

## AVTA Background and Goal

- The Advanced Vehicle Testing Activity (AVTA) is conducted for DOE by the Idaho National Laboratory (INL) and Electric Transportation Engineering Corporation (ETEC), with Argonne National Laboratory providing testing support
- AVTA Goal

- Provide vehicle and fueling infrastructure benchmark data to technology modelers, research and development programs, and target and goal setters
- Assist fleet managers (often the early adaptors of alternative fuel vehicles) and the public in making informed vehicle purchase, deployment and operating decisions


## AVTA Testing History

- Plug-in hybrid electric vehicles (PHEV)
- 9 models, $\sim 75$ vehicles
- Hybrid electric vehicles (HEV)
- 14 models, 4 million test miles

- Hydrogen ICE (internal combustion engine) vehicles
- 7 models, 400,000 test miles
- Full-size electric vehicles
- 40 EV models, 5+ million test miles
- Neighborhood electric vehicles

- 16 models, 200,000 test miles
- Urban electric vehicles
- 3 models, 1 million test miles


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## AVTA Testing Objectives

- Benchmark and reduce operational uncertainties of emerging technologies
- Perform independent vehicle testing in track, laboratory and on-road/fleet environments
- Document battery life, charging patterns and demand profiles, vehicle operations, and fuel use
- Document fueling infrastructure requirements and costs in real-world environments (both electricity and gasoline)
- Document life-cycle costs



## PHEV Definition

- An electric grid recharged hybrid electric vehicle that is powered by combinations of gasoline and electricity
- Contain an internal combustion engine, electric motor, and battery pack that allow more all-electric or electricassist operations than a conventional HEV, someday with an all-electric range greater than 10 miles
- Currently recharged by plugging into standard 110 V, 15 amp (or greater) wall outlets



## Advanced Batteries are Improving, But

- Consumer acceptance of HEVs due to the durability of NiMH batteries
- Gradual displacement of NiMH batteries is expected as lithium ion promises increased performancellonger life
- Cost of Li ion batteries for consumer electronics is now below that of NiCd and NiMH batteries (<\$500/kWh)
- Li ion viewed as most viable energy storage option due to potential for higher energy and power densities
- Current Li ion batteries are 8X the DOE PHEV goal (\$2000/kWh today vs. \$250/kWh goal in 2015)
- Further Li ion improvements are needed before a large penetration of PHEVs can occur and a transition to EV's can take place
- Projections of 10-15 year life are based on limited data, with questions on abuse tolerance and low-temperature performance


## 9 PHEVs Models in Testing/Demonstrations



- Most equipped with lithium traction batteries
- Hymotion Prius
- Hymotion Escape
- EnergyCS Prius
- Electrovaya Escape
- Hybrids Plus Escape
- Hybrids Plus Prius
- Manzanita Prius (lead acid)
- Ford Escape
- Renault Kangoo (NiCad)


## Hymotion Prius - UDDS Fuel Use

- 5 kWh A123 lithium \& Prius packs - AC kWh



## Hymotion Prius - HWFET Fuel Use

- 5 kWh A123 lithium \& Prius packs - AC kWh

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## PHEV Accelerated Testing

- Accelerated testing in Phoenix over 5,440 miles
- GPS units track distance, average and maximum speeds

| Cycle <br> $(\mathrm{mi})$ | Urban <br> $(10 \mathrm{mi})$ | Highway <br> $(10 \mathrm{mi})$ | Charge <br> $(\mathrm{hr})$ | Reps <br> (N) | Total <br> $(\mathrm{mi})$ | Reps <br> $(\%)$ | Miles <br> $(\%)$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 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 - Accelerated Testing

| Cycle | Urban | Highway | Charge | Reps | Total | Electricity | Gasoline |  |
| ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: |
| $(\mathbf{m i})$ | $(10 \mathrm{mi})$ | $(10 \mathrm{mi})$ | $\mathbf{( h r )}$ | $\mathbf{( N )}$ | $\mathbf{( m i )}$ | $\mathbf{k W h}$ | 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 | 2540 | 3100 | 1404 | 167 | 5,440 | Weighted Average | 86.4 |  |

