EcoActive Technologies

PRIMOVE
Catenary-Free Operation

In many city centres overhead lines and their surrounding infrastructure contribute to visual pollution of historic streets, parks or architectural landmarks. Catenary-free tracks for trams and light rail vehicles heighten the attractiveness of a city and provide for unobstructed views.

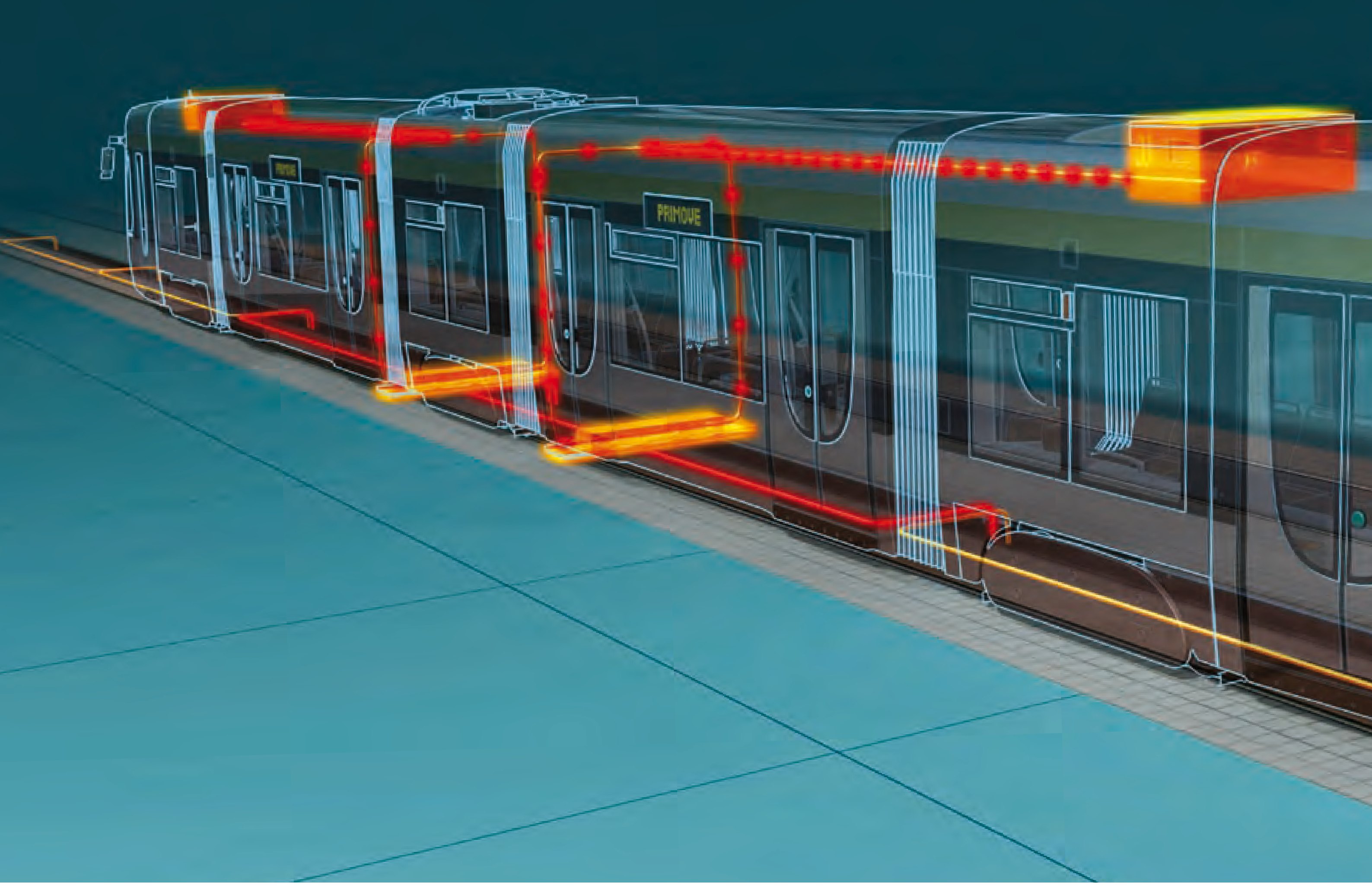
A world-premiere: contactless power transfer for urban rail vehicles

The new and unique *BOMBARDIER* PRIMOVE** system allows catenary-free operation of *FLEXITY** trams over distances of varying lengths and in all surroundings as well as on underground lines – just like any conventional system with overhead lines. What makes it outstanding is that the power transfer is contactless; the electric supply components are invisible and hidden under the vehicle and beneath the track.

The benefits are evident:

- Elimination of overhead wires – increasing a city's attractiveness
- Safe inductive power transfer
- No wear of parts and components
- Resistant to all weather and ground conditions including storms, snow, ice, sand, rain and water

The *PRIMOVE* system is connected to the *BOMBARDIER* MITRAC** Energy Saver, which stores electrical energy that is gained during operation and braking on board the vehicle by using high-performance double layer capacitor technology. Doing so optimizes power supply and saves energy.



Catenary-free operation – energy flow

Bombardier is at the forefront of continuously improving rail transportation as an ecologically leading mode of transport

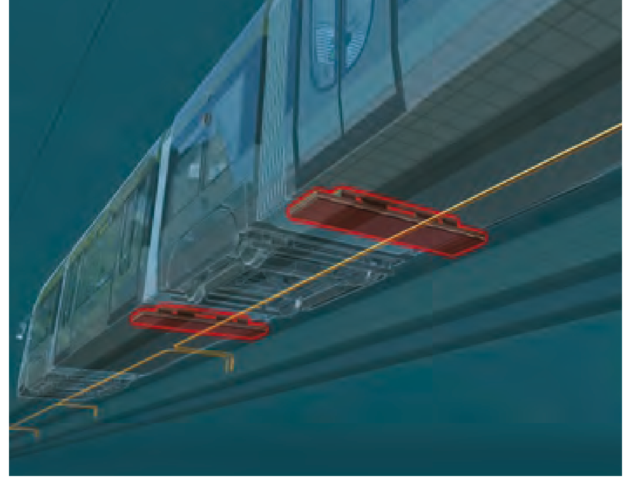
Preserving our environment by reducing emissions and using energy resources in an efficient and responsible way are undoubtedly major challenges which communities all over the world face today. Exhaust emissions and noise are some of the main factors that lead to a deterioration in the quality of life in our cities. In urban transport, railbound operations are making a major contribution to relieving congestion as well as cutting CO_2 and noise emissions.

Why Catenary-Free operation?

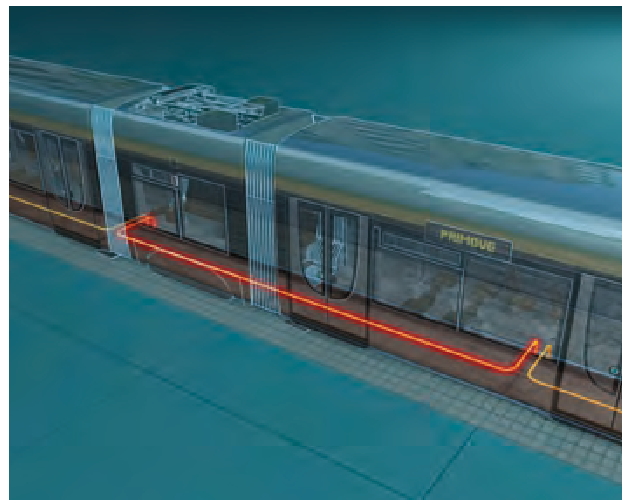
In addition to these well-known factors, municipal authorities are increasingly facing visual pollution caused by power poles and overhead lines obstructing the visibility of landmark buildings and squares. With *PRIMOVE* catenary-free operation trams can even run through heritage-protected areas, such as parks and gardens, historic market and cathedral squares, where conventional catenary systems are not permitted, thus preserving natural and historic environments. Additionally, when planning a new system or extensions catenary-free operation will contribute to an attractive and forward-looking appearance.

PRIMOVE Catenary-free operation – safe, cost-efficient, reliable and flexible:

- Due to invisible and contactless power supply, operation of the *PRIMOVE* catenary-free system is safe for pedestrians and other road users such as bikes, motorbikes or cars
- With no direct contact during energy transfer there is no wear of parts and components which keeps service and maintenance costs at a minimum – the initial construction costs lie far below those of any comparable solution on the market
- Reliable performance in all weather and ground conditions
- Same vehicle performance as with conventional catenary systems
- With the on-board *MITRAC* Energy Saver the system can continuously recharge the energy levels needed for uninterrupted maximum performance
- The *PRIMOVE* system can be tailored to the individual needs of each city: it is adaptable to different topographical conditions, performance expectations and distances



Pick-up coils



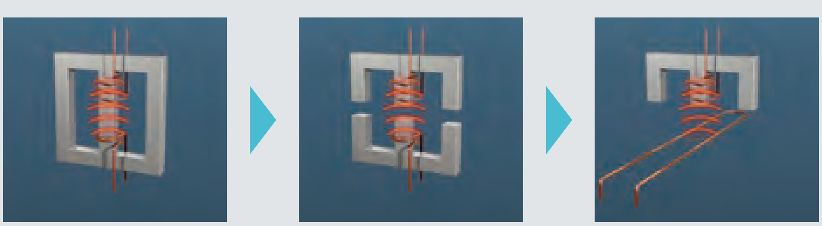
Underground cables

How does the PRIMOVE system work?

When running on conventional systems, trams and light rail vehicles take their energy from an overhead electrical line. Equipping the tracks and the vehicle with the *PRIMOVE* components also allows operation without a catenary. Cables laid beneath the ground are connected to the power conditioning and supply network. They are only energized when fully covered by the vehicle, which ensures safe operation. A pick-up coil underneath the vehicle turns the magnetic field created by the cables in the ground into an electric current that feeds the vehicle traction system.

Inductive power transfer principle

The functional principle is based on the inductive power transfer of a transformer (see illustration below) – a principle that is up to now has only been used in certain industrial applications (in the automotive industry for transportation systems in manufacturing) or with household appliances (i.e. electric toothbrush).



Transformer

Air gap in iron core

Primary winding extended as loop

Bottom iron core removed

Working principle – inductive power transfer

PRIMOVE Catenary-Free Operation

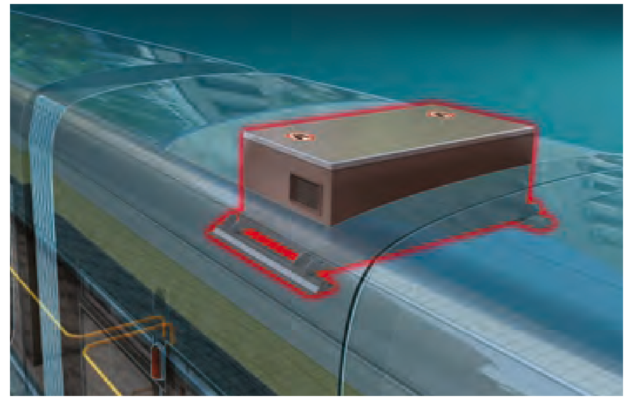
MITRAC Energy Saver

The vehicle mounted *MITRAC* Energy Saver stores the energy gained during braking and is constantly charged up during operation, either when the vehicle is in motion or waiting at a stop, picking up the power from the underground section. Doing so allows both maximum vehicle performance and constant inductive power levels, ensuring continuous operation of the vehicle just like conventional catenary systems.

Testing at Bombardier in Bautzen

The new *PRIMOVE* catenary-free solution is undergoing extensive testing at the test track of the Bombardier site in Bautzen, Germany. A low-floor tram and the test track are equipped with the *PRIMOVE* components and different phases simulating regular operation are being carried out.

ECO4 – Energy, Efficiency, Economy and Ecology
PRIMOVE **catenary-free operation forms part of Bombardier's *ECO4** environmentally friendly technologies. Addressing the growing challenges among operators to reduce Energy consumption, improve Efficiency, protect the Ecology while making sense Economically, *ECO4* is the concrete validation of Bombardier's declaration – *The Climate is Right for Trains**.**



MITRAC Energy Saver

Performance of the PRIMOVE System

- 250 kW continuous output of the *PRIMOVE* system, designed for a typical light rail vehicle (30 metres long, operating at a speed of 40 km/h with a gradient of six percent). A prototype vehicle is currently undergoing tests at Bombardier in Bautzen
- Performance can be provided to vary from 100 to up to 500 kW, depending on the respective vehicles and system requirements: length and number of vehicles, topographic conditions, range of application

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BOMBARDIER

primove
Wireless eMobility

Change the way to charge

BOMBARDIER
the evolution of mobility

No emissions
No wires
No hassle

eMobility redefined

The BOMBARDIER PRIMOVE solution is a game-changing technology that enables the wireless charging of electric vehicles. Based on inductive power transfer, the PRIMOVE system liberates eMobility from the constraints of cables, wires and plugs – making urban transport more flexible and convenient than ever before.

The innovative PRIMOVE system provides a contactless power source for all types of electric transport – from light rail and bus networks to commercial vehicles and cars.

Discover how the PRIMOVE solution is ready to transform the eMobility landscape today.

The primove advantages

Invisible
The principle of inductive power transfer allows energy to be transferred in a contactless manner – no more plugs, wires or overhead cables. The necessary components are buried underground and hidden beneath the vehicle, making the PRIMOVE solution a safer, less cluttered system that gives urban planners and public transport operators more freedom over the design of urban mobility solutions.

Clean and quiet
Electric vehicles generate no emissions at the point of use – no carbon dioxide, no noxious gases, no particulates. This brings significant and sustainable improvements in air quality, thereby raising the level of passenger comfort and making the urban environment cleaner and more pleasant for its residents.

No recharging constraints
Due to the high level of power that can be transferred with the PRIMOVE system, vehicles can recharge quickly enough to avoid lengthy waiting periods. Regular stops are turned into convenient charging opportunities that have no disruptive effect on the timetable. This means that vehicle availability and service reliability can be ensured.

Flexible and reliable
PRIMOVE technology offers a variety of charging solutions for all electric vehicles that is compatible with all weather and ground conditions. It can be adapted to any city, course and topography – perfect for fast-tracking the acceptance of sustainable mobility practices.

Convenient
Thanks to the intelligent vehicle detection function that makes the charging process fully automated, recharging is driver-friendly and hassle-free. No specific training or qualifications are required and the driver never comes into contact with electricity, ensuring that the entire process is safe.

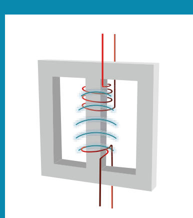
Competitive
The PRIMOVE solution makes the electric vehicle market competitive and attractive again. By maximising the concept of opportunity charging at high power levels, the PRIMOVE system reduces total cost of ownership and provides an affordable and attractive solution without reverting to impractical solutions like battery swapping.

Easy integration
The PRIMOVE system is quick and easy to install. Prefabricated and tested modules can easily be integrated into any ground surface and the system can be fitted onto any new or existing rail or road infrastructure. It has no moving parts and only a small number of components, all of which are buried underground or hidden beneath the vehicle. This significantly minimises wear and tear, while guaranteeing protection against vandalism. The result is lower maintenance costs and higher service reliability.

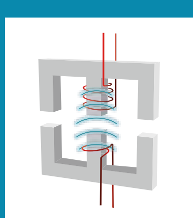
The technology behind primove

The inductive principle

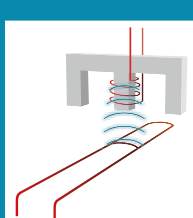
Based on the principle of inductive power transfer, PRIMOVE technology allows energy to be transmitted without contact between components buried underground and receiving equipment installed beneath the vehicle. The principle functions as follows: an electric conductor creates a magnetic field, which generates an electric current in another conductor placed within that field. When applied in conjunction with the PRIMOVE system, this electric current generates energy that is then used to propel vehicles forward in a clean, efficient way.



Electric current in a primary coil (winding) creates a magnetic field, which induces current in a secondary coil.



This power transfer occurs even if there is a gap in the iron core, enabling the process to be contactless.



If the primary coil is extended in a loop, the secondary coil can receive power anywhere along this loop.

Introducing high power opportunity charging

Range and recharging constraints are the key concerns when it comes to converting an entire delivery fleet or bus network to electric power. In order to address these issues while offering a solution that is light, easy to integrate and competitive, the PRIMOVE system combines a regular charging pattern with energy transfer at high power levels. The charging process is seamlessly integrated into existing operations, thereby ensuring uninterrupted service without any need for additional fleet vehicles or batteries.

Light rail

Charging segments are integrated at every tram stop and the following few metres to enable recharging while letting passengers on/off and during acceleration.

Bus

Charging stations are positioned in the depot and/or en route at bus stops for recharging while letting passengers on/off without extended dwell times.

Automotive

Charging stations are installed at strategic points (e.g. loading docks for delivery vans, taxi ranks in airport waiting areas, supermarket parking spaces) to allow fast charging at convenient times when the vehicle is periodically not in use.

primove light rail
Liberating trams from overhead lines

In many ways, trams and light rail vehicles are the ultimate form of eMobility. Yet despite being clean, silent and convenient, they have always been hampered by one disadvantage – catenaries. Catenary power systems are complex to install, demanding to maintain and clutter the urban space with unattractive infrastructure.

No compromise on performance

• Same great performance as with catenary systems
• Reduction of energy consumption by up to 30 % when combined with an energy storage solution

Thanks to PRIMOVE contactless charging, light rail vehicles can now run without any need for unsightly poles and overhead lines. The energy source is moved underground and charges the vehicle via inductive power transfer. It now becomes possible to integrate light rail vehicles into urban areas where conventional catenary networks are prohibited or unwelcome – city centres, parks, gardens and protected heritage sites. The cityscape is left untouched, minimising visual pollution and improving the overall appeal of the city.

Minimised visual pollution

• Elimination of wires and poles – all components are hidden under the vehicle and beneath the track
• Installation is possible even in previously unsuitable areas such as heritage-protected sites

Reduced infrastructure

- Less land take needed than for catenary systems
- Less maintenance: no wear of pantographs and overhead lines, no risk of vandalism

Operational under all conditions

- Reliable even under adverse weather and ground conditions such as snow, ice and sand
- Compatible with all road surfaces and tracks

Augsburg, Germany

Demonstrating safe high power inductive charging for trams

In September 2010, Bombardier Transportation installed the contactless and catenary-free PRIMOVE system for trams on a 600-metre section of Line 3 to the Augsburg trade fair centre. The pilot project is being co-funded by the German Federal Ministry for Transport, Building and Urban Development (BMVBS) and realised in cooperation with the Augsburg Transport Authority (Stadtwerke Augsburg Verkehrs-GmbH) with the aim of demonstrating reliable operation under the real conditions of daily operation in an urban environment.

Federal Ministry
of Transport, Building
and Urban Development

Facts & figures

Start of operations:
September 2010

Vehicle type:
1 Bombardier bidirectional low-floor tram

Charging power:
200 kW

Lommel, Belgium

Taking the primove concept to the road

In October 2010, Bombardier joined the Flanders' DRIVE project in Lommel (Belgium), in which a consortium of industrial companies and R&D specialists came together to research the potential of inductive charging for electric road vehicles.

The project demonstrates high power transfer in both dynamic and stationary use, as well as the intermodal charging compatibility of the system. The project also demonstrates the system's operational efficiency in a real urban environment, on different road surfaces and under all weather conditions.

Facts & figures

Start of operations:
October 2010

Vehicle type:
1 Van Hool bus, 1 Volvo C30 car

Charging power:
40 kW & 80 kW (bus), 22 kW (car)

primove bus
Going electric

The bus market is experimenting with alternatives to combustion-driven vehicles, but few of these approaches offer a sustainable solution to our dependence on fossil fuel. More often than not, they involve serious compromises in vehicle availability, service reliability, aesthetics, or resources (e. g. battery swapping, requiring extra fleet vehicles or turning to conductive charging). In essence, these solutions fail to address the key issue of making the electric bus market competitive and attractive.

PRIMOVE technology represents a major leap forward by offering a wireless charging system that is easy to install and convenient to use. By incorporating high power charging at the most convenient points along bus routes, the PRIMOVE system ensures optimum fleet availability. The wireless charging process is seamlessly integrated into existing operations to allow uninterrupted service without reverting to impractical, unattractive or unaffordable solutions.

Continuous operations

- High power charging stops are integrated into routes
- No battery swapping, no extra fleet, no dwell time

Smaller, lighter system

- Extends battery life and lowers energy consumption
- Vehicles can carry passengers, rather than heavy batteries

Enhanced passenger comfort

- Elimination of unpleasant smell from gas fumes
- Less noise and vibration for a more enjoyable passenger journey

Lower Total Cost of Ownership (TCO)

- Reduction of the total cost of ownership, as well as lifecycle expenses
- No need to maintain two technologies compared with hybrids

primove automotive
eMobility unplugged

With virtually all electric devices now going wireless, it makes little sense to keep electric road vehicles tied to the leash in the form of charging plugs. Not only is plugging in the vehicle a real inconvenience but this type of system is also inherently unsuitable for energy transfer at very high power levels.

Moreover, several studies suggest that the key barriers preventing entry into the electric automotive market are fears about range constraints and the hassle associated with plug-in systems.

When it comes to commercial fleets, vehicle availability and service reliability are even more crucial to ensuring commercial success. This is why the PRIMOVE charging concept is designed around existing operations, ensuring continuous service for anything from delivery vans to taxis. With the opportunity charging approach coupled with high power transfer, the PRIMOVE system overcomes the key constraints, liberating electric fleets from range limitations with a charging process that is fast, convenient and safe.

Uninterrupted service

- Designed to ensure a continuous flow of fleet operations
- Minimised range and recharging constraints thanks to high power charging

Easy integration

- Prefabricated and tested modules are quickly integrated into any ground surface
- The system can be fitted onto any new or existing infrastructure

Lower maintenance and lifecycle costs

- Reduced total infrastructure costs and risk of vandalism
- No moving parts, no wear and tear

Driver-friendly

- No hassle with plugs, no special qualifications or training required
- No risk of human contact with electricity

Mannheim, Germany

A state-of-the-art eMobility facility

Committed to innovation and the continued development of PRIMOVE technology, Bombardier has opened a dedicated eMobility facility in Mannheim (Germany). This new Centre of Excellence supports partnerships, projects and opportunities in the fast-moving electric mobility sector. It hosts a complete power lab test set-up for all applications. Vehicles have been acquired to ensure that testing at the facility is conducted independently and in a real-life setting. Current tests are being performed on a minivan with a new prototype power receiver (pick-up) specifically designed for vehicles of this size. Further tests will help fine-tune and optimise the overall system and the functionality of individual components such as the cooling system, compatibility with external components and charging efficiency.

Facts & figures

Inauguration date:
September 2011

Number of vehicles tested:
1 bus, 2 minivans

Number of engineers:
50 highly-qualified employees

BOMBARDIER
100 years of experience in eMobility

As the global leader in the rail industry, Bombardier has over a century of experience in electric mobility. With 64 production and engineering sites in 26 countries, Bombardier Transportation develops, manufactures and services the broadest portfolio of mobility products in the world, making it the ideal partner for taking eMobility into the next phase of its evolution.

PRIMOVE technology is one of the highlights within the innovative BOMBARDIER ECO4 portfolio of technologies, which offer energy and cost-efficient solutions for total mobility performance.

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BOMBARDIER
the evolution of mobility

primove

Wireless eMobility

Change the way to charge

BOMBARDIER

the evolution of mobility

No emissions
No wires
No hassle

e-mobility redefined

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The innovative PRIMOVE system provides a contactless power source for all types of electric transport – from light rail and bus networks to commercial vehicles and cars.

Discover how the PRIMOVE solution is ready to transform the e-mobility landscape today.

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Clean and quiet
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No recharging constraints
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Flexible and reliable
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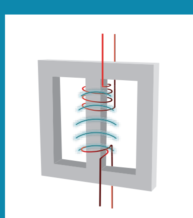

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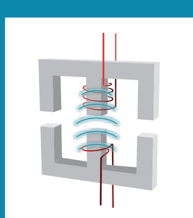

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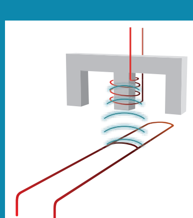

If the primary coil is extended in a loop, the secondary coil can receive power anywhere along this loop.

