Technology Convergence: Real World Adoption of Vehicle Electrification Strategies

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POLICY & REGULATORY

BALANCING ECONOMICS & COMPLIANCE

VEHICLE TECHNOLOGY

CONSUMER DEMANDS
WHAT **TRENDS** ARE SHAPING THE FUTURE OF ELECTRIFICATION?
Increasingly stringent efficiency and fuel economy regulations.
Efficiency improvements are desired but only adopted at point of positive economic value.
Heavy influence of consumer electronics and the need to be connected at all times.
Shift towards more aggressive accident voidance driver assist technologies.
Changing attitudes toward transportation in high-congestion areas.
Opportunity to improve access to transportation in urban areas and to underserved populations.
Development of closed-loop product lifecycle and material management.
WHAT WILL DRIVE ENERGY STORAGE DEMANDS ON VEHICLES?
Low voltage electrification combined with other efficiency technologies will deliver near-term improvement.
AUTOMAKERS ARE PIVOTING TO SATISFY OTHER CONSUMER DEMANDS

GREATER COMFORT & SAFETY

- Active safety systems
- Automated driver assist technology

INCREASED EFFICIENCY

- Transmission & driveline technologies
- Engine technologies

Braking & steering technologies

- Electrification strategies

Interior electronic features

- Vehicle & body technologies

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NOT ALL ELECTRICAL LOADS ARE CREATED EQUAL

Impact on Battery Power

- Impact on Battery Energy
  - High
  - Med
  - Low

- Low Power
  - 120V AC Outlet
  - Rear Defrost
  - Electric Oil Pump
  - Electric Water Pump
  - Audio Amplifier
  - Electric Assist Steering
  - Starter (ICE)
  - Starter (Start-Stop)
  - Electric A/C
  - Active Steer/Brake
  - Elec Assist Turbo
  - Auto Parking
  - Starter-Alt (MHEV)
  - Active Suspension

- Med Power
  - General Key Off Loads
  - Infotainment
  - Power Seats
  - Power Windows
  - V2V Commun.
  - General ECU
  - Radar and Cameras
  - Wireless Phone Charging

- High Power
  - Lighting Systems
  - Electric Assist Steering
  - Electric Water Pump
  - Electric A/C
  - ISG (MHEV)

- High Med Low [kW]
- [WHr] < 0.5 kW < 2.5 kW < 20 kW

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INCREASED VEHICLE AUTONOMY BRINGS
CHANGING CONCEPTS OF RELIABILITY AND SAFETY

<table>
<thead>
<tr>
<th>Monitored Driving</th>
<th>Non-monitored Driving</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Level 0</strong> (Driver Only)</td>
<td><strong>Level 5</strong> (Full Automation)</td>
</tr>
<tr>
<td>Eyes-ON</td>
<td>Eyes-OFF</td>
</tr>
<tr>
<td>Hands-ON</td>
<td>Eyes-OFF</td>
</tr>
<tr>
<td><strong>Level 1</strong> (Assisted)</td>
<td><strong>Level 4</strong> (High Automation)</td>
</tr>
<tr>
<td>Eyes-ON</td>
<td>Eyes-OFF</td>
</tr>
<tr>
<td>Hands-ON</td>
<td>Hands-OFF</td>
</tr>
<tr>
<td><strong>Level 2</strong> (Partial Automation)</td>
<td></td>
</tr>
<tr>
<td>Eyes-ON</td>
<td><strong>Hands temp. OFF</strong></td>
</tr>
<tr>
<td><strong>Level 3</strong> (Conditional Automation)</td>
<td><strong>Hands temp. OFF</strong></td>
</tr>
<tr>
<td>Eyes-OFF</td>
<td>Hands-OFF</td>
</tr>
<tr>
<td><strong>Fail Safe</strong></td>
<td><strong>Fail Operational</strong></td>
</tr>
<tr>
<td>The vehicle responds to a failure in a way that will cause no harm or at least minimal harm</td>
<td>The vehicle responds to a failure by keeping the system functional until such time that the driver can assist with safe operation</td>
</tr>
</tbody>
</table>
The majority of vehicles will require significantly better energy storage than today.
BATTERY REQUIREMENTS FOR LOW VOLTAGE ELECTRIFICATION