Each total distance slightly greater than 600
and 640 miles. HEV version $=44 \mathrm{mpg}$

## EnergyCS Prius - Accelerated Testing

| Cycle | Urban | Highway | Charge | Reps | Total | Electricity | Gasoline |  |
| ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: |
| $\mathbf{( m i )}$ | $\mathbf{( 1 0 ~ m i )}$ | $(10 \mathrm{mi})$ | $\mathbf{( h r )}$ | $\mathbf{( N )}$ | $\mathbf{( m i )}$ | $\mathbf{k W h}$ | 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 | $600^{*}$ | Testing |  |  |
| 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 |  |  |

*Software updated and cells replaced. Rerun. Each total distance slightly greater than 600 miles. HEV version $=\mathbf{4 4} \mathbf{~ m p g}$

## Hymotion Escape - Accelerated Testing

| Cycle | Urban | Highway | Charge | Reps | Total | Electricity | Gasoline |  |
| ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: |
| $(\mathbf{m i})$ | $(10 \mathrm{mi})$ | $(10 \mathrm{mi})$ | $\mathbf{( h r )}$ | $\mathbf{( N )}$ | $\mathbf{( m i )}$ | AC kWh | Gals | MPG |
| 10 | 1 | 0 | 4 | 60 | 600 | Testing |  |  |
| 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 |  |  |

Each total distance slightly greater than $\mathbf{6 0 0}$ miles. HEV version $=\mathbf{2 7} \mathbf{~ m p g}$

## Electrovaya Escape - Accelerated Testing

| Cycle | Urban | Highway | Charge | Reps | Total | Electricity | Gasoline |  |
| ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: |
| $(\mathrm{mi})$ | $(10 \mathrm{mi})$ | $(10 \mathrm{mi})$ | $\mathbf{( h r})$ | $\mathbf{( N )}$ | $(\mathrm{mi})$ | AC kWh | Gals | MPG |
| 10 | 1 | 0 | 4 | 60 | 600 |  |  |  |
| 20 | 1 | 1 | 8 | 30 | 600 |  |  |  |
| 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 |  |  |  |
| Total | 2340 | 3100 | 1344 | 162 | 5440 | Weighted Average |  |  |

Each total distance slightly greater than 600 miles. HEV version $=\mathbf{2 7} \mathbf{~ m p g}$

## Renault Kangoo - Accelerated Testing

| Cycle | Urban | Highway | Charge | Reps | Total | Electricity |  | Gasoline |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| (mi) | $(10 \mathrm{mi})$ | $(10 \mathrm{mi})$ | (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 |  |  |  |  |
|  |  |  | * Testing dista | nded w ce sligh | en gaso ly greate | ne engine a than 600 m $\qquad$ | d inverter fa les. | led. Ea <br> ney | total <br> 15 |

## Hymotion Prius - Fuel Costs



## PHEV Vs. HEV and ICE Fuel Costs per Mile


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## PHEV Fleet Testing Partners

- With Hymotion, collecting onboard data from 50 PHEVs
- Onboard, cellular V2Green data loggers collect vehicle fuel use, performance, and charging and driving profiles
- NYSERDA - original PHEV demos @ \$100k per model
- City of Seattle, King County, Port of Seattle, Puget Sound Clean Air Agency and Tacoma Power, 15 PHEVs
- Washington State, Port of Chelan lead, 14 PHEVs
- UC Davis, with 70 public drivers, 13 PHEVs
- National Rural Electric Coop Association, 7+ PHEVs
- Maui and Oahu, HECO, MECO, State, University, County, and Air Force, 6 PHEVs, Nov 2008