Introducing high power opportunity charging

Range and recharging constraints are the key concerns when it comes to converting an entire delivery fleet or bus network to electric power. In order to address these issues while offering a solution that is light, easy to integrate and competitive, the PRIMOVE system combines a regular charging pattern with energy transfer at high power levels. The charging process is seamlessly integrated into existing operations, thereby ensuring uninterrupted service without any need for additional fleet vehicles or batteries.

Light rail

Charging segments are integrated at every tram stop and the following few metres to enable recharging while letting passengers on/off and during acceleration.

Bus

Charging stations are positioned in the depot and/or en route at bus stops for recharging while letting passengers on/off without extended dwell times.

Automotive

Charging stations are installed at strategic points (e.g. loading docks for delivery vans, taxi ranks in airport waiting areas, supermarket parking spaces) to allow fast charging at convenient times when the vehicle is periodically not in use.

primove light rail
Liberating trams from overhead lines

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No compromise on performance

- Same great performance as with catenary systems
- Reduction of energy consumption by up to 30 % when combined with an energy storage solution

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Augsburg, Germany

Demonstrating safe high power inductive charging for trams

In September 2010, Bombardier Transportation installed the contactless and catenary-free PRIMOVE system for trams on a 800-metre section of Line 3 to the Augsburg trade fair centre. The pilot project is being co-funded by the German Federal Ministry for Transport, Building and Urban Development (BMVBS) and realized in cooperation with the Augsburg Transport Authority (Stadtwerke Augsburg Verkehrs-GmbH) with the aim of demonstrating reliable operation under the real conditions of daily operation in an urban environment.

Federal Ministry
of Transport, Building
and Urban Development

Facts & figures

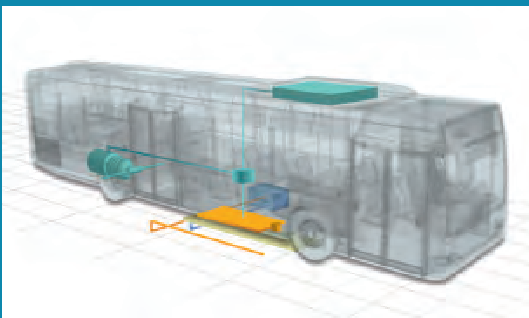
Start of operations:
September 2010

Vehicle type:
1 Bombardier bidirectional low-floor tram

Charging power:
200 kW

Braunschweig, Germany

Taking the primove concept to the road



Bombardier's first PRIMOVE bus project for passenger operation has been kicked off in the city of Braunschweig, Germany, which marks a significant leap forward in bringing clean e-mobility solutions to urban areas. A 12 km section of the bus network is turned into an eco-friendly electric route which is served by two PRIMOVE equipped buses. The German Federal Ministry of Transport, Building and Urban Development is granting Bombardier and its project partners, the public transport operator Braunschweiger Verkehrs-AG, the local energy company BS Energy, as well as the Technical University of Braunschweig, the sum of 2,9 million EUR to fund the initiative.

Federal Ministry
of Transport, Building
and Urban Development

Facts & figures

Start of operations:
Q3 2013

Vehicle type:
2 Solaris buses (12 m and 18 m)

Length of route:
12 km

primove bus
Going electric

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Continuous operations

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Smaller, lighter system

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Lower Total Cost of Ownership (TCO)

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primove automotive
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When it comes to commercial fleets, vehicle availability and service reliability are even more crucial to ensuring commercial success. This is why the PRIMOVE charging concept is designed around existing operations, ensuring continuous service for anything from delivery vans to taxis. With the opportunity charging approach coupled with high power transfer, the PRIMOVE system overcomes the key constraints, liberating electric fleets from range limitations with a charging process that is fast, convenient and safe.

Uninterrupted service

- Designed to ensure a continuous flow of fleet operations
- Minimised range and recharging constraints thanks to high power charging

Easy integration

- Prefabricated and tested modules are quickly integrated into any ground surface
- The system can be fitted onto any new or existing infrastructure

Lower maintenance and lifecycle costs

- Reduced total infrastructure costs and risk of vandalism
- No moving parts, no wear and tear

Driver-friendly

- No hassle with plugs, no special qualifications or training required
- No risk of human contact with electricity

Mannheim, Germany

A state-of-the-art e-mobility hub

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Facts & figures

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September 2011

Applications tested:
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January 2012

Interim Guidance for Electric and Hybrid-Electric Vehicles Equipped With High Voltage Batteries

The National Highway Traffic Safety Administration (NHTSA) is committed to ensuring the highest standards of safety on our Nation's roadways. To better protect consumers and the public safety community from the potential risk of fire and other hazards related to vehicles that have been involved in a motor vehicle crash, NHTSA has developed "Interim Guidance for Electric and Hybrid-Electric Vehicles Equipped With High Voltage (HV) Batteries." Developed with the assistance and expert input of the National Fire Protection Association, the Department of Energy (DOE) and others, the interim guidance for electric and hybrid-electric vehicles identifies appropriate post-crash safety measures for vehicle owners and the general public, emergency responders, and for towing/recovery operators and vehicle storage facilities.

NHTSA does not believe that electric vehicles present a greater risk of post-crash fire than gasoline-powered vehicles. In fact, all vehicles—both electric and gasoline-powered—have some risk of fire in the event of a serious crash. However, electric vehicles have specific attributes that should be made clear to consumers, the emergency response community, and tow truck operators and storage facilities. Out of an abundance of caution to prevent injury and loss of property, the interim guidance identifies considerations and actions for all electric and hybrid-electric vehicle crashes, including those involving the growing number of vehicles powered by lithium-ion batteries.

This interim guidance is intended to serve as a general reference for vehicle operators and responders. It was developed using current best practices and instructions from vehicle and battery manufacturers and others. It is not intended to replace information issued by the vehicle manufacturer, but rather to be used as a supplement to vehicle-specific guides. For more information about specific vehicle models, individuals should consult guidance provided by the vehicle manufacturer.

NHTSA, together with the Department of Energy, is continuing to explore strategies to ensure that the public and responder community receive the best information in the shortest possible time. The agency hope that this guidance will help to inform activities to educate responders and the public about electric vehicles including efforts already underway by DOE, NFPA, vehicle manufacturers, and others.

Interim Guidance for Electric and Hybrid-Electric Vehicles Equipped With High Voltage Batteries (Vehicle Owner/General Public)

ELECTRIC AND HYBRID-ELECTRIC VEHICLE CONSIDERATIONS

In the event of damage to or fire involving an electric vehicle (EV) or hybrid-electric vehicle (HEV):

- Always assume the high voltage (HV) battery and associated components are energized and fully charged.
- Exposed electrical components, wires, and HV batteries present potential HV shock hazards.
- Venting/off-gassing HV battery vapors are potentially toxic and flammable.
- Physical damage to the vehicle or HV battery may result in immediate or delayed release of toxic and/or flammable gases and fire.

VEHICLE INFORMATION

- Know the make and model of your vehicle.
- Review the owner's manual and become familiar with your vehicle's safety information and recommended safety practices.
- Do not attempt to repair damaged electric or hybrid-electric vehicles yourself. Contact an authorized service center or vehicle manufacturer representative for service.

EMERGENCIES

CRASH: A crash or impact significant enough to require an emergency response for conventional vehicles would also require the same response for electric or hybrid-electric vehicles.

If possible

- Move your car to a safe, nearby location and remain on the scene.
- Roll down windows before shutting the vehicle off.
- Place the vehicle in Park, set the parking brake, turn off the vehicle, activate hazard lights, and move keys at least 16 feet away from the vehicle.

Always

- Call 911 if assistance is needed and advise that an electric or hybrid-electric vehicle is involved.
- Do not touch exposed electrical components or the engine compartment, as a shock hazard may exist.
- Avoid contact with leaking fluids and gases, and remain out of the way of oncoming traffic until emergency responders arrive.
- When emergency responders arrive, tell them that the vehicle involved is an EV or HEV.

FIRE: As with any vehicle, call 911 immediately if you see sparks, smoke, or flames coming from the vehicle.

- Exit the vehicle immediately.
- Advise 911 that an electric or hybrid-electric vehicle is involved.
- As with any vehicle fire, do not inhale smoke, vapors, or gas from the vehicle, as they may be hazardous.
- Remain a safe distance upwind and uphill from the vehicle fire.
- Stay out of the roadway and stay out of the way of any oncoming traffic while awaiting the arrival of emergency responders.

POST-INCIDENT

- Do not store a severely damaged vehicle with a lithium-ion battery inside a structure or within 50 feet of any structure or vehicle.
- Ensure that passenger and cargo compartment remain ventilated, i.e., open a window, door or trunk.
- Notify an authorized service center or vehicle manufacturer representative as soon as possible as there may be other steps they can take to secure and discharge the HV battery.
- Call 911 if you observe leaking fluids, sparks, smoke, flames, or hear gurgling or bubbling from the HV battery.

Interim Guidance for Electric and Hybrid-Electric Vehicles Equipped With High Voltage Batteries (Law Enforcement)

ELECTRIC AND HYBRID-ELECTRIC VEHICLE CONSIDERATIONS

In the event of damage to or fire involving an electric vehicle (EV) or hybrid-electric vehicle (HEV):

- Always assume the high voltage (HV) battery and associated components are energized and fully charged.
- Exposed electrical components, wires, and HV batteries present potential HV shock hazards.
- Venting/off-gassing HV battery vapors are potentially toxic and flammable.
- Physical damage to the vehicle or HV battery may result in immediate or delayed release of toxic and/or flammable gases and fire.

IDENTIFY VEHICLE

Determine if the vehicle is an electric or hybrid-electric vehicle, and if it is, advise Dispatch and all responders that an electric or hybrid-electric vehicle is involved.

IMMOBILIZE VEHICLE

- Always approach vehicle from the sides to stay out of potential travel path. It may be difficult to determine if the vehicle is running due to lack of engine noise.
- If possible, chock the tires, place the vehicle into Park and set the parking brake.

DISABLE VEHICLE

- Place vehicle in Park, set parking brake, turn off the vehicle, activate hazard lights, and move vehicle keys at least 16 feet away from vehicle.
- If your local standard operating procedures (SOPs) allow, and if you are properly trained and equipped, disconnect the 12-volt battery. CAUTION: Safety restraints, air bags and other safety systems may be active for up to five minutes after disconnecting the 12-volt battery.

EMERGENCIES

NOTE: Follow local standard operating procedures (SOPs) for personal protection and safety.

CRASH:

- If you detect leaking fluids, sparks, smoke, flames, increased temperature, gurgling, popping or hissing noises from the HV battery compartment, ventilate passenger area (i.e., roll down windows or open doors) and request fire department response.
- Request Emergency Medical Services if there are injuries as a result of the crash.
- If you detect any unusual odors or experience eye, nose, or throat irritation, move away from the vehicle and evacuate others from the immediate area.
- Avoid contact with orange high voltage cabling and areas identified as high voltage risk by warning labels.
- Remain a safe distance upwind and uphill from the vehicle and stay out of the way of oncoming traffic until other appropriately equipped emergency responders arrive.
- Be alert. There is a potential for delayed fire with damaged lithium-ion batteries.

FIRE:

- If you are unable to quickly remove the occupants, use a fire extinguisher to protect them from the flames.
- As with any vehicle fire, the byproducts of combustion can be toxic and all individuals should be directed to move to a safe distance upwind and uphill from the vehicle fire and out of the way of oncoming traffic.

POST-INCIDENT

- Always assume the HV battery and associated components are energized and fully charged during investigation and storage.
- Ensure that passenger and cargo compartment remain ventilated, i.e., open window, door, or trunk during investigation and storage.
- Notify an authorized service center or vehicle manufacturer representative as soon as possible as there may be other steps they can take to secure and discharge the HV battery.
- Do not store a severely damaged vehicle with a lithium-ion battery inside a structure or within 50 feet of any structure or vehicle.
- Request fire department if you observe leaking fluids, sparks, smoke, flames, or hear gurgling or bubbling from the HV battery.

Interim Guidance for Electric and Hybrid-Electric Vehicles Equipped With High Voltage Batteries (Emergency Medical Services)

ELECTRIC AND HYBRID-ELECTRIC VEHICLE CONSIDERATIONS

In the event of damage to or fire involving an electric vehicle (EV) or hybrid-electric vehicle (HEV):

- Always assume the high voltage (HV) battery and associated components are energized and fully charged.
- Exposed electrical components, wires or HV batteries present potential HV shock hazards.
- Venting/off-gassing HV battery vapors are potentially toxic and flammable.
- Physical damage to the vehicle or HV battery may result in immediate or delayed release of toxic and/or flammable gases and fire.

IDENTIFY VEHICLE

Determine if the vehicle is an electric or hybrid-electric vehicle, and if it is, advise Dispatch and all responders that an electric or hybrid-electric vehicle is involved.

IMMOBILIZE VEHICLE

- Always approach vehicle from the sides to stay out of potential travel path. It may be difficult to determine if the vehicle is on due to lack of engine noise.
- If possible, chock the tires, place the vehicle into Park and set the parking brake.

DISABLE VEHICLE

- Place vehicle in Park, set parking brake, turn off the vehicle, activate hazard lights, and move vehicle keys at least 16 feet away from the vehicle.
- If your local standard operating procedures (SOPs) allow and if you are properly trained and equipped, disconnect the 12-volt battery. CAUTION: Safety restraints, air bags, and other safety systems may be active for up to five minutes after disconnecting 12-volt battery.

EMERGENCIES

NOTE: Follow local standard operating procedures (SOPs) for personal protection and safety

CRASH:

- Request law enforcement response if you need assistance with traffic control or scene safety.
- If you detect leaking fluids, sparks, smoke, flames, increased temperature, gurgling, popping or hissing noises from the HV battery compartment, ventilate passenger area (i.e., roll down windows or open doors) and request fire department response.
- Avoid contact with orange high voltage cabling and areas identified as high voltage risk by warning labels.

- Move away from the vehicle and evacuate others from the immediate area if you detect any unusual odors or experience eye, nose, or throat irritation. Rapid extrication may be needed for injured or trapped occupants.
- Remain a safe distance upwind and uphill from the vehicle and out of the way of oncoming traffic until other appropriately equipped emergency responders arrive.
- Be alert. There is a potential for delayed fire with damaged lithium-ion batteries.

FIRE:

- If you are unable to quickly remove the occupants, use a fire extinguisher to protect them from the flames.
- As with any vehicle fire, the byproducts of combustion can be toxic and all individuals should be directed a safe distance upwind and uphill from the vehicle fire and out of the way of oncoming traffic.

POST-INCIDENT

- Always assume the HV battery and associated components are energized and fully charged.
- Ensure that passenger and cargo compartment remain ventilated, i.e., open window, door, or trunk if and when inside vehicle providing patient care.
- Notify authorized service center or vehicle manufacturer representative as soon as possible as there may be other steps they can take to secure and discharge the HV battery.
- Do not store a severely damaged vehicle with a lithium-ion battery inside a structure or within 50 feet of any structure or vehicle.
- Request fire department if you observe leaking fluids, sparks, smoke, flames, or hear gurgling or bubbling from the HV battery.

Interim Guidance for Electric and Hybrid-Electric Vehicles Equipped With High Voltage Batteries (Fire Department)

ELECTRIC AND HYBRID-ELECTRIC VEHICLE CONSIDERATIONS

In the event of damage to or fire involving an electric vehicle (EV) or hybrid-electric vehicle (HEV):

- Always assume the high voltage (HV) battery and associated components are energized and fully charged.
- Exposed electrical components, wires, and HV batteries present potential HV shock hazards.
- Venting/off-gassing HV battery vapors are potentially toxic and flammable.
- Physical damage to the vehicle or HV battery may result in immediate or delayed release of toxic and/or flammable gases and fire.

IDENTIFY VEHICLE

- Determine if the vehicle is an electric or hybrid-electric vehicle, and if it is, advise Dispatch and all responders that an electric or hybrid-electric vehicle is involved.

IMMOBILIZE VEHICLE

- Always approach vehicle from the sides to stay out of potential travel path. It may be difficult to determine if the vehicle is running due to lack of engine noise.
- If possible, chock the tires, place the vehicle into Park, and set the parking brake.

DISABLE VEHICLE

- Place vehicle in Park, set parking brake, turn off the vehicle, activate hazard lights, and move vehicle keys at least 16 feet away from vehicle.
- If your local standard operating procedures (SOPs) allow and if you are properly trained and equipped, disconnect the 12-volt battery. CAUTION: Safety restraints, air bags, and other safety systems may be active for up to five minutes after disconnecting the 12-volt battery.

EMERGENCIES

NOTE: Follow local standard operating procedures (SOPs) for personal protection and safety

CRASH:
- If you detect leaking fluids, sparks, smoke, flames, increased temperature, gurgling or bubbling sounds from the HV battery compartment, assume there is a battery fire and ventilate the passenger area (i.e., roll down windows, or open doors).
- If there is fire, and occupants are still inside the vehicle or are trapped, use a fire extinguisher to protect the occupants until a hose line is available or until the occupants are removed.

- Request Emergency Medical Services if there are injuries as a result of the crash.
- Request law enforcement if you need assistance with traffic control or scene safety.
- Move away from the vehicle and evacuate others from the immediate area if you detect any unusual odors or experience eye, nose, or throat irritation. Wear full Personal Protective Equipment (PPE) and Self-Contained Breathing Apparatus (SCBA) if rapid extrication is necessary for injured or trapped occupants.
- Be alert. There is a potential for delayed fire with damaged lithium-ion batteries.

FIRE:

NOTE: If the fire involves a lithium-ion battery, it will require large, sustained volumes of water for extinguishment. If there is no immediate threat to life or property, consider defensive tactics and allow fire to burn out.

- If there is active fire, follow local SOP for vehicle fires. Wear appropriate Personal Protective Equipment (PPE) and Self Contained Breathing Apparatus (SCBA) at all times.
- If occupants are still inside the vehicle or are trapped, use a fire extinguisher to protect the occupants until a hose line is available or until the occupants are removed.
- Establish a safe perimeter around the vehicle.
- Consider establishing a water supply to support long-term operation.
- Use a hose line to apply water to extinguish the fire while continuing to cool the HV battery and its casing. Never attempt to penetrate the HV battery or its casing to apply water.
- Avoid contact with orange high voltage cabling and areas identified as high voltage risk by warning labels.
- Be alert. There is a potential for delayed ignition or re-ignition of a lithium-ion battery fire even after it is believed to be extinguished. This may remain an issue until the lithium-ion battery is properly discharged.
- As with any vehicle fire, the byproducts of combustion can be toxic and all individuals not properly trained, dressed, and equipped to fight the fire should be directed a safe distance upwind and uphill from the vehicle fire and out of the way of oncoming traffic.

POST-INCIDENT

- Always assume the HV battery and associated components are energized and fully charged.
- Ensure that passenger and cargo compartments remain ventilated, i.e., open window, door or trunk if and when inside vehicle providing patient care.
- Notify an authorized service center or vehicle manufacturer representative (dealer) as soon as possible as there may be additional steps they can take to secure and discharge the HV battery.
- Do not store a severely damaged vehicle with a lithium-ion battery inside a structure or within 50 feet of any structure or vehicle.
- Vehicle should be monitored for leaking fluids, sparks, smoke, flames, gurgling or bubbling sounds from the HV battery, and if detected, assume the HV battery is burning and follow above guidance to extinguish the fire.

Interim Guidance for Electric and Hybrid Vehicles Equipped With High Voltage Batteries (Towing and Recovery Operators and Vehicle Storage Facilities)

ELECTRIC AND HYBRID-ELECTRIC VEHICLE CONSIDERATIONS

In the event of damage to or fire involving an electric vehicle (EV) or hybrid-electric vehicle (HEV):

- Always assume the high voltage (HV) battery and associated components are energized and fully charged.
- Exposed electrical components, wires, and HV batteries present potential HV shock hazards.
- Venting/off-gassing HV battery vapors are potentially toxic and flammable.
- Physical damage to the vehicle or HV battery may result in immediate or delayed release of toxic and/or flammable gases and fire.

IDENTIFY VEHICLE

- Determine if the vehicle is an electric or hybrid-electric vehicle, and if it is, advise your Dispatch and all other responders that an electric or hybrid-electric vehicle is involved.
- If you detect leaking fluids, sparks, smoke, flames, increased temperature, gurgling, popping or hissing noises from the HV battery compartment, ventilate passenger area (i.e., roll down windows or open doors) and call 911.
- Be alert. There is a potential for delayed fire with damaged lithium-ion batteries.

RECOVERING /TRANSPORTING VEHICLE:

- **Call an authorized service center or vehicle manufacturer representative, if necessary, to determine additional steps that you should take to safely recover or transport the vehicle.**
- Always approach vehicle from the sides to stay out of potential travel path. It may be difficult to determine if the vehicle is running due to lack of engine noise.
- Place vehicle into Park, set parking brake, turn off the vehicle, activate hazard lights, and remove keys to a distance at least 16 feet away from the vehicle until loading vehicle for transport.
- Refer to vehicle manual/recovery guide to locate proper attachment/connection points and transport method.
- Avoid contact with orange high voltage cabling and areas identified as high voltage risk by warning labels.

STORING VEHICLE

- **Notify authorized service center or vehicle manufacturer representative as soon as possible as there may be additional steps necessary you or they can take to secure and, discharge, handle, and store the HV battery and vehicle.**
- Do not store a severely damaged vehicle with a lithium-ion battery inside a structure or within 50 feet of any structure or vehicle.
- Ensure that passenger and cargo compartments remain ventilated.
- Prior to placing and while located in storage area/tow lot, continue to inspect vehicle for leaking fluids, sparks, smoke, flames, gurgling or bubbling sounds from the HV battery and call 911 if any of these are detected.
- Maintain clear access to stored vehicles for monitoring and emergency response if needed.

Resource Guide

The National Highway Traffic Safety Administration is dedicated to achieving the highest standards of excellence in motor vehicle and highway safety. NHTSA provides the public with facts on vehicle safety, driving safety, and research.
www.nhtsa.gov
www.safercar.gov
www.ems.gov

Electric Vehicle Safety Training is a nationwide program through the National Fire Protection Association to help firefighters and other first responders effectively deal with emergency situations involving electric and hybrid-electric vehicles. The Web site hosts an EV blog, calendar of events, training videos, emergency field guides from 19 auto manufacturers, research reports, as well as an online training course for the Chevy Volt.
www.evsafetytraining.org

SAE International is a resource for vehicle safety codes and standards. It has recently developed and revised safety standards for electric vehicles.
www.sae.org/standards

The Electric Drive Transportation Association is a resource for learning about different types of hybrid-electric and electric vehicles. It also has a fact sheet that details the numbers of hybrid vehicles on the road now and how many we can expect in the future.
www.electricdrive.org

The Alternative Fuels and Advanced Vehicles Data Center provides information, data, and tools to help fleets and other transportation decision-makers find ways to reduce petroleum consumption through the use of alternative and renewable fuels, advanced vehicles, and other fuel-saving measures.
www.afdc.energy.gov/afdc

HybridCars has detailed resources on every hybrid model on the road today. Its research section also provides studies and surveys about hybrid and electric vehicles in relation to technology, the environment, culture, and law.
www.hybridcars.com

The National Alternative Fuels Training Consortium promotes programs and activities that lead to energy independence, and encourages the greater use of cleaner transportation.
www.naftc.wvu.edu

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National Highway
Traffic Safety
Administration

NHTSA
www.nhtsa.gov

National Fire Protection Association
The authority on fire, electrical, and building safety

COVER STORY

Elemental Questions

As lithium-ion battery use increases, so do the concerns related to the fire-safety hazards of these devices. Through a series of research efforts and partnerships, NFPA is analyzing storage and safety issues surrounding the power source fueling hundreds of millions of devices — from iPhones to electric vehicles — worldwide.

NFPA Journal®, *March/April 2012*

By Fred Durso, Jr.

On a November evening in 2009, residents of Trail, British Columbia, were jolted by explosions that some people thought were part of a fireworks display. The bursts were actually the result of a fire at nearby Toxco Inc., a battery recycling facility. The explosions intensified as the fire ripped through the battery discharge building, and flaming projectiles from a bunker filled with "primary" lithium batteries caused the fire to spread to the adjoining district recycling facility.

