Wireless Electrification

Eighth International Hydrail Conference
Ryerson University – Centre for Urban Energy, Toronto, Canada

2013.06.11 & 12

Tim Dickson, Ph.D., P. Eng
Agenda

1. BOMBARDIER OVERVIEW
2. MEGATRENDS
3. INTRODUCTION TO PRIMOVE
4. ANSWERS TO QUESTIONS
Bombardier is the world’s only manufacturer of both planes and trains, with a worldwide workforce of 70,000* people.

Bombardier is headquartered in Montréal, Canada. Our shares are traded on the Toronto Stock Exchange (BBD) and we are listed on the Dow Jones Sustainability World and North America indexes. In the fiscal year ended December 31, 2011, we posted revenues of $18.3 billion USD with 93% of revenues generated outside Canada.

* as at December 31, 2011
### BOMBARDIER Overview

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<tbody>
<tr>
<td>Company start-up</td>
<td>Diversification into mass transit market</td>
<td>Entry into aerospace through Canadair acquisition</td>
<td>Aerospace: Short Brothers (UK), Learjet (US), de Havilland (CA)</td>
<td>CRJ Series, Global Express, Challenger 300</td>
<td>CRJ NextGen family, Learjet 85, Q400 NextGen, CSeries, Global 7000, Global 8000</td>
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<tr>
<td>Development of passenger and personal snowmobiles</td>
<td>Learning of new industry</td>
<td>Consolidation of North American mass transit position and reinforcement of presence in Europe</td>
<td>Transportation: BN (BE), ANF (FR), Deutsche Waggonbau (DE), Concarril (MX), Talbot (DE), Adtranz (DE)</td>
<td>Tilting train, AGC (Autorail Grande Capacité)</td>
<td>Hybrid AGC, ZEFIRO, ECO4</td>
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<tr>
<td>Vertical integration</td>
<td>1982 New York metro contract secured strong position in American market</td>
<td>Sale of Recreational products business unit</td>
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<td>primove technology for wireless urban mobility</td>
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<td>Energy crisis provoked market collapse</td>
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### BOMBARDIER Overview

**Bombardier Transportation**
- Revenues*: $9.8 billion
- Backlog*: $31.9 billion
- Employees**: 36,200

**Bombardier Aerospace**
- Revenues*: $8.6 billion
- Backlog*: $22.0 billion
- Employees**: 33,600

* as at December 31, 2011
** as at December 31, 2011 (includes contractual employees)
64 production/engineering sites and 19 service centres

Present in > 64 countries  ◊ Global Headquarters
BOMBARDIER Transportation
The broadest portfolio in the rail industry

**Rail Vehicles**
- Light rail vehicles
- Metros
- Commuter trains
- Regional trains
- Intercity trains
- High speed trains
- Locomotives

**Transportation Systems**
- Monorail systems
- APM systems
- Light rail systems
- ART systems
- Metro systems
- Intercity systems
- Transit Security

**Services**
- Monorail systems
- APM systems
- Material Solutions
- Component re-engineering and overhaul

**Rail Control Solutions**
- Integrated control systems
- Automatic train protection and operation
- Interlocking systems
- Wayside equipment
- Services

**Propulsion & Controls**
- Traction converters
- Auxiliary converters
- Traction drives
- Control and communication

**Bogies**
- Portfolio to match entire range of rail vehicles
- Full scope of service over the lifetime of a bogie

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*BOMBARDIER the evolution of mobility*
Bombardier INNOVIA Monorail 300 System
Seamless integration through high flexibility

Slender guide way and sleek, low profile vehicle
Sharp curve radii and steep grades

- Minimized impact on existing infrastructure
- Unobtrusive stations
- Fast install
Bombardier Transportation in North America
Manufacturing Capacity and Centers of Competence

Thunder Bay
Ontario, Canada

La Pocatière
Québec, Canada

St-Bruno
Québec, Canada

Mississauga
Ontario, Canada

Plattsburgh
New York, United States

Pittsburgh
Pennsylvania, United States

Kingston
Ontario, Canada

Sahagun and Huehuetoca
Mexico
BT Systems in Kingston Engineering & Testing

Offices: 1,486 m²
Test Facility: 3,437 m²
Four Test Tracks
Certified IRIS  
(Business Management)
Certified ISO 14001:2004  
(Environmental Management)
Certified OHSAS 18001:2007  
(Health and Safety Management System)
Capability Model Integration (CMMI)  
Level 3
THE CLIMATE IS RIGHT FOR TRAINS
Megatrend overview

