Beyond Hybrids – HTUF Process and Pathway for Plug-in Hybrids

Advanced Transportation Technologies
Clean Transportation Solutions

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Fuels Program Manager

PHEV2007 – Winnipeg, Manitoba
November 1, 2007
WestStart-CALSTART is dedicated to the growth of an advanced transportation technologies industry and markets that will:

- Create high-quality jobs;
- Clean the air;
- Reduce dependence on foreign oil; and
- Prevent global warming
WestStart: A Strategic Broker for Advanced Transportation

2007

145+ Worldwide Participant Network

4 Offices in US

Four focus areas:

- Efficient vehicles
- New fuels
- Mobility/transit
- Industry support

National and International Programs

CALSTART is WestStart’s California Operating Division
High Energy Costs Here to Stay

• US Energy Information Agency projections show sharply higher crude prices
• OPEC working to keep benchmark price of oil high, crude costs up
• US EIA forecasts heavy demand will keep imported oil prices on rise until 2014; new supplies after then may ease supply crunch, cause decline in crude costs
Fighting Global Warming

IPCC Climate Change Mitigation Report (May 4):

- More fuel efficient vehicles
- Hybrid vehicles
- Cleaner diesel vehicles
- Biofuels
- Modal shifts to rail and public transport
- Non-motorized vehicles
- Land use and transit planning
The New “Strike Zone” in Transportation

Balances all three competing needs

Air Quality

Integrated Solutions Needed

Energy Security

Climate Change

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Why Hybrids Are Gaining Traction with Fleets

- **Rising fuel costs**: Optimizing urban truck drivelines is becoming critical for fuel efficiency, emissions.
- **Major engine changes** – and increased cost/complexity – coming in 2007-2010 to comply with EPA emissions requirements.
- **Trend toward integrated engine/drivelines** in trucks.
- **Increasing electrical power needs** in heavy vehicles and equipment.
- **Idle Management** is a growing issue.
- **Productivity/performance** complaints from cleaner engines.
Timeline to Commercialization: Hybrid Tech Just Starting in Trucks

Trucks are not Priuses!
Tech introduction 10 years behind cars
BUT: big fuel impact per truck

Development
Test prototypes and systems

Pre-Production
Field pilot assessments (10-50 vehicles)

Production Intent
Assembly line builds up to 100+

Early Production
Initial commercial volumes – still high incremental cost

TOOLS:
R&D Support
Purchase Incentives
Pre-Production Deployment Support (HTUF)
Efficient Vehicles: Hybrid Truck Users Forum (HTUF)

- Goal: Speed the development and introduction of commercially viable medium- and heavy-duty hybrid trucks in the U.S.
- User driven process involving more than 80 fleets with > 1 million trucks
- Joint WestStart-U.S. Army program
• Two and a half day forum at Qwest Field, Seattle
• More than 430 attendees, one quarter fleet users – *a new record*
• 19 med. and heavy-duty hybrids in ride and drive – *a new industry record*
• All major trucks makers and suppliers involved in process
HTUF Working Groups

- 6 Core Working Groups of fleet truck users now operating, plus:
  - 1 WG partnership with NTEA (light truck)
  - 1 new Forum forming (construction equip.)
  - 1 Task Force: Plug-in HE Trucks (PHET)

- Main Working Groups:
  - Utility/Specialty trucks – George Survant, Florida Power & Light, lead
  - Parcel Delivery trucks – Sid Gooch, Fed Ex Express; Bob Dengler, FedEx Ground; Robert Hall, UPS – user leads
  - Refuse Truck Working Group – Matt Stewart, City of Chicago Sanitation, lead
  - Bus Working Group – launched with support of Federal Transit Administration
  - Class 8 Working Group – underway
  - Incentives Working Group – underway
• Working Group Activities (continued)
  – Refuse Vehicle
    • Making final decisions on RFP for hybrids
    • Targeting 10+ pre-production trucks
  – Hydraulic Hybrid Parcel Delivery
    • Reviewing proposals for hydraulic parcel demo
  – Shuttle Bus
    • Spec info being gathered from fleets
  – Plug-in Hybrid Truck (PHET)
    • Successful workshop at CHDV conference in Feb.
    • Next steps
      – Develop a PHET business case
      – Define best target vehicles and applications
      – Select fleets and regions that can be “first-movers”
      – Additional values of PHETs
Hybrid Electric Utility Truck – Field Testing

