ELECTRIC DRIVE
STATUS AND CHALLENGES
July 24, 2012
### Key DOE Technical Targets

#### Traction Drive System

<table>
<thead>
<tr>
<th>Year</th>
<th>Cost ($/kW)</th>
<th>Specific Power (kW/kg)</th>
<th>Power Density (kW/l)</th>
<th>Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010*</td>
<td>19</td>
<td>1.08</td>
<td>2.60</td>
<td>&gt;90%</td>
</tr>
<tr>
<td>2012</td>
<td>17</td>
<td>1.12</td>
<td>2.86</td>
<td>&gt;91%</td>
</tr>
<tr>
<td>2015</td>
<td>12</td>
<td>1.17</td>
<td>3.53</td>
<td>&gt;93%</td>
</tr>
<tr>
<td>2020</td>
<td>8</td>
<td>1.44</td>
<td>4.00</td>
<td>&gt;94%</td>
</tr>
</tbody>
</table>

#### Power Electronics

<table>
<thead>
<tr>
<th></th>
<th>($/kW)</th>
<th>(kW/kg)</th>
<th>(kW/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010*</td>
<td>7.9</td>
<td>10.8</td>
<td>8.7</td>
</tr>
<tr>
<td>2012</td>
<td>7</td>
<td>11.2</td>
<td>10</td>
</tr>
<tr>
<td>2015</td>
<td>5</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>2020</td>
<td>3.3</td>
<td>14.1</td>
<td>13.4</td>
</tr>
</tbody>
</table>

#### Electric Motors

<table>
<thead>
<tr>
<th></th>
<th>($/kW)</th>
<th>(kW/kg)</th>
<th>(kW/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010*</td>
<td>11.1</td>
<td>1.2</td>
<td>3.7</td>
</tr>
<tr>
<td>2012</td>
<td>10</td>
<td>1.24</td>
<td>4</td>
</tr>
<tr>
<td>2015</td>
<td>7</td>
<td>1.3</td>
<td>5</td>
</tr>
<tr>
<td>2020</td>
<td>4.7</td>
<td>1.6</td>
<td>5.7</td>
</tr>
</tbody>
</table>

* 2010 traction drive cost target achieved with development of the GM integrated traction drive project.

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**Traction Drive Requirements:** 55 kW peak power for 18 sec; 30 kW continuous power; 15-year life.

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**Vehicle Technologies Program – Advanced Power Electronics and Electric Motors**

eere.energy.gov
Traction drive cost reduction and performance improvements are necessary to achieve the **EV Everywhere** Grand Challenge

**Chevy Volt**
- ~40 mile electric range
- HEV: 32 mpg /300 miles
- 120 kW electric drive
- electric drive cost:~$2,400

**Nissan Leaf**
- ~75 mile electric range
- 80 kW electric drive
- electric drive cost:~$1,600

**Tesla Model S**
- ~250 mile electric range
- 270 kW electric drive
- electric drive cost:~$5,400

<table>
<thead>
<tr>
<th>EV Everywhere Target Analysis</th>
<th>Current Status</th>
<th>PHEV 40</th>
<th>AEV 100</th>
<th>AEV 300</th>
</tr>
</thead>
<tbody>
<tr>
<td>System Cost</td>
<td>$/kW</td>
<td>20</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Motor Specific Power</td>
<td>kW/kg</td>
<td>1.2</td>
<td>1.9</td>
<td>1.3</td>
</tr>
<tr>
<td>PE Specific Power</td>
<td>kW/kg</td>
<td>10.5</td>
<td>16</td>
<td>12</td>
</tr>
<tr>
<td>System Peak Efficiency</td>
<td>%</td>
<td>90</td>
<td>97</td>
<td>91</td>
</tr>
</tbody>
</table>
On-board charging capability is essential to *EV Everywhere*

Current status and future targets are as follows:

<table>
<thead>
<tr>
<th>3.3 kW Charger</th>
<th>2010</th>
<th>2015</th>
<th>2022</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>$900 - $1,000</td>
<td>$600</td>
<td>$330</td>
</tr>
<tr>
<td>Size</td>
<td>6-9 liters</td>
<td>4.0 liters</td>
<td>3.5 liters</td>
</tr>
<tr>
<td>Weight</td>
<td>9 -12 kg</td>
<td>4.0 kg</td>
<td>3.5 kg</td>
</tr>
<tr>
<td>Efficiency</td>
<td>90 – 92 %</td>
<td>93%</td>
<td>94%</td>
</tr>
</tbody>
</table>

- Cost is the most significant challenge
- Weight and volume reductions are necessary
- Traction drive and vehicle-level integration
- Integrated functionality is key
- Long-term solutions for fast charging and wireless power transfer
## Key Traction Drive Requirements & Targets

- Establish electric drive vehicle performance requirements
- Traction drive performance modeling and simulation
- Hardware-In-the-Loop and benchmark testing