MOST IMPORTANT

- SAFETY – MEET REQUIREMENTS AND CONSUMER EXPECTATIONS
- VEHICLE COST IMPACT – MAXIMIZE BENEFIT TO COST RATIO
- POWER – CHARGE AND DISCHARGE POWER DENSITY
- LIFE CYCLE – CYCLE LIFE, PERFORMANCE LIFE AND RECYCLABILITY
- REAL WORLD USABILITY – TEMPERATURE, WEIGHT, VOLUME AND PACKAGING LOCATION

STILL IMPORTANT
CURRENT PRODUCTS FOR SINGLE BATTERY 12-VOLT APPLICATIONS
AGM LEAD-ACID & LITHIUM-ION

- For single battery architectures there is no perfect solution
- AGM Lead-Acid continues to lead market
- Lithium-ion entering for select applications
DUAL BATTERY ARCHITECTURES – SYSTEM REDUNDANCY AND ENERGY MANAGEMENT

12-volt Dual System
- Start-stop functions, plus
- Moderate regeneration (~3 kW)
- System redundancy for coasting
- Improved power quality

48-volt Dual System
- Adv. Start-Stop functions, plus
- Strong regeneration (~12 kW)
- Enabling greater energy management
- Potential for traction power (~20 kW)
CHANGING EXPECTATIONS FOR RELIABILITY IN POWER SUPPLY AND BATTERY SYSTEM

- Shift away from MTBF toward Failures In Time (FIT) as measure of reliability
- Studies show that FIT for traditional single battery system is approx. 10 – 20
- FIT targets for semi-autonomous vehicle systems is 1 failure per billion hours
- Dual battery systems predicted to improve FIT to within targets
- More study needed to assess impact of different chemistries and electronics
HOW WILL THESE NEEDS DRIVE BATTERY TECHNOLOGY?
12-VOLT DUAL BATTERY – LEVERAGE COMPLEMENTARY CHEMISTRIES

- Significant increase in throughput
  - Lithium-titanate provides high charge power
  - AGM battery still cycles but less aggressively
- Cost impact of lithium-ion is minimized
  - Focus limited to charge/discharge power
  - Capacity of 10 Ah is sufficient
- Voltage alignment allows for reduced system complexity
  - Passive or switched connection
  - No DC/DC converter required
- Redundancy to improve reliability for safety-critical functions

AGM and LTO Dual Battery Performance
WLTP Drive Cycle
First gen systems continue to use lead-acid as primary battery
  - Engine starting
  - Overall reliability

Chemistry choices for lithium-ion less constrained
  - Voltage alignment challenges eliminated by DC/DC
  - NMC-Graphite preferred

Second gen systems will push toward more power and energy
  - Stronger hybridization
  - Greater component electrification
BATTERY SOLUTIONS FOR LOW-VOLTAGE ELECTRIFICATION

Dual Battery for 12-volt
- NMC-LTO chemistry
- Well-aligned with existing 12-volt network
- Charge and discharge power up to 3.5 kW
- Wide operating temperature range

Dual Battery for 48-volt
- NMC-Graphite chemistry
- Most cost-effective solution
- Charge and discharge power up to 15 kW
- Maximize useable energy
SUMMARY

- Electrification will be a necessary part of efficiency improvements in vehicles
- Factors besides efficiency will also drive the need for electrification
- ADAS and other safety critical functions will put new expectations on batteries
- Dual battery systems provide a greater level of redundancy and reliability
- Shifting to 48-volt Micro Hybrid can provide a new energy management platform
- Battery performance in low-voltage applications will be driven by power, cycle life and cost