- Class 6-7
- 24,000-33,000 GVW
- Engine DT466, 225 hp
- Automated Manual Transmission
- Battery-electric, 44 kW electric motor
- Engine-off PTO operations
- 25 kW / 5 kW export power

International-Eaton
North American Deployment & Assessment

24 Truck Deployment Locations

14 Fleets

- AEP
- Alabama Power
- Baltimore Gas & Electric
- Duke Energy
- Entergy
- Exelon
- Florida Power and Light
- Georgia Power
- Hydro Quebec
- Missouri Dept. of Trans.
- PG&E
- Pepco/PHI
- Southern Calif Edison
- TXU

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Utility Hybrid Truck: The 3-Year Process

Form HTUF Utility Working Group FALL 2002

Collect Fleet Data, Duty and Use Cycles

Identify, Select Key Performance Parameters (KPPs) SUMMER 2003

HTUF Develops Buy-Down Funds

Final KPPs and Additional Functionality FALL 2003

Supplier Team Selected SUMMER/FALL 2004

RFP Sent to Manufacturers SPRING 2004

Fleet Commitment Letters WINTER 2003 Letter of Notice Sent to Manufacturers

First Truck Deliveries 2006

Validator Truck Testing SUMMER 2005

Final Fleet Orders WINTER 2005

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Field Deployment Status

- All 24 trucks delivered to fleets
- 23 in field; 1 truck in fleet controlled testing
- Staggered deployment but 12 trucks have been in use over 1 year
- Standard comparison units in same locations
- 25 kW APG – installed in field; some units with 5 kW APG

First Truck Deliveries Winter/Spring 2006

Training & In-service Winter/Spring 2006

Start Field Deployments Summer 2006

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Field Testing – Key Findings

Key Findings

- Reliability greatly improving
- Availability very high (99%)
- Users finding truck meets needs
- Fuel consumption improvements measured up to 54%
- Reduced noise
- Duty cycle is very important
- Best place in urban setting with high PTO use

- Reliability/Availability
- User acceptance
- Performance data
- Maintenance data

- 24 HEV
- 20 Baseline Trucks
- 12+ Months
- 14 Fleets
• Overall savings as high as 54%

• Total Gallons over Total Operation hours, capturing engine ON and OFF operation

• Dependant on duty cycle!

Decrease 2.1 to 1.4 gal/h totals fuel saving from 14.7 - 9.8 gallons, or 34%
Lab Testing savings from 12.5 – 7.5 gallons, or 40%
Plug-in Hybrid Electric Vehicles

- Lots of attention and interest in PHEVs among policy makers, environmentalists
- Benefits: increased fuel economy, GHG reductions, possible zero emission driving
- Cost and life cycle of energy storage (batteries) are prime limiter
- Most focus is on passenger cars – trucks offer additional challenges
- All current PHEVs are conversions from small firms – very few on road
- No OEM production dates set – though increasingly “hinted at”
Attraction of PHEVs

- Best of Both Worlds – IC engine + electric-drive
- Fuel Savings & Emission Reduction increase over hybrids
- Petroleum Displacement with electricity-Cheaper-Cleaner-Domestic
Toyota to Develop Plug-In Hybrids?

- LA Times says Toyota to develop plug-in hybrid which can travel longer distances without using its gas engine.
- Plug-ins considered feasible as production costs coming down, price of gas going up – making economic case for company.
- Also developing flex fuel vehicle using E-85 – hybrid FFV coming?
- Will double offerings of conventional hybrids from its current 14 models by 2010.
GM Announces Possible PHEVs

- GM says plans to build a plug-in hybrid Saturn SUV, to use 2-mode hybrid system (city/highway modes), features Li-Ion batteries
- No debut date announced – depends on business case
- Also showcases advanced “flexible” driveline car, Chevy “Volt”
- Volt could be standard hybrid, fuel cell hybrid, PHEV, BEV
- No production timing
Several Plug-in Hybrid Truck (PHET) Efforts Underway

- DaimlerChrysler to expand its fleet of Sprinters in hybrid, PHET and battery electric
- Believes big leap in battery technology necessary to make plug-ins viable
- Odyne fielding and testing several PHETs, including refuse truck in Fresno, CA
- PG&E and EPRI developing PHET Class 5 utility truck – possible completion in 2008
- Roughly 24 hybrid and plug-in school buses moving into test using IC/Enova system
Newest Plug-In Prototype: Dueco-Odyne Utility Truck

- 33,000 pound Material handler chassis/body
- 50kw electric motor provides mild driving assist – connects via PTO
- Main function is to operate truck at work site without main engine operating
- Features possible 8 hour operation; electric air conditioning
- 35 kwh lead-acid battery pack; recharge off grid or optionally off engine
Plug-in Hybrid Electric Truck (PHET) Task Force of HTUF

- Biggest User Interests:
  - Fuel Savings & Emission Reduction increase over hybrids
  - Petroleum Displacement with electricity-Cheaper-Cleaner-Domestic
  - Down the road: carbon reduction?
  - Fuel savings sufficient to justify business case?