- Climate change
- Urbanization and population growth
- Congestion
- Oil scarcity and price of energy
- Aging of societies
THE CLIMATE IS RIGHT FOR TRAINS
Megatrends – climate change

Challenge
CO₂ emissions are a contributing factor to climate change

Solution
Rail has lower CO₂ emissions than other modes of motorized transport

THE CLIMATE IS RIGHT FOR TRAINS
Megatrends – urbanization and population growth

Challenge
Increasing demand for passenger transportation, esp. in urban areas

Solution
Rail provides capacity for projected urban population growth

Population Growth

<table>
<thead>
<tr>
<th>Year</th>
<th>Rural [billion]</th>
<th>Urban [billion]</th>
</tr>
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<tbody>
<tr>
<td>1975</td>
<td>4.1</td>
<td>9.2</td>
</tr>
<tr>
<td>2000</td>
<td>6.1</td>
<td>100%</td>
</tr>
<tr>
<td>2025</td>
<td>8.0</td>
<td>100%</td>
</tr>
<tr>
<td>2050</td>
<td>9.2</td>
<td>100%</td>
</tr>
</tbody>
</table>

THE CLIMATE IS RIGHT FOR TRAINS
Megatrends - congestion

Challenge
Congestion wastes time, energy, money and creates pollution

Solution
Rail uses considerably less land and carries high number of passengers

Number of people transported per hour in urban environment

<table>
<thead>
<tr>
<th></th>
<th>Car</th>
<th>Bus</th>
<th>Tram</th>
<th>Metro</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
<td>2,100</td>
<td>9,000</td>
<td>22,000</td>
<td>50,000</td>
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</tbody>
</table>

1 Number of people crossing a 3 to 5 metre-wide space in an hour in an urban environment
Source: International Association of Public Transport (UITP)
THE CLIMATE IS RIGHT FOR TRAINS
Megatrends – oil scarcity and price of energy

Challenge
Oil becoming scarce and energy prices will continue to be volatile

Solution
Rail consumes dramatically less energy

Energy consumption during operation plus vehicle production

Source: Report DOE/EIA-0484(2008), Release Date: September 2008
“Better urban mobility in developing countries”, IAPT, 2003
Federation of Canadian Municipalities, National Transit Strategy, March 5, 2007
THE CLIMATE IS RIGHT FOR TRAINS
Megatrends – aging of society

Challenge
Aging of population
(Especially in developed countries)

Solution
Rail provides easily accessible transport systems to all age groups

primove

Easy Urban Mobility

Contactless and catenary-free electric operation
# primove e-mobility

## Game changing solution for all types of electric vehicles

<table>
<thead>
<tr>
<th>Feature</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>One infrastructure for all electric vehicles</td>
<td>Wirelessly transfer power to electric vehicles without the need for charging stations.</td>
</tr>
<tr>
<td>Wireless inductive power transfer</td>
<td>Power is transmitted from the charging infrastructure to the vehicle via an electromagnetic field.</td>
</tr>
<tr>
<td>Unlimited mobility and no recharging hassles</td>
<td>Vehicles can travel long distances without needing to stop for recharging.</td>
</tr>
<tr>
<td>Underground – safe, invisible and tamper-proof</td>
<td>Power transfer is conducted underground, ensuring safety, invisibility, and protection against tampering.</td>
</tr>
<tr>
<td>Zero emissions and low maintenance</td>
<td>Vehicles produce no pollutants and require minimal maintenance.</td>
</tr>
</tbody>
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### Project partners:

![Project Partner Logos]

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primove is ready
emission-free mobility

First inductively charged
PRIMOVE e-bus
in passenger operation in 2013

Commercial e-bus projects:
Braunschweig, Mannheim,
Berlin, Germany and
Bruges, Belgium

