440	Weighted Average		79.5

EnergyCS Prius Valence

Cycle	Urban	Highway	Charge	Reps	Total	Electricity	Gasoline	
(mi)	(10 mi)	(10 mi)	(hr)	(N)	(mi)	kWh	Gals	MPG
10	1	0	4	60	600	115.58	4.78	128.1
20	1	1	8	30	600	86.21	7.95	77.9
40	4	0	12	15	600	25.00	14.29	42.7
40	2	2	12	5	600	31.52	11.05	56.1
40	0	4	12	5	600	32.44	11.36	55.5
60	2	4	12	10	600	65.00	5.90	103.7
80	2	6	12	8	640	39.04	10.09	65.8
100	2	8	12	6	600	22.67	8.81	70.8
200	2	18	12	3	600	12.98	10.46	57.8
Total	2340	2500	984	147	4840	Weighted Average		66.1

Hymotion Escape

Cycle	Urban	Highway	Charge	Reps	Total	Electricity	Gasoline	
(mi)	(10 mi)	(10 mi)	(hr)	(N)	(mi)	AC kWh	Gals	MPG
10	1	0	4	60	600	198.93	11.52	53.1
20	1	1	8	30	600	163.29	13.51	45.7
40	4	0	12	15	600	57.51	14.91	41.1
40	2	2	12	15	600	76.29	15.99	38.7
40	0	4	12	15	600	114.14	11.92	51.5
60	2	4	12	10	600	97.18	13.70	45.3
80	2	6	12	8	640	77.69	16.05	41.3
100	2	8	12	6	600	58.64	15.69	39.8
200	2	18	12	3	600	26.09	17.72	33.5
Total	2340	3100	1344	162	5440	Weighted Average		42.5

Electrovaya Escape

Cycle	Urban	Highway	Charge	Reps	Total	Electricity	Gasoline	
(mi)	(10 mi)	(10 mi)	(hr)	(N)	(mi)	AC kWh	Gals	MPG
10	1	0	4	60	600	135.24	9.55	65.1
20	1	1	8	30	600	101.13	17.54	34.7
40	4	0	12	15	600	71.3	16.42	37.3
40	2	2	12	15	600	69.8	14.34	43.1
40	0	4	12	15	600	55.84	20.73	29.8
60	2	4	12	10	600	44.79	16.64	37.3
80	2	6	12	8	640	42.72	16.30	40.8
100	2	8	12	6	600	20.85	21.17	29.2
200	2	18	12	3	600	13.31	19.01	30.9
Total	2340	3100	1344	162	5440	Weighted Average		36.7

Renault Kangoo

Cycle	Urban	Highway	Charge	Reps	Total	Electricity		Gasoline	
(mi)	(10 mi)	(10 mi)	(hr)	(N)	(mi)	AC kWh	Mi/kWh	Gals	MPG
10	1	0	4	60	600	359.60	1.7	0	
20	1	1	8	30	600	131.96	4.6	0	
40	4	0	12	5	200	35.18	5.6	0	
40	2	2	12	5	200	33.22	6.0	0	
40	0	4	12	5	200	28.60	7.0	0	
60	2	4	12	10	600	57.96	10.4	13.3	45.1
80	2	6	12	8	640	44.62	14.4	16.6	38.6
100	2	8	12	6	600	Deleted			
200	2	18	12	3	600	Deleted			
Total	1560	1480	876	123	3,040				

