U.S. Department of Energy
Energy Efficiency and Renewable Energy
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FreedomCAR & Vehicle Technologies Program

# Plug-In Hybrid Electric Vehicles




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**Redmond, WA**

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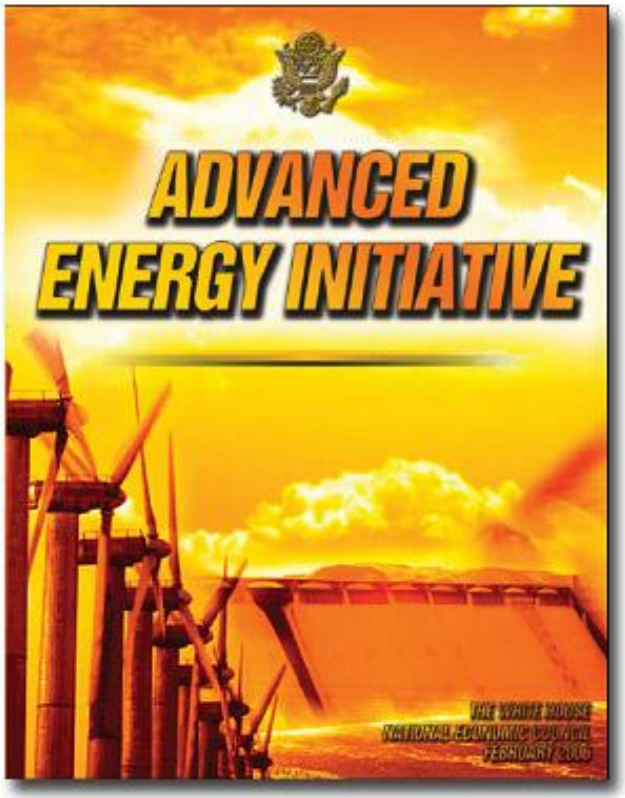
# Outline

- PHEV Background and goals
- Focus on the enabling research:
  - Energy storage
  - Power electronics and electric motors
  - Vehicle simulation and testing
- Summary and conclusions

# PHEV Mandate/Expectations




"… plug-in hybrid-electric vehicle to have a 40-mile range operating solely on battery charge."

"… electric vehicle for the majority of driving that takes place within 40 miles of home."

"… fuel efficiency … could exceed 80 or more miles per gallon … in urban areas."

"… charged at night, when electric utilities have spare generating capacity"

"Simply adding additional batteries is not practical … 'lithium-ion' batteries … can be adapted for vehicle use."