Homologation e-bus,
Mannheim, Germany

Pilot car, Lommel, Belgium

2012

Pilot bus, Lommel, Belgium

2010

Pilots tram, Bautzen and Augsburg, Germany

2008

Technology development

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SUCCESSFUL HOMOLOGATION

PRIMOVE 200 system for e-bus in Mannheim, Germany, homologated by TÜV SÜD for passenger operation on public roads in November 2012

PRODUCT OF CHOICE

PRIMOVE 200 system now available with 12m electric buses of different European OEMs
primove e-bus

**Automatic, fast charging**
Charging as part of operations, no battery swapping, no extra buses, no extra dwell time

**Invisible charging infrastructure**
No cables, no overhead lines, immune to bad weather

**Smaller, lighter system**
Vehicles can carry passengers, not batteries

**Higher passenger comfort**
No emissions, no noise, no vibrations

**Lower Total Cost of Ownership (TCO)**
Reduction of TCO and lifecycle expenses
primove automotive
Hassle-free solution for electric vans and cars

Automatic charging process
Nothing to plug in – convenient and intelligent energy transfer requiring no special qualification or training

100% availability and reliability
High power transfer to ensure uninterrupted operations without range constraints

Lighter system for optimal performance
Smaller, lighter batteries for longer battery life thanks to fast charging at convenient points and times
### primove Rail

**The most advanced catenary-free technology available**

- Invisible, no visual pollution.
- Components hidden under the vehicle and beneath the track
- Safe inductive power transfer (IPT)
- Non-contact, no wearing of parts
- All-weather performance
- Customizable to specific needs of every city, including:
  - diverse performance expectations
  - varying distances
  - Different topographical conditions
  - Brownfield or greenfield
- Easy to Install
- Same performance as with catenary system
Advantages of primove Rail: Safe

The PRIMOVE system is compliant to all applicable codes and standards for electromagnetic compatibility.

No health or safety hazard to passengers and pedestrians as all electric devices are fully isolated.

No interference with other systems and equipment.

No impact on electrical appliances like mobile phones or heart pacemakers.

- Bombardier works closely with independent assessors to establish top standards for safety.

Pacemaker Testing
Advantages of primove Rail:

Reliable

- Vehicle operation even under adverse weather and ground conditions
- No risk of power loss due to contact break – unlike other ground power supply technology
- Redundancy of overhead lines and poles clears the view for impressive cityscapes, landmark buildings or green areas

Runs in sand, snow, salty slush
primove Rail
Two options to suit every city

100% CFO – Premium solution
- PRIMOVE inductive charging system + Li-Ion battery
- Especially suitable for new systems and complete tram lines
- primove at stations, on grades, or at crossings, where needed

Partial CFO – Standard solution
- Overhead lines at tram stops to charge Li-Ion battery via pantograph
- Especially suitable for existing catenary systems where CFO is required on sections up to 2 km
primove Rail
Inductive Power Transfer Technology

Power receiver (pick-up) mounted under the vehicle

Power cable fully isolated and invisible in the ground

Energy storage device combined with propulsion unit for optimized performance
The inductive principle has been well known for many years. It can now set new standards in electric mobility:

Schematic principle of a transformer
- Iron core
- Primary and secondary windings

Iron core can be split
- Air gap between primary and secondary winding possible

Primary side can be modified
- Primary winding around iron core can be replaced by several cables
primove Rail
System Components

Energy storage device

Vehicle

Power receiver (Secondary winding)

Antenna (Transmitter)

Track

Primary winding

Detection loop

SCADA cable

Wayside

Decoder

Inverter

DC feeder (750V)

Substation

Energy storage device

PRIMOVE CFO solution
primove Rail
Energy storage on the vehicle

- Energy savings up to 30% for light rail systems without regen
- Boost to the vehicle’s power for higher acceleration
- Optimization of power supply
- Reduced infrastructure investment
- Catenary-free operation for short distances and as a part of the primove solution for longer distances

Energy storage device stores electrical energy released when braking

- Storing energy while braking
- Using stored energy during acceleration
**primove Rail**
Lithium-ion energy saver battery for fewer segments

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**Station**
- 45 m
- PRIMOVE 100%
- 9 m segments
- Battery loading