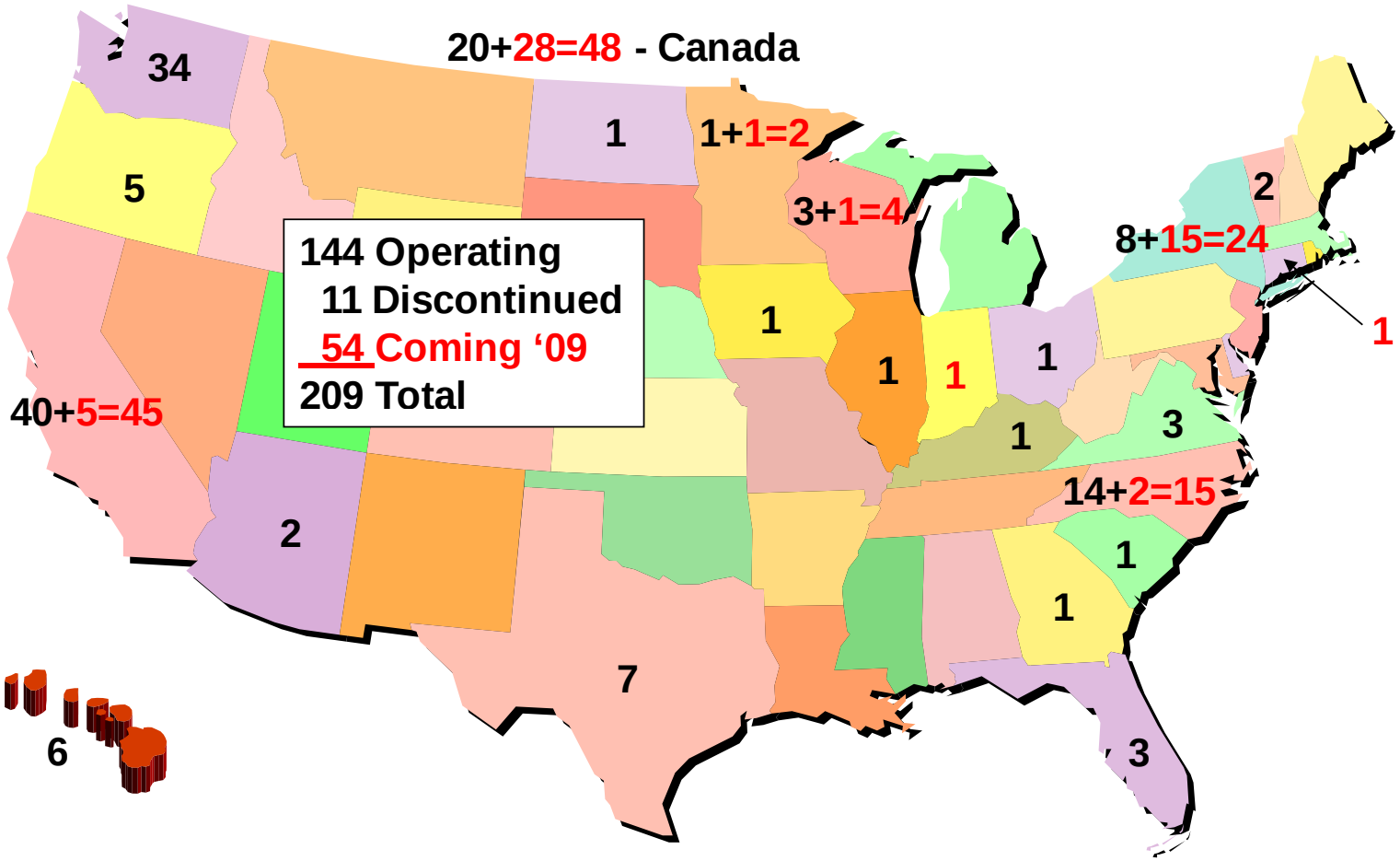
* Last two cycles were omitted due to problems with the vehicle's inverter and internal combustion engine

PHEV Fleet Demonstrations

Use on-board data loggers to do the following:

- Measure PHEV energy consumption during undirected operation across a wide range of usage conditions
- Understand how varying vehicle driving and charging behavior impacts energy efficiency
- Document charging profiles and electrical energy demand in order to assess the potential impact of PHEVs on the electrical power infrastructure

PHEVs and Demonstration Locations



As of March, 2009

PHEV Demonstration Partners include:

- A123Systems
- EnergyCS
- New York State Energy Research and Development Agency
- National Rural Electric Cooperative Association
- University of California Davis
- Fairfax County, Virginia
- Google.org
- Austin Energy
- Central Vermont Public Service Corporation
- Duke Energy
- Advanced Energy
- Progress Energy
- San Diego Gas and Electric
- Basin Electric
- Buckeye Power
- Wisconsin Public Power Inc.
- Madison Gas and Electric
- SCANA Corporation
- City of Seattle
- Port of Seattle
- Seattle City Lights
- Hawaii Center for Advanced Transportation Technologies.

