Hybrid Solutions for MD Commercial Vehicles

ERC Symposium
University of Wisconsin, Madison
June 10, 2009
Eaton Worldwide

- Founded in 1911 by J.O. Eaton
- WHQ in Cleveland, Ohio USA
- Customers in > 125 countries
- > 75,000 employees worldwide
- Chairman & CEO – Alexander M. Cutler
- Power Management company
  - “We make what’s important work”
Outline

- Hybrid Market Overview & Key Drivers
- Eaton Hybrid Overview
- Current Challenges and Technology Roadmap
- Future of Hybrid
Key drivers for Commercial Hybrid Vehicles

• Fuel Economy
  • Saving are dependent on level of hybridization (mild ➔ Full)
  • Independence on Foreign Oil
  • Diesel Price Volatility (-)

• Emissions
  • Strengthening Regulatory Environment
  • Improve Green Image
  • Reduce Carbon Foot Print

• Idling
  • Reduced Noise
  • Low cost Power requirement
  • Anti-idling regulation

• Life Cycle Cost
  • Engine brake wear
  • Maintenance issues
Hybrid Commercial Vehicle Forecast

• The North American Commercial Hybrid Vehicle Industry is expected to show robust growth rates after 2010, after the industry puts the EPA ’10 regulation Compliance Issues and economic Slowdown behind it.

• While Class 8 Hybrid vehicles production is targeted for 2009, its market penetration will lag behind Light and Medium Duty vehicles until the value proposition is validated.

Source: Frost & Sullivan – May ’09
Many Potential Applications
Outline

• Hybrid Market Overview & Key Drivers

• Eaton Hybrid Overview

• Current Challenges and Technology Roadmap

• Future of Hybrid
In 1899 Dr Ferdinand Porsche, then a young engineer at Jacob Lohner & Co, built the first hybrid-powered vehicle, with a constant speed gasoline engine powering hub-mounted electric motors.

*Credits: www.hybrid-vehicle.org*
Eaton Hybrid Programs

Electric Hybrids

- Eaton has focused on building parallel hybrid electric systems, as they provide the best balance between costs and benefits.
- FedEx Express, UPS, and a number of utilities have incorporated the Eaton hybrid electric system into their fleets. We are also working with Coca-Cola and a number of others.

Hydraulic Hybrids

- Eaton has active programs on both parallel and series hybrid hydraulic systems. The target applications range from light to heavy duty commercial vehicles.
- The first Eaton parallel hybrid hydraulic system will be commercialized for refuse trucks in 2009.
Outline

• Hybrid Market Overview & Key Drivers

• Eaton Hybrid Overview ➔ Electric Hybrid

• Current Challenges and Technology Roadmap

• Future of Hybrid
Eaton HEV History & Status

>1,400 Systems Shipped and >15M Reliable Customer Miles
Eaton MD Hybrid Electric Power Systems
1,401 Systems Sold to Date

Global Hybrid Sales Since Gate 4 (July ’07)

• **By Region** *(through April ’09)*:
  - NAFTA: 916
  - Europe: 27
  - Asia: 252

• **Leading Fleet Customers:**
  - Coke: 327
  - FedEx Express: 230
  - Florida Power & Light:: 56
  - UPS: 50 (plus, 200 on order for 3/4Q ’09)
  - Beijing City Transit: 50
  - Guangzhou (China): 32
  - AEP: 20
  - Powers Distribution: 15
  - New Bern Transport (Pepsi): 11 *(more on order)*
  - Cox Communications: 9
  - Penske: 6
Hybrid Deployment Map

- Eaton Engineering
- Existing Customers
- Potential Customers
- Manufacturing & Assembly
Eaton HEV Main Applications

Current Eaton HEV system is integrated into 3 main Applications:

**City Delivery & MD P&D**
- Fuel
- Emissions
- Reliability
- R.O.I.

Save on soaring fuel costs and meet evolving local pollution and noise regulations – while maintaining reliability

**Utility & Telecomm**
- Fuel costs
- Idle reduction
- Auxiliary power
- Noise
- R.O.I.

Save money on fuel, generate power and reduce work site noise & emissions

**Buses & Shuttles**
- Fuel economy
- Emissions reduction
- Noise
- R.O.I.

Save on soaring fuel costs, improve productivity and meet evolving local pollution and noise regulations.