The Canadian Broadcasting Corporation reported that the fire was so intense that firefighters could only attempt to contain the blaze for several hours before letting it burn out; lithium is highly reactive to water, and it was feared that attempts to douse the flames might have intensified the blaze. While there were no injuries or deaths, the fire destroyed the battery discharge building. A cause was never identified, but officials speculated that the fire was the result of an internal short in one of the stored batteries.

Incidents like the Toxco fire underscore the flammability and combustibility hazards associated with lithium batteries, which encompass dozens of different chemistries using pure lithium metal or lithium compounds-from the non-rechargeable primary lithium batteries used in industrial applications to the rechargeable lithium-ion cells that power our cameras, mobile phones, and even electric vehicles. Their range of uses is fueling their growing popularity; market projections indicate that the use of lithium-ion batteries, for example, is growing at about 20 percent per year.

YOUTUBE VIDEO INTERVIEW

Senior project manager Andrew Klock gives some insight into the National Highway Traffic Safety Administration's new electric vehicle guidelines and how they can help emergency responders.

Cabot, a global performance materials company, reports that battery makers sold about $8 billion of lithium-ion batteries globally last year. By 2020, Cabot says, that number is expected to increase to more than $18 billion. Concerns related to the protection of large quantities of lithium-ion batteries in storage settings against potential fires are expected to rise as more technologies embrace this popular power source.

Among the many industries looking to this emerging power source is the auto industry, which has incorporated lithium technology into its latest crop of electric vehicles (EVs). President Barack Obama has pledged to have a million EVs on U.S. roadways by 2015, a goal supported by U.S. Department of Energy Secretary Steven Chu, who recently said the country has a "good shot" of attaining this target. But the rechargeable lithium-ion battery technology used in these vehicles recently came under scrutiny when a Chevrolet Volt caught fire weeks after a crash test performed as part of a new-vehicle evaluation by the National Highway Traffic Safety Administration (NHTSA). The incident prompted an NHTSA investigation as well as a congressional hearing, where politicians grilled NHTSA and General Motors officials on the vehicle's safety, as well as on the timing of the NHTSA study. (For more on the NHTSA study, see "Crash + Burn.")

As dialogue on battery safety continues, NFPA is working with government agencies, insurers, and car manufacturers to address a national issue of emergency responder and consumer safety, and is offering its input and expertise to address the potential risks. The Fire Protection Research Foundation has initiated a study to identify the hazards, research gaps, and best suppression methods for batteries in storage settings. NFPA's Electric Vehicle Safety Training Project continues to educate the emergency responder and law enforcement communities on the safe handling of these batteries. Staff members have worked with NHTSA to develop guidelines for emergency responders on handling fires involving EVs and hybrid-electric vehicles.

"NFPA is uniquely situated to assist NHTSA and America's responders in looking at the challenges posed by the next generation of vehicles," says Ken Willette, NFPA division manager of Public Fire Protection. "We can draw from our technical expertise to provide best practices when responding to incidents involving these cars. If you add the Foundation's efforts in examining lithium-ion battery storage practices and extinguishing fires involving these battery packs, NFPA was the right choice to support NHTSA's work."

The storage challenge

Much of the current research and safety activity is aimed at lithium-ion batteries, which pack more energy per volume than other rechargeable battery chemistries and are in part responsible for lighter and sleeker designs for consumer electronics. (See "Staying Energized" for a primer on the science of lithium-ion batteries.) The appeal of this battery type extends beyond its size and power, since these power sources are able to maintain the bulk of their charge for months at a time when not in use and typically require minimal maintenance.

SIDEBARS

Crash + Burn

How a puzzling after-the-fact fire launched an investigation of the Chevrolet Volt's lithium-ion battery.

French Connection

Upcoming seminar underscores global impact of European research on lithium-ion batteries.

Staying Energized

A primer on the science fueling the lithium-ion battery market.

But the technology also comes with its own hazards. Late last year, retailer Best Buy and the Consumer Product Safety Commission recalled battery cases made for specific Apple iPhones following incidents of batteries overheating that burned more than a dozen users. In a very different application of the technology, tests on the lithium-ion battery packs in the Chevrolet Volt-General Motors' EV that also relies on a gasoline generator for power once the battery pack is discharged-also resulted in fires, though no incidents of Volt fires on roadways have been documented.

Addressing the potential fire hazards related to this technology, the Fire Protection Research Foundation's Property Insurance Research Group (PIRG) initiated the Lithium-Ion Battery Storage Protection Project last year to address potential fire risks involving these batteries in bulk storage and distribution settings. "What we're seeing is an emerging issue," says Richard Gallagher, line of business director-property for Zurich Services Corporation Risk Engineering and a PIRG member. "We realized that we're going to see warehouses filled with these batteries, but we really don't know how to protect them. Nowhere is there guidance to direct a building owner on how to protect this commodity."

The project's first phase was a literature review commissioned last year by the Foundation that identified these gaps in fire protection and assessed battery hazards. Among the hazard issues addressed in the final report, Lithium-Ion Batteries Hazard and Use Assessment, was the battery's makeup, particularly its high energy density and flammable solvent that aids ion movement in battery cells during charging. The report also identified the rare, yet potentially dangerous, circumstances leading to battery failure, including poor cell design or defects leading to short circuits, cell manufacturing flaws, external abuse of cells, and charging inadequacies. The rapid self-heating of a cell, known as "thermal runaway," is what the report terms an "energetic failure" that may cause the electrolyte to combust, potentially leading to a fire spreading to other battery cells or venting of potentially flammable vapors.

While there have been numerous studies conducted on small quantities of cells and small battery packs, little is known about the fire hazards of thermal runaway reactions, how these batteries burn in large quantities, or what suppression tactics are most effective. "This is a commodity that's become ubiquitous, and the fact that it's become ubiquitous before we've resolved these kinds of issues tell how well [lithium-ion batteries] work," says Celina Mikolajczak, senior managing engineer with Exponent, the engineering and scientific consulting firm that developed the research report for the Foundation. "They have been in the marketplace for about 20 years, originally in small volumes. As more cells are being shipped and more people use them, we certainly want to be aware of the associated risks, especially as bigger batteries are developed and we contemplate greener technologies."

PIRG met last August at the Foundation's Lithium-Ion Battery Storage Hazard Assessment Workshop in Baltimore to discuss findings from the Foundation's report and remaining gaps in fire hazard and suppression research. The workshop's "general battery storage" subgroup agreed that full-scale fire tests in these settings would determine the appropriate containment methods.

Heeding this advice, PIRG will begin testing this year as part of the second phase of its research project, which also includes determining the appropriate fire protection commodity classification for lithium-ion batteries. Exponent has already identified various commodity types and their challenges relative to bulk storage protection. PIRG has condensed its research list to two particular commodity types: small-format battery packs, and cells packed in large modules that when combined form EV batteries. PIRG will share the commodity classifications and testing results with NFPA 13, Installation of Sprinkler Systems, technical committees in order to aid the development of provisions related to lithium-ion battery storage. "Once the nature of the commodity is understood, the next step is to identify compatible fire extinguishing agents and design guidelines that the NFPA 13 committees can use to fill the current voids," says Gallagher.

The EV challenge

Lithium-ion car batteries received their fair share of attention over the past year. NHTSA, which occasionally assesses vehicles that incorporate new technology, initiated a series of tests on EVs last year. According to the agency's Chevrolet Volt Battery Incident Overview Report published in January, a crash test in May involving the Volt resulted in the leakage of battery coolant, damage to some of the battery's cells, and an electric short that precipitated a fire three weeks after the crash. During another round of tests in November, batteries began to smoke and emit sparks, while another caught fire a week after the tests.

While NHTSA isn't aware of any roadway crashes resulting in EV battery fires, it opened a defect investigation on the Volt in late November to further analyze the findings. A month later, GM proposed several modifications to the Volt, including the strengthening of the car's structure to further protect the battery pack during a collision and the addition of a sensor to monitor battery coolant levels. The upgrades will be applied to vehicles in production, as well as to the more than 8,000 Volts already on the road.

Also in November, NHTSA contacted NFPA to help assemble a series of interim guidelines for emergency responders, tow truck operators, consumers, and storage facilities to consider in the event of an EV or hybrid-electric vehicle fire. Staff members and consultants with NFPA's Electric Vehicle Safety Training Project and Public Fire Protection Division, who are well versed on handling various hazardous materials and response procedures, collaborated for the new project. NFPA is incorporating the interim guidelines into its EV training project, which instructs emergency responders on the growing fleet of EVs and related hazards through a series of online and classroom trainings.

"I'd compare NFPA's role in developing the interim guidelines to a fire ground commander calling in a specialty team to assist with a challenging situation," says NFPA's Willette. "NHSTA called us to provide technical guidance and insight into the development of the interim guidelines. The NFPA team responded, with all members focusing on their tasks until the mission was accomplished." With that input, Willette says, NHSTA was able to draft the interim guidelines.

Following the creation of the guidelines and structural safeguards for the Volt, NHTSA concluded its investigation in January. "NHTSA does not believe that the Chevy Volt or other electric vehicles pose a greater risk of fire than gasoline-powered vehicles," the agency said in a statement. (NFPA statistics indicate that in 2010 there were roughly 184,000 highway vehicle fires, nearly all of them in gasoline-powered vehicles, which resulted in 285 deaths.) "The agency expects this guidance will help inform the ongoing work by NFPA, the Department of Energy, and vehicle manufacturers to educate the emergency response community, law enforcement officers, and others about electric vehicles."

The manner in which NHTSA responded to the series of fires involving the Volt perplexed some politicians. A subcommittee of the House Oversight and Government Reform Committee held a hearing in January with NHTSA Administrator David Strickland, along with Dan Akerson, General Motor's chairman and chief executive officer, to question NHTSA on why it waited six months after the initial battery fire to launch an official investigation. The proceedings were at times acrimonious. "Your agency dropped the ball on this," U.S. Rep. Mike Kelly, a Pennsylvania Republican and committee member, said to Strickland at the hearing, according to the Grand Rapids Press. "For me, it comes down to taxpayer dollars being used to subsidize a product that this administration wants to go forward."

Strickland acknowledged the safety of the Volt and pointed out that there had been no on-the-road incidences of battery fires. He also testified that engineers used that time to meticulously analyze the cause of the fires. Had there been a public safety concern, Strickland said, NHTSA would have brought the issue to light sooner.

Gregory Cade, NFPA division director of Government Affairs, attended the hearing and noted that both Strickland and Akerson complimented NFPA for its involvement in developing the interim guidelines and on its collaboration with GM on aspects of NFPA's Electric Vehicle Safety Training Project. "The dilemma is that GM is only one carmaker using one battery technology," says Cade. "We've got to continue to reach out to other car and battery manufacturers. They're not all using the same technology."

NFPA has also continued expanding its EV training to other interested parties. The Department of Energy, which had initially awarded NFPA a $4.4 million grant in 2010 for its EV training project, recently extended participation to EMS and law enforcement officials. More than 15,000 people have already registered for an online training course featuring electrical and safety information on the Volt.

The course complements the project's "train the trainer" classroom courses attended by about 800 fire service professionals in 20 states. Anticipated for release this year is a reference guide that instructs emergency responders on identifying all makes and models of hybrid cars and EVs as well as how to safely respond to the vehicles in an emergency.

The training developments underscore NFPA's role as the authority on EV battery safety, says Andrew Klock, senior project manager for the EV Safety Training Project. "The training is exceeding our expectations," he says. "The attendance across the country has been much better than we anticipated. We thought we would have 45 fire service trainers in each state taking the course. In many states, we're pushing over 100. The EV Safety Training Project website is also becoming the place where the emergency responder community is getting their hybrid and EV safety information."

Looking ahead, the Foundation is partnering with the automotive industry and the Department of Energy (DOE) this year to develop best practices for the safe handling and disposal of damaged automotive batteries by emergency responders. The project is yet another aspect of the larger effort to assess and address the fire protection strategies of this rapidly emerging technology.

"EV battery safety represents a special challenge as this technology is in a rapid state of evolution," says Kathleen Almand, the Foundation's executive director. "Both NFPA and the Foundation have been proactively addressing many new energy-related technologies, from solar panels, to biofuel safety, to electric safety aspects of plug-in EVs to ensure that NFPA standards are appropriately addressing all of these emerging issues."

Fred Durso, Jr. is staff writer for NFPA Journal.

SIDEBAR

Crash + Burn

How a puzzling after-the-fact fire launched an investigation of the Chevrolet Volt's lithium-ion battery

The following is adapted from NHTSA's "Chevrolet Volt Battery Incident Overview Report."

As part of its New Car Assessment Program (NCAP), NHTSA conducted four side-pole crash tests of the Chevrolet Volt in 2011 to evaluate the vehicle's crashworthiness and occupant protection. All of the tested vehicles met compliance test requirements and were favorably rated for the NCAP program. Based on its performance, the Volt received an NHTSA five-star rating for both frontal and side-impact vehicle crashworthiness and occupant protection.


An EV battery damaged in a crash test started a fire that destroyed four vehicles at a test facility in Wisconsin. (Photo: NHSTA)

A side-pole crash test of a Chevrolet Volt was conducted on May 12, 2011, at MGA Research, a test facility in Wisconsin. On June 6, 2011, MGA Research personnel notified NHTSA that a fire event had occurred over the previous weekend and had been discovered by laboratory staffers that morning. The laboratory provided details of the vehicles involved in the event, which included the Chevrolet Volt that had been subjected to an NCAP pole test three weeks earlier.

After informing NHTSA about the fire, MGA notified the local fire authorities, who performed an initial scene investigation that focused on identifying possible arson issues. NHTSA contracted with a battery and fire expert, Hughes Associates, to investigate the origin and cause of the fire. The initial forensic inspection was conducted June 13–14 at the MGA facility. In

July 2011, Hughes Associates' preliminary findings indicated that the fire incident at MGA most likely originated in the Chevrolet Volt.

This preliminary finding triggered further investigation. The vehicle, along with the fire-damaged lithium-ion propulsion battery, was shipped to NHTSA's Vehicle Research and Test Center in East Liberty, Ohio. Hughes Associates, NHTSA, and General Motors (GM) representatives conducted a forensic inspection and battery teardown. The inspection of the crash damage to the Volt revealed that the transverse stiffener located under the driver's seat had penetrated the tunnel section of the battery compartment, damaged the lithium-ion battery, and ruptured the battery's liquid cooling system. Review of the crash test photographs and video confirmed that coolant had leaked from the battery compartment. Hughes Associates concluded that damage to some of the Volt's battery pack cells and electric shorting precipitated the fire.

In September 2011, NHTSA performed a fifth side-pole NCAP crash test on a Chevrolet Volt at the MGA facility. The objective was to observe any battery cell damage, shorting, battery coolant system rupture, or post-crash battery fire. The test vehicle was fitted with additional cameras and equipment to monitor post-crash events. This test resulted in no intrusion into the battery compartment, no cell damage or shorting, no leakage of coolant, and no post-impact fire. The vehicle was monitored for three weeks after the crash.

Six additional tests were performed on Volt lithium-ion battery packs to isolate potential factors involved in the MGA vehicle fire. Of the six tests, two batteries caught fire — one six days after the test, the other a week after testing. Another experienced a short arcing event with sparks and flames, one battery showed signs of heating at the connector, and another battery showed no test-related activity other than a slow discharge of one cell group. The sixth battery was inadvertently consumed by one of the batteries that caught fire. Despite the fires, NHTSA was unable to replicate the specifics of the MGA fire event in either the battery component testing or the full-scale vehicle tests and is not aware of any real-world post-crash fires involving an EV battery cell venting event.

In November 2011, NHTSA opened a defect investigation on the Chevrolet Volt. GM proposed a potential change (field fix) to mitigate intrusion of the transverse stiffener into the battery. NHTSA observed the installation of the proposed reinforcement into a 2012 production Chevrolet Volt, and the vehicle was shipped to MGA Research where an NCAP-style side-pole test was performed in December. The vehicle was monitored for three weeks. There was no intrusion into the battery compartment, no leakage of coolant, and no post-impact fire observed.

In November 2011, NHTSA also began working with NFPA to assist first and second responders in identifying vehicles powered by lithium-ion and other lithium-type batteries in taking appropriate steps in handling these batteries following a crash. NHTSA has also been working with vehicle manufacturers to develop appropriate post-crash protocols for dealing with lithium-ion battery powered vehicles.

SIDEBAR

French Connection

Upcoming seminar underscores global impact of European research on lithium-ion batteries

To truly understand the hazardous nature of lithium-ion batteries, and to develop corresponding safety measures against potential threats, the batteries must undergo a series of destructive tests.

That's what's occurring inside the STEEVE — the English-language acronym translates to Electrochemical Energy Storage for Electric Vehicles — research facility in Verneuil-en-Halatte, France, where researchers damage these devices through crashes, fires, and electrical malfunctions.

Used lithium-ion cell phone batteries in a recycling facility. (Photo: AP/Wide World)

In operation since 2010, the testing facility's sole purpose is to examine the ramifications of battery abuse. The French National Institute for Industrial Environment and Risks (INERIS), which addresses risks impacting life and property safety through studies and research programs, developed STEEVE in order to take a close look at lithium-ion batteries and to try to determine what has led to a smattering of international battery fires. Its latest research will be discussed during the High Challenge Storage Protection Seminar in Paris on June 27. Presented by the Fire Protection Research Foundation, the seminar addresses high-hazard commodities in storage settings and new approaches to fire protection.

While INERIS has yet to initiate research on lithium-ion batteries in storage settings, it has begun researching the life cycle of these devices and has identified potential hazardous scenarios along the way. The session at the Foundation seminar will identify the scenarios, including possible incidents involving the toxic components of these batteries, and prevention measures that optimize building protection.

"In a [battery] recycling plant, you'll never know the state of health of the batteries," says Guy Marlair, technical advisor and research scientist with INERIS. "They may be very close to the thermal runaway process [rapid self-heating of battery cells], or very far from that. It's difficult to have a clear idea. The way you will develop prevention and protection measures in a recycling facility will have to be different than warehouses storing new cells and batteries."

A technical panelist for the Foundation's Lithium-Ion Battery Storage Protection Project, Marlair says he plans to share current and future research findings for the good of the project. "This project is quite timely," he says. "We have to consolidate the research effort. We should concentrate on collecting all pieces of new information to achieve a satisfactory level of safety for the storage of these batteries. All of these different types of defects will need to be analyzed to ensure protection."

For more information on the Research Foundation's High Challenge Storage Protection Seminar, visit nfpa.org/foundation.

— Fred Durso, Jr.

SIDEBAR

Staying Energized

A primer on the science fueling the lithium-ion battery market

A lithium-ion battery's ability to provide considerable amounts of energy using lighter materials than its competitors has made this technology a popular option for consumer electronics and the growing electric vehicle industry. Here's a simplified look at the science responsible for powering many of today's gadgets.

Salar de Uyuni, in Bolivia, holds the world's largest reserve of lithium. (Photo: Corbis)

Lithium in its purest form — a silvery-white metallic element — is not found in lithium-ion cells. Rather, a chemical compound containing lithium (in some cases, lithium cobalt oxide) is used. The term "lithium-ion" refers to the positively charged atoms responsible for the battery's charging and discharging. A lithium-ion battery's metallic case contains a lithium-ion cell consisting of anodes (negative electrodes) that are commonly composed of lightweight elements, such as carbon, and cathodes (positive electrodes), a ceramic material made from the lithium cobalt oxide or other materials. The cathodes and anodes are placed onto individual copper or aluminum foils, separated by a porous piece of film, and submerged in an organic solvent known as an electrolyte. As the battery charges, the electrolyte aids the lithium ions (charged atoms created by the lithium salt in the electrolyte) that move through the film from the cathode to the anode. The direction of the ions is reversed during discharge, creating a flow of an electrical current. The batteries produce a higher voltage and can be recharged for hundreds of cycles, making these devices an increasingly popular power source. Cell phones, for example, use single-cell lithium-ion batteries, while notebook computers and other larger devices use multi-cell batteries.

Since lithium-ion batteries are sensitive to extreme temperatures, the battery pack or individual cell typically have a range of overcharge protection devices. Whereas comparable battery technologies use a water-based solvent as its electrolyte, lithium-ion batteries use a flammable solvent to perpetuate ion movement. Research has indicated that the device's high energy density and flammable solvent pose risks and challenges related to the storage and handling of these batteries.

— Fred Durso, Jr.

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BBC NEWS

BUSINESS

15 February 2013 Last updated at 11:15 ET

Airbus A350 to avoid Boeing 787-style lithium-ion batteries

Airbus says it will not use lithium-ion batteries in its forthcoming A350 plane because of problems that have grounded rival Boeing's 787 Dreamliner.

The European planemaker said it would use traditional nickel-cadmium batteries instead, as already used in the A380 and other models.

Investigations are continuing after battery problems came to light on 787s operated by Japan's top two airlines.

Airbus said they remained "unexplained to the best of our knowledge".

The firm said it did not expect any further delays to the launch of the A350. The maiden flight is due to take place later this year, with the first passenger flight expected in the second half of 2014.

In a statement, Airbus said it was "confident" that the lithium-ion battery that it had been developing with French battery-maker Saft was "robust and safe".

It added that A350 test flights would continue with the lithium batteries.

"However, to date, the root causes of the two recent industry Li-ion main batteries incidents remain unexplained to the best of our knowledge," Airbus said.

"In this context, and with a view to ensuring the highest level of programme certainty, Airbus has decided to activate its Plan B and therefore to revert back to the proven and mastered nickel-cadmium main batteries for its A350 XWB programme at entry into service (EIS).

"Airbus considers this to be the most appropriate way forward in the interest of programme execution and A350 XWB reliability."

The A350 is intended as a rival to the Dreamliner, which was grounded last month after a lithium-ion battery on a Japan Airlines plane caught fire, while an All Nippon Airways flight was forced to make an emergency landing because of a battery malfunction.

These planes use lithium-ion batteries because they are relatively powerful compared to their size and weight. They are used for significant functions such as providing the starting and emergency power supply on the A350 aircraft.

Lithium batteries are also commonly used in other planes, but these are much smaller batteries, running much more minor things such as a small set of lights.

Shares in battery-maker Saft fell after the announcement. When it agreed the Airbus contract in 2008, it said it expected it to be worth 200m euros ($267m; £172m) over 25 years.

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Boeing proposes full 787 battery fix to FAA: sources

By Andrea Shalal-Esa and Alwyn Scott
WASHINGTON/SEATTLE | Fri Feb 22, 2013 6:54pm EST

(Reuters) - Boeing Co on Friday gave U.S. aviation regulators its plan to fix the volatile battery aboard its new 787 Dreamliner, even though investigators have not yet determined what caused the batteries to overheat on two planes last month.

Boeing did not propose abandoning the lithium-ion batteries and is not working on a backup or longer-term fix for the problem that has grounded its entire fleet of 50 Dreamliners for nearly five weeks, three sources familiar with the plan said.

The company and the U.S. Federal Aviation Administration said no firm result emerged from the meeting between Deputy Transportation Secretary John Porcari, FAA Administrator Michael Huerta and other FAA officials and Boeing Commercial Airplanes CEO Ray Conner and other senior Boeing executives in Washington.

With Boeing's costs mounting by millions of dollars a day while the planes are on the ground, the FAA said it is "reviewing a Boeing proposal and will analyze it closely. The safety of the flying public is our top priority and we won't allow the 787 to return to commercial service until we're confident that any proposed solution has addressed the battery failure risks."

Boeing declined to comment on the details of its proposal, but said the meeting with the FAA was productive.

The proposal to the FAA includes measures to address a range of possible causes of short-circuits in the batteries, the sources said.

Five weeks ago, U.S. authorities grounded the worldwide fleet of 787s. U.S., Japanese and French investigators are still not certain what caused the battery fire aboard an All Nippon Airways 787 in Boston and an overheated, smoking battery on a Japan Airlines 787 in Japan.

The proposed fix includes adding ceramic insulation between the cells of the battery to help keep cells cool and prevent a "thermal runaway" in which one cell overheats and triggers overheating in adjacent cells. It also includes building a stronger, larger stainless steel box with a venting tube to contain a fire and expel fumes outside the aircraft should a battery catch fire again, the sources said. In addition, the plan proposed wiring changes, self-torquing screws that won't come loose and battery alterations to prevent moisture and vibration problems, one of the sources said.

