TriMet

Prototype Battery System Beta Test

13 September, 2010

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Background and History

- The problem:
  - Short battery life (10 months on average)
  - Dead batteries in the yard
  - Dead batteries at layovers
  - Increasing on-board electrical power demands
  - Need for a solution that scales to future requirements

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Background and History

- Dead batteries impact our customers and TriMet's cost per operating mile:
  - Jump starting buses
  - Exchanging batteries in buses
  - Recharging\Reconditioning batteries
  - Maintaining battery inventories
  - Battery contract management, procurement, and warranty

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What Has Been Done

- Installed parasitic draw stops
- Turned batteries off over weekends
- Updated battery testing equipment along with our maintenance procedures
- Specifying and purchasing batteries with heavier lead plates
- Improved the maintenance response to dead buses, pull out, and in service

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The Problem Exists Because

- A 3 to 6 amp draw from all the electronics on our buses that stay energized with the bus turned off
- A requirement to turn the engine off but keep interior\exterior lighting on at layovers
- High amperage charge rate at restart which wears down batteries
- High battery operating temperatures

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The Benefits to Solving This Problem for TriMet

- Better service to our customers
- A reallocation of maintenance labor
- A reduction in inventory costs, with associated procurement and management savings
- Lowered costs per operating mile
- A reduction in TriMet's waste steam

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The Advance Battery Pack Benefits

- Very little modification to the buses
  - Fits into the existing battery rack
  - Added sensor wires to the alternator
  - Added wires with indicator light for the drivers dash
- Minimal training and trouble shooting for maintenance
  - Repairs are generally made by replacing modular circuit boards
- Power capacity
  - The ability to keep the bus in service when there is a charging problem

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TriMet and Rogue Energy Partnership

- TriMet began discussions with Rogue Energy in December of 2007
- As a result there was realization that the challenges went beyond simply replacing old batteries
  - A comprehensive hardware and software solution was required to best address the challenges
- A public/private partnership was formed to:
  - Find a simple and fundamental breakthrough solution
  - Refine the application to work on across the range of the fleet vehicles
  - Not available from any other source

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Project Scope

The project goal was to demonstrate to TriMet fleet operating cost savings by:

1. The reduction of annual fuel consumption per bus by at least 3%
2. A reduction in battery replacement and maintenance costs through longer battery operating lifecycles saving $850 per year
3. A reduction in CO2 and diesel particulate emissions by a commensurate amount of fuel saved
4. Provide a robust energy foundation for future electrification of bus systems

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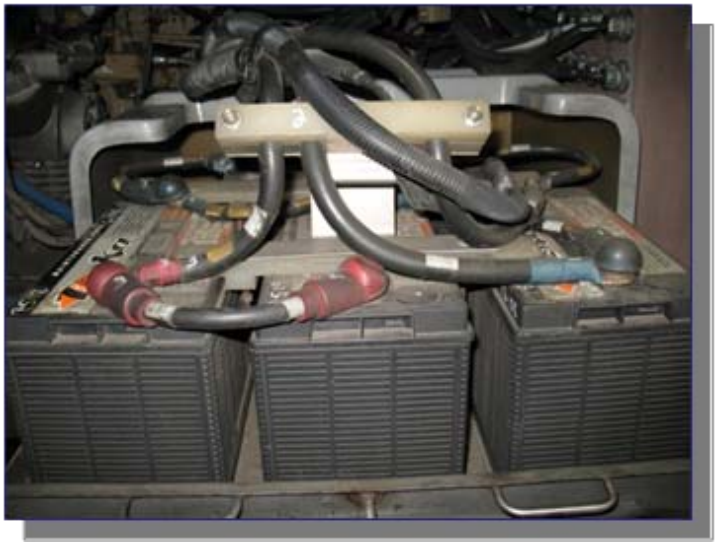
The Old – Deka Pack



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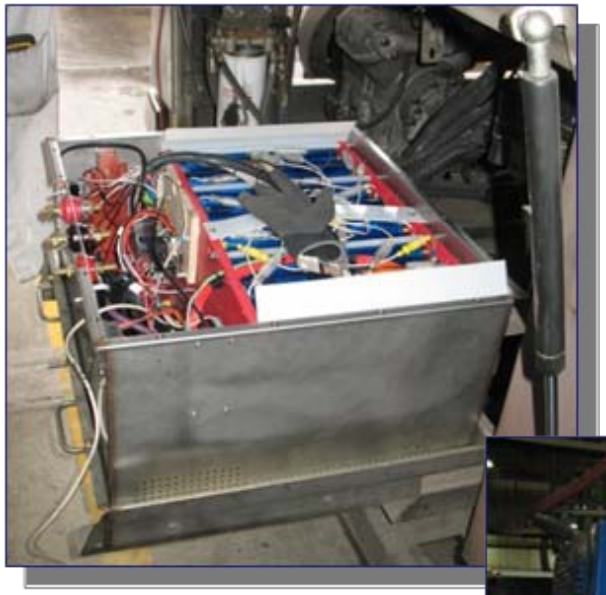
The New – Rogue LiX Smart Pack