- Other benefits we expected from PHETs
  - Extended life-time due to reduced idling
  - Increased maintenance periods and lower maintenance costs
  - Replace diesel generators on trucks
  - Benefit of extended quiet operations
  - Benefits of export power and V2G
  - Health and environmental benefits

- How do we include those into the business case?

- HTUF developing “road map” and possible next steps for PHET
### PHET Challenges: Similar, Yet Very Different

<table>
<thead>
<tr>
<th></th>
<th>HEV</th>
<th>PHET</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plug</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Battery</td>
<td>~ 1-2 kWh</td>
<td>&gt;&gt;&gt;&gt; 2-10X</td>
</tr>
<tr>
<td>Charging</td>
<td>Motor only</td>
<td>Motor &amp; Plug</td>
</tr>
<tr>
<td>Type of Battery</td>
<td>Power</td>
<td>Energy</td>
</tr>
<tr>
<td>SOC range</td>
<td>30/40 – 60/70%</td>
<td>20 – 80+%?</td>
</tr>
<tr>
<td>Thermal mngt</td>
<td>Yes</td>
<td>Yes*</td>
</tr>
<tr>
<td>Electrified components*</td>
<td>Valuable but not required</td>
<td>Yes</td>
</tr>
<tr>
<td>Electric drive</td>
<td>Launch</td>
<td>Full range</td>
</tr>
<tr>
<td>System weight</td>
<td>300-500 lbs</td>
<td>400-1000+ lbs</td>
</tr>
<tr>
<td>System Cost</td>
<td>$40-60k +</td>
<td>TBD (battery)</td>
</tr>
</tbody>
</table>

*Not simply a Hybrid Scale-up Strategy!

*Not yet commercially available in trucks

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# Plug-in Hybrid Truck (PHET) Fleet Survey Results

<table>
<thead>
<tr>
<th>Category</th>
<th>65% (2-3h)</th>
<th>21% (1-2 h)</th>
<th>14% (0.5-1 h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engine-off operations</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electric-only driving range</td>
<td>35% (40 mi)</td>
<td>28% (30 mi)</td>
<td>21% (20 mi)</td>
</tr>
<tr>
<td>Available time to plug-in</td>
<td>21% (8h)</td>
<td>14% (6 h)</td>
<td>15% (10+)</td>
</tr>
<tr>
<td>Time of day</td>
<td>71% (5pm - 6am)</td>
<td>29% (11pm - 6am)</td>
<td></td>
</tr>
<tr>
<td>Weight Penalty</td>
<td>50% (1000 lbs)</td>
<td>50% (500 lbs)</td>
<td></td>
</tr>
<tr>
<td>Fuel Displacement</td>
<td>43% (50% fuel)</td>
<td>22% (60% fuel)</td>
<td>14% (40% fuel)</td>
</tr>
<tr>
<td>On-board Power</td>
<td>79% (Y)</td>
<td>21% (N)</td>
<td></td>
</tr>
<tr>
<td>Amount of Power</td>
<td>37% (20 kW)</td>
<td>14% (10 kW)</td>
<td>7% (5 kW)</td>
</tr>
<tr>
<td>Type of Power</td>
<td>29% (single phase)</td>
<td>14% (3-phase AC)</td>
<td>14% (single &amp; 3-phase)</td>
</tr>
<tr>
<td>Tools</td>
<td>57 % (Electric &amp; Hydraulic)</td>
<td>43% (Hydraulic only)</td>
<td></td>
</tr>
</tbody>
</table>