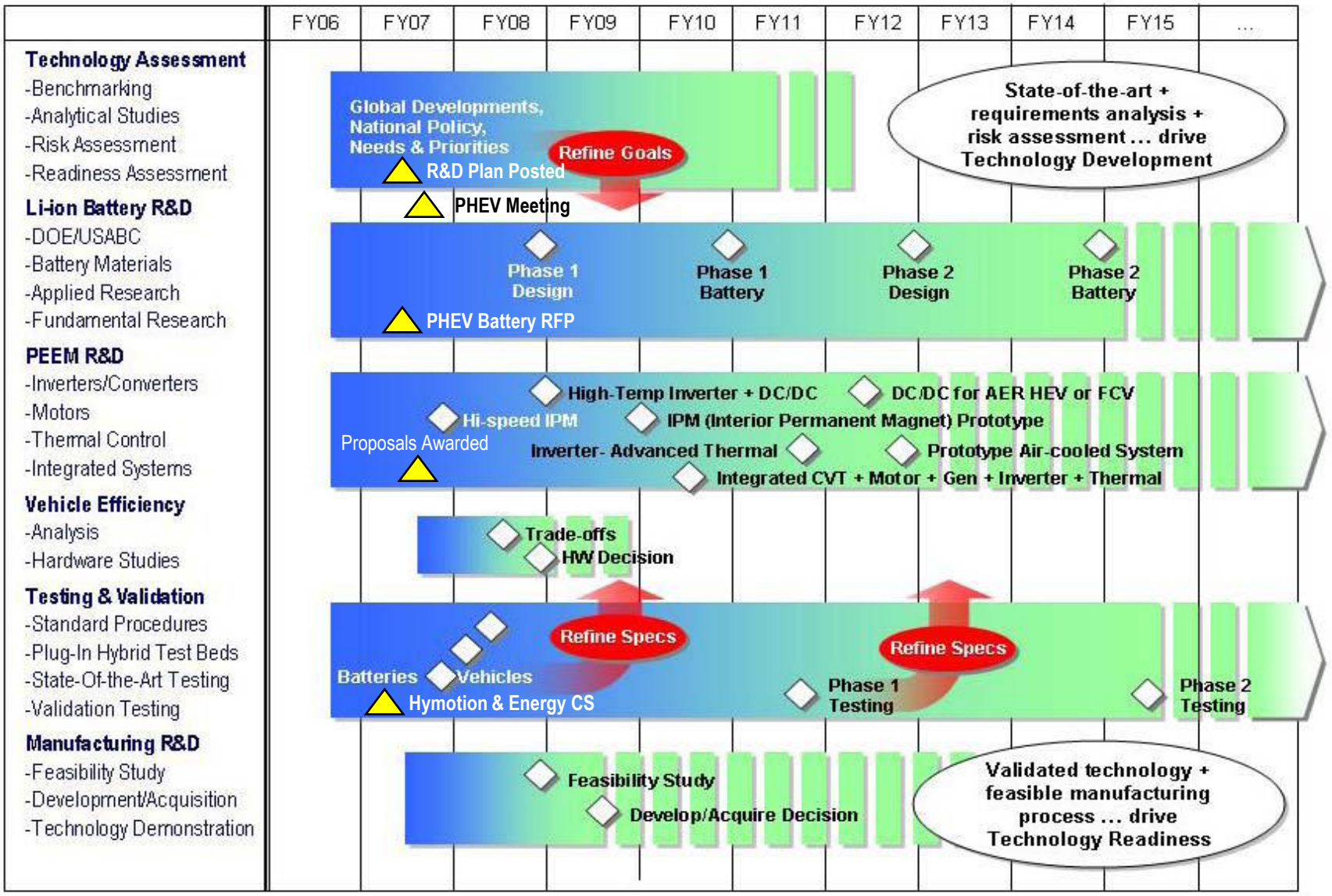
# Overall PHEV Performance Goals

- DOE preliminary goals for PHEVs
  - Near-term focus on adapted technology; equivalent electric range of 10-20 miles
  - Mid-term (3-5 years) development for PHEV-specific designs; equivalent electric range of 20+ miles or charge-depleting
  - Long-term (5-10 years) development projects will target components/capabilities to meet the 40+ miles equivalent electric range target.
- Key metric should be minimum fuel consumption; not all electric range.

# DOE Role

- Set policy.
- Support pre-competitive R&D.
- Act as an impartial broker of PHEV information (testing, analysis, codes, standards, test procedures, etc.).
- Analyze PHEVs technically, economically, environmentally.
  - Assess the benefits of PHEVs versus alternatives.
  - Quantify the value proposition for automotive manufacturers, electric utilities, consumers and the nation.
- Promote PHEVs if warranted.
  - Technology demonstration.
  - Remove barriers.
  - Provide incentives.
  - Educate consumers.

# PHEV R&D Schedule



# PHEV Technologies: Energy Storage

- DOE and USABC issued a $28 million solicitation for PHEV battery development on April 5th
  - Proposals are due May 31st
  - RFP includes initial PHEV battery requirements
  - Projects are expected to range from cell development activities to module design and testing, based on the maturity of the proposed technology

- Purpose: to identify developers having electro-chemical energy storage technologies which have the potential to meet the DOE/USABC near and long-term criteria for PHEV energy storage