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The New – Rogue LiX Smart Pack

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Total ROI Projected at 3% Fuel Savings Target

Diesel at $2.85/Gallon	Year 1	Year 2	Year 3	Year 4	Year 5	Totals
Presumed Diesel Cost	$2.85	$3.14	$3.61	$4.15	$4.56	
Fuel Cost Savings/Bus	$782	$858	$983	$1,126	$1,223	**$4,973**
Hardware & Labor Savings	$1,394	$1,394	$ 1,394	$1,394	$1,394	**$6,970**
Total Savings	**$2,176**	**$ 2,252**	**$ 2,377**	**$2,520**	**$2,617**	**$11,943**

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What Was Measured (Phase II)

- Operational real time data monitoring included:
  - Fuel consumption (mpg)
  - Speed (mph)
  - Engine (rpm)
  - Battery enclosure temperature
  - Current flow
  - Pack and module voltage
- Data sampling every second
  - 86,400 data points per day
  - Over 1.1 million for the trial period

Trial Background – Bus 2720 LiX Pack

- Test period from 2/1/10 to 3/20/10 and was extended to 5/17/10 – 202 hours of data and 11,000 miles
  - Bus rolling – 310 hours – 26%
  - Bus idling – 159 hours – 13%
  - Bus engine on – 460 hours – 39%
  - Average speed – 12.2 mph
- Pretrial average mpg – 4.46 (11/09 through 1/10)
  - Average speed 12.4 mph
  - Target improvement (3%) – 4.59 mpg

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Trial Results – LiX Smart Pack

- Fuel efficiency determined using engine processing unit (EPU) and also based on analog odometer values
  - EPU results were superior to odometer results (both were favorable)
- Results ranged from:
  - 5.54 mpg (24.2% improvement) to
  - 5.26 mpg (17.98% improvement)

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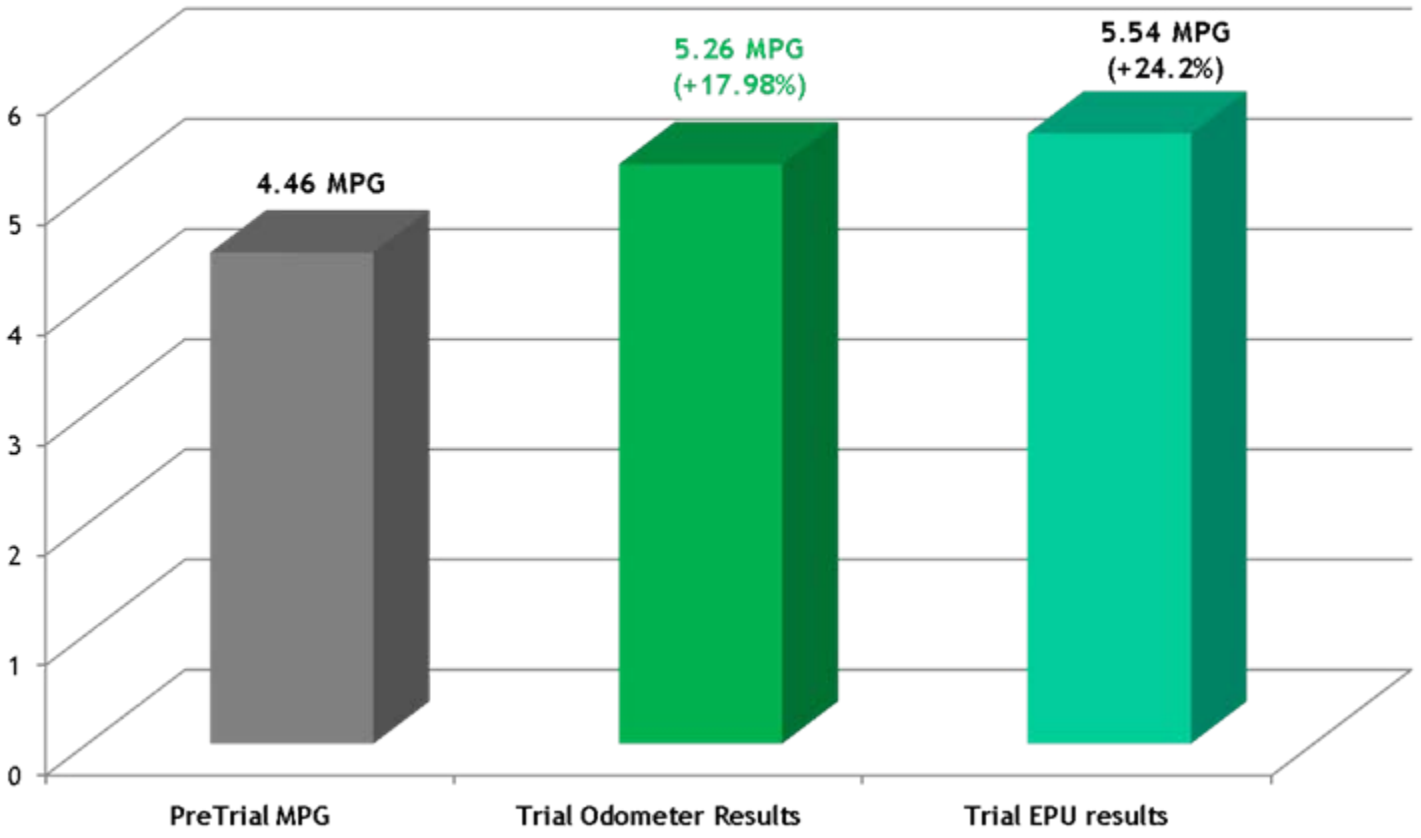
TriMet Bus 2720
Trial MPG Results Comparison