PHEV Fleet Statistics – 2008

Vehicle Model	Number of Vehicles	Trips Logged	Distance Logged (mi)
Hymotion Prius (Gen 1 and Gen 2 packs)	102	32,814	296,601
EnergyCS Prius (Valence)	5	1,966	16,470
EnergyCS Prius (Altairnano)	2	915	7,312
Manzanita Prius (Hawker)	2	1,436	16,122
Hymotion Escape	2	675	11,065
Hybrids Plus Escape (Hybrids Plus)	7	2,737	20,475
Total	120	40,543	368,045

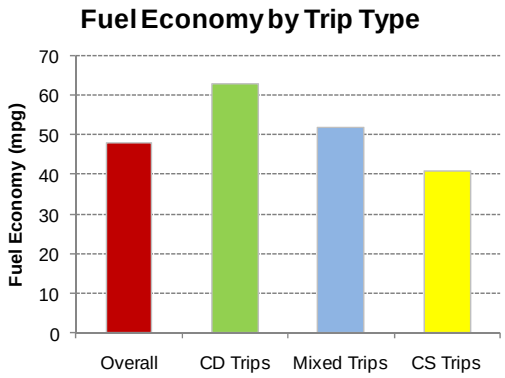
Hymotion Prius Gen 1 – 2008

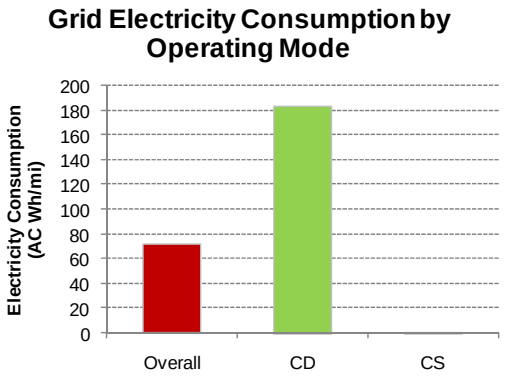
Energy Consumption and CD Range

	Gasoline Fuel Economy (mi/gal)	Electrical Energy Consumption (AC Wh/mi)
Overall	48	72
CD Trips	63	183*
Mixed Trips	52	
CS Trips	41	0