# PHEV Technologies: Energy Storage

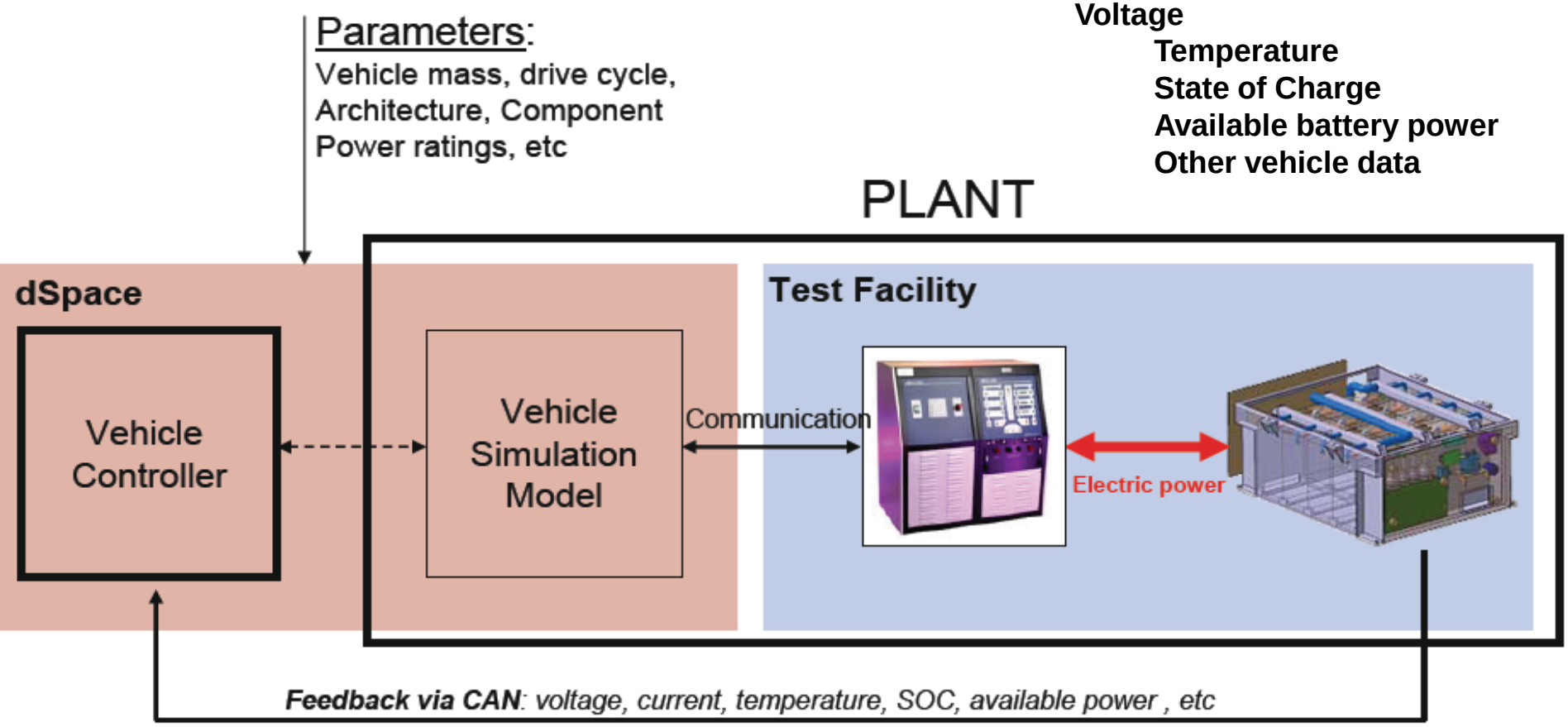
- PHEV battery performance requirements are developed in collaboration with the USABC

| PHEV Battery Characteristics at End of Life | Units | High Power/ Energy Ratio Battery | High Energy/ Power Ratio Battery |
|---|---|---|---|
| Reference Equivalent Electric Range | miles | 10 | 40 |
| Peak Pulse Discharge Power - 2 Sec / 10 Sec | kW | 50 / 45 | 46 / 38 |
| Peak Regen Pulse Power (10 sec) | kW | 30 | 25 |
| Available Energy for CD (Charge Depleting) Mode, 10kW Rate | kWh | 3.4 | 11.6 |
| Available Energy for CS (Charge Sustaining) Mode | kWh | 0.5 | 0.3 |
| CD Life / Discharge Throughput | Cycles/MWh | 5,000 / 17 | 5,000 / 58 |
| CS HEV Cycle Life, 50 Wh Profile | Cycles | 300,000 | 300,000 |
| Calendar Life, 35°C | year | 15 | 15 |
| Maximum System Weight | kg | 60 | 120 |
| Maximum System Volume | Liter | 40 | 80 |
| Maximum System Production Price @ 100k units/yr | $ | $1,700 | $3,400 |