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Projected Savings at 17.98% Fuel Efficiency Improvement

17.98% Improvement

Diesel at $2.59/Gallon	Year 1	Year 2	Year 3	Year 4	Year 5	Totals
Presumed Diesel Cost	$2.59	$2.69	$2.80	$2.91	$3.03	
Fuel Cost Savings/Bus	$4,260	$4,350	$4,442	$4,504	$4,304	$21,861
Gallons Saved Per Bus	1,645	1,645	1,645	1,645	1,645	8,223
Hardware & Labor Savings	$1,394	$1,394	$1,394	$1,394	$1,394	$6,970
Metric Tons CO2 Reduced	16.7	16.7	16.7	16.7	16.7	83.5
	$5,654	$5,744	$5,836	$5,898	$5,698	$28,831
Accumulative	**$5,654**	**$11,398**	**$17,234**	**$ 23,132**	**$28,831**	

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Projected Savings at 24.2% Fuel Efficiency Improvement

24.2% Improvement

Diesel at $2.59/Gallon	Year 1	Year 2	Year 3	Year 4	Year 5	Totals
Presumed Diesel Cost	$2.59	$2.69	$2.80	$2.91	$3.03	
Fuel Cost Savings/Bus	$5,733	$5,818	$5,901	$5,929	$5,478	$28,859
Gallons Saved Per Bus	2,214	2,214	2,214	2,214	2,214	11,068
Hardware & Labor Savings	$1,394	$1,394	$1,394	$1,394	$1,394	$6,970
Metric Tons CO2 Reduced	22.5	22.5	22.5	22.5	22.5	112.5
	$7,127	$7,212	$7,295	$7,323	$6,872	$35,829
Accumulative	**$7,127**	**$14,340**	**$21,635**	**$28,958**	**$35,829**	

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ROI Estimates

* After Battery Pack (LiX) is 100% Expensed

- At 17.98% fuel savings
  - 5 Year ROI Per Bus*
    - Over $10,000 in fuel savings
    - Over $17,000 in total savings
  - Break even in 24 months

- At 24.2% fuel savings
  - 5 Year ROI Per Bus*
    - Over $17,500 in fuel savings
    - Over $24,500 in total savings
  - Break even in 20 Months

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Other Considerations

- Reduced brake wear
- Better performance for more electrical systems
  - Brakes
  - Steering
  - Wipers
  - Cab heating (reduces idling)
- Reduced hydraulic maintenance costs
- Almost double the bus off time possible without battery damage
- Carbon/emissions reduction – future rewards?

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LiX Smart Pack vs. Lead Acid

	LiX Smart Pack	Traditional Lead
Life Span	More than 5 years	10 months
Weight	130 pounds*	272 Pounds
Usable Kilo Watt Hours/Pack (kWh)	4.1	1.1
Deep Discharge Damage	Not Possible	Inevitable
Over Charging Damage	Not Possible	Inevitable
Energy Density (watt hours/kg)	120Wh/Kg	40Wh/Kg
Power Density (watts/kg)	1,400	180
Overall Energy Density	Best	Worst
Maximum Charge Available w/o Cell Damage	80%	45%
Weight	48% of lead	100% (nothing heavier)
Volume	Half of lead	Bulky
Working Temperature (Min)	-20 C	-10 C
Working Temperature (Max)	60 C	40 C
Discharge Curve	Best	Worst
Environmental Issues	None	Hazardous waste (lead)

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Next Steps

- Finding funding for an expanded test at TriMet
- Finding other transit districts willing to test and verify the results we have found
- Once verified by an expanded test, getting these units available in new bus orders

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