But there was also a plan to use a different battery type or some other longer-term fix, the sources said.

"I have talked to a number of people who are working directly on these batteries. No one is on the Plan-B team," said a person familiar with Boeing's efforts who was not authorized to speak publicly about them.

A second source, who also was not authorized to speak publicly, said Boeing does not view its proposal as a temporary "band-aid" that would be supplanted by another solution later.

Boeing spokesman Marc Birtel said in a statement: "We are encouraged by the progress being made toward resolving the issue and returning the 787 to flight for our customers and their passengers around the world."

Birtel reiterated that hundreds of engineers and technical experts are working "around the clock" to return the 787 fleet to service. "Everyone is working to get to the answer as quickly as possible and good progress is being made," Birtel said.

Boeing's stock closed up 65 cents, or 0.86 percent, at $75.66 on the New York Stock Exchange.

Richard Aboulafia, aerospace analyst with the Teal Group in Virginia, said Boeing needed a backup plan in case the FAA did not approve its proposal.

"It's a bit tone deaf to propose containment and management when the political winds are favoring an elimination of the risk," he said, citing Transportation Secretary Ray LaHood's insistence that the plane would return to flight only when it was "1000 percent safe" and similar remarks by other officials.

"They need to be out there talking about a bigger solution beyond mere containment because the political winds and public opinion are not going to favor a solution that's focused on fire and smoke management," Aboulafia said.

He noted that Airbus had already signaled its plan to switch back to more traditional nickel cadmium batteries for its A350 airliner, but the 787 was far more dependent on electrical power, which would complicate any effort to switch to a different type of battery. A complete redesign could take around nine months to implement, he said.

Others said that kind of solution could take two years.

The U.S. National Transportation Safety Board is still investigating the Boston fire and the Japan Transportation Safety Board is investigating the battery failure in Japan. Neither has found a root cause for the problems.

The sources said the NTSB might never find the root cause because the battery in Boston was severely damaged by the fire.

Given the financial cost of the grounding for Boeing and the airlines that own the jets, estimated at $200 million a month, Boeing decided to address all possible causes with the measures, rather than wait for the NTSB to identify one specific cause, the sources said.

Boeing engineers have been working with outside experts and U.S. government officials to address possible cause of the battery issues. The team includes experts from the U.S. Navy and the National Aeronautics and Space Administration, which uses a lithium-ion battery on board the International Space Station.

Boeing engineers went through a "fault tree" and "came up with a list of half a dozen things that could have led to problems," said a congressional source who had been briefed on the matter, but was not authorized to speak publicly.

"They have a list of things that it could be, and the fixes are designed to address that list of problems," the source said.

If the NTSB's investigation turns up additional possible causes, those would be added to the mix, another of the sources said.

Asked why the company's extensive testing of the batteries had not revealed problems with the batteries and the electrical systems used to operate them, one of the sources said test environments had limitations and the real test of an aircraft always came when it was actually operating.

If the Boeing plan is approved by FAA Administrator Huerta and Transportation Secretary LaHood, company officials expect the 787 fleet to return to service within eight weeks, one source said.

Another source, who is also familiar with the 787 investigation but not authorized to speak publicly, said a key challenge for Boeing would be to redesign the battery box so that it could truly contain a fire if one occurred.

Despite Boeing's statements about containment being the plan for a battery issue from the start, the blue box that held the current lithium-ion battery was clearly "not designed to contain a fire," said the source.

Another person familiar with the engineering work said the new box would be made of stainless steel nearly half an inch thick. It would be capable of containing an explosion, and would have a tube to vent smoke and flame outside the jet.

However, the source said engineers have raised questions about the safety of venting flames outside the plane, especially if it is on the ground and being fueled. The effect could be something like a flamethrower, this person said.

(Reporting by Andrea Shala-Esa and Alwyn Scott; Editing by Gerald E. McCormick, Dan Grebler, David Gregorio and Gunna Dickson)

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Statement of National Highway Traffic Safety Administration On Possible Fires in Lithium-Ion Vehicles Involved in a Crash

For Immediate Release
Friday, November 11, 2011
Contact: Lynda Tran, 202-366-9550

WASHINGTON, DC — The National Highway Traffic Safety Administration (NHTSA) issued the following statement today regarding the potential risk of post-crash fires in vehicles powered by lithium-ion batteries:

Electric vehicles show great promise as an innovative and fuel-efficient option for American drivers. These vehicles have already demonstrated their potential to save consumers money at the pump and help protect the environment — and they could pave the way to the kind of clean energy jobs that will help our country compete on a global scale. As manufacturers continue to develop vehicles of any kind — electric, gasoline, or diesel — it is critical that they take the necessary steps to ensure the safety of drivers — and first responders — both during and after a crash.

That's why the National Highway Traffic Safety Administration is working with all vehicle manufacturers to ensure they have the appropriate post-crash protocols. Let us be clear: NHTSA does not believe electric vehicles are at a greater risk of fire than other vehicles. It is common sense that the different designs of electric vehicles will require different safety standards and precautions. The Department of Energy and the National Fire Protection Association already collaborate to ensure first responders know the risks and the appropriate steps to take so they can perform their jobs safely given the shock hazard that a damaged electric vehicle may present, and NHTSA will work closely with these organizations to ensure that guidance for the emergency response community reflects the information NHTSA obtains.

In the near term, NHTSA is focused on identifying the best ways to ensure that consumers and emergency responders are aware of any risks they may encounter in electric vehicles in post-crash situations. The agency has asked all of the manufacturers who currently have electric vehicles on the market (or plans to introduce electric vehicles in the near future) to provide information on the protocols they have established for discharging and handling their lithium-ion batteries — including any recommendations for mitigating fire risks in these vehicles. Ultimately we hope the information we gather will lay the groundwork for detailed guidance for first responders and tow truck operators for use in their work responding to incidents involving these vehicles.

NHTSA has carefully investigated an incident involving a fire in a Chevy Volt that occurred more than three weeks after that vehicle had been crash tested as part of the agency's New Car Assessment Program on May 12 of this year. NHTSA has concluded that the crash test damaged the Volt's lithium ion battery and that the damage led to a vehicle fire that took several weeks to develop after the test was completed. That incident — which occurred at the test facility and caused property damage but no injuries — remains the only case of a battery-related fire in a crash or crash test of vehicles powered by lithium-ion batteries, despite a number of other rigorous crash tests of the Chevy Volt separately conducted by both NHTSA and General Motors. In the coming weeks, in collaboration with the Department of Energy, NHTSA will conduct additional testing of the Volt's lithium-ion batteries and will continue to monitor these vehicles — as the agency does with all vehicles on our nation's roadways — should any safety issues arise.

Based on the available data, NHTSA does not believe the Volt or other electric vehicles are at a greater risk of fire than gasoline-powered vehicles. In fact, all vehicles — both electric and gasoline-powered — have some risk of fire in the event of a serious crash. NHTSA urges the following precautions in the event of a crash involving an electric vehicle:

- Consumers are advised to take the same actions they would in a crash involving a gasoline-powered vehicle — exit the vehicle safely or await the assistance of an emergency responder if they are unable to get out on their own, move a safe distance away from the vehicle, and notify the authorities of the crash.
- Emergency responders should check a vehicle for markings or other indications that it is electric-powered. If it is, they should exercise caution, per published guidelines, to avoid any possible electrical shock and should disconnect the battery from the vehicle circuits if possible.
- Emergency responders should also use copious amounts of water if fire is present or suspected and keeping in mind that fire can occur for a considerable period after a crash should proceed accordingly.
- Operators of tow trucks and vehicle storage facilities should ensure the damaged vehicle is kept in an open area instead of a garage or other enclosed building.
- Rather than attempt to discharge a propulsion battery, an emergency responder, tow truck operator, or storage facility should contact experts at the vehicle's manufacturer on that subject.
- Vehicle owners should not store a severely damaged vehicle in a garage or near other vehicles.
- Consumers with questions about their electric vehicles should contact their local dealers.

For more information, visit www.SaferCar.gov.

Kinki Sharyo selects GS Yuasa to power its ameriTRAM™ Next Generation Light Rail Vehicle

March 15, 2011, Kyoto, Japan: GS Yuasa's LIM30H-8A lithium-ion battery module has been selected by the Kinki Sharyo Co., Ltd. for the company's next generation LRV, the ameriTRAM™. ameriTRAM™ is a 100% low-floor LR\ designed specifically for the US market.

ameriTRAM™ is able to operate in locations where exterr electric power is not always available. Energy stored in th onboard Li-ion batteries is used to power the traction syst and all auxiliary loads in parts of the track where an overh catenary is not available. When external power is availabl is used for all onboard loads and to recharge the batteries needed. The batteries also store regenerative braking ene for reuse. Vehicle testing began in May 2010 at Kinki Sha test track in Osaka, Japan. Demonstrations in the US are under way.

The ameriTRAM™ battery system is based on GS Yuasa's existing LIM30H-8A lithium-ion battery module and was jointly developed by GS Yuasa and Kinki Sharyo. The union of GS Yuasa's proven high performance and high pow lithium-ion batteries and Kinki Sharyo's latest LRV technologies enables operators to meet energy usage goals and provides uncommon value.

GS YUASA manufactures large format lithium-ion cells for aviation, space, electric vehicle (EV) and hybrid electric vehicle (HEV) applications. GS Yuasa also manufactures large format lithium-ion cells, modules and battery management electronics (BME) for industrial automated guided vehicles (AGVs), railway way-side energy storage systems, and industrial hybrid applications such as rail switchers and rubber tire gantry cranes (RTGCs).

The 'LIM30H-8A' module was developed and commercialized specifically for industrial large capacity hybrid system The module's features include:

- **High current charge and discharge capability**
- **Low cell impedance and long service life through minimized of impedance growth rate**
- **Lightweight and compact**
- **Forced air cooling**
- **Battery monitoring electronics and balancing**

Functionality includes: individual cell voltage monitoring, cell balancing, module temperature measurement, state of health, and data communication.

External dimensions	l, w, h: 389, 231, 147 (mm)	**Weight**	19.5Kg
Nominal voltage	28.8V	**Nominal cell voltage**	3.6V
Nominal capacity	30Ah	**Operating voltage range**	23.2~33.2V
Maximum pulse current	600A	**Continuous current**	100A
Operating temperature	0~45 °C	**Monitoring system**	Monitors each cell volta and module temperatur

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For additional information, please contact:

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communiqué de presse press release

N° 18-10

Saft batteries provide high-tech traction battery for Sitras HES hybrid energy storage system on Siemens Mobility's trams

- *Siemens Sitras HES hybrid energy storage system incorporates a Saft Ni-MH integrated battery system that enables the tram to operate without an overhead contact line (OCL) for distances up to 2,500 metres*
- *First tram with Sitras HES is now in passenger service with MTS in the south of Lisbon, Portugal*

Paris, May 6, 2010 – Saft, the world specialist in the design and manufacture of high-tech industrial batteries, has supplied Ni-MH (nickel-metal hydride) integrated traction battery systems to Siemens Mobility for use in the development of a new generation of trams equipped with the Sitras HES hybrid energy storage system. The first tram with Sitras HES, equipped a Saft battery system onboard, has completed more than one year of successful passenger service trials in Portugal with the Siemens Mobility customer MTS (Metro Transportes do Sul, S.A.), Since the end of 2008, it has been operating services between Almada and Seixal, two cities to the south of Lisbon.

The trams with Sitras HES can operate autonomously, without external power from an overhead contact line (OCL), over long sections of track. The concept is ideally suited for areas where impact on the local landscape must be minimized, such as in historic city centres, and is especially environmentally-friendly as well as saving energy.

The Sitras HES concept comprises two energy-storing components: the Sitras MES mobile energy storage unit based on a double-layer capacitor (DLC) and the traction battery system. The two components work together to provide a very efficient energy storage system.
"Saft's Ni-MH traction batteries for the Sitras HES system was primarily chosen by Siemens Mobility because they were commercially available and could be integrated in the test programme quickly, without a long development period. Furthermore, they met Siemens stringent specifications in terms of weight, size, reliability and high energy performance".

Regenerative braking
When the tram is running the energy storage units are charged regeneratively during braking. The vehicle can use this stored energy to travel over distances of up to 2,500 metres over sections of track where no OCL is available. This distance represents a very significant increase in autonomous operation compared with the typical 500 metre capability of a tram relying on battery power only, without regenerative braking. The high energy Ni-MH battery also improves the reliability of the tram service as it allows continued operation when the OCL is temporarily unavailable, such as in the case of failure or planned maintenance.

The Sitras HES system is designed for roof-mounting on the tram and is electrically connected to the vehicle feed-in point by means of a DC/DC-chopper. This new autonomous connection concept, enables, the energy storage system to be integrated into new trams or retro-fitted into existing vehicles. Under optimum operating conditions, the Sitras HES is expected to reduce the future energy demand of a vehicle by up to 30 percent, producing up to 80 tonnes less CO_2 emissions per year.

Sitras HES battery unit

The Sitras HES battery unit has been adapted by Saft from its range of fully integrated battery systems developed to meet the needs of the new generation of tramways. It is based on Saft's NHP Ni-MH cells designed specifically for high power applications to offer excellent power storage in a compact maintenance-free package. To ensure maximum reliability and safety, each battery system incorporates an active cooling device and battery management control (BMC). The unit is supplied to Siemens Mobility as a 'plug and play' package in a custom built tray complete with power and communications connections.

The exact battery system voltage and capacity for future systems would vary according to the specific application. A typical specification would be 44 cell blocks of NHP10-340 cells connected in series, providing a nominal 528 V and capable of storing 18 kWh of energy and sustaining a peak power of 105 kW. The total battery weight is 826 kg.

About Saft

Saft (Euronext: Saft) is a world specialist in the design and manufacture of high-tech batteries for industry. Saft batteries are used in high performance applications, such as industrial infrastructure and processes, transportation, space and defence. Saft is the world's leading manufacturer of nickel batteries for industrial applications and of primary lithium batteries for a wide range of end markets. The group is also the European leader for specialised advanced technologies for the defence and space industries and world leader in lithium-ion satellite batteries. Saft is also delivering its lithium-ion technology to the emerging applications of clean vehicles and renewable energy storage. With approximately 4,000 employees worldwide, Saft is present in 18 countries. Its 15 manufacturing sites and extensive sales network enable the group to serve its customers worldwide. Saft is listed in the SBF 120 index on the Paris Stock Market.

*For more information, visit Saft at **www.saftbatteries.com***

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STADLER
Clevere Lösungen auf der Schiene

MVG

Tram without overhead line - Battery-powered tram for Munich produced by Stadler Pankow GmbH sets a new world record

Velten, 25.05.2011 – A Munich tram, type Variobahn, is on its way into the Guinness Book of Records. Today, the vehicle which is equipped with a newly developed lithium ion battery drove 16 km without overhead lines and with this result, the tram set a new record for the book of world records. Thus, the attempt which was performed on a test track in Velten, took place under the supervision of a notary and the accompaniment by experts. The pantograph of the Variobahn had to be sealed for the duration of the world record attempt. The tram which was staffed with two drivers was only allowed to have a standstill of 5 seconds maximum for the change of the driving direction on the single-track that has a length of approx. 3.5 km. All activities were additionally supervised by track officials next to the track and documented with cameras. In order to be published in the Guinness Book of Records, the Variobahn had to drive at least 1 km only battery-powered.

The tram, which is intended to drive in Munich, is a Variobahn produced by Stadler Pankow GmbH. The Munich city utilities (Stadtwerke München SWM) have decided that the vehicle for the Munich transport corporation (Münchner Verkehrsgesellschaft MVG) is equipped with the high-performance battery to be able to realise an operation without overhead lines on a section in the Bavarian capital. A specific application would be the so-called ring road north. It is proven to have an especially high traffic benefit, because it would be possible to establish a tangential connection with a length of approx. 8 km between Neuhausen-Nymphenburg to Bogenhausen with a gap closure of only approx. 2 km. According to all forecasts, this connection will be highly frequented and thus contribute effectively to easing the burden of the inner-city roads. A further connection to St. Emmeram would allow an extension of up to 13 km. A section of one kilometre of the new line crosses the English Garden.

For this very reason, a first plan approval procedure failed in 2001. At that time, the responsible approving authority was apprehensive of the fact that the overhead line and the masts had a negative effect on the landscape. Hence, SWM/MVG now plan to drive through the English Garden with a battery-powered tram, without the need of overhead lines.

The battery, that has a weight of 380 kg, meets all requirements emerging from the Munich track characteristic. Among other aspects, the length of the track without overhead line through the English Garden (approx. 1 km), one passenger stop, another stop required due to operational reasons, each time with braking and start driving as well as the topography were taken into consideration. Furthermore, the battery is designed for passing this section with the tram not only one time but two times without the need of recharge, given that, apart from that, it is driven by using the overhead line and the recharging of the storage is enabled. As soon as the technical supervisory authority granted the approval for the vehicles type Variobahn to the government of Upper Bavaria, the test vehicle will return to Munich. Further test drives will be performed in the network of the MVG in Munich. If it turns out during these test drives that the battery technology works smoothly and meets all requirements, SWM/MVG strive for another application for plan approval procedure for the ring road north.

The battery tram is one of four vehicles of the first delivery lot for Munich. Ten further Variobahn vehicles are currently being assembled and they will be delivered to SWM/MVG until the end of the year 2011. All vehicles are prepared for the retrofitting with batteries.

Michael Daum, chairman of the board of Stadler Pankow GmbH:"After successfully being in worldwide operation and thereby having driven more than 30 million kilometres, thanks to modern technology, the Variobahn is now in a position to drive considerable distances without overhead lines. Stadler makes tram history with this test drive today."

Herbert König, chairman of the board of MVG and CEO of SWM traffic: "Since several years we have been dealing with the possible application of energy storages on a tram vehicle. Thereby, the different possibilities have been discussed intensively with the industry. First experiences were also taken into consideration, e.g. the battery application on the light rail vehicle in Nice. A lithium ion battery is best suitable for our first application – crossing a section with a length of 1 km. This type of battery stores the energy slower than supercaps, which are used in Heidelberg for example. However, they can absorb more energy and are thus capable of crossing longer distances without the need to recharge. Today's attempt showed that, thanks to the lithium ion battery, we can easily realise an operation without overhead line in the English Garden

Further on, König said: "One thing is certain: In contrast to today's record attempt during which the distance was demonstrated that is technically possible today, it is important for practical applications that the battery is designed exactly adjusted to the local requirements, precisely fitted – also with regards to the possible axle load of the vehicles – and as economically as possible. An important aspect is that the battery discharge is normally only 10-15%, because in this case, the battery has the highest durability. The battery is exactly designed and optimized for the application case 'ring road north Munich': discharge of the battery when crossing the English Garden only to 85-90 % of its capacity, afterwards recharge under the overhead line of the rest of the route. Like this, a stable operation with sufficient reserves and optimized battery durability would be possible. This was proven today! "

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Development of Contact-Wire/Battery Hybrid LRV

Masamichi OGASA
Senior Researcher, Laboratory Head, Traction Control, Vehicle Control Technology Division

Contact-wire/battery hybrid vehicles run on a hybrid power source that enables energy to be fed from contact wires and/or onboard batteries. Regenerated energy is returned to the contact wires and/or onboard batteries during braking in track sections, thereby ensuring the effective utilization of energy (Fig. 1). In track sections where no contact wires are installed, such vehicles can run using energy supplied only from the onboard batteries (Fig. 2).
In electrified track sections, hybrid running saves energy because regeneration cancellation does not occur, thereby improving the reliability of the regenerating brake. Additionally, running in non-electrified track sections (which offer savings in terms of contact wire installation and maintenance costs) prevents the degradation of urban landscapes to preserve the value of sightseeing resources and improves passenger convenience by enabling through-operation to/from electrified track sections.
As one of the targets of this study, the Traction Control Laboratory developed a contact-wire hybrid car and had it manufactured. The data of running distance after one spell of charging using only energy from the onboard batteries, and energy consumption during hybrid running in actual track sections compared with that of existing inverter vehicles was acquired. And the battery performance in low-temperature areas was also checked.
As another target, the laboratory developed a method of charging to quickly supply energy to the vehicles in midway stations distributed at intervals of several kilometers, while aiming at continuous running in non-electrified track sections using only energy from the onboard batteries.
The purposes and results of the study are outlined below.

(1) The Traction Control Laboratory developed the various element technologies required to enable continuous battery driving. It adopted, for example, a system for contact charging through a pantograph from rigid contact wires, and conducted a stationary test at a charging current of 1,000 A to confirm that the contact point would not melt. It also developed a structure to cool the onboard lithium ion batteries (thereby suppressing increases in their temperature), determined the interval between the cells in the battery module, and ascertained the required volume of cooling air through tests and thermal simulation. The laboratory then installed a cooling fan with a maximum capacity of 5 m/sec on the vehcile. It also developed a dual-voltage contact-wire hybrid exchanger with a quick-charge function and a capacity of 600 kW, suitable for application both to 1,500 V and 600 V DC voltages.

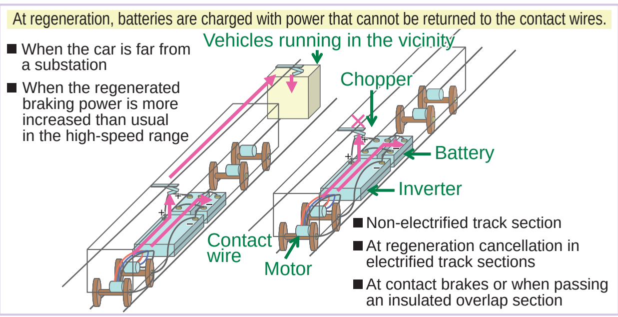


Fig. 1 Contact-wire/hybrid power flow (at regeneration)

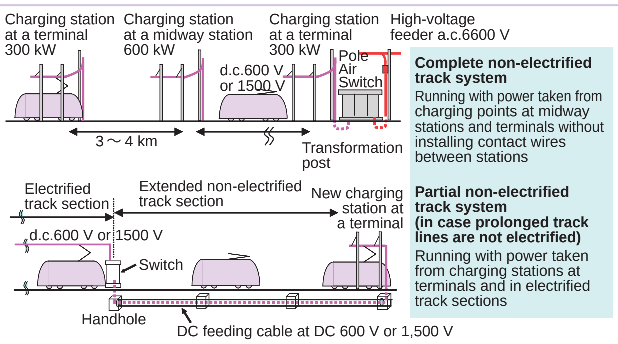


Fig. 2 Running in non-electrified track sections

(2) The Laboratory had a contact-wire/battery-type hybrid car manufactured that reflected the element technologies developed, including those introduced above, in its design (Fig. 3).
In consideration of the number of batteries to be mounted for running in non-electrified track sections, the car was designed with an onboard battery system featuring a nominal capacity of 72 kWh at a nominal voltage of 600 V. It was demonstrated that batteries and a charger could be mounted in a compact formation on the LRV carbody with the smallest dimensions of all LRV cars in Japan.

(3) The laboratory implemented a test on quick charging from rigid contact wires for the LRV car developed (Fig. 4). In this test, the onboard batteries were charged over a period of about 60 seconds at a charging current of 1,000 A with enough energy to run 4 km or more (Table 1). The test therefore proved the feasibility of quick charging with no melting at the contact point and restriction of the temperature increase in the onboard batteries to 3° C.

(4) The LRV car developed was put into test on a commercial service line of Sapporo City's Transport Bureau. It ran 25.8 km on an actual operation diagram while heating the passenger room without power from external sources, and recorded a regeneration ratio of 41% (the volume of regenerated power divided by the power consumed in running) (Fig. 5). During running in electrified track sections while charging the batteries, energy consumption was cut by 30% over that of existing inverter cars.

This study was promoted under a contract with the NEDO (New Energy and Industrial Technology Development Organization).

