Momentum Dynamics

Fully Automated Inductive Charging for all types of Electric Buses

Automatic On-Route and In-Depot Charging.
This Bus is Charging.
The transition to zero-emission electric transit vehicles is inevitable and correct.

The issue is how to transition cost effectively and with minimal disruption to current operations.
The Big Issues:

• **Cost Effectiveness**
  - Acquisition cost
  - *Operational costs: The cost of fueling must consider the cost of people*
  - Implementation (and the cost of land)
  - Energy management (and managing the cost of energy used)
  - Maintenance
  - Total Cost of Ownership (TCO)

• **Minimal Disruption of Current Operations**
  - Driving range (must run all day without return to depot for charging)
  - Physical Footprint (must allow for tight stacking of buses for depot charging)
  - Labor (must minimize incremental training/labor requirements)
  - Procedures (maintain current SOPs)
The Answer: Automatic On-Route Wireless Charging

- High-power
- High efficiency (>90%)
- **On-route charging provides unlimited range**
- All-weather Operation (snow, ice, mud)
- No plugs or wires to manipulate or maintain
- No overhead mechanical units
- No moving parts to wear out
- No incremental labor requirements
- Minimal footprint
- OEM/Vehicle agnostic (modular – can be installed on any vehicle)

**Fully automatic – just park and charge**
So instead of this... Or this...
You can have this...

One electric bus can replace one diesel or CNG bus.
On-Route Charging Can Completely Eliminate the Need for Daily In-Depot Charging
Importance to Electric Vehicles

- Automatic charging encourages more frequent charging. Charging happens in background, no human required.
- More frequent charging solves the problem of limited driving range – the biggest impediment to both commercial and consumer EV sales.
- Batteries last longer when you avoid full cycling and charge quickly at middle State-of-Charge.
- 50 kW automatic fast charging is the industry “sweet spot” that can be installed ubiquitously.
- The combination of 200-mile range EVs and automatic fast (wireless) charging translates into effectively unlimited EV range.
Opportunity Charging: Commercial and Transit

On route charging for commercial and transit vehicles

- Bus stops
- Truck stops
- Train stations
- Taxi Queues
- Loading docks
Case Study  
Link Transit, Wenatchee WA

System Overview

<table>
<thead>
<tr>
<th>Bus: BYD K9S</th>
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<tr>
<td>Bus Batteries: 270 kWh</td>
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<td>Bus Driving Range: 190 miles (Prior to wireless charging system, bus did not complete a full day, sometimes only completing a half a day of service)</td>
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<td>Charging System: 200 kW</td>
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<td>Only one on-route charger</td>
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<td>Date: December 2017</td>
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Key Findings – Momentum Wireless Charging Performance

| Vehicle Integration: Vehicle Integration was seamless. The BMS will rarely utilize the full charging capacity |
| Battery Usage: Opportunity charging (Partial State of Charge) enabled over 190% of bus battery capacity used every day. A smaller battery could be used to provide virtually unlimited range. |
| Driving Range: Range extension of 313 miles, or almost unlimited driving range. |
| Charging Rate: Bus charged 7-10 mins every hour, up to 16 hours/day, typically maintaining 75% SOC, Bus was returned end of day with 75% SOC. |
| Weather impacts: no impacts from extreme hot or cold temps, rain, or snow |
| Reliability: with exception of utility power outage, the system has performed reliably to specifications since installation. |
| Maintenance/Costs: requires less than 1 hour maintenance per month, costs are comparable to in-depot DC Fast Charging, but far less than Overhead On-Route Charging. |

Richard DeRock, GM Link Transit: “The Momentum Dynamics product is a game changer in battery charging technology”
First Generation Wireless Charging System

**Ground Assembly**
- Control Unit (Industrial Cabinet)
- Charging Pad

**Vehicle Assembly**
- Wireless Charging Receivers
- Modular Configuration
  - Up to 4 - 75 kW charging modules (300 kW)
Second Generation Wireless Charging