* Includes miles from CD trips and CD portion of mixed trips

Average Charge Depleting Range (mi)	31.6

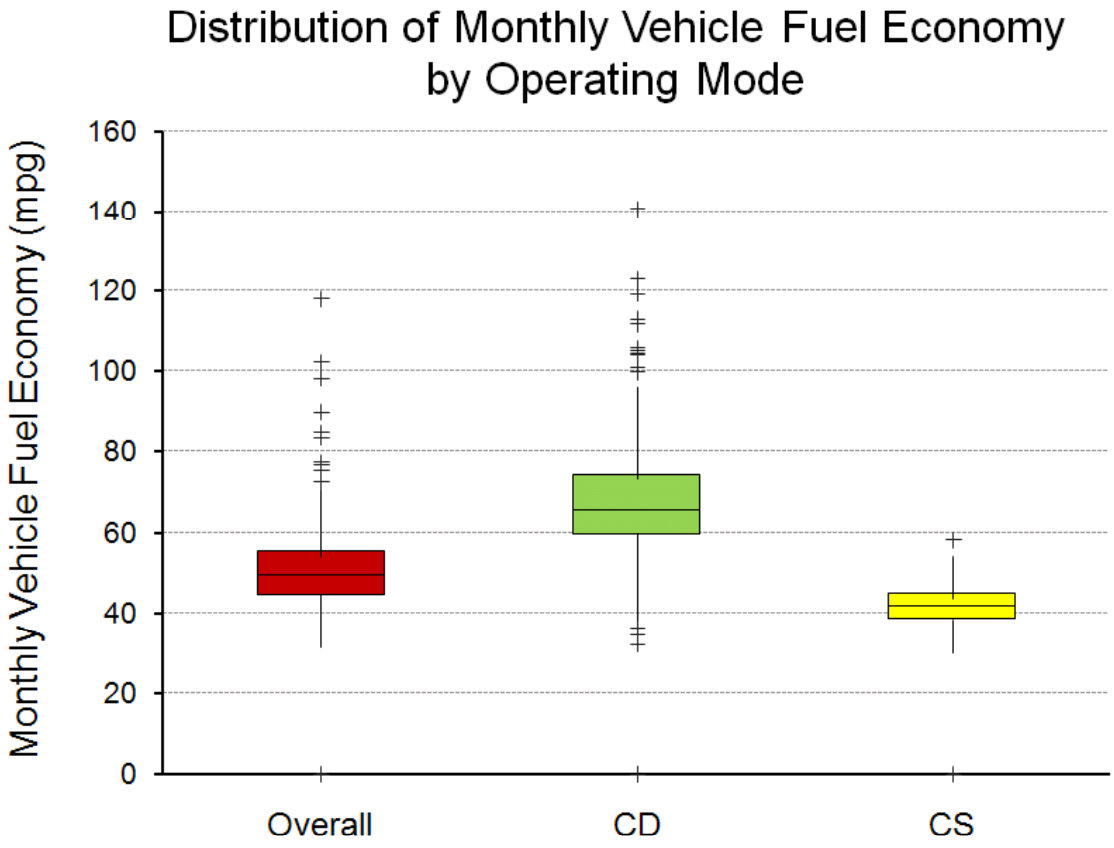




Definition of Trip Types

- CD Trip = trip that begins and ends in charge depleting mode
- Mixed Trip = trip that begins in charge depleting mode and ends in charge sustaining mode
- CD Trip = trip that begins and ends in charge sustaining mode

Hymotion Prius Gen 1 – 2008



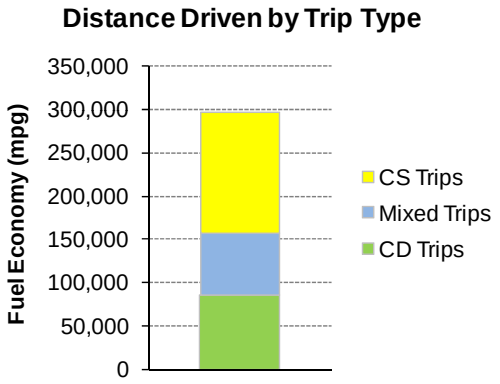
Monthly fuel economy shown for all vehicle months in 2008 when a vehicle drove > 300 mi

Hymotion Prius Gen 1 – 2008

Distance Driven Relative to Charging

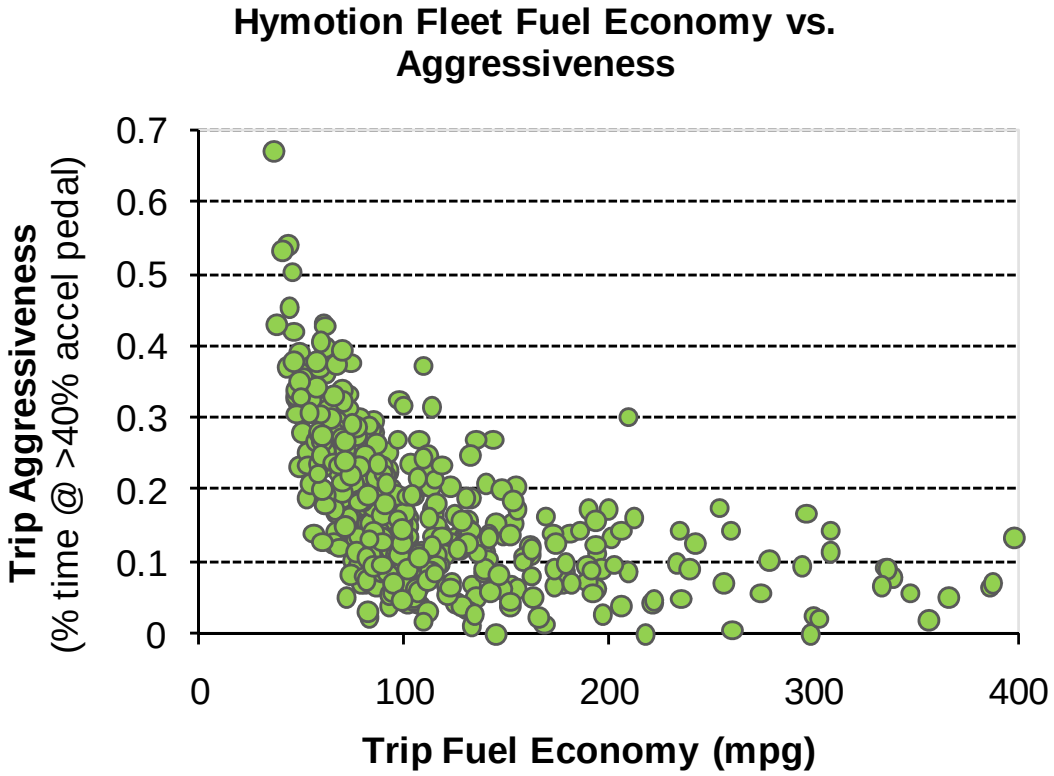
Trip Type	Trips	Distance (mi)	Percent of Total Distance
CD	17,913	85,225	29%
Mixed	2,894	72,737	24%
CS	12,007	138,642	47%