Fig. 3 Contact-wire/battery hybrid LRV

Fig. 4 Quick charging from rigid contact wires

Table 1 Energy obtained by quick charging

Battery charging current and duration	Power charged at battery terminals	Running distance after a one short time of quick charging (without air conditioning)	Running distance after a one short time of quick charging (at the maximum air conditioning load)
1,000 A x 61 sec	13.7% of the capacity	Equivalent to 7.9 km	4.0 km or over
500 A x 3 min and 16 sec	21.9% of the capacity	Equivalent to 12.7 km	6.4 km or over

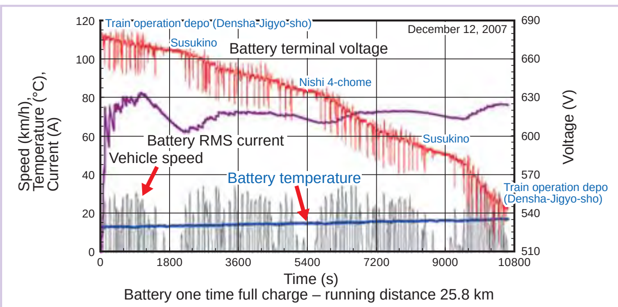
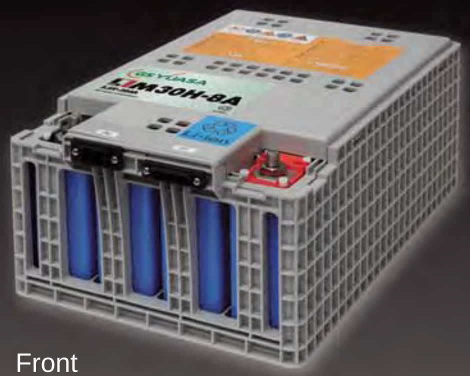


Fig. 5 Running with batteries after a spell of charging

GS YUASA

Rechargeable LIM Li-ion Battery series

Lithium ion battery for Industrial use LIM series



Front

Back

Overview

The LIM series, lithium-ion rechargeable battery for industrial applications, has been developed based on our state of the art technology and extensive experience in manufacturing small lithium-ion and large-scale industrial batteries. As a high energy and power source, the LIM series is your answer for long life in a compact size for most industrial applications.

Applications

- Hybrid crane systems
- Hybrid train
- Hybrid vehicle
- AGV(Automated Guided Vehicle)
- Power storage system for railway
- Load leveling systems
- Other industrial systems

Features and Benefits

- High charge / discharge power density
- Sealed structure
- No memory effect
- Easy periodical check
- Outstanding cycle life
- Fan-forced air cooling control with thermal sensor
- Integrated module design

Specifications

Model	Cell Qty	Charge Voltage (V)	Dimensions(mm)			Mass (Kg)	Maximum Charge Current(A)	Maximum Disharge Current(A)
			Length	Width	Height			
LIM30H-8A	8	28.8	414	231	147	19.5	600 (20C)	600 (20C)

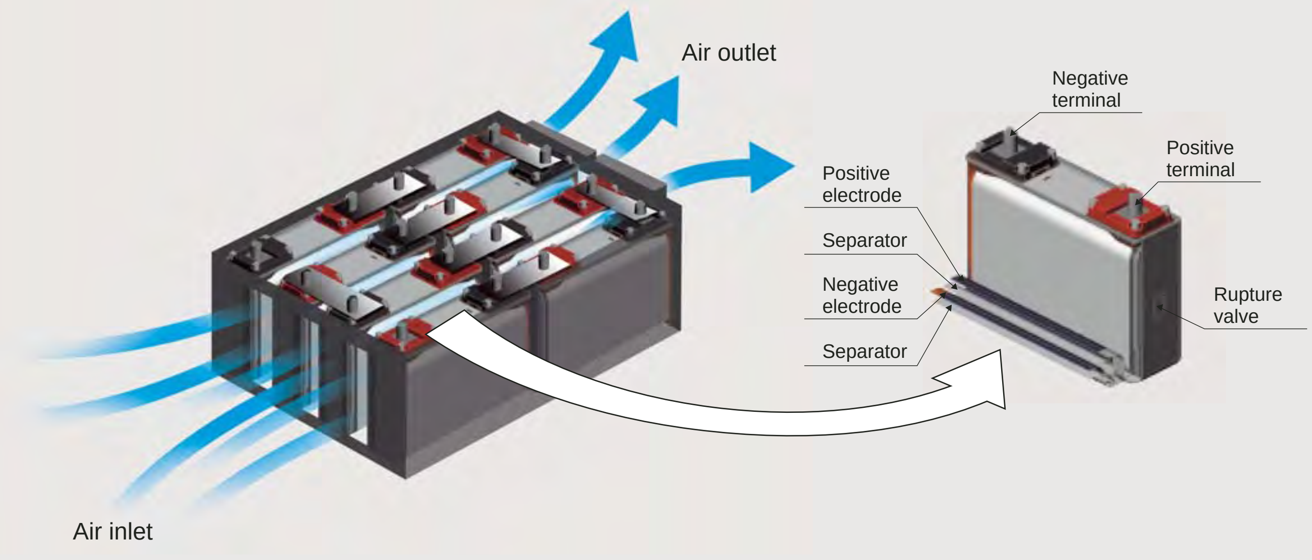
Charge temperature (°C) : 0～45　　Discharge temperature (°C) : 0～45

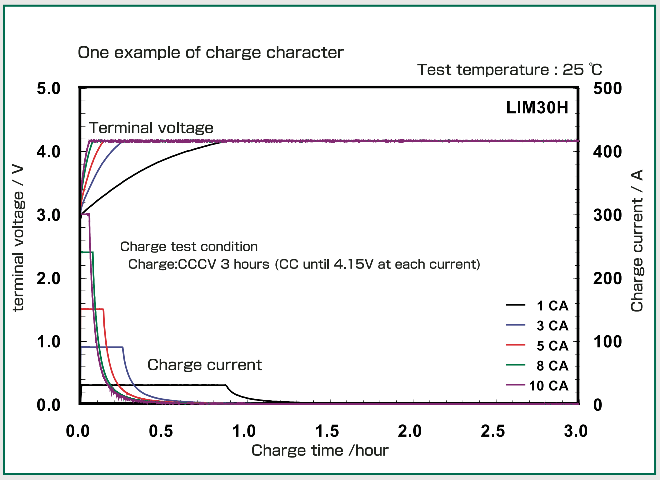
Monitoring system

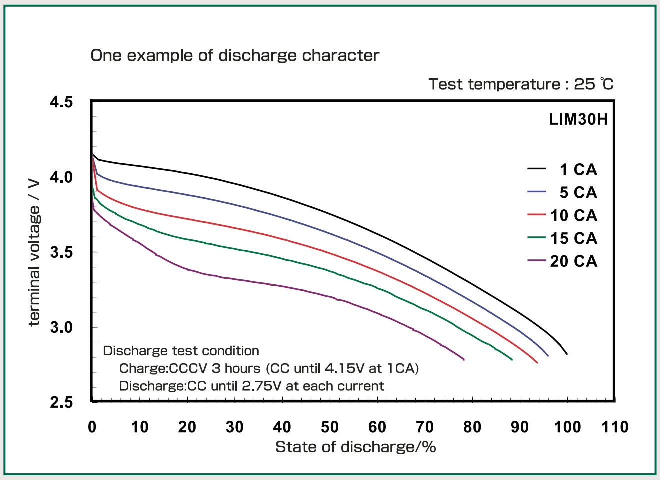
Items	Functions	Items	Functions
Voltage monitoring	Each cell voltage is monitored.	Alarm signals	Overvoltage,Undervoltage,
Temperature monitoring	Each module temperature is monitored.		High temperature,Low temperature
Status signals	Voltage rise,Voltage fall,Fan operation	Balancer	Voltage difference between each cell is controlled.

Structure of Battery Module

Structure of a single cell







Safety and protection of Lithium Ion battery

GS Yuasa LIM modules are equipped with protective functions that can detect overcharge, overdischarge, high temperature and other abnormal operating conditions. The LIM modules must be operated with a dedicated charger that can monitor the LIM battery management signals and automatically terminate charging or discharging.

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News Release

March 26, 2012

GS Yuasa Corporation

JR Freight's First Mass-produced Hybrid Locomotive Commences Service with GS Yuasa's Industrial-use Lithium-ion Battery Module Installed

GS Yuasa Corporation (Tokyo Stock Exchange: 6674) announced today that its industrial-use lithium-ion battery module has been installed in Japan Freight Railway Company's ("JR Freight") first mass-produced hybrid shunting locomotive, which was launched from the Tokyo Freight Terminal Station in February 2012.

Prior to mass production, JR Freight tested GS Yuasa's lithium-ion battery modules in a prototype locomotive (model HD300-901) from April 2010 under various operating conditions to verify its environmental performance and other capabilities. The performance of the GS Yuasa lithium-ion battery modules was highly rated, and as a result JR Freight decided to install the modules in its first mass-produced locomotive (HD300-1).

The power for the hybrid shunting locomotive is provided through a system that combines a small diesel engine generator with high-capacity lithium-ion batteries. These batteries provide a crucial support function as they store regenerative braking energy and use the energy to power the diesel engine during start-up acceleration and at other times. Compared to conventional diesel locomotives (DE-10), this system reduces nitrogen oxide (NOx) emissions by 61%, fuel consumption by 36%, and noise levels by 22db.

Currently, many of Japan's railway operators are conducting field tests on new hybrid railway vehicles which equip railway vehicles with storage batteries. GS Yuasa is providing lithium-ion batteries for these railway vehicles and expects wider adoption of the batteries in the future as mass-produced railway vehicles commence service. GS Yuasa will strive to expand the adoption of industrial-use lithium-ion battery modules in environmentally friendly railway vehicles in order to further contribute to lowering the environmental burden.

Features of the LIM30H-8A Lithium-ion Battery Module

1. High current charge/discharge performance
   The maximum current capacity is 600A and the Direct current capacity is 100A, which ensures stable charge and discharge performance.

2. High input-output performance and longer operating life through reduced internal resistance

3. Lightweight, compact design
   The use of plastic resins in the outer module casing enables a lightweight, compact design. The plastic resins have superior insulation properties, enabling them to be used even under high voltage conditions.

4. Forced-air cooling
   The modules use cooled air, which helps to raise the efficiency of the cooling system.

5. Standard battery-monitoring system to continuously monitor battery status
   A proven battery-monitoring device for industrial-use lithium-ion batteries is a standard feature. The device continuously monitors the voltage of all cells as well as the module temperature. The device has a function to send battery data to the charging device and the system.
   By adding a GS Yuasa battery management unit (BMU), battery data can also be output to external devices.

LIM30H-8A Lithium-ion Battery Module Specifications

Dimensions (mm)	W:231 x D:389 x H:147	Mass (kg)	approx. 20
Nominal voltage (V)	28.8	Nominal voltage per cell (V)	3.6
Capacity (Ah)	30	Operating voltage range (V)	23.2 ~ 33.2
Maximum current (A)	600	Direct current (A)	100
Temperature range (˚C)	0 ~ 45	Monitoring device	All-cell monitoring; Module temperature monitoring

Images

1. LIM30H-8A Lithium-ion Battery Module

2. JR Freight's first mass-produced hybrid shunting locomotive (HD300-1)

Access the below link for a clip of the HD300-1 in action
http://www.gs-yuasa.com/jp/news/movie/20120326.wmv

Overview of lithium-ion batteries installed in hybrid shunting locomotive

Configuration	LIM30H-8A x 78 units (26 units connected in series/ 3 units connected in parallel)
Nominal voltage (V)	748.8
Capacity (Ah)	90
Total energy output (kWh)	67.4

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Development of New Generation Supercapacitors for Transportation Applications

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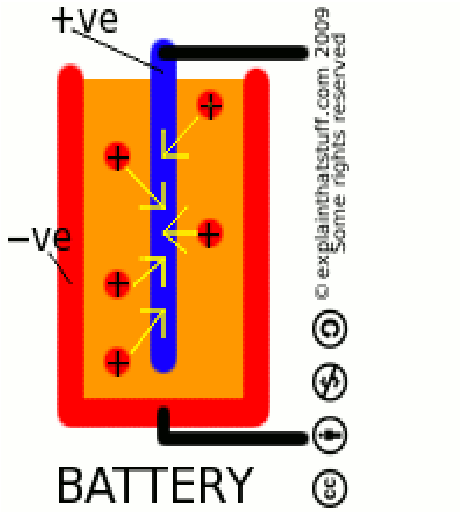
National Research Council Canada   Conseil national de recherches Canada

Canada

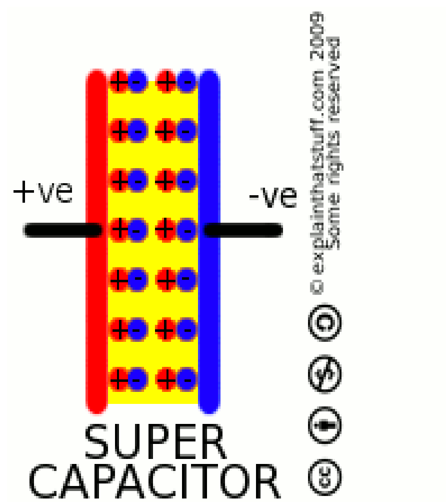
Outline

- Description of electric energy storage devices
- Description of supercapacitors
- Objectives of the project
- Results
  - Active materials
  - Current collectors
  - Separators
  - Complete cell testing
- Conclusions

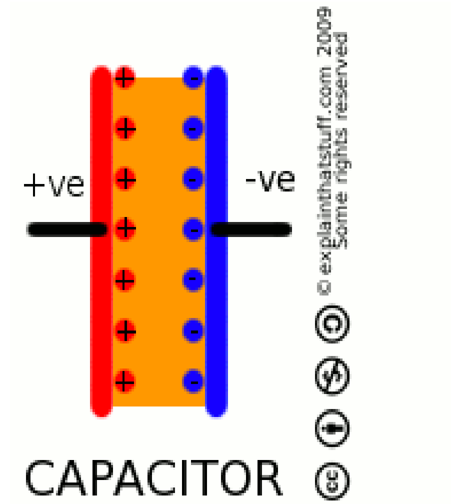
Electric Energy Storage Devices



stores energy using **chemical reactions** happening between an electrolyte, a positive electrode and a negative electrode.



stores more energy than ordinary capacitors by creating a **double layer of separated charges** between two plates made from porous, typically carbon-based materials .



consists of two conducting surfaces separated by an insulating material (dielectric).

Stores energy in an **electric field.**

Electric Energy Storage Devices

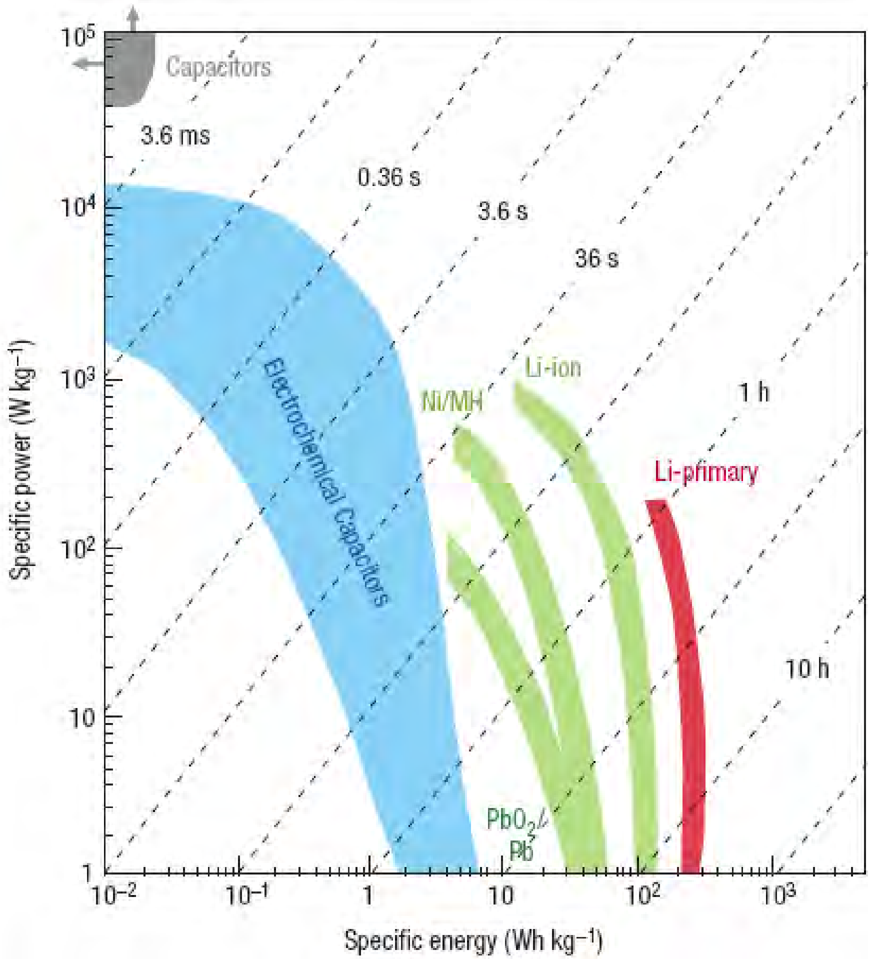
DEVICE	BATTERY	SUPERCAP	CAPACITOR
CHARGING TIME	hours	msec - minutes	µsec - msec
DISCHARGING TIME	minutes - months	msec - minutes	µsec - msec
CYCLE LIFE	200 - 1000	10^6 -10^8	10^6 -10^8
SPECIFIC POWER (W/Kg)	< 500	1000 - 3000	> 10,000
SPECIFIC ENERGY (Wh/Kg)	50 - 300	0.5 - 5	< 0.01

Supercapacitors and batteries are complimentary technologies!

Supercapacitors

Ideal devices for delivering a quick surge of power

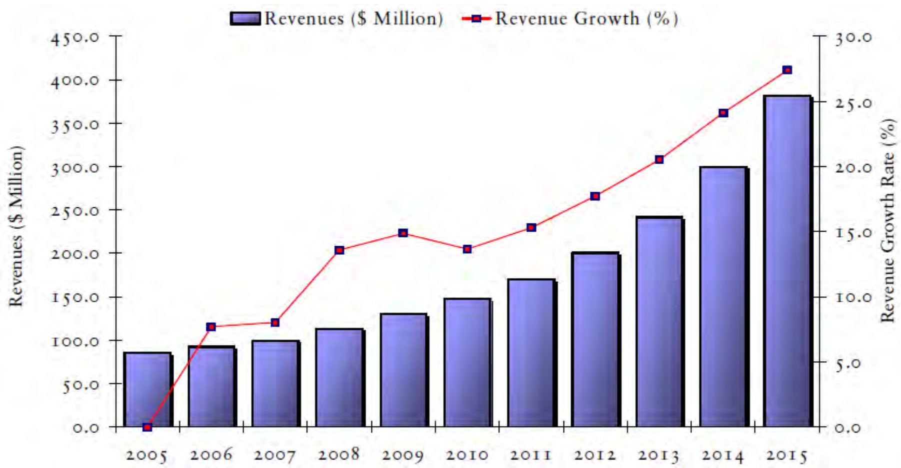
- ➡ Stop-start applications
- ➡ Regenerative braking
- ➡ Power vehicle accelerations
- ➡ Provide power during stops (radio, lights, air conditioning) , while battery provides range
- ➡ Cold starts



P. Simon & Y. Gogotsi, *Nature Materials, Vol.*7 (2008) 845-854.

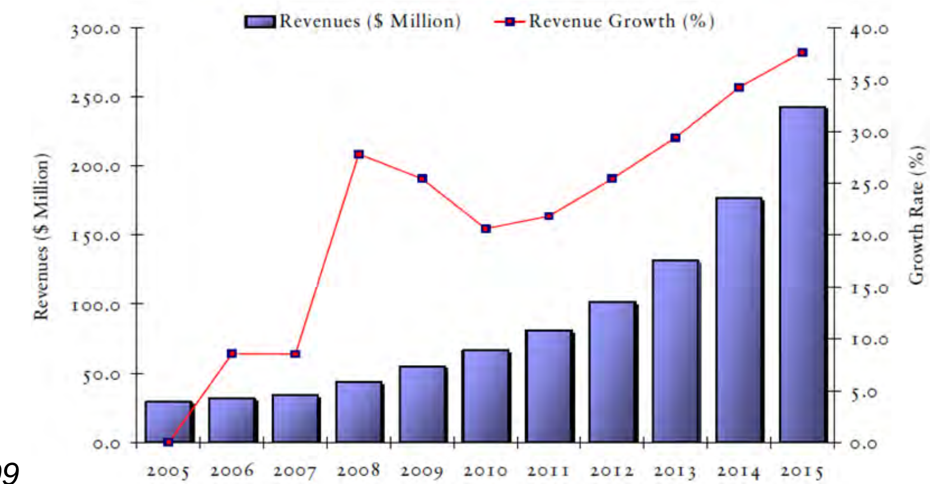
Supercapacitors Market Forecast

Global Market Growth Forecast



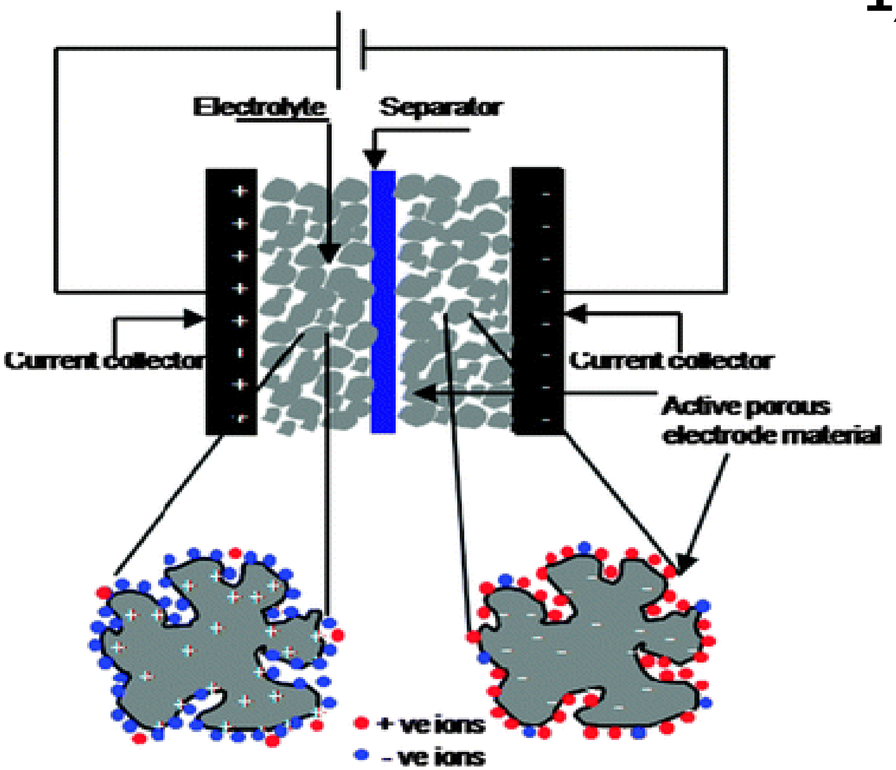
Maxwell's Boostcap®

Transportation Market Forecast



Data from *World Ultracapacitor Markets - Frost &Sullivan report, 2009*

Supercapacitors: Challenges



Graphic from: Zhang et al., *Chem. Soc. Rev., 38* (2009) 2520-2531.

1) Improve performance

- *Increase the energy output*
  - high surface area nano-carbons
  - high capacitance metal oxides or conducting polymers
- *Increase the power output*
  - increase electronic conductivity of active materials
  - texturing current collectors (decrease charge transfer resistance)
  - highly porous separators (increase ion mobility)
- *Increase voltage that device can handle*
  - metal oxides in aqueous medium (2V)
  - ionic liquid electrolytes (4V)

2) Decrease costs

Project Objectives

- Increase both the energy density and the power density of supercapacitors, using **low cost** components and an **asymmetric configuration** (MnO_2/ carbon).
- Investigate the following key issues :
  - **Active materials**: "core" component of the device
  - **Electrolyte**: for better ion intercalation into the active materials
  - **Current collectors**: for a better interface with the active materials
  - **Separator**: for a better ion freedom of movement in the electrolyte
- Evaluate lab scale supercapacitor cells to meet the requirements of transportation applications.
- Develop scale-up strategies for the production of full-scale prototypes.