Up to 30% Fuel Saving
Up to 60% Fuel Saving
Up to 20% Fuel Saving
Importance of drive cycle

• Drive cycle - DAF
Importance of drive cycle

- Drive cycle - CILCC
LF vehicle with DAF drive cycle

Engine operating points

Regen Braking
LF vehicle with other drive cycle

Minimized Friction brakes
Friction brake is minimized
City Delivery HEV System Diagram
Fuller Automated Transmission (AMT)

120VAC/60Hz Power Panel (Optional)

DC/DC Converter (Optional)

Motor Controller/Inverter

Auxiliary Power Generator (APG)
Inverter (Optional)

Power Electronics Carrier (PEC)
Lithium Ion Batteries and Battery Controls

Hybrid Electric Motor

Electric Clutch Assembly
## Summary of IRS Approval Status

### Eaton Hybrid-Equipped Vehicles

<table>
<thead>
<tr>
<th>Weight Range</th>
<th>Max for 30%-39% FE Increase (20% of Incremental)</th>
<th>Max for 40%-49% FE Increase (30% of Incremental)</th>
<th>Max for ≥ 50% FE Increase (40% of Incremental)</th>
</tr>
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<tbody>
<tr>
<td>8,501 – 14,000 lb</td>
<td>$1,500</td>
<td>$2,250</td>
<td>$3,000</td>
</tr>
<tr>
<td>(Max Allowable $7,500)</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>14,001 – 26,000 lb</td>
<td>$3,000</td>
<td>$4,500</td>
<td>$6,000</td>
</tr>
<tr>
<td>(Max Allowable $15,000)</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>≥ 26,001 lb</td>
<td>$6,000</td>
<td>$9,000</td>
<td>$12,000</td>
</tr>
<tr>
<td>(Max Allowable $30,000)</td>
<td></td>
<td></td>
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</tbody>
</table>
Outline

• Hybrid Market Overview & Key Drivers

• Eaton Hybrid Overview ➔ Hydraulic Hybrid

• Current Challenges and Technology Roadmap

• Future of Hybrid
Hybrid Hydraulic systems continue to gain traction

**Parallel Hybrid (Eaton HLA® System)**
- Works with existing transmission
- 20 to 30% improved fuel economy
- 2009 launch with Peterbilt

**Series Hybrid**
- Replaces the transmission
- 50 to 70+% improved fuel economy with corresponding reductions in criteria emissions
- UPS first in Industry to purchase Eaton Series Hydraulic Hybrid Vehicles

“There is no question that hydraulic hybrids, although little known to the public, are ready for prime time use on the streets of America.”
– David Abney, UPS COO
Hydraulic Launch Assist System for HD

• Eaton began delivering a fleet of refuse trucks with pre-production HLA systems to end users in December 2007. There are currently 11 vehicles in real world refuse collection service in Texas and Colorado.

• Eaton plans to release the HLA system for use in Peterbilt 320 refuse chassis in Q4 2009.
Chassis rolls test data

<table>
<thead>
<tr>
<th>Vehicle Weight (lb)</th>
<th>NO\textsubscript{x}</th>
<th>CO\textsubscript{2}</th>
<th>Fuel economy (mpg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12,000</td>
<td>17.5%</td>
<td>20.8%</td>
<td>26.2%</td>
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</tbody>
</table>

Significant improvements in fuel economy and emissions

Ford E-450, 6.0L diesel engine, 5 speed automatic transmission with an Eaton Generation 3 HLA system on LA-4 city driving cycle
Class 8 Refuse Truck Test Data

<table>
<thead>
<tr>
<th></th>
<th>Economy Mode</th>
<th>Productivity Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel Economy Improvement¹</td>
<td>28%</td>
<td>17%</td>
</tr>
<tr>
<td>Vehicle Acceleration</td>
<td>+2%</td>
<td>+26%</td>
</tr>
<tr>
<td>Productivity (Cycle Time Improvement)</td>
<td>N/A</td>
<td>11.5%</td>
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<tr>
<td>Brake Life</td>
<td>&gt;2x</td>
<td>&gt;2x</td>
</tr>
</tbody>
</table>

¹ During waste pickup (100 feet between stops)

Vehicle Configuration: Peterbilt 320 chassis @ 63,000 lb GVW
CAT C-10 315 hp engine
Allison 4560 5-speed automatic transmission
Series Hybrid Hydraulic Drivetrain: Current Status

- Vehicle configuration:
  - International 1652-SC chassis with VT-365 engine
  - 23,400 lb GVW

- The series hybrid hydraulic UPS truck demonstrated 50-70% better fuel economy than a standard UPS truck over the EPA City Cycle with no degradation in performance.