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<table>
<thead>
<tr>
<th>Rank</th>
<th>Performance Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Fuel Displacement in %</td>
</tr>
<tr>
<td>2</td>
<td>Eliminate engine idling</td>
</tr>
<tr>
<td>3</td>
<td>Emission reductions better than HEV</td>
</tr>
<tr>
<td>4</td>
<td>No mobility compromise at end of workday</td>
</tr>
<tr>
<td>5</td>
<td>Required length of time operating from battery only</td>
</tr>
<tr>
<td>6</td>
<td>Weight penalty of battery and HEV system limit</td>
</tr>
<tr>
<td>7</td>
<td>On-board power generation</td>
</tr>
<tr>
<td>8</td>
<td>Payload capacity loss limit</td>
</tr>
<tr>
<td>9</td>
<td>Charging Infrastructure Modifications</td>
</tr>
<tr>
<td>10</td>
<td>Grid Recharge Time</td>
</tr>
<tr>
<td>11</td>
<td>Drivetrain/mounted equipment performance</td>
</tr>
</tbody>
</table>
### PHET Benefits

<table>
<thead>
<tr>
<th>Benefits</th>
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</thead>
<tbody>
<tr>
<td>Quiet work at night</td>
</tr>
<tr>
<td>Use of company power</td>
</tr>
<tr>
<td>Extended engine-off time</td>
</tr>
<tr>
<td>Increase run time on full electric</td>
</tr>
<tr>
<td>Improve fuel economy, lower maintenance</td>
</tr>
<tr>
<td>Increased electric driving range, reduced emissions</td>
</tr>
<tr>
<td>Less maintenance costs</td>
</tr>
<tr>
<td>Peak savings, electricity savings and fuel economy</td>
</tr>
<tr>
<td>Fuel cost savings and extras to offset added cost of PHET</td>
</tr>
</tbody>
</table>

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Additional Values of PHEV

• Introduction of new technology opens up new applications – transportation and…
• Stored electricity in batteries can be used for applications other than driving
• Advantages of electric power – fast response, clean, quiet, versatile
Auxiliary Power Generation

International 4300 Series Hybrid

- 120 VAC single-phase, battery
- 208 VAC 3-phase, engine
- Replaces towed diesel generator
- Use as back-up power, emergency power (e.g. Katrina restoration)

5 and 25 kW APG
Use of Power from Grid Connected Vehicles

- Power can flow both ways – charge batteries and discharge to the grid (V2G)
- Two-way flow and vehicle-grid interactions create many new opportunities and uses

Grid-connected vehicle can provide:

1. Emergency or back-up power supply
2. Power support, electrical or telecom substation
3. Profitable Grid Management - Ancillary Services
4. Storage / integration with renewables (e.g. wind power)
Chargers and Charging Rate

- Public Level 2 charger
  - 208 VAC, 32 Amps 6.6 kW
- Public Level 3AC charger (100A line)
  - 208 VAC, 80 Amps 16.6 kW
- Larger residential appliance
  - 240 VAC, 40 Amps 9.6 kW
- 120 VAC, 15 Amps 1.8 kW
- 120 VAC, 30 Amp 3.6 kW
Vehicle to Grid

Arrows indicate direction of power flow

(Kempton and Tomic, JPS, 2005)
Grid Management - Ancillary Services

- Grid Management - Maintain grid reliability
- Balance Supply and Demand
- Support transmission of electric power
- A/S requirements 5-10% of the system load
Ancillary Services

- **Regulation**: On-line generation synchronized to the grid to keep frequency and voltage steady. Energy is increased/decreased instantly (~2-3 min) via automatic generation control (AGC).

- **Spinning Reserves**: Additional generating capacity synchronized and ready to respond for ~10 min in case of failures.

- **Payments consist of**: Capacity price ($/MW-h) + Energy price ($/MWh)

- **Vehicle available when not in use, parked**
The Key Drivers for PHEV

Need to understand better where this cross over is

Energy Storage/System Cost

Fuel Savings (effic + lower fuel cost) + Additional Value

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HTUF PHET Roadmap
How do we get there faster?

Stage 1:
Added energy storage and grid connection

Add modular energy storage to existing trucks, assess with fleets (providing more engine off time at work site)
10-20+ trucks

Stage 2:
Optimize hybrid driveline for added energy storage

Flash upgrade deployed trucks with greater driveline functionality (existing deployed trucks and 50 new)

Stage 3:
Integrate electrified components for low-speed, short range electric drive and start-stop capability

Capability added to new trucks with all above features and lower driveline cost, assess with urban work fleets

Goal: Organic growth - PHET offered as variant to commercial hybrid drivelines, takes advantage of commercial path improvements

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