Average number of charging events per vehicle per month when driven	17.8
Average number of charging events per vehicle per day when driven	1.1
Average distance between charging events	39.0
Average number of trips between charging events	4.3



Hymotion Prius Gen 1 – 2008

Driving Aggressiveness



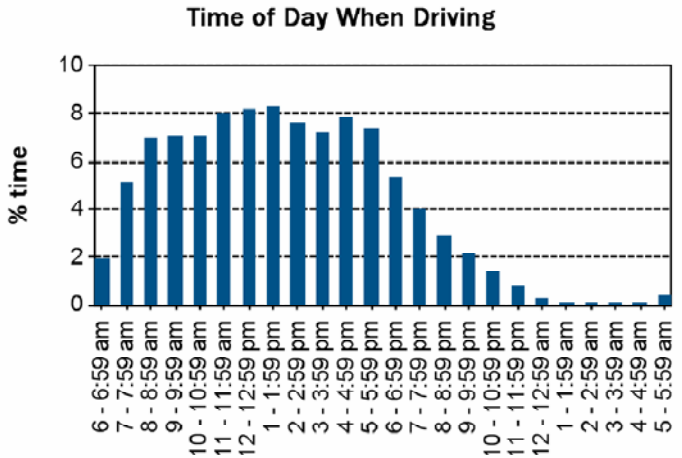
Data from 700 CD trips driven in ideal conditions:

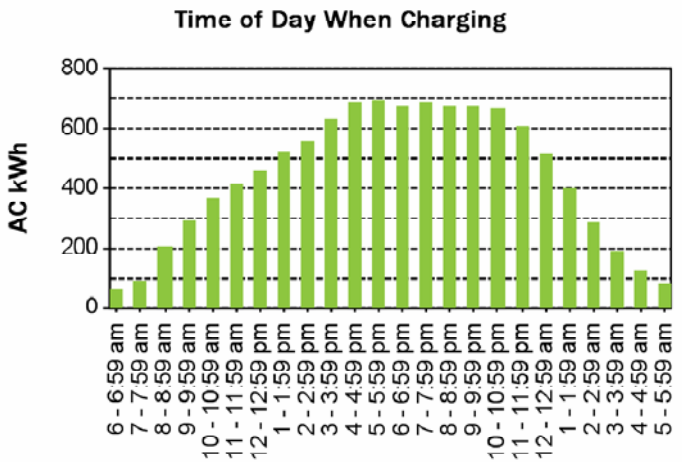
- Warm ambient and vehicle operating temperatures
- No climate control usage

Hymotion Prius Gen 1 – 2008

Charging Behavior

Duration of charging event – average time drawing power from the grid per charging event (hr)	2.8
Duration of charging event – average time plugged in per charging event (hr)	17.4
Average energy consumed per charging event (AC kWh)	2.5
Average energy consumed per vehicle per month (AC kWh)	46.4
Total number of charging events	3,974
Total charging energy consumption (AC kWh)	10,128