# PHEV Technologies: Energy Storage HIL Testing

- Battery HIL Allows Hardware Characterization in a Virtual Vehicle Environment

**Battery Parameters measured**
**Voltage**
**Temperature**
**State of Charge**
**Available battery power**
**Other vehicle data**

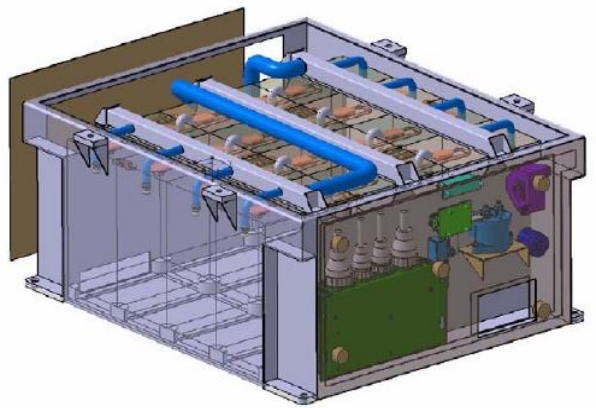


# PHEV Technologies: Energy Storage HIL Testing

- Main Li-ion VL41M Specifications
  - 41Ah @ C/3
  - 72 cells (194.4 – 288 V)
  - 61 kW for 30 sec. at 50% SOC, 30 degrees C
  - 10 kWh total
  - Liquid-cooled

| | |
|---|---|
| **Virtual Vehicle Class/Mass** | **Midsize, 1633 kg/3600 Lb** |
| **Virtual Vehicle Configuration** | **Pre-transmission parallel** |
| **Real Battery used for HIL** | **41 Ah SAFT VL41M** |
| **Virtual Motor model** | **75 kW peak power** |
| **Engine Model** | **2.3 L Ford Duratec** |

- The vehicle was run on consecutive Urban cycles to calculate its All-Electric Range (AER)



# PHEV Technologies: Energy Storage HIL Testing

- Main results from AER study for this particular vehicle

| | Units | HIL |
|---|---|---|
| AER from 0.9 to 0.3 SOC | mi | 24.79 |
| Battery Ah Depleted | Ah | 25 |
| Battery Electrical Energy | kWh | 6.29 |
| Energy Consumption | Wh/mi | 253.7 |

- Next steps:
  - Study the combined performance of high energy density batteries with ultra capacitors decoupled through fast-response power electronics
  - Actively control the HIL battery test stand cooling loop using a heat pump and temperature controller

# PHEV Technologies: Recent Power Electronics Awards

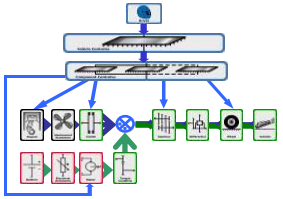
- Award winners announced April 23, 2007
  - High temperature (105°C), 3-phase inverters
    - Delphi Automotive Systems
    - Virginia Polytechnic Institute and State University
  - High-speed electric motor
    - General Electric Global Research
  - Combined traction motor and inverter
    - General Motors Corporation
  - Bi-directional DC/DC converter
    - U.S. Hybrid Corporation
- DOE will contribute $19.2 million to these projects, with a total project budget of $33.7 million including industry cost share
- Awards are currently being negotiated and work is anticipated to begin in Q3 of 2007

# PHEV Technologies: Vehicle Simulation and Testing

- Modeling and Simulation Studies
  - PHEV Control Strategies
  - PHEV Energy Storage and Power Electronics & Electric Machines Requirements
  - PHEV Cost Projections
- Integration and Validation
  - Li-Ion Battery Packs for PHEVs
- Laboratory and Field Evaluations
  - PHEV test procedures validated and second draft is out for review
  - Current PHEV conversion testing includes the EnergyCS and Hymotion Prius

