A Review of Battery Exchange Technology for Refueling of Electric Vehicles

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C. Arthur MacCarley
California Polytechnic State University, San Luis Obispo, California, USA

and

Loragen Corporation, San Luis Obispo, California, USA

Transportation Electronics Laboratory, Cal Poly, San Luis Obispo
Refueling Options for Battery-only Electric Vehicles

- Fast charging, in which batteries are charged in-vehicle at an accelerated rate.
- Battery material reloading or refueling, in which the energy-carrying elements of the battery are replaced or replenished.
- Battery interchange, involving the complete exchange of the battery pack, usually with the aid of some semi-automated mechanism.
Battery Energy Storage Capacity in Perspective

- Unleaded gasoline has a specific energy density (LHV) of approximately 11,300 Watt-hours per kg (Wh/kg).

- A typical lead-acid deep-cycle battery has an energy density of only 25 Wh/kg, a factor of 450 less than gasoline.

- Considering several efficiency-improving factors in favor of electric propulsion, the effective energy density ratio may shrink to as little as 62, which is still poor.

- The most ambitious targets for advanced battery development are as high as 1000 Wh/kg, which could reduce the effective gasoline to battery energy density ratio to as little as 1.55, but cost and life-cycle limitations are expected to remain.
Recharge Rates in Perspective

- Gasoline flowing through a nozzle into an auto fuel tank is equivalent to a recharge rate of over 20 MW.

- For RBI, the exchange of a 1000 kg, 48kWh lead-acid battery (for a 20-passenger electric bus) in one minute is equivalent to a recharge rate of 2.9 MW.

- When all energy efficiency factors are included, the usable energy transfer rates for gasoline and lead-acid RBI both become approximately 2.5 MW.

- Fast charging from a 200 Amp 220VAC can supply only 43 kW, and with greatly reduced utilization efficiency.
Progress in Battery Exchange Technology, 1895-2000

- Over 100 successful commercial deployments, almost all in limited fleet service or short-lived demonstration projects.
- Only significant current deployment is semi-automated battery exchange for indoor-operated forklift trucks.
- Over 50 US Patents relating to the automation of electric vehicle battery replacement.
- Six exchange configurations most common...

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Battery Exchange Configurations.
One of over 1000 Electric "Hacks" Serviced at the Rue Cardinet Battery Exchange and Charging station, Paris, 1899.

New York City Electric Taxi and Charging Station, 1896, from Scientific American, 1899.

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Safety Considerations Related to Vehicular Battery Exchange

- Accidental release of battery module, loss of battery integrity or release of fluids or gasses in event of collision (FMVSS 571.216).
- Battery protection from the elements.
- Ventilation of released gases during charge and discharge.
- High voltage / current and reliability of battery electrical connectors.
- Docking and proper alignment with exchange apparatus.
- Battery exchange unit must be readily accessible, but pose no hazard to operators or general public.
- Concurrent recharging of multiple batteries by exchange apparatus could draw significant electric power.

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Economic Factors for RBI v.s. Slow and Fast Charge Options

Four Vehicle Use Scenarios

- Commuter service.
  - 50 miles/day, 12,500 miles/year maximum.

- Non-transit fleet service.
  - 100 miles/day, 25,000 miles/year maximum.

- Transit Service.
  - 150 miles/day, 37,500 miles/year maximum.

- Mixed private use.
  - 50 miles/day 4 days/week, 100 miles/day 1 day/week, 300 miles/day, 4 days/year, 16,200 miles/year maximum.

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Economic Factors for RBI v.s. Slow and Fast Charge Options

Four Vehicle Ownership and Deployment Scenarios

- One electric automobile or light truck with dedicated support equipment.
- Twenty vehicle fleet of automobiles or light trucks with common support equipment.
- Fleet of twenty electric public transit vehicles.
- Mixed Public Service Station serving 100 private automobiles or light trucks per day.

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# Imaging Systems Tested

<table>
<thead>
<tr>
<th>Company and Product</th>
<th>Received Wavelength Band (μm)</th>
<th>Focal Plane Temperature and Cooler Type</th>
<th>Detector Type</th>
<th>Array Size (pixels)</th>
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<tbody>
<tr>
<td>AGEMA Thermovision</td>
<td>8 to 12</td>
<td>77 K Sterling</td>
<td>HgCdTe</td>
<td>5 elements, X-Y mechanical scan</td>
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<tr>
<td>Cincinnati Electronics IRRIS-256ST</td>
<td>3 to 5</td>
<td>77 K Sterling</td>
<td>InSb</td>
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<td>FSI PRISM</td>
<td>3.6 to 5</td>
<td>77 K Sterling</td>
<td>PtSi</td>
<td>320 x 244</td>
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<tr>
<td>GEC/Marconi Sentry IR20</td>
<td>8 to 14</td>
<td>Ambient</td>
<td>Microbolometer</td>
<td>200 x 200</td>
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<tr>
<td>Inframetrics 600</td>
<td>3 to 5 and 8 to 12</td>
<td>77 K Cryogenic</td>
<td>PtSi and HgCdTe</td>
<td>1 element, X-Y mechanical scan</td>
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<tr>
<td>Inframetrics 760</td>
<td>8 to 12</td>
<td>77 K Sterling</td>
<td>HgCdTe</td>
<td>1 element, X-Y mechanical scan</td>
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<tr>
<td>Inframetrics InfraCam</td>
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<td>75 K Sterling</td>
<td>PtSi</td>
<td>256 x 256</td>
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<tr>
<td>Insight/Starsight</td>
<td>8 to 14</td>
<td>Ambient</td>
<td>Pyroelectric BST</td>
<td>256 x 256</td>
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<tr>
<td>Mitsubishi IR-M300</td>
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<td>TI Nightsight</td>
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<td>Ambient</td>
<td>Pyroelectric BST</td>
<td>256 x 256</td>
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<tr>
<td>TRW Multispectral Scanner</td>
<td>94 GHz (millimeter-wave)</td>
<td>Ambient</td>
<td>HEMT*-heterodyne</td>
<td>1 element, X-Y mechanical scan</td>
</tr>
</tbody>
</table>

* HEMT = high electron mobility transistor

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Placement of Analysis Window in Comparable Images

Texas Instruments NightSight
Pyroelectric Longwave IR

Agema ThermoVision 1000
HgCdTe Quantum Detector
Longwave IR

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Chromatic vs Monochromatic Images

Agema ThermoVision 1000
HgCdTe Quantum Detector
Longwave IR

Burle TC209 Color CCD Camera (Visible Reference)

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Conclusions and Observations

- Rapid battery interchange methods have been used for over 100 years to overcome the range and charging time limitations of battery-only EVs.

- RBI is an economical alternative to rapid in-vehicle battery charging.

- Safety issues not fully known, but RBI does not appear to add significantly to the risk of operation compared with conventional EVs.

- Survey results suggest that the majority of vehicle, equipment and battery manufacturers view the concept favorably but with skepticism.

- Best implemented by vehicle manufacturers.

- RBI is highly dependent upon support infrastructure. Near-term feasibility only for fleet applications, with vehicles serviced from a central location.

- Battery configuration standards needed if general deployment ever to be considered.

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