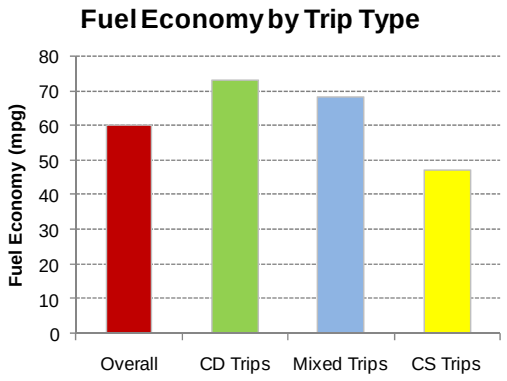
EnergyCS Prius Valence – 2008

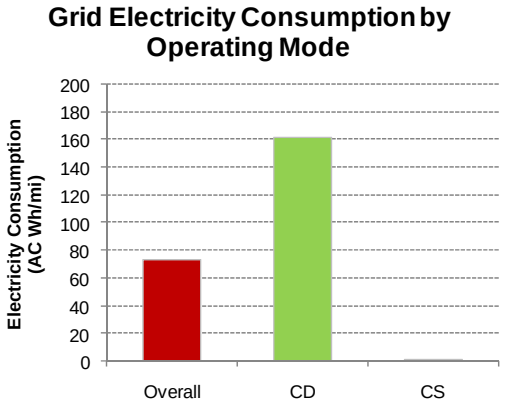
Energy Consumption and CD Range

	Gasoline Fuel Economy (mi/gal)	Electrical Energy Consumption (AC Wh/mi)
Overall	60	73
CD Trips	73	161*
Mixed Trips	68	
CS Trips	47	0

* Includes miles from CD trips and CD portion of mixed trips

Average Charge Depleting Range (mi)	31.5



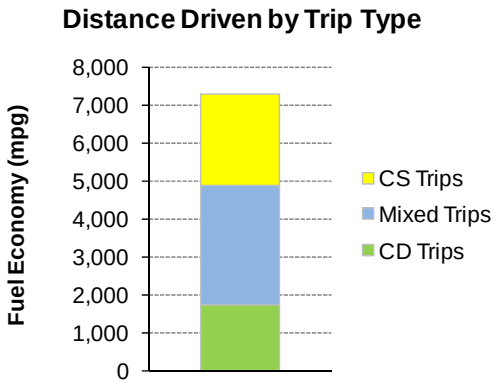


EnergyCS Prius Valence – 2008

Distance Driven Relative to Charging

Trip Type	Trips	Distance (mi)	Percent of Total Distance
CD	475	1,724	24%
Mixed	101	3,157	43%
CS	339	2,431	33%

Average number of charging events per vehicle per month when driven	17.2
Average number of charging events per vehicle per day when driven	1.2
Average distance between charging events	33.7
Average number of trips between charging events	4.2



Manzanita Micro Prius Hawker VRLA

Energy Consumption

- Plug-in pack parameters not available so sensing operating mode is not possible

	Fuel Economy (mpg)	Electrical Energy Consumption (AC Wh/mi)
Overall	46	33

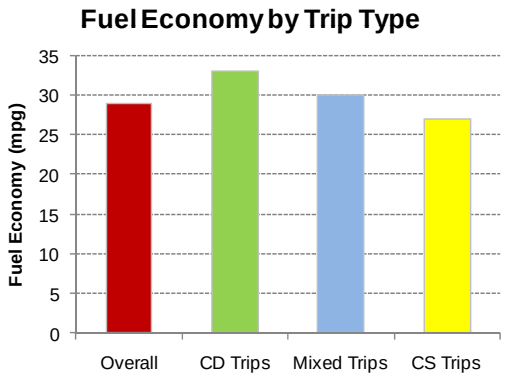
Hymotion Escape – 2008

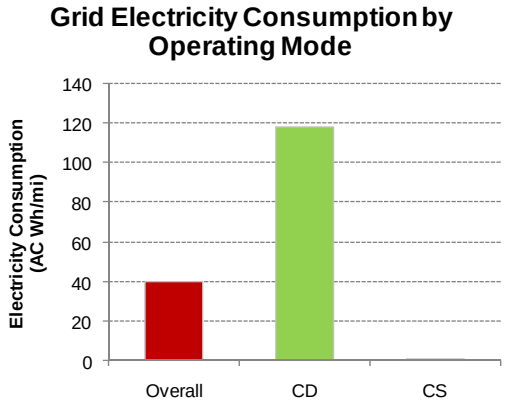
Energy Consumption and CD Range

	Gasoline Fuel Economy (mi/gal)	Electrical Energy Consumption (AC Wh/mi)
Overall	29	40
CD Trips	33	118*
Mixed Trips	30	
CS Trips	27	0