## Single Hymotion Prius Charging Profiles

- 3 months, 2212 miles, 35 charges





## Single Hymotion Prius Charging Profiles

- 3 months, 2212 miles, 35 charges






## 26 Hymotion Prius - January thru May 2008

- Below averages do NOT tell the whole PHEV energyuse potential - see following May-only slides

| Charge / Operating Mode | Number <br> of Trips | Distance Traveled <br> (Miles) | Miles per <br> Gallon |
| :--- | :---: | :---: | :---: |
| Charge Depleting (CD) | 3,073 | 14,820 | 59 |
| Mixed CD / CS | 404 | 11,121 | 49 |
| Charge Sustaining (CS) | 1,358 | 16,059 | 40 |
| All trips combined | 4,835 | 42,000 | 48 |



## 13 Hymotion Prius in May 2008 - MPG

- Below averages do NOT tell the whole PHEV energy use potential - see following slides

| Charge / Operating Mode | Number <br> of Trips | Total <br> Distance <br> (Miles) | Average Trip <br> Distance <br> (miles) | MPG | DC kWh <br> per Mile |
| :--- | :---: | :---: | :---: | :---: | :---: |
| Charge Depleting (CD) | 575 | 3,040 | 5.3 | 72.0 | 0.138 |
| Mixed CD / CS | 67 | 1,840 | 27.5 | 52.1 | 0.050 |
| Charge Sustaining (CS) | 133 | 1,411 | 10.6 | 40.2 |  |
| Electric vehicle only (EV) | 137 | 127 | 0.9 |  | 0.236 |
| Total | 912 | 6,417 | 7.0 |  |  |
| CD, CS, CDICS results | 775 | 6,291 | 8.1 | 55.9 |  |



## 13 Hymotion Prius and MPG



## 13 Hymotion Prius and MPG



## 13 Hymotion Prius and Aggressive Driving



## AVTA PHEV Demos with Data Loggers



## PHEV Charging Infrastructure

- National Electric Code requires
- Dedicated branch circuit
- GFCI (ground fault circuit interrupt)
- "EV" extension cord
- Unique connector "plug"
- NEC being updated



## PHEV Market Status - Converters

- Hymotion: 100+ Prius (\$9995) and 5 Escapes
- Prius only battery production ramp-up now, replaced all 67 Version I batteries. Recall Escapes
- Prius crash-tested and obtaining CARB certification
- Conversions and warranty work in Boston, Los Angeles, Minneapolis, San Francisco, and Seattle
- Hybrids Plus: 35 Prius and Escapes, (\$21,600 to \$36,150). Some operational issues
- EnergyCS: $\sim 30$ Prius ( $\sim 40,000$ ). Some past operational issues, only doing custom conversions in future
- Manzanita lead acid Prius conversions $(\$ 12,000)$ by several groups. Some operational issues
- Electrovaya: 2 Escapes. Some operational issues
- Various single conversion "companies"


## PHEV Market Status - OEMs

- Daimler Benz - 6 Sprinters late 2008, 1 to AVTA
- Ford: 20 Escapes in 2008/2009. 2 currently
- General Motors: Volt late 2010. Maybe Vue earlier
- Chrysler: potential 1 of 3 PHEV I EV models in 2010
- Renault Kangoo: ~1,200 NiCad range-extender PHEVs in Europe (was 1 in U.S.), but shipped AVTA's to Brussels for repair and sale
- Toyota: ~20 Prius NiMH PHEVs in U.S., France and Japan, gaining operational knowledge. To fleets in 2009
- Volvo and other OEMs have made various PHEV announcements
- DOE/s PHEV TADA solicitation: Ford, Chrysler/GE, and GM in negotiations. AVTA to test products


## AVTA Webpage Use and Gasoline Costs



# Additional Information 

http:/lavt.inl.gov<br>or<br>http://wwww1.eere.energy.gov/vehiclesandfuels/avtal

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