Transports Canada
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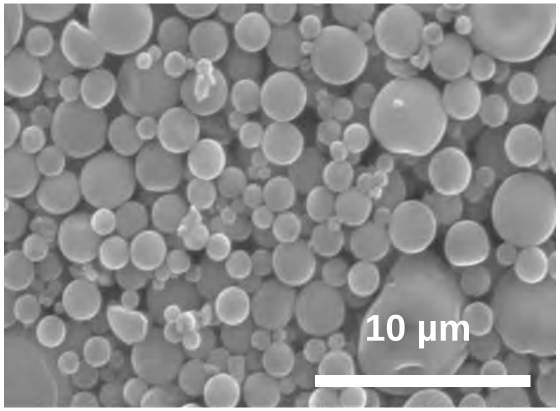
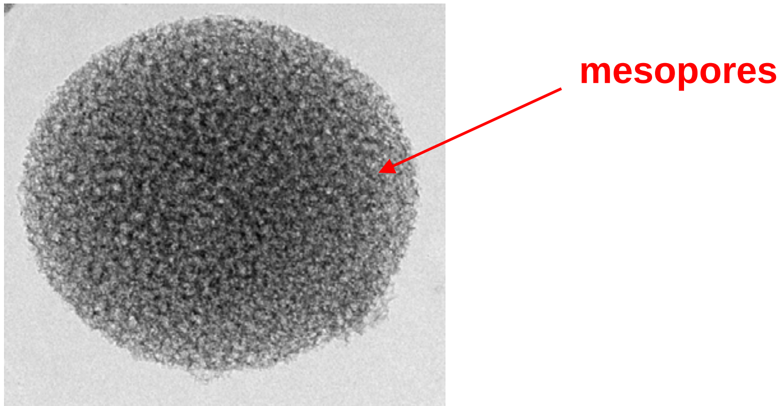
Innovation, Appliquée

Active Materials

Development of high surface area mesoporous carbons

Controllable synthesis of porous carbon spheres by template-assisted ***ultrasonic spray pyrolysis*** (USP, **patented by IFCI**).





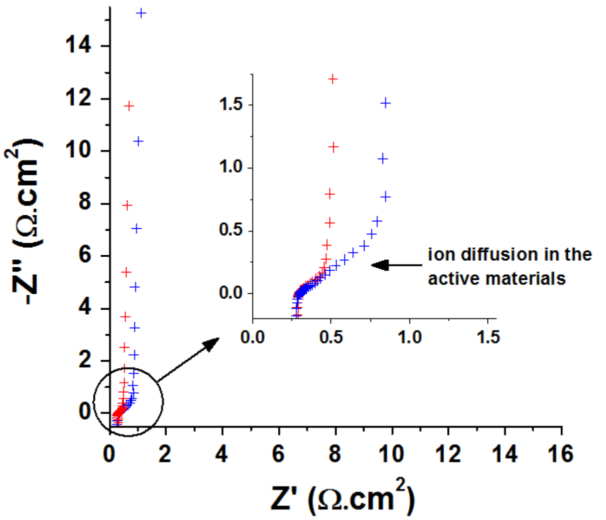
Characteristics of MPC:

- Particle size: 1-5 µm
- Pore size: ~ 7 nm
- Specific surface area : ~ 1800 m^2/g

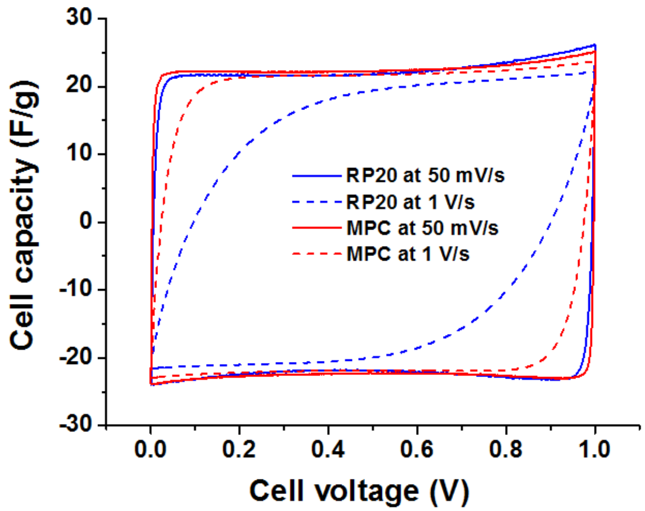
Active Materials

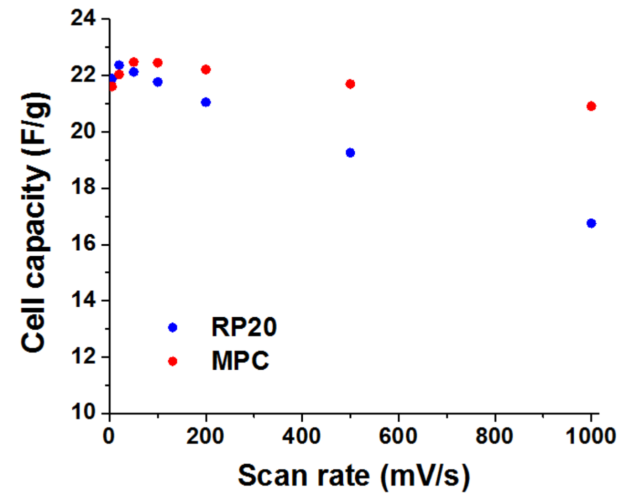
Electrochem. testing of MPC in aqueous supercapacitors

Impedance spectroscopy



Cyclic voltammetry





- Lower diffusion resistance to ions in the porosity of MPC compared to a typical activated carbon (RP20)
- Similar capacity (cell ~ 22 F/g, electrode ~ 90 F/g)
- Better ion mobility in the MPC (probably due to a more open structure)
- Higher capacity retention at high scan rates (high power demand)

Active Materials

MnO_2 as positive active material in supercapacitors

- **Highly capacitive:**
  - theory: ~ 1200 F/g
  - actual: from 100 F/g (bulk phase) to 700 F/g (composites with conducting nanocarbons)
- **Low electric conductivity** (high resistance)
- Many different crystalline structures
- **Important overpotential of water oxidation** (cell voltage increased over 1.23 V)

Chemical synthesis

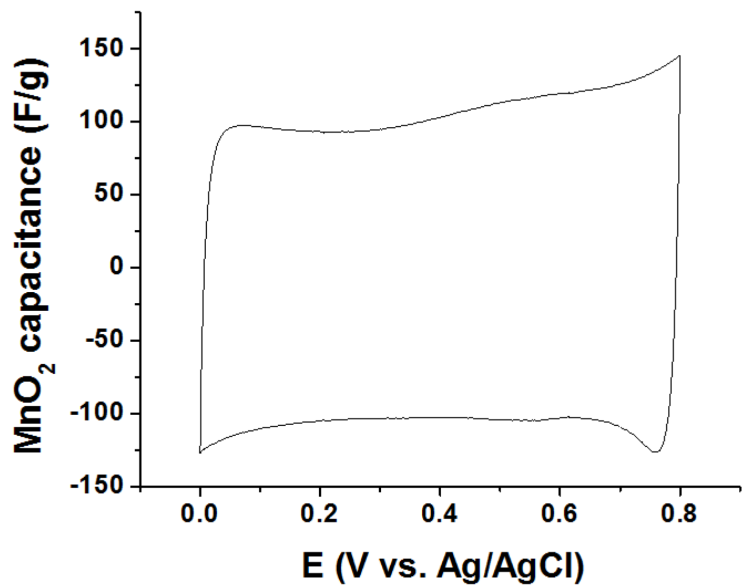
- Very simple chemistry
- Multi-gram scale
- Birnessite type obtained (lamellar structure)

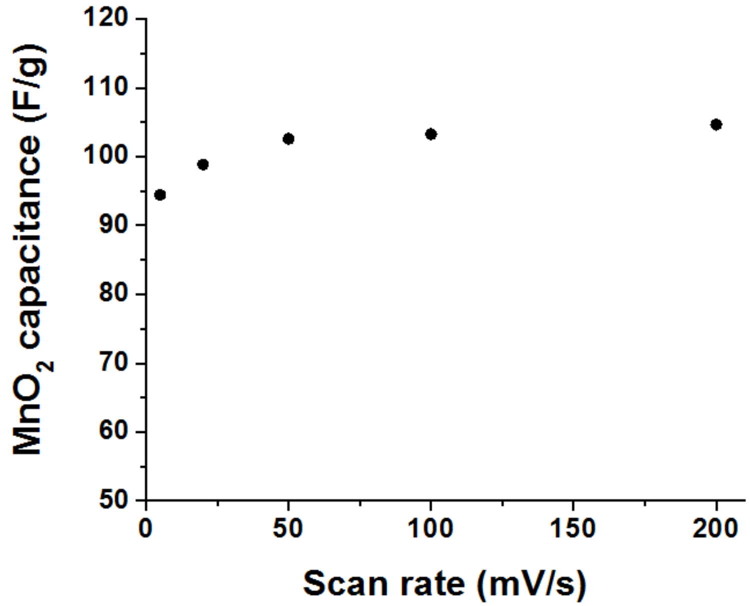
$$MnO_4^- + Mn^{2+} \xrightarrow[\text{base}]{\text{strong}} 2\ MnO_2$$

Active Materials

Electrochem. testing of MnO_2 in aqueous supercapacitors

Cyclic voltammetry



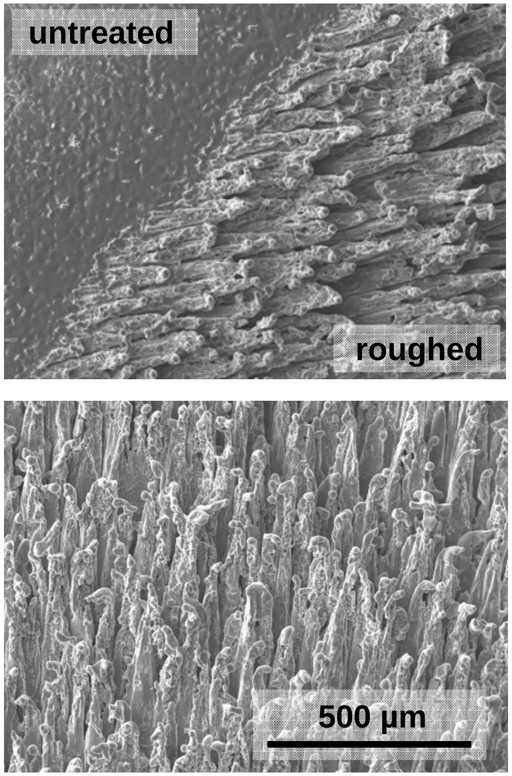


- Typical rectangular charge/discharge profile
- Capacitance: ~ 103 F/g (corresponding to bulk MnO_2)
- High capacitance retention at high scan rate

Current Collectors

Surface roughening of stainless steel and aluminum

- Increase the interface with the active materials
- Improve the mechanical anchoring of the active materials



SEM pictures of roughened Al foil

EDS surface elemental mapping

Element	Weight%	Atomic%
Carbon	3.78	8.11
Oxygen	1.03	1.67
Aluminum	94.01	89.76
Iron	0.81	0.37
Silver	0.37	0.09
Total	100.00	

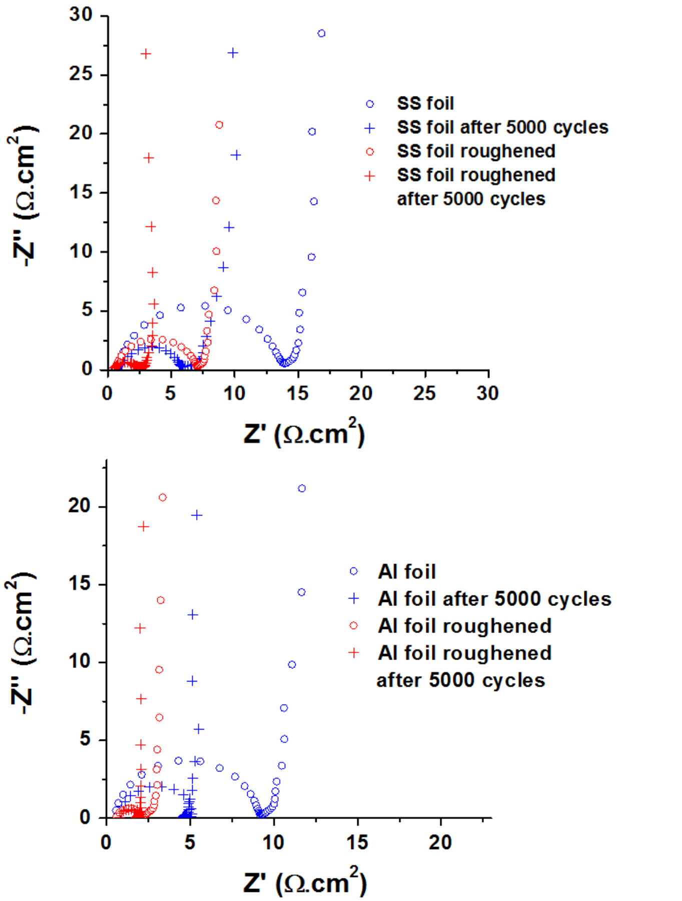
Low oxidation level ensuring low interface resistance

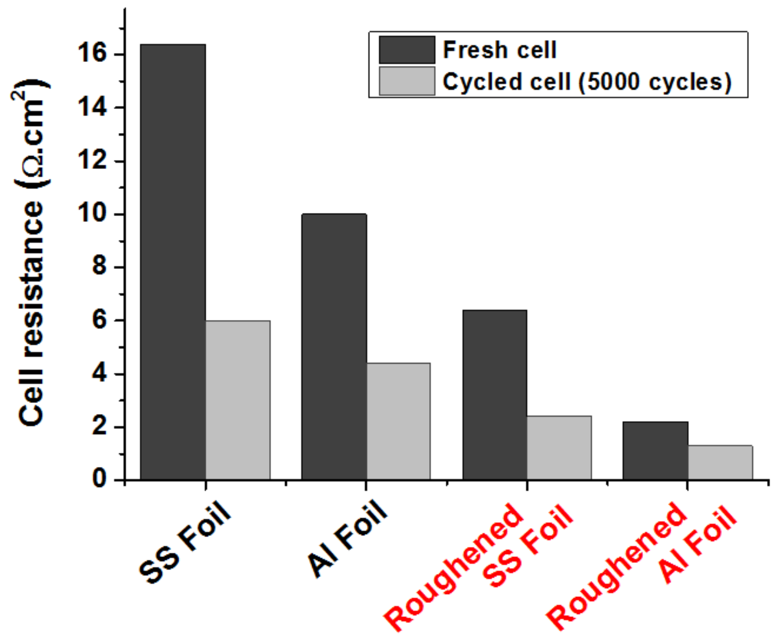
Current Collectors

Electrochemical testing in supercapacitor cells

(conventional symmetric carbon-based cell in mild aqueous electrolyte)

Impedance of SS and Al current collectors



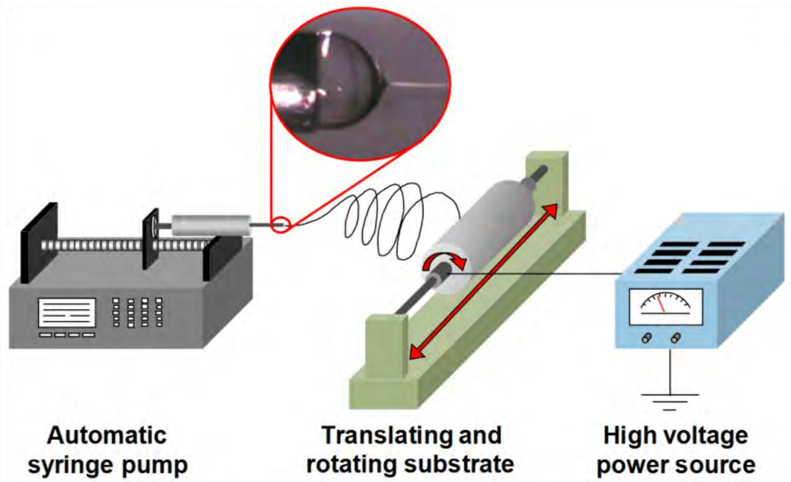


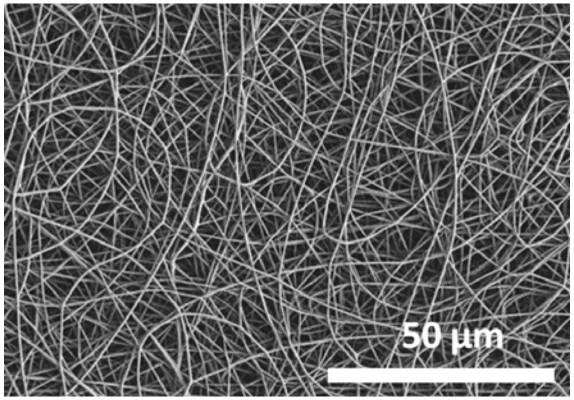
- Higher interface area with the active layer
- Better adhesion of the active materials

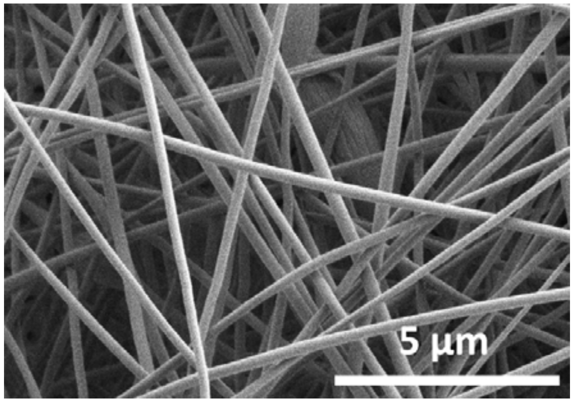
⇨ **Lower cell resistance**

Separators

Electrospinning of nanofibrous nonwoven separators







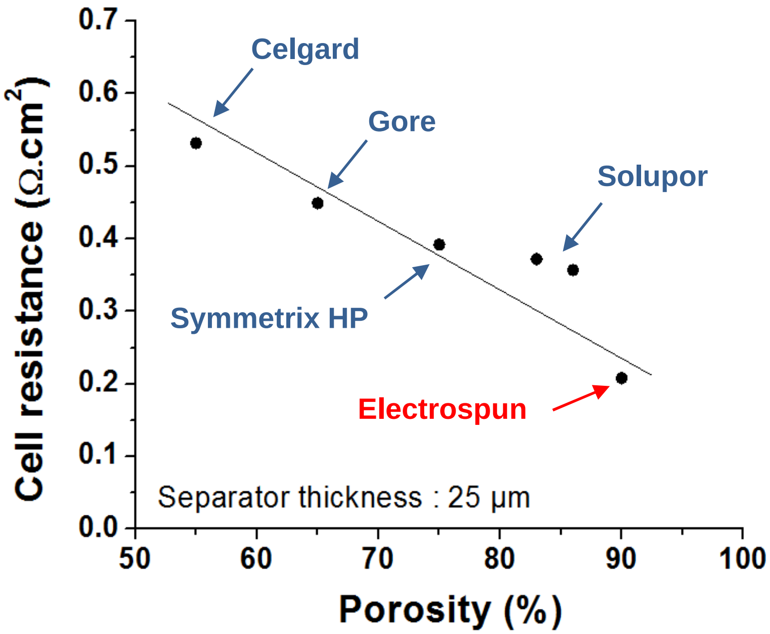
Electrospun separator characteristics:

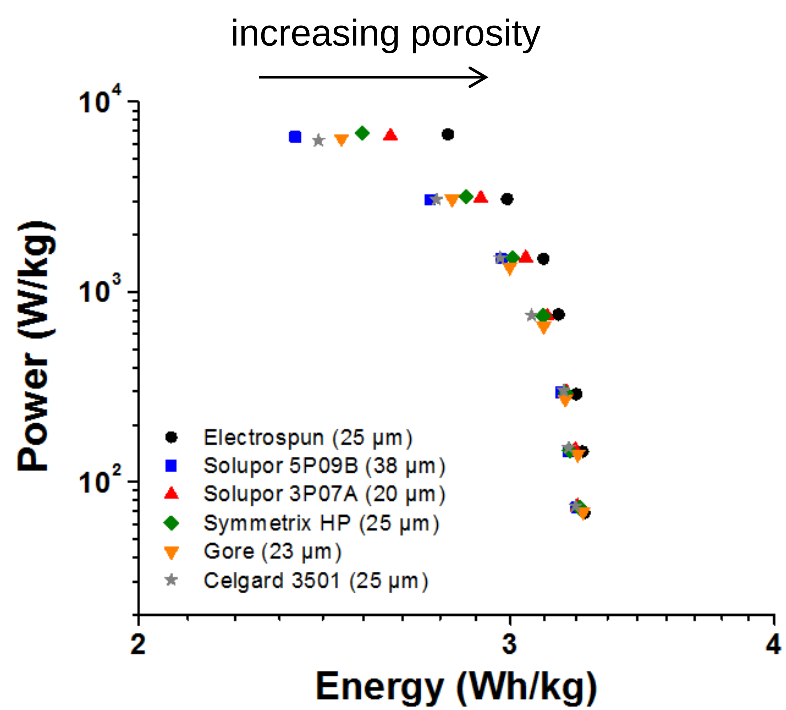
- Material: polyacrylonitrile
- Fiber diameter: 240 ± 30 nm
- Membrane thickness: 25 ± 3 µm
- Membrane porosity: 90 %

Separators

Comparative testing with commercial separators

(conventional symmetric carbon based cell in mild aqueous electrolyte)





- Higher porosity and pore size
- Better ion motion
- Lower internal cell resistance

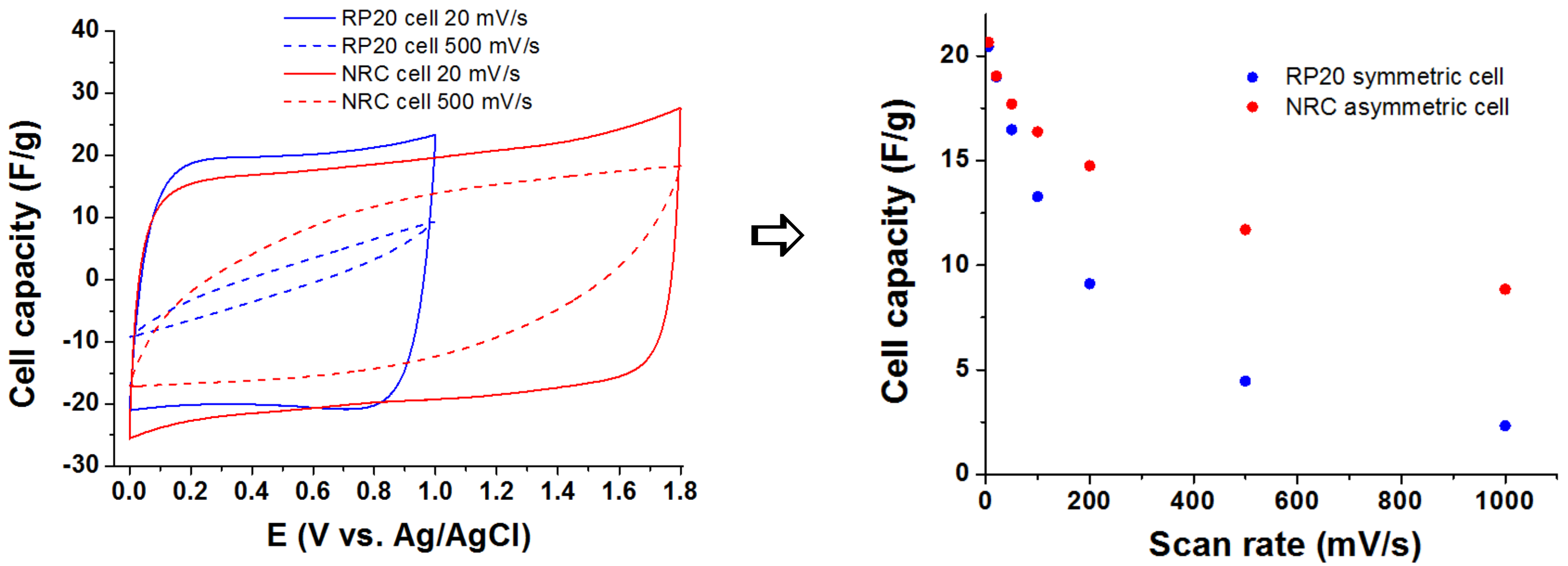
⇨ **Improved power and energy output**

NRC Asymmetric Cell Design

	State-of-the-art cell	NRC cell design
Cell configuration	Symmetric (carbon/carbon)	**Asymmetric** (MnO_2/carbon)
Current collectors	SS foil (AISI 316L)	**Surface roughened** SS foil (AISI 316L)
Separator	Gore (hydrophilic PTFE, 23 µm)	**Electrospun** (polyacrylonitrile, 20 µm)
Electrolyte	Na_2SO_4 0.5 M in water	Na_2SO_4 0.5 M in water
Active layer	Activated carbon (Kuraray, RP20)	**MnO_2** as positive material **MPC** as negative material
	Ketjenblack as conducting additive	Ketjenblack as conducting additive
	PTFE binder	PTFE binder