- Up to 75kW (>90% Efficiency) per module
- 800V capable, up to 125A
- 600mm square, 30mm height
- Simple installation, mounting bracket customizable
- Light Weight: <25kg
- Modules can be coupled for higher power

Prototype installed on Tier 1 technology demonstration vehicle.
Unlimited Range with On-Route Charging

Green Lines are Charging Events

Gold Lines are SOC

4.5 Minute Charge at 200kW
Adds 15 kWh - ~9 miles

4.5 min charge at 300 kW - 13.4 miles

12 Hours of Customer Charging Data from 8/31/2018 – 75% end of day SOC

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In Conclusion- Benefits of Wireless Charging

- 100% automatic – requires no human action or work.
- Low acquisition cost with near-zero maintenance costs.
- Low installation costs. No overhead structures, simple installation.
- Lowest TCO. No cables to replace. No moving parts.
- Just as powerful as plug-in chargers (300 kW+).
- 90% power transfer efficiency (comparable to plug-in).
- Modular design can be upgraded and moved from vehicle to vehicle. Capacity can be added incrementally.
- Works with any mix of vehicle manufacturers and vehicle sizes.
- Immune to weather – Operates through ice, snow and water
- Fast on/off – charging within 5 seconds of applying parking brake.
- Enables Charging-as-a-Service revenue model
Thank you

For more information:
info@momentumdynamics.com
Backup Slides
Momentum Dynamics

Wireless Power Technology Developer
Located in Malvern, PA

• Only company with high power that can treat four vertical markets – Cars, Trucks, Buses, and Industrial Vehicles
• Commercial systems installed and operational at 200 kW
• Systems available now at 300kW+
• Turnkey system installation
Opportunity Charging using Wireless Charging

- With opportunity charging any battery electric bus can replace a diesel bus on 1-1 basis with unlimited range.
- Modular. Available in scalable power levels (50 kW to 300 kW+)
- Efficient. Power transfer efficiency as efficient as plug-in systems (>90%)
- Universal. In Depot/On Route – Same vehicle equipment (50 kW in Depot/300 kW on route)
- Lowest TCO. Low acquisition and installation costs; lowest TCO.
- 100% automatic – requires no human action or work
- Immune to weather – Operates through ice and snow
- Fast on/off – charging within 5 seconds of applying parking brake
Recent Installations

- Link Transit (Wenatchee, WA) – 200kW
- CARTA (Chattanooga, TN) – 200kW
- RTA (Howard County, MD) – 50kW
- NREL (Golden, CO) – 25kW
- Several others under contract
Wireless Architecture

- Power Converter and Wireless Data Link
- Wireless Receiver
- MD Power Panel
- Supply power
- Battery / BMS
- MD Wireless Transmitter

Receiver

Transmitter
We use induction to transmit energy across an air gap.

This is the same technology developed primarily by Nicola Tesla and in use in myriad devices such as cooktops, transformers, motors, generators, and transformers.
200 kW installation in Wenatchee, WA (Generation 1 technology).

24 months with no interruption of service.

Bus has unlimited driving range despite winter and summer extremes.

After 12-hours of continuous operation, battery state of charge never falls below 75%
LIMITED DRIVING RANGE IS THE SINGLE BIGGEST IMPEDIMENT TO THE RAPID ADOPTION OF COMMERCIAL AND CONSUMER ELECTRIC VEHICLES
Optional Co-located Battery Grid Storage

- Multiple high-power charging systems can cause high-cost peak demand charges from utility
- Adding co-located storage can reduce peak demand costs
- Creates stability on grid by creating a constant load profile
- Adding storage can limit infrastructure upgrade costs
With opportunity charging after each driving circuit, the battery SOC never falls below 50%.

If once-a-day depot charging is used, SOC will decline steadily and driving range will be limited.
Electric Bus State of Charge For 16 Hours with Wireless Charging System Operating (customer data)

No On-route Charging

Wireless Charging

Insufficient reserve to continue operating after 8 hours.

67% after 16 hours of operation while using wireless charging.