- A UPS truck equipped with the series hybrid hydraulic drivetrain was put into service in the Detroit area and achieved 45-50% better fuel economy in “real world” use.
Eaton Supports a Growing Range of Applications

Production Offering from Major OEM’s - Today

<table>
<thead>
<tr>
<th></th>
<th>Step Van P&amp;D</th>
<th>City Delivery</th>
<th>Utility Vehicle</th>
<th>City Bus</th>
<th>Shuttle Bus</th>
<th>School Bus</th>
<th>Refuse Trucks</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>LD</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Up to 19,500 lb GVW</td>
<td>HEV</td>
<td>HEV</td>
<td>HEV</td>
<td>HEV</td>
<td>HEV</td>
<td>SHH</td>
<td></td>
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<tr>
<td>MD</td>
<td>HEV</td>
<td>HEV</td>
<td>HEV</td>
<td>HEV</td>
<td>HEV</td>
<td>HEV</td>
<td>HEV</td>
</tr>
<tr>
<td>19,501 to 33,000 lb GVW</td>
<td>HEV</td>
<td>HEV</td>
<td>HEV</td>
<td>SHH</td>
<td>HEV</td>
<td>HEV</td>
<td>HEV</td>
</tr>
<tr>
<td>HD</td>
<td>HEV</td>
<td>HEV</td>
<td>HEV</td>
<td>HEV</td>
<td>HEV</td>
<td>HEV</td>
<td>HEV</td>
</tr>
<tr>
<td>&gt;33,000 lb GVW</td>
<td>HEV</td>
<td>HEV</td>
<td>HEV</td>
<td>SHH</td>
<td>HEV</td>
<td>HEV</td>
<td>HEV</td>
</tr>
</tbody>
</table>

**Legend**
- **Production Released**
- **Pre-production / Prototype Phase**
- **Early Development / Market Research Phase**

[Image of Eaton logo]
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• Hybrid Market Overview & Key Drivers

• Eaton Hybrid Overview

• Current Challenges and Technology Roadmap

• Market Incentives
Hybrid System Challenges

- The two main differentiators in an Hybrid Powertrain are:
  - The Energy Storage
    - Chemistry / technology
    - Thermal Management
    - Storage Capacity and limitation (usable Vs. available energy)
    - Energy flow (rate of discharge / charge)
    - Power density (packaging)
    - Price
  - The Traction System
    - Peak and continuous power and Torque
    - Rotational speed
    - Price
    - Series Vs. Parallel
    - Automatic Vs. Automated Vs. Dual Clutch Vs. CVT
Many Applications - Diverging Needs

### Potential Range

- **Energy Storage:** 2 – 20 kWh
- **Power:** 20 – 80 kW
- **Torque:** 200 – 1000 Nm
- **EV mode:** None – 10 mile range
- **IC engine:** Diesel, Gasoline, NG
- **Electrification:** None – full
- **Plug-in:** Yes – no
- **Export power:** Yes – no
- **Other unique requirements**
  - Emergency power, anti-idle, reefer, etc
Energy capacity needs will go up with growth in features and electrification of vehicle accessories.
State of the Art Battery Pack Performance
Cell Form Factor Convergence?