NRC Asymmetric Cell Design

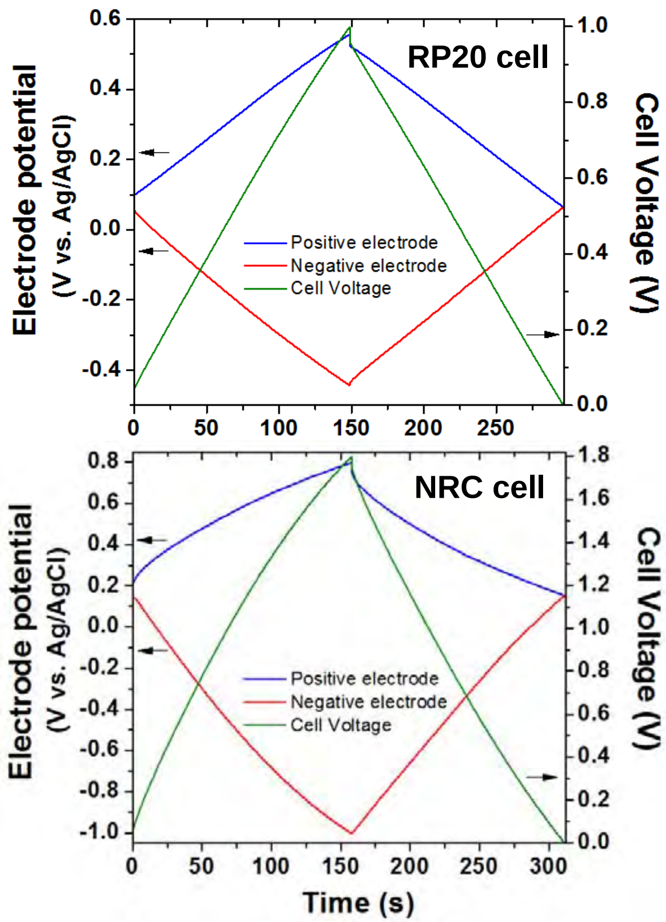
Cyclic voltammetry



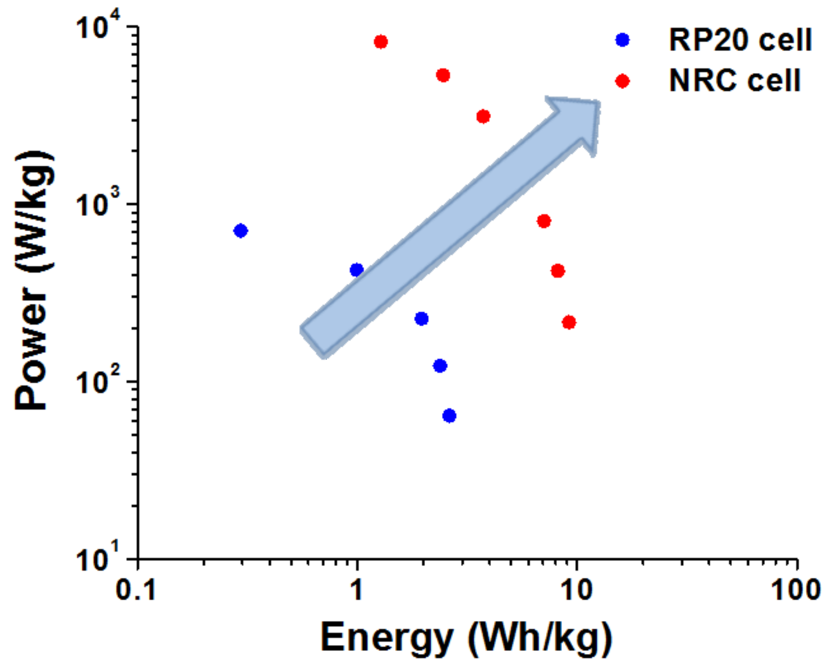
- Higher voltage leads to higher capacity (energy) stored
- Lower internal resistance at the separator and current collectors
- Better capacity retention at high scan rates

NRC Asymmetric Cell Design

Galvanostatic cycling

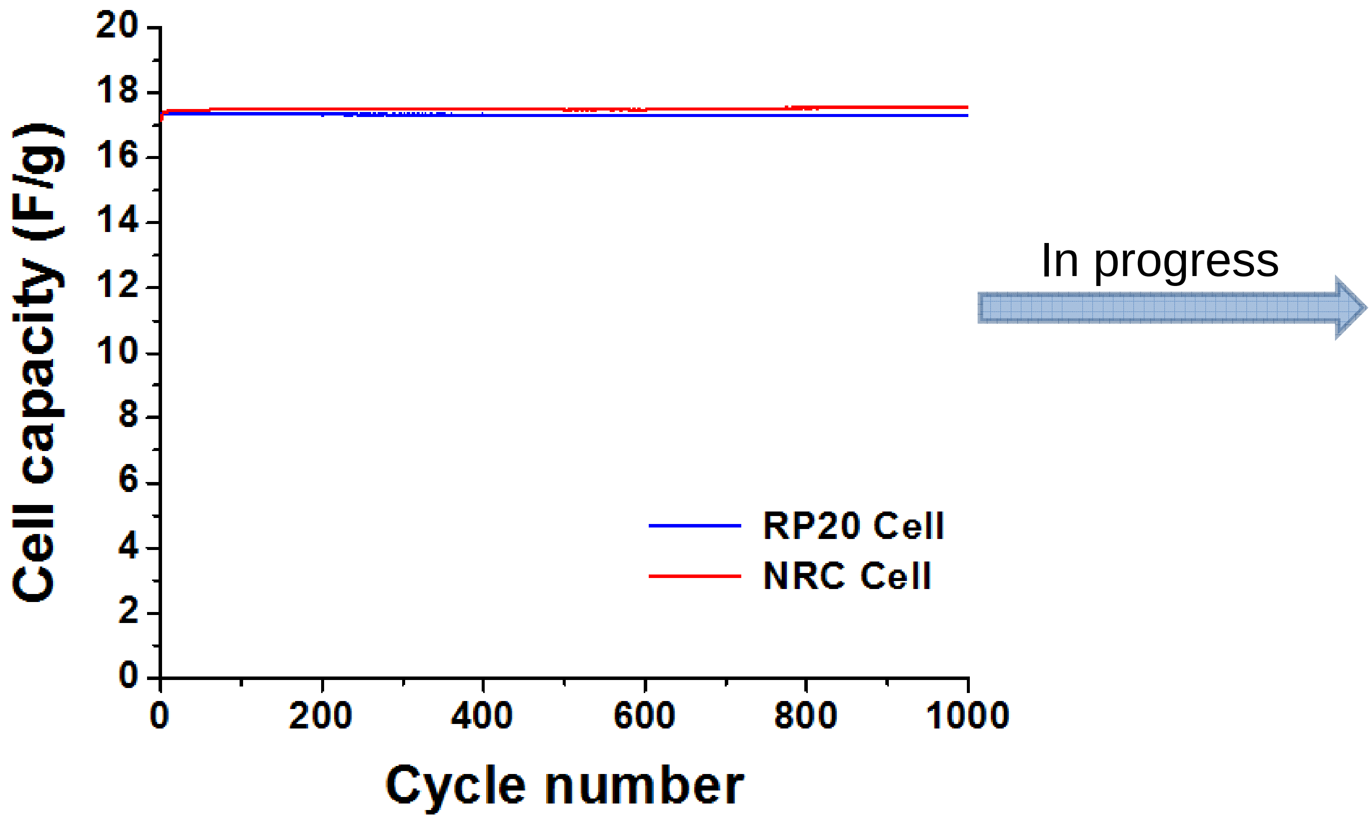


Ragone plot



Improved energy and power output

NRC Asymmetric Cell Design



Conclusions

The objective of the project is to improve performance of supercapacitors by the development of novel components and cell architecture:

- **Mesoporous carbons** as active material demonstrated a more open structure for better electrolyte impregnation and ion mobility (*NRC patented technology).*
- **MnO_2 as positive electrode** allowed the cell to reach a voltage of 1.8 V, increasing significantly the global performance.
- **Surface roughening of current collectors** resulted in a significant reduction of the cell resistance by improving the interface with the active material.
- **Ultraporous electrospun separators** (90% porosity) allowed a significant reduction of the electrolyte layer resistance.

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China's Largest Bus Manufacturer Selects Maxwell Technologie: Efficient, Low-Emission, Hybrid Drive System

Ultracapacitors Provide Cost-Effective, Low Maintenance, Energy Storage Solution

Follow More

SAN DIEGO, Sept. 12, 2011 /PRNewswire/ -- Maxwell Technologies, Inc. (Nasdaq: MXWL) announced today that Zhengz Yutong Bus Co., Ltd. (Yutong), China's largest bus manufacturer, has selected Maxwell ultracapacitors for energy storage power delivery in fuel-efficient, low-emission, diesel-electric hybrid buses that Yutong is producing for public transit agenci worldwide.

Yutong's hybrid drive system incorporates 16 of Maxwell's 48-volt ultracapacitor modules to support braking energy recup and torque assist functions that enable hybrid transit buses to achieve fuel savings and CO2 emission reduction of approx 25 percent and reduce particulate emissions by up to 90 percent compared with conventional diesel buses.

"Ultracapacitors' ability to charge and discharge rapidly enables them to efficiently capture regenerative braking energy an provide instant power for acceleration," said Wang Feng , Yutong's overseas marketing director. "In addition, their long op life and minimal maintenance requirements in demanding public transit operating conditions make ultracapacitors a very c effective energy storage solution for hybrid buses."

"Yutong has developed an innovative hybrid drive system for efficient, environmentally friendly, transit buses and other he vehicles," said David Schramm , Maxwell's president and chief executive officer. "This opportunity to work closely with a w leader in transportation technology is helping us to better understand the requirements of hybrid-electric vehicles and cont optimizing our products to deliver world-class performance and value."

Maxwell ultracapacitors are powering some 4,000 hybrid transit buses currently in service worldwide, and are being emplo several other transportation applications, including a stop-start idle elimination system developed by Continental AG for m hybrid diesel automobiles now being produced by PSA Peugeot Citroen in Europe.

Unlike batteries, which produce and store energy by means of a chemical reaction, ultracapacitors store energy in an elec This electrostatic energy storage mechanism enables ultracapacitors to charge and discharge in as little as fractions of a s perform normally over a broad temperature range (-40 to +65 degrees Celsius), operate reliably through one million or mo charge/discharge cycles and resist shock and vibration. Maxwell offers ultracapacitor cells ranging in capacitance from on 3,000 farads and multi-cell modules ranging from 16 to 125 volts. For more information on Maxwell's ultracapacitor produc please visit our web site, Maxwell.com.

About Yutong: Headquartered in the city of Zhengzhou in China's Henan Province, Zhengzhou Yutong Group Co., Ltd. is industrial group mainly specializing in bus production. It is one of China's top 500 enterprises, with additional strategic bus activities, including construction machinery, automotive parts and components and real estate. Zhengzhou Yutong Bus Co the core enterprise of Yutong Group, was established in 1963, and now is located in Zhengzhou Yutong Industrial Park in million square-meter facility with a daily production capacity of over 170 buses. It has become one of the world's largest ar most technically advanced manufacturers of large and medium-sized buses and is China's largest producer of medium an buses.

About Maxwell: Maxwell is a leading developer and manufacturer of innovative, cost-effective energy storage and power solutions. Our ultracapacitor cells and multi-cell modules provide safe and reliable power solutions for applications in cons and industrial electronics, transportation and telecommunications. Our high-voltage grading and coupling capacitors help e ensure the safety and reliability of electric utility infrastructure and other applications involving transport, distribution and measurement of high-voltage electrical energy. Our radiation-mitigated microelectronic products include power modules, r modules and single board computers that incorporate powerful commercial silicon for superior performance and high relial aerospace applications. For more informat on, please visit our website: www.maxwell.com.

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Maxwell Technologies
Enabling Energy's Future™

Maxwell Ultracapacitor Transportation Solutions

Carbon emissions, the depletion of natural resources, traffic congestion and the rising costs of fossil fuels are all issues pushing the world to search for alternative means of transportation. Mass-transit buses, fleet vehicles, long-haul trucks and other heavy-transportation vehicles such as trains, light rail, trams and metros, all benefit from the adoption of a hybrid power train approach with the use of ultracapacitors. Every day, in nearly 5,000 buses from China to Italy, Maxwell ultracapacitors are enabling hybrid and all-electric drive vehicles to save fuel and reduce emissions. Consequently, primary energy demand and maintenance costs can be considerably reduced.

Ultracapacitors quickly capture energy from braking and then use that energy to provide a short burst of power during acceleration and to dramatically reduce the use of fuel in a conventional internal combustion engine or battery drain in an electric/hybrid system. Maxwell ultracapacitors are compact, high-performance, have exceptionally long-life and fulfill many of the functions of batteries but with dramatically higher reliability and are virtually impervious to any climate condition.

Heavy transportation vehicles - such as trains, trams and metros - place particular demands on energy storage devices. Such devices must be very robust and reliable, displaying both long operational lifetimes and low maintenance requirements. Further, the devices must operate efficiently under harsh conditions including handling peak currents, high duty cycles and frequent deep discharging. Maxwell Technologies solved these issues with its ultracapacitor HTM125 module for braking energy recuperation and torque assist systems in trains, trams and metro transportation vehicles.

Download our Ultracapacitor Bus Application Brief

Maxwell Ultracapacitor Transportation Quick Facts:

- Fuel economy 76 percent better than conventional gasoline-powered buses and 22 percent better than diesel-powered buses
- Scalable for 6 to 16 liter engines
- The only e-mark ultracapacitor module for transportation 2004/104/EEC
- Higher resistance to heat and fire – lasts longer than batteries that may explode
- A green, maintenance-free energy storage and power-delivery solution

Maxwell Ultracapacitor Transportation Applications:

Maxwell ultracapacitors can be used to complement batteries or replace batteries altogether in buses and trucks, including these solutions:

Regenerative Braking Systems

Maxwell ultacapacitors can absorb and store virtually all kinetic energy from a braking system. The emission-free stored electrical energy in ultracapacitors is then available to assist in acceleration, to reduce fuel consumption and accompanying emissions or battery drain, as well as power the air conditioner, operate power steering or perform other electrical functions. As an added bonus, regenerative braking takes most of the load off mechanical brakes, reducing brake maintenance and replacement expenses.

Start-Stop Technology Gets a Boost from Ultracapacitors

Start-stop technology enables the engine in conventional, electric or hybrid-electric delivery trucks and refuse vehicles to shut down when they come to a stop at a red light, picking up or dropping off passengers, or when sitting in traffic. Maxwell Technologies ultracapacitors then provide a short burst of energy that restarts the motor. With 100 percent reliability at temperatures from -25oC to 45oC, low lifecycle cost, and the ability to capture energy from regenerative braking. Maxwell ultracapacitors can save millions of barrels of oil as well as improve fuel economy 76 percent over conventional gasoline-only powered vehicles.

Bus and Truck Starter Systems

Maxwell ultracapacitors provide a lower cost of ownership for trucks and fleets and prevent lost down time due to no-start, overnight “hotel” loads, and are especially beneficial for heavy-duty vehicles in cold climates or that require repetitive starts. Trucks place heavy demand on energy storage devices and depend on the reliability of ultracapacitors, but the real benefit comes in removing up to three lead acid batteries, freeing up under-hood and step-well space, enabling load stabilization and preventing "brown out." Starter systems for buses in cold climates eliminate morning idle heat up and the cost of jump starting.

As design engineers have found, batteries have high-energy capability while the ultracapacitors have high power capability. In an optimal hybrid alternative drive system, both technologies could be combined in a way that maximizes the benefits of both.

Maxwell Ultracapacitor Transportation Customer Applications:

Siemens Sitras

NYC Hybrid Buses

Voith Hybrid Buses

Maxwell Ultracapacitor Transportation Products:

Maxwell Technologies offers the most comprehensive ultracapacitor product line for the transportation industry. The time for efficient and environmentally-friendly energy storage and management has come and Maxwell's ultracapacitor solutions have proven themselves to fulfill this requirement.

125V Heavy Transportation Module

This module stores more energy per unit volume, delivers more power per unit volume and weight, and lasts longer than any other commercially-available ultracapacitor solution. Especially designed for vehicles requiring the highest power performance available with shock and vibration immunity. (Hybrid buses and trucks)

48V Ultracapacitor Module

This module provides efficient cooling and a maximum continuous current of 90A without compromising reliability. Used primarily with hybrid buses and train engine starting systems.

16V Ultracapacitor Module

Engine starting systems for buses.

K2 Ultracapacitor Cells

A solution for hybrid train systems where the ultracapacitor is integrated into custom modules.

Maxwell Technologies offers the most comprehensive ultracapacitor product line for the transportation industry. The time for efficient and environmentally-friendly energy storage and management has come and Maxwell's ultracapacitor solutions have proven themselves to fulfill this requirement. These solutions are an essential part in today's innovative, efficient hybrid system for public transportation and heavy transportation applications, allowing an increase in power efficiency and a reduction in fuel consumption and global CO2 emissions. Our commitment is to help our worldwide customers design and implement ultracapacitor solutions for existing and unique heavy-duty transportation needs.

Ultracapacitors for Transportation Systems

Every day, in nearly 5,000 buses from China to Italy, Maxwell ultracapacitors are enabling hybrid and electric drive vehicles to save fuel and reduce emissions.

ULTRACAPACITORS

BUS APPLICATION BRIEF

Carbon emissions, the depletion of natural resources, traffic congestion and the rising costs of fossil fuels are all issues pushing the world to search for alternative means of transportation. Mass-transit buses, fleet vehicles, trains and heavy-transportation vehicles all benefit from the adoption of a hybrid power train approach with the use of ultracapacitors.

Ultracapacitors quickly capture energy from braking and then use that energy to provide a short burst of power during acceleration to dramatically reduce the use of fuel in a conventional internal combustion engine or battery drain in an electric/hybrid system. Maxwell ultracapacitors are compact, high-performance, have exceptionally long-life and fulfill many of the functions of batteries but with dramatically higher reliability and are virtually impervious to any climate condition.

Ultracapacitors:
- Breakthrough energy storage and delivery devices

Ideal for:
- Regenerative braking systems
- Start-stop systems
- Cold climate starting
- Hybrid electric vehicles:
  - Buses, trains, trolleys, light rail

Green technology:
- High efficiency with fewer CO_2 emissions
- Lead free

Used in over 4,000 buses worldwide:
- MAN
- Gillig
- New Flyer
- NYC Hybrid
- BAE Bus

Maxwell® TECHNOLOGIES
Enabling Energy's Future™

ULTRACAPACITORS

BUS APPLICATION BRIEF



Specifications

	K2 Series	48 V Modules	125 V Modules
Capacitance	650 - 3,000 F	83 - 165 F	63 F
Voltage	2.70 V	48 V	125 V
ESR, DC	0.29 - 0.8 mohm	6.3 - 10 mohm	18 mohm
Leakage Current	1.5 - 5.2 mA	3.0 - 5.2 mA	10 mA
E_{max}	4.1 - 6.0 Wh/kg	2.6 - 3.9 Wh/kg	2.3 Wh/kg
P_{max}	12,000 - 14,000 W/kg	5,600 - 6,800 W/kg	3,600 W/kg

Images not to scale.

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R and D

ACR System

General Description

The ACR project developed by CAF in conjunction with Trainelec (a CAF group company), is an on-board energy storage system based on the use of ultracapacitors which enables trams to run between stops without catenaries, as well as to save energy through the full regeneration of braking energy.
This system is compatible with other technologies and suitable for use on rolling stock of any type and manufacturer, and on new or existing facilities and infrastructure.

- Efficient and energy saving in catenary powered operation
    - Energy saving and reduction of current peaks in catenary powered operation.
    - Maximum energy regeneration from braking processes.
- Safe running range in emergency situations in the event of sudden power failures.
- Catenary-free Operation.
    - Temporary (1 section between stations due to power line failure).
    - Permanent (several consecutive sections between stations).
    - Up to 1000 metres of catenary-free running range, depending on route characteristics, required performance and installed capacity.

Onboard Energy Storage System with UltraCaps of Railway Vehicles

Dr. Michael Fröhlich
Bombardier Transportation, Mannheim, Germany

Dr. Markus Klohr
Bombardier Transportation, Mannheim, Germany

ABSTRACT

The on board energy storage system with Ultracaps for railway vehicles presented in this paper proved to be a reliable technical solution with an enormous energy saving potential. Bombardier Transportation already made a lot of experiences in this field, e.g. equipped one bogie of a prototype LRV (light rail vehicle) for the public transportation operator RNV in Mannheim with a MITRAC Energy Saver. Outstanding feature was the daily operation of the energy storage unit in daily passenger service, and this over remarkable 4 years, since September 2003. With 4 years revenue service the new technology can be seen now as reliable. The very positive experience was the base for an order to equip several LRVs with MITRAC Energy Saver, which was just placed by RNV –the best confirmation of successful experience the customer could make.

The measured traction energy saving of approximately 30% confirmed fully the former calculations. The revenue service of the prototype LRV is stopped now to concentrate fully on the new order.

Running the energy storage device on board of a tram brings additionally following benefits:

- a dramatic reduction of the peak power demand, resulting on considerable benefits in the infrastructure. In the example presented in this paper a reduction to 6 substations from original 8 substations became feasible by introducing MITRAC Energy Saver on board of LRVs
- “catenary free operation” on several hundred meters without power supply from the catenary
- catenary free city center by on board storage and recharging stations

Applying the energy storage devices in Metro systems has a similar effect as in case of LRVs. However the savings distribution in the whole system will be a little bit different. Due to higher regeneration capability of metro systems the expected share of the train propulsion saving will be lower. It will be compensated by a considerable reduction of the line losses, especially for systems with low rated catenary voltages (600V or 750V).

Very promising are energy storage applications in propulsion systems of Diesel-Electrical Multiple Units (DEMUs). These vehicles lack possibilities to use the braking energy of the train. Energy storage systems on board of DEMUs bring high fuel savings together with the corresponding emission reduction. On top of that the energy storage leads to a booster effect – extra power during acceleration from the storage, by adding the limited weight of the MITRAC Energy Saver.

INTRODUCTION

Modern LRVs and Metros have the ability to convert the mechanical braking energy of the train into electrical energy and to feed it back into the catenary or the third rail. However this energy can be only used if there are in the neighborhood of the braking vehicle simultaneously other trains with high energy demand (Note that typical LRV systems have cheap diode bridge rectifiers in the substation and can therefore not regenerate into the power grid). In cases, this requirement can’t be fulfilled the braking energy must predominantly be (useless) dissipated in the brake resistors of the vehicle converter.

The challenging alternative is to store the braking energy on the train and use it during the next acceleration of the vehicle. Bombardier Transportation has selected energy storage systems on basis of UltraCaps.