## Main Tools

PSAT

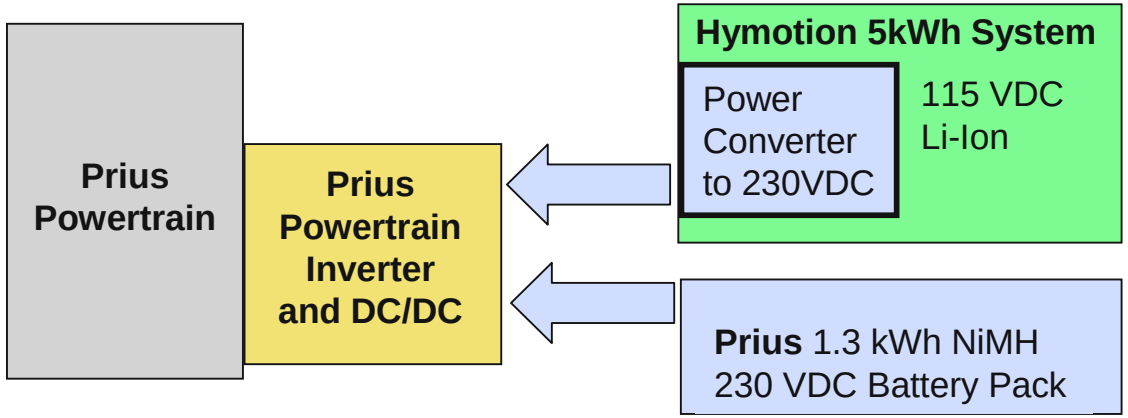


MATT

APRF

# PHEV Technologies: PHEV Testing - Hymotion

- 5kWh Li-Ion battery and power converter in parallel with production Prius battery pack
- Charge depletion operation is enabled through CAN bus communication to Prius Hybrid ECU
  - use of the production “EV mode” button
  - And SOC signal manipulation
- Tests conducted on chassis dynamometer with fully instrumented Level II Prius
  - UDDS (cold and hot start)
  - HWY
  - US06
- On-board Charger
  - 110VAC
  - 15 Amps

# Summary of Preliminary PHEV Test Results

- Measured *gasoline* economy ranges from 62 – 200 mpg over the UDDS (electrical energy consumption also varied greatly from 6 – 128 DC Wh/mi)
- Additional calibration is needed to reach acceptable tailpipe emissions levels
- Engine operating efficiency is reduced in charge depletion operation by not maintaining high engine load and by charging the battery during low vehicle loads


# PHEV Technologies: Vehicle Simulation and Testing


- DOE is conducting vehicle evaluations for NYSERDA for these conversion vehicles:
  - Prius: EnergyCS, Hymotion, Hybrids Plus
  - Escape: Hymotion and Electrovaya
  - Civic: Hymotion
- DOE is working with EnergyCS to collect onboard fleet data for their vehicles operating in California, Canada & Arizona
- Fleet data will be collected by DOE on at least two different PHEV models, 20 total PHEVs, introduced into New York State fleets
- DOE is collecting fleet data on AVTA operated vehicles, currently EnergyCS & Hymotion PHEV Priuses, & Renault Kangoo PHEV
- PHEV data from South Coast Air Quality District conversion vehicles will also be collected

# PHEV Grid Impacts are of interest to many DOE offices

- Office of Electricity topics of interest for PHEVs include:
  - PHEV charging efficiency and load profiles
  - Possible vehicle to grid (V2G) interactions
  - The impacts PHEVs have on electricity generation, transmission, and distribution
  - Potential for utilities to purchase, lease, or subsidize PHEV batteries – possibly at end of life
  - National and local environmental impacts
- Solar energy supporters are interested in PHEVs as a means of storing energy captured by photovoltaics
- PHEVs are also seen as a load to capture wind energy during otherwise low-load conditions

# Vehicle Technologies Budget Information

| | FY 2007 ($ Millions) | | |
|---|---|---|---|
| FY 2008 Structure | **HEV** | **PHEV** | **Total** |
| Energy Storage R&D | 23.5 | 7.6 + 10 | 41.1 |
| Adv. Power Electronics & Electric Machines | 11.7 | 2.0 | 13.7 |
| Vehicle & Systems Simulation & Testing (Light Duty Portion) | 6.0 | 4.4 + 4 | 14.4 |
| Total | 41.2 | 14.0 + 14 | 69.2 |

# Summary

- DOE is actively involved in critical aspects of PHEV research, development, testing, and analysis.
- Maximum fuel economy is the key metric rather than all electric range.
- There is an interest in future PHEV demonstration and deployment activities.
- Draft DOE PHEV R&D Plan published.
- June 13 PHEV Meeting in Washington, DC