* Includes miles from CD trips and CD portion of mixed trips

Average Charge Depleting Range (mi)	51.7



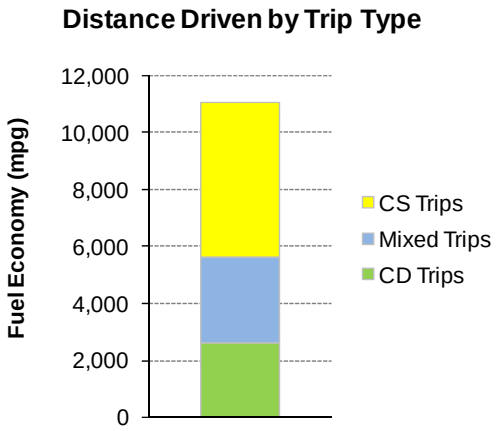


Hymotion Escape – 2008

Distance Driven Relative to Charging

Trip Type	Trips	Distance (mi)	Percent of Total Distance
CD	375	2,605	24%
Mixed	90	3,037	27%
CS	210	5,422	49%

Average number of charging events per vehicle per month when driven	6.6
Average number of charging events per vehicle per day when driven	0.7
Average distance between charging events	101.5
Average number of trips between charging events	6.2



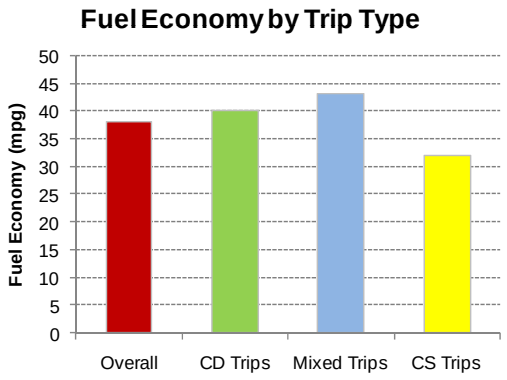
Hybrids Plus Escape – 2008

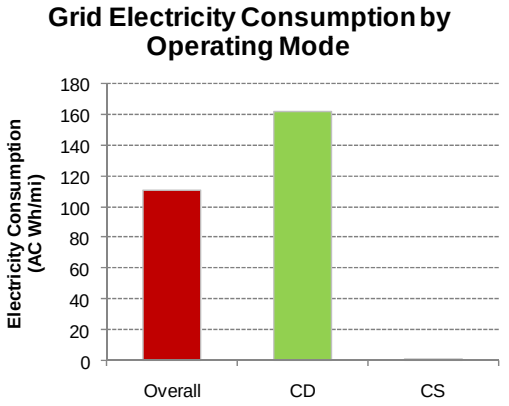
Energy Consumption and CD Range

	Gasoline Fuel Economy (mi/gal)	Electrical Energy Consumption (AC Wh/mi)
Overall	38	111
CD Trips	40	162*
Mixed Trips	43	
CS Trips	32	0

* Includes miles from CD trips and CD portion of mixed trips

Average Charge Depleting Range (mi)	63.8



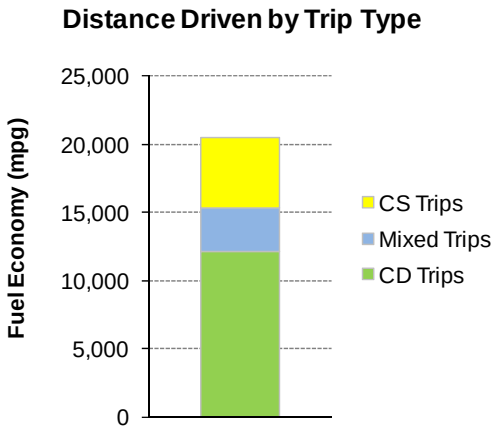


Hybrids Plus Escape – 2008

Distance Driven Relative to Charging

Trip Type	Trips	Distance (mi)	Percent of Total Distance
CD	2,104	12,130	59%
Mixed	57	3,164	15%
CS	576	5,180	25%

Average number of charging events per vehicle per month when driven	30.7
Average number of charging events per vehicle per day when driven	2.0
Average distance between charging events	29.3
Average number of trips between charging events	3.9



Conclusion

- Aftermarket conversion PHEVs tested in controlled conditions show potential for significant petroleum displacement
- Some vehicles operating in field have achieved high monthly fuel economy (80 to 120 mpg) sustained over significant distances (> 300 mi)
- Most PHEVs in fleet fall short of this potential, however
- Reasons
  - Inadequate charging relative to distance driven
  - Conversion vehicles sensitive to driving behavior and other conditions

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Additional Information

http://avt.inl.gov
or
http://www1.eere.energy.gov/vehiclesandfuels/avta*l*