- Mobile electronic cell technology has converged on laminated cell technology
- Hybrid vehicle cell technology appears headed in the same direction
Flexible Architecture Benefits

• Optimized for each application
• Enable electrification across many vehicle platforms while avoiding massive integration effort
• Enable OEM application differentiation while simultaneously maintaining commonality on core components
• Most probably path to a cost effective PHEV solution
• Upgradability: add energy storage capacity, plug-in capability, export power, etc after first sale
• Scalable battery and motor specific to application
Diesel Hybrid Emission Road Map

- **Standard HEV (1.87kWh)**
  - HC: -58% to -100%
  - CO: -50% to -77%
  - CO2: -18% to -29%
  - NOx: -3% to -12%
  - PM: -50% to -100%
  - FE Impt: 30% ave

- **HEV W/ Anti Idling (1.87kWh)**
  - Estimated Additional 8.3% CO2 reduction

- **HEV w/ Anti Idling & Engine Off (1.87kWh)**
  - Estimated Additional 15.3% CO2 reduction

- **PHEV W/ anti idling & Engine off (16kWh)**
  - Estimated Additional 15.3% CO2 reduction

Emission reductions based on CILCC cycle, light duty vehicles (Class 3 / 4) and class 5 (with extended ePTO) for PHEV
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Hybrid Future Cost Drivers

- **Increase EV mode** capability and capacity (higher speeds, distances)
  - Increased vehicle electrification and Kwh capacity (eMotor, Batteries)
  - Lower vehicle emissions, increased fuel economy

- **Investment in new hybrid technologies and volume scale**
  - Battery cost per Kwh estimated to drop by 60% over the next 2-5 years
  - eMotor capacity estimated to increase by 45% over the next 2-5 years
  - Leverage portfolio for maximum commonality and global scale
  - Battery replacement cost and logistics

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**Relative Cost**
(Typical Automotive/Truck Components)

![Graph showing relative cost over volume](image)

**How do we get both scale and hit market bulls-eye?**
Hybrid Future Cost Drivers

- Hybrid components and infrastructure
- Develop North American Battery and Motor manufacturing Footprint
- Increase volume to drive price reduction
- Development of a hybrid communication standard to enable easy plug-n-play between vehicle components

Global Economy

- Diesel Fuel price (dropped in 2008 from $4.79/gal to $2.27/gal)
- Financing and Leasing options to early adopters
- Available cash flow at fleets to spend on alternative transportation

Government incentives to spur investment in hybrid.

- Legislation, Tax incentives, or other fleet incentives to drive “Green”
- Increased government incentivization to help potential buyers to abandon the “wait and see strategy”.
- Probable Carbon Tax / cap forcing OEMs and operators to look at alternative transportation.
Thank You

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helenelcornils@eaton.com
Background data

Dyno results on emissions
## Utility Truck Emissions Detail

<table>
<thead>
<tr>
<th>Mission Cycle ID (given in Table 8)</th>
<th>HC (g/ml) %</th>
<th>CO (g/ml) %</th>
<th>NOx (g/ml) %</th>
<th>PM (g/ml) %</th>
<th>Fuel (mpg) % (increase)</th>
<th>Miles Driven</th>
<th>Hours of Operation (hydraulic + electric)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>58</td>
<td>50</td>
<td>34</td>
<td>25</td>
<td>68</td>
<td>70</td>
<td>1.5</td>
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<tr>
<td>B</td>
<td>73</td>
<td>94</td>
<td>34</td>
<td>34</td>
<td>80</td>
<td>70</td>
<td>4.5</td>
</tr>
<tr>
<td>C</td>
<td>78</td>
<td>73</td>
<td>61</td>
<td>37</td>
<td>139</td>
<td>48</td>
<td>3</td>
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<td>D</td>
<td>80</td>
<td>74</td>
<td>58</td>
<td>32</td>
<td>150</td>
<td>38</td>
<td>3</td>
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Southwest Research Institute Emission Test result - 2005
## SwRI Test Results

Pre-Production E700 improvement over Baseline W700 and 2004 W700

<table>
<thead>
<tr>
<th></th>
<th>Baseline W700</th>
<th>2004 W700</th>
</tr>
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<tbody>
<tr>
<td>HC</td>
<td>- 100%</td>
<td>- 100%</td>
</tr>
<tr>
<td>CO</td>
<td>- 82%</td>
<td>- 77%</td>
</tr>
<tr>
<td>NOx</td>
<td>- 65%</td>
<td>- 12%</td>
</tr>
<tr>
<td>PM</td>
<td>- 96%</td>
<td>- 96%</td>
</tr>
<tr>
<td>CO2</td>
<td>- 37%</td>
<td>- 29%</td>
</tr>
<tr>
<td>MPG</td>
<td>+ 57%</td>
<td>+ 42%</td>
</tr>
</tbody>
</table>