**Acceleration**
- 0 to 140 m
- PRIMOVE 100%
- Long segments when speed over 15 kph
- Power support

**Coasting / Breaking**
- 680 m
- No PRIMOVE elements in track
- Relays on battery only

**Station**
- 45 m
- PRIMOVE 100%
- 9 m segments
- Battery loading

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**Average distance between stations:** 865m
- Total distance PRIMOVE: 45 to 185 m which is 5% to 21% of guide way

- No primove elements for coasting/braking, battery not unloaded excessively
- Primove elements on other critical locations (e.g., grades)
Selected Projects

Commercial projects

- Braunschweig
  - Circular bus line
  - 2 + 4 e-buses

- Bruges
  - City centre bus line
  - 3 e-buses

- Mannheim
  - Inner-city bus line
  - 2 e-buses

- Berlin\(^1\)
  - Inner-city bus line
  - 8 e-bus

Development projects

- Lommel
  - Inductive charging tests
  - e-bus + e-car

- Mannheim
  - Dynamic charging tests
  - e-bus

- Augsburg
  - Static & dynamic charging tests
  - Tram, e-bus, e-van

\(^1\) Subject to funding approval and contract by the German Government and the city of Berlin
**primove Rail**

**Augsburg Pilot**

Demonstrated the system’s technical capability and compliance with all standards for electromagnetic compatibility under real conditions of operation in urban environment.

Co-funded by the German Federal Ministry for Transport, Building and Urban Development (BMVBS)

Realised in cooperation with the Augsburg Transport Authority (Stadtwerke Augsburg Verkehrs GmbH)

Continuous power transfer, dynamic & static

2x100 kW power max

Safe
**PRIMOVE e-bus – Mannheim, Germany**

Inductive opportunity charging on demanding city route

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**Timeline**
- Project start: October 2012
- Construction completed: October 2013
- Vehicle tests: Q1 2014
- Start of operations: Q2 2014

**Project scope**
- 2 x 12m e-buses (HESS)
- 1 x e-van (Mercedes Vito)

**Route**
- Line 63: 9 km inner-city line, SORT 1

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**Charging stations:**
- 2 x at end stops
- 4 x at intermediate & selected bus stops
- 2 x in the depot (e-bus and e-van)
BOMBARDIER
the evolution of mobility

http://primove.bombardier.com
primove Rail
Vehicle Components
primove Rail
Vehicle Power Receiver (Generation 2)
primove Rail
Wayside and Track Elements, Schematic
Windings are easy to install

All components are pre-tested and certified prior to commissioning

Existing tracks can be easily modified to allow installation of wayside components

Track and wayside components are completely covered to allow movement of normal traffic over the track area

1. Inverter
2. Cover
3. Detection loop
4. Cable support
All PRIMOVE wayside components fit completely in the envelope of the vehicle

No additional foundation required

- Maximum depth below top of rail: less than 600mm

Primary windings fit completely between rails

Less land surface needed than for catenary systems
primove Rail
Batteries and Supercaps

**MITRAC Energy saver (Supercaps)**
- Energy saving (ES) operation with good efficiency.
- Cost-effective solution for ES.
- CFO for short distances.
- Series product since 2009
- Over 3 million km driven to date.

**Traction battery**
- Battery is a good solution for CFO applications due to the large amount of stored energy – long range.
- Battery is cost effective for CFO.
### primove Rail

Segments for acceleration extend battery life

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**Power between 2 stations; max. speed 50 km/h**

- **Power boost in acceleration phase** => up to 4 times less battery stress
  
  (Battery stress ~ r i^2 ; 2 times less power => 4 times less stress)

- **Opportunity**: 10 s power on in front of running vehicle may be acceptable
  => longer segments when speed over 15 kph

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**Battery Stress Calculation**:

- **E_{batt} ~ 0 kW-h**

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**Diagram Notes**:

- 30 s: 3.3 kW-h
- 17 s: 2.3 kW-h
- 43 s: 1.9 kW-h
- 12 s: -2.5 kW-h
- -2.2 kW-h

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**Legend**:

- **Vehicle Power**
- **PRIMOVE**
- **Battery**