<table>
<thead>
<tr>
<th>Key Parameter</th>
<th>PHEV</th>
<th>AEV</th>
</tr>
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<tbody>
<tr>
<td>Traction Drive Usage</td>
<td>Multiple modes</td>
<td>Full range</td>
</tr>
<tr>
<td>Peak Output Power</td>
<td>55 to 150 kW</td>
<td></td>
</tr>
<tr>
<td>Continuous Output Power</td>
<td>20 to 85 kW</td>
<td>65 kW</td>
</tr>
<tr>
<td>Power Density</td>
<td>4 kW/l</td>
<td></td>
</tr>
<tr>
<td>Specific Power</td>
<td>1.4 kW/kg</td>
<td></td>
</tr>
<tr>
<td>Efficiency</td>
<td>94%</td>
<td></td>
</tr>
<tr>
<td>Cooling Temperature</td>
<td>75°C</td>
<td></td>
</tr>
<tr>
<td>Cost Target</td>
<td>$ 8/kW</td>
<td></td>
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</table>
Opportunities to Achieve Traction Drive Cost Target

- Inverter: cold plate, drive boards, thermal interface material, bus bar, current sensors, housing, control board, etc.
- Motor: bearings, housing, sensors, wire varnish and insulation, potting materials, shaft, etc.

- Reduce motor losses, eliminate use of rare earth PMs, improve thermal management
- High-temperature solutions using WBG, improve power electronics performance, integrate functionality, improve efficiency
- Reduce capacitance req., increase capacitor performance
- Reduce part count and material costs, increase efficiency
- Reduce part count, simplify manufacturing

2010 R&D Cost Target: $19/kW
2020 R&D Cost Target: $8/kW

* Inverter: cold plate, drive boards, thermal interface material, bus bar, current sensors, housing, control board, etc.
Motor: bearings, housing, sensors, wire varnish and insulation, potting materials, shaft, etc.
Power Electronics for Traction Drive Applications

- Cost needs to decrease
- Power Density and Specific Power need to increase

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<th>Year</th>
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2007 Camry
2008 Lexus
2010 Prius
2015 Target
2020 Target
# Electric Motors for Traction Drive Applications

Cost needs to decrease
Power Density and Specific Power need to increase

## Motor Targets

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- 2007 Camry
- 2008 Lexus
- 2010 Prius
- 2015 Target
- 2020 Target
Traction Drive Challenges & Issues

- **Cost is the biggest challenge**
  - What is the most cost effective solution?
  - Are integrated systems worth the tradeoffs?
- **Packaging improvements are needed**
  - At device and component levels
  - Higher temperature and manufacturability
- **Advanced materials and designs**
  - High temperature silicon vs. WBG devices
  - Low-cost, high-temperature bus capacitors
  - Motors with reduced or eliminated rare earth content
- **Reliability**
  - Simultaneous vibration & temperature
  - Service life requirements
- **Thermal management**
  - Reduce heat generation
  - Improve heat transfer
  - System and vehicle-level integration

*ORNL/University of Wisconsin-Madison*
Power Electronics Challenges & Issues

- **Cost is the biggest challenge**
  - Power module and passive components
  - Emphasis on modular, scalable designs
- **Volume and mass reductions are needed**
  - Driven by passive devices
  - Packaging issues exist at all levels
- **Packaging and Advanced materials required**
  - Higher temperature capability
  - Increase thermal conductivity
- **Reliability**
  - Wirebonds, die and substrate attach, solders, & connectors
  - Substrates and epoxies
- **Thermal Management**
  - Liquid cooling to air
  - Single sided or double sided
- **Efficiency**
  - Idle or quiescent loads

![Diagram of 55 kW Delphi Inverter with Viper Power Module](image)
Electric Motor Challenges & Issues

- **Costs are the biggest challenge**
  - Rare earth costs and uncertainty
  - Uncertainty of copper prices
- **Volume and mass reductions are needed**
  - Higher operating speeds
  - Low loss laminations
  - Higher slot fill
- **Thermal Management**
  - Temperature limitations of existing materials
  - Improve heat transfer
- **Packaging and Advanced materials required**
  - Higher temperature capability
  - Increase thermal conductivity
- **Reliability**
  - Stake-welds, solders, connectors, insulation
  - Epoxies
- **Efficiency**
  - System level component matching
Combining the battery charger, inverter, inverter controls, electric motor, and thermal management into one integrated traction drive will enable cost reduction.

Challenges exist with advanced materials and devices:
- WBG switches and diodes
- Non-rare earth magnets
- Small, high temperature passive devices
- Innovative packaging and advanced designs
- High reliability to meet service life and warranty
- High voltage insulation systems
Information Sources

• DOE VTP FY 2011 Advanced Power Electronics and Electric Motors Annual Progress Report

• USDrive Electrical and Electronics Technical Team Roadmap
  • http://www1.eere.energy.gov/vehiclesandfuels/pdfs/program/eett_roadmap_12-7-10.pdf

• DOE Vehicle Technologies Multi-year Program Plan 2011-2015; Section 2.2.1
Contact Information

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