The most challenging operating conditions for storage devices on board of traction vehicles (LRVs, Metro-trains, DEMUS) are:

-high number of load cycles during the vehicle lifetime
-relatively short charge/discharge times
-high charge and discharge power values

Proposed storage technologies aiming at brake energy storage are UltraCaps or Flywheels, while batteries do not achieve the necessary load cycles, see [5,8,9]. Outstanding feature of our prototype vehicle is the operation in daily passenger service, and this even since September 2003. For pure catenary free applications further alternatives can be discussed, Batteries or a 750V ground power supply, of course not leading to similar energy saving effects, see [5,8]. Bombardier preferred UltraCaps (double-layer-capacitors) with outstanding features such as high load cycle capability, high energy density (ca. 6Wh/kg) and very high power density (ca. 6 kW/kg). For the railway applications discussed here they are seen as superior to NiMH or Li-Ion batteries and flywheels. The drawback of NiMH and Li-Ion batteries is the limited load cycle capabilities NiMH batteries have furthermore a rather poor power cycle (charge/discharge) capability. Li-Ion batteries have until now safety concerns, at least in the volumes required by railway applications. Flywheel systems achieve a similar energy density on system level, but at reduced power and at the moment with open topics on safety.

MITRAC ENERGY SAVER IN REGULAR PASSENGER SERVICE

Fig. 1: Prototype Vehicle in Mannheim

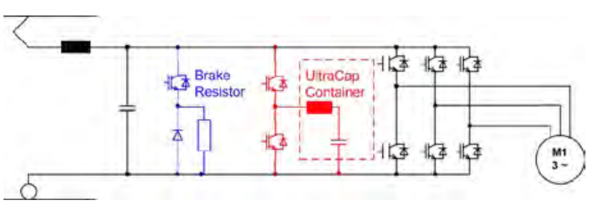


Fig 2: circuit diagram

To demonstrate the benefits of using energy storage systems on traction vehicles Bombardier Transportation equipped one LRV (light rail vehicle) with a roof mounted *MITRAC* Energy Saver (Fig 1). This energy storage vehicle has the unique feature of passenger operation, which has not been achieved by other experimental railway vehicles. Since September 2003 the vehicle has been trouble-free running in the regular passenger service of the operator RNV in Mannheim. The experimental LRV has two powered bogies with two motors each. The *MITRAC* Energy Saver unit is connected to the dc-link of the traction inverter of the powered bogie in the front (Fig 1). The inverter of the other powered bogie in the rear remains without energy storage. Such configuration of the tram propulsion system allows comparison of the energy consumption of both bogie drives and leads directly to traction energy savings.

The *MITRAC* Energy Saver system installed on the vehicle in 2003 consists of:

- a UltraCap bank with energy content of about 1kWh, with housing dimensions of : 1900mm x 950mm x 455mm and a mass of about 450 kg
- a bidirectional IGBT chopper controlling the energy flow is installed in the converter

Reduction of the Peak Power Demand and Infrastructure Losses

The current demand from the line is roughly halved by installing two energy storage units on the vehicle, see (Fig. 3). It means the MITRAC Energy Saver reduces not only the energy consumption of the vehicle but also reduces power losses in the infrastructure, which go with the square of the current.

The mass transit operator pays energy costs as well as peak power costs, both reduced by the energy storage system on board of the vehicle.

Reduction of the line current by 50% causes an identical reduction of the line voltage drop. It is obvious that UltraCap storage devices onboard of traction vehicles stabilize the catenary voltage. It can be confirmed by comparison of line voltages with and without ES in the bottom diagram of the Fig 3.

This significant advantage of system with energy storage can be exploited in different ways:

- Increasing of the distance between substations for the planned new lines

- Reducing of time intervals between following trains at existing lines
- Acceptance of longer trains on existing lines

There are also some disadvantages of the energy storage on board of traction vehicles, e.g.:

- Increase of the train mass by approximately 2%
- Additional space to accommodate the energy storage container is necessary

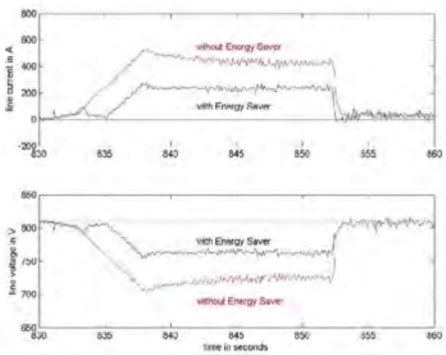


Fig. 3: Line current and voltage with and without MITRAC Energy Saver

REDUCTION OF THE INFRASTRUCTURE INVESTMENTS

In a computer simulation the influence of the number of and distance between substations has been analyzed. The chosen example is a 17,7km line with a reduction from 8 to 6 substations, when using vehicles with on board energy storage. The headway is 5 min and the distance between stations is always 680m. All the vehicles with an operational maximum speed of 60km/h are either equipped with or without a 0.76kWh energy storage device.

The following system solutions have been directly compared:

a) Line section with 8 substations, all trains without energy storage devices
b) Line section with 6 substations, all trains equipped with ES systems

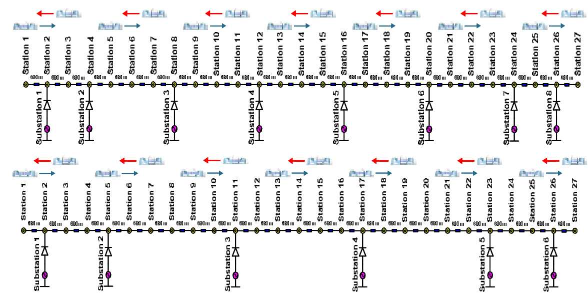


Fig. 4:. top: Reference line using conventional vehicles and 8 substations
bottom: Alternative with energy storage vehicles and only 6 substations.

The simulation results allow the following important conclusion:

The substation load currents as well as the catenary voltage drops remain in case b) despite of decreased number of substations in the same range or are even slightly lower than in case a).

Two main results were achieved by the simulation: The rated current of the substations in both cases remained in the same range as well as the voltage drop between 2 stations remained in the same region.

For example the effective values of the “Substation 2” load current are:

- **307.3A** for conventional vehicles and 8 substations
- **305.5 A** for vehicles with energy storage devices and 6 substations

The voltage drop between two substations measured on the pantograph of the vehicle is presented in Figure 5. Please note that the voltage drop during acceleration is the designing figure, see the green part in Fig 5. In both cases conventional vehicles with 8 substations and energy storage vehicles with only 6 substations the voltage drop is in the same range.

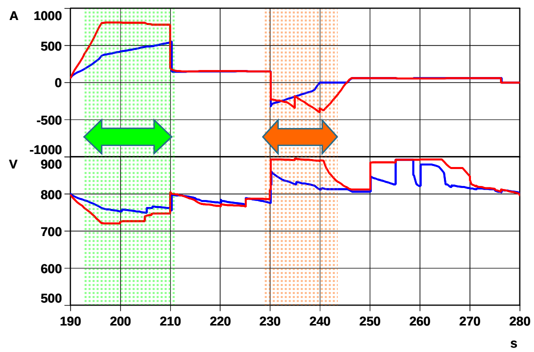


Fig 5: Line currents and voltages for trains, starting at the same time at "Station 14".
Red: casa a (trains without ES, 8 substations)
Blue: casa b (trains with ES devices, 6 substations)

The comparison of the catenary voltage curves (measured on the vehicle pantograph) for corresponding trains without and with energy storage (s. Fig 5) shows even some advantages of the solution b) with energy storage systems and only 6 substations, may be a further reduction of substations is possible. Especially the impedance voltage drop between the source in a substation and the present vehicle location is in case b) lower. This feature is very important because it results in a higher available power or lower load currents.

The trains with ES systems have better recovery abilities as well, see time between 230 and 240sec in Fig 5. Since quite a big part of the trains braking power is used for charging the energy storage, the relatively low amount of the surplus energy usually can be regenerated, utilized by other trains in the system.

In case a) the amount of energy offered by braking trains is very often higher than the present demand of other consumers in the catenary system. In such cases a part of the braking energy is wasted in the brake resistors.

The recovery of the braking energy in the own energy storage is very effective, because a big part of it will be reused locally and doesn't need to be supplied to sometimes far away consumers. It results in reduced losses in the catenary system.

With this simulation it could be proven that it is possible to reduce the number of substations by using vehicles with energy storage. This is a very important feature since the costs for substations are very high. Sometimes, especially in downtown areas, there are even problems to find an appropriate location for an additional substation.

Please note that the Return of Investment (RoI) for a new energy storage system is quite interesting. For the example of 6 instead of 8 substations and 21vehicles the RoI was below 2 years.

The RoI is very interesting from an overall point of view, but sometimes struggling with the Bid process. Infrastructure and vehicles are often handled by different departments and quite often in different stages of the project. To make use of all benefits of on board energy storage requires flexibility of all involved parties.

CATENARY FREE OPERATION

Another advantage of the on board energy storage system is the possibility to move the vehicle without external power supply. This can be used in special cases as operation during power loss but also for the so called Catenary Free Operation.

Even with limited installed energy storage of e.g. 2*650Wh, which is optimized for the energy saving effect of a 30m tram, several hundred meters could be bridged by just using the energy stored in the on board storage. In an experiment with the prototype LRV in Mannheim the train with only 1kWh installed energy covered successfully a 500m distance without power supply from the catenary. The maximal train speed was about 26 km/h. The fact, that only one bogie of the experimental vehicle in Mannheim was equipped with an energy saver makes the performance even more impressing.

This feature with limited installed energy storage allows the vehicle:

- To evacuate the track (especially tunnels) after breakdowns of the catenary power supply
- Independent movements within depots or workshops

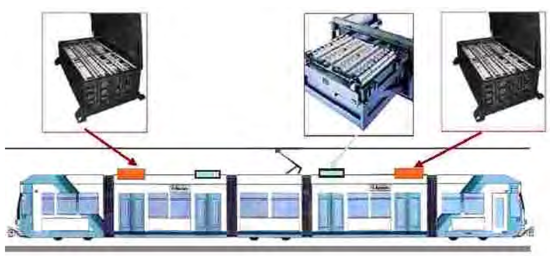
Catenary Free Operation of an LRV is an increasing market demand. The main aspired benefit is possibility to reduce overhead wires for esthetical reasons. There are typically 2 different interests:

- Short track sections without catenary (e.g. Old Town sections or track fragments in front of historical buildings – where the building authorities doesn't allow the installation of overhead lines) This demand can be fulfilled by appropriate dimensioning of the on board storage. In most cases 2*1,7kWh installed energy on a 30m vehicle are enough. Please note that it was possible to run some 500m with the prototype vehicle which has just 1kWh installed energy

- Inner city without catenary or several sections without catenary.

This demand can be served by on board storage and recharging in stopping stations. E.g. several sections of e.g. 500m between stops

Fig. 6: Recharging station with "overhead busbar"



: Fig. 7: Availability through redundant storages, 2 MITRAC Energy Saver and vehicle battery

Recharging in the stations.

Recharging of the on board storage could be done during stops in the stations. The stopping stations should be able to deliver a power of at least 600kW. The time to recharge an energy portion of 3kWh into an on board energy storage is just 20 seconds, assuming 600kW and an efficiency of 85%. This fits very well to a 30m long tram, where the installed energy is 3,4kWh (2*1,7kWh). Please note that during the braking into the station the on board energy storage is already charged quite a bit, so that only the remaining part has to be recharged by energy from outside of the vehicle. Even in a 20 second stop there is enough time to optimize the recharging procedure to e.g. reduced overall losses. One possible realization of a recharging station could be an overhead busbar. The normal pantograph is able to handle currents up to 1kA in standstill by using the bigger contact surface of a busbar instead of an overhead wire. In this case the 600kW could be delivered from a simple recharging station by just adding an overhead busbar fed by the standard substations. LRV under catenary also have a power demand of about 600kW during acceleration.

Availability of the vehicle in Catenary Free Sections The availability of the vehicle in a catenary free section is mainly solved by redundancy of the energy storage system. A 30m long vehicle contains typically 2 independent on-board MITRAC Energy Saver as well as the vehicle battery. The following operation situations are possible:

- One failed MITRAC Energy Saver. In most of the application cases the remaining MITRAC Energy Saver can still run the vehicle through the catenary free sections by reduced performance, e.g the Aircon should be switched off and the speed might be reduced
- Two failed MITRAC Energy Saver. Even in this case the vehicle can run some 3…5 km in an emergency mode without help from outside, by using the vehicle battery. Of course the performance is very limited, Auxiliaries have to be switched off as much as possible and the vehicle speed is restricted to a few km/h, e.g. with a step up chopper from battery to dc-link to about 4km/h. The vehicle battery has quite significant energy stored, typically more than 8kWh, which should be enough for 3...5 km with limited performance. Please note that this emergency mode will nearly never happen and therefore the battery can be stressed to its maximum. For more details and a comparison battery and UltraCaps see [5]

METRO APPLICATION WITH MITRAC ENERGY SAVER

The principle of the on-board energy storage system for metro applications is very similar to the already described system for Light Rail Vehicle (LRV) [6,7, 16]

However there are some differences which can be especially for metro systems with low catenary voltages (600V or 700V) of significant importance:

- Metro systems show usually a higher regeneration ability than LRV's, especially when the line is coupled through. The reason is a big number of vehicles connected to the catenary system capable to use braking energy.
- Due to high line currents, the share of infrastructure losses in overall system losses considerably higher than in LRV systems.

Bombardier Transportation started some detailed simulations of one European metro system to evaluate the infrastructure losses and effects of high regeneration levels. The schematic diagram of the simulation model is shown in the Fig. 8. It represents a 5,4 km downtown tunnel section of the track. The average distance between substations is about 2,5 km, while the average distance between stops equals 1,4 km.

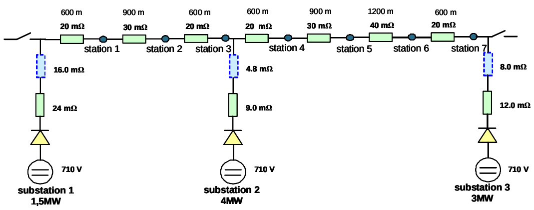


Fig. 8: Infrastructure section of a Metro system

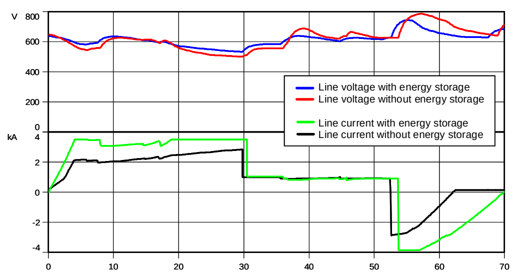


Fig. 9: Recharging station with "overhead busbar" : Simulation during the rush hour - vehicle line currents and voltages with and without Energy Saver.

The most relevant parameters and assumptions for the simulations were:

- 8 car trains with 165 t tare weight and 45 t average load
- 6 *MITRAC* Energy Savers with 1,5kWh each
- max acceleration 1,2 m/s^2, max deceleration - 1,2 m/s^2
- open circuit catenary voltage: 670 V
- brake chopper activation level: 790 V

The simulation results in Fig 9 refer to the rush hour conditions.

The bottom part of the diagram shows the comparison of line currents of the same train for two following hypothetical cases:

a) green curve - all trains in the simulated track section without energy storage
b) black curve – all trains are equipped with energy storage systems

The line current during acceleration of the train in case b) is approx. 70% of the line current in case a). It results in reduction of the line losses by approx. 50%.

Fig. 9 shows the comparison of line voltages. These rather complex curves depend not only on the temporary line current of the observed train, but is a function of the load currents and present location of all other trains in the section. In case of trains with energy storage systems (blue curve), the voltage decrease during acceleration as well as the voltage overshoot at braking is evidently lower than for trains without ability to store braking energy (red curve). The Energy Storage Units of the trains have obviously a stabilizing effect on the catenary system.

Trains equipped with energy storage systems reduce also the load currents of the substations. Especially the peak current demand will be significantly cut – see Fig. 10 (comparison of load current curves of the substation 2 during the rush hour).

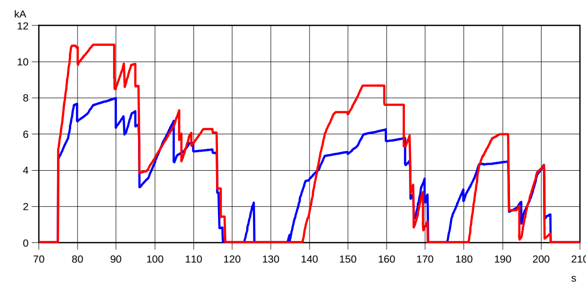


Fig. 10: top: Load currents of the substation 2 for trains without (red) and with Energy Storage Systems (blue).

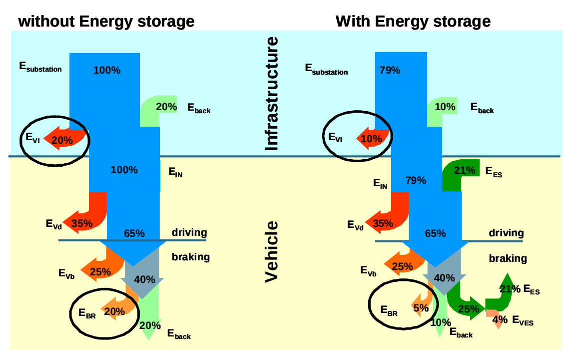


Fig. 11: Infrastructure section of a Metro system, Energy Consumption and Losses in a Metro System

The same section of the line was also simulated in the evening, where there is still a train every 4 min → 4 trains running in the section. In this case the regeneration capability is reduced, so more losses are wasted in the brake resistor or stored in the Energy Saver, while the current flow in the line is reduced, which reduces the line losses. Both effects nearly compensate each other, so the energy saving effect remains nearly constant.

A typical energy flow diagram is shown in Fig. 11. On the left side the energy flow of a vehicle without Energy Saver is shown. On vehicle level (yellow area in Fig 11) the Metro without Energy Saver takes up 100% energy from the line, there are losses during the motoring phase of about E_{Vd} = 35%, during braking of about E_{Vb} = 20%. So that the remaining braking energy of 40 % is split e.g. between losses in the brake resistor E_{BR}=20% and regeneration into the line E_{back} = 20%. In this case the regeneration is 20% (E_{back} /E_{IN} → 20% / 100%). In this example the line losses of E_{VI} = 20% are compensated by the regenerated Energy of E_{back} = 20%. The Energy supplied by the substation is 100%.

On the right side of Fig 11 the Metro with Energy Saver is presented. On vehicle level the energy taken from the line is reduced to to E_{IN} = 79%, since braking energy stored in the Energy Saver is reused E_{ES} = 21%. The losses during driving and braking are the same, while the remaining braking energy of 40% is split between reduced losses in the brake resistor E_{BR} = 5%, reduced regeneration into the line E_{back} = 10% and the storage of E_{ES} = 25% in the Energy Saver. In this case the regeneration is still 13% (E_{back}/E_{IN} → 10% / 79%). The losses in the Energy Saver are in the region of 4% (round trip efficiency 85%). In this example the line losses of E_{VI} = 10% are compensated by the regenerated Energy of E_{back} = 10%. The Energy supplied by the substation is 79%.

Figure 11 shows an example of a Metro with high regeneration, where high losses in the infrastructure are expected. In that case the energy saving effect on vehicle level as well as on substation level are both in the same region, e.g. 21% energy savings (79% consumption) as shown in Fig 11.

In Metro systems where the line is not "coupled through", or to less extend, the situation changes a bit. "Coupled through" means that the 3rd rails of several sections of the line are connected via "coupling switches", a train in one section could principally regenerate into another accelerating vehicle in another section. In a system which is not coupled through, the regeneration becomes less. Energy wasted in the brake resistors is higher while losses in the infrastructure are less.

The energy storage of brake energy on board of vehicles delivers several further advantages over and above the energy saving.

- Reduced power demand from the line – the Energy Saver delivers additional power – could result in Metro systems with less substations (less voltage drop allows bigger distance between substations), could avoid upgrades of infrastructure or could enable more or more powerful vehicles in an existing network
- Booster Effect: The additional power from the Energy Saver could also be used to "boost" the vehicle when the line current is limited.
- Rescue in tunnel, becomes possible in case of e.g. a power loss. In this case the vehicle could move to the next station by using the energy stored in the Energy Saver. Typical distance achieved is about 1000 to 1500 m from standstill to stop in a flat area, depending e.g. on the size of the Energy Saver. The principal has been demonstrated by the LRV prototype vehicle
- Feeding gaps in the 3rd rail system due to track switches or isolation between different sections in the track, could be bridged by the stored energy in the Energy Saver even without reducing the traction power
- Vehicle movement in a depot or workshop without 3rd rail becomes possible

DIESEL-ELECTRIC MULTIPLE UNIT WITH ENERGY STORAGE

There are two main reasons for using the *MITRAC* Energy Saver on board the Diesel-Electric Multiple Units:

1. The Booster Effect:
   The *MITRAC* Energy Saver enhances the vehicle performance by providing additional power for acceleration
2. Energy Saving:
   The *MITRAC* Energy Saver stores braking energy and reuses it during acceleration

It is possible to use both mentioned effects simultaneously.

Fig. 12: Principle scheme of a diesel electric vehicle equipped with MITRAC Energy Saver

To illustrate the impact of the *MITRAC* Energy Saver on the vehicle performance, the following two versions of a typical three-car DEMU will be analyzed and compared:

- DEMU with two diesel power packs (2*315kW) and without *MITRAC* Energy Saver

- As above but with an additional 4,5 kWh *MITRAC* Energy Saver

The average weight of this train is about 100 t.

Booster effect

The main job of the *MITRAC* Energy Saver is to store the braking energy and to use it afterward for supporting the vehicle acceleration. The additional power from the *MITRAC* Energy Saver increases the vehicle tractive power and thus allows significantly higher train accelerations. In this way the energy saver compensates the disadvantage of the usually limited power of the diesel engines.

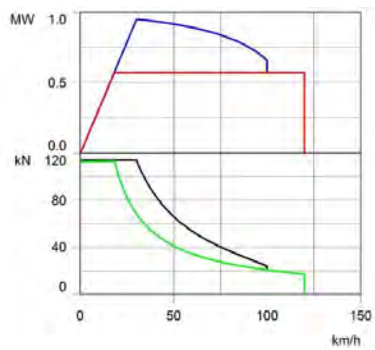


Fig. 13: Tractive power & effort curves with and without 4,5kWh Energy Saver

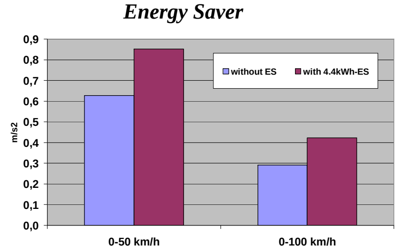


Fig. 14: Average acceleration values from 0 to 50km/h and from 0 to 100km/h

The "booster" effect of the energy storage can be very well recognized in Fig. 13. The blue curve – tractive power of the train with energy storage – lies in the speed range between 20km/h and 100km/h well over the red curve representing the same quantity of the vehicle with only diesel engines. A similar relation is valid for the tractive effort curves in the bottom part of the diagram. The comparison of the average acceleration values 0…50km/h and 0…100km/h for both train versions confirms the booster effect of the *MITRAC* Energy Saver, see Figure 14

Energy savings and emission reduction

In the previous sections a special attention was paid to reduction of the running times. However it's possible to use the booster effect thanks to additional energy from the energy storage in another way – to optimize the energy saving by allowing the same runtime, thus allowing for extended coasting.

The red curve in Fig. 15 showing a short coasting sector before braking (4% of the running time) represents the speed of a train without energy storage. The acceleration ability of the train with ES (blue curve) is much better. For this vehicle it's possible to extend the costing sector to 38% and still to achieve the same running time as the train without *MITRAC* ES.

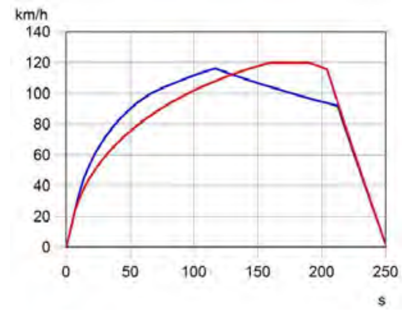


Fig. 15: Runtime simulations with and without Energy Saver. Relative fuel saving of the train with ES (blue curve): 28%

The energy consumption of the vehicle with energy storage on the 6km track is about 9kWh or 28% lower than that of the train without ES. At first glance it's amazing, that the absolute energy saving is much higher than the installed energy (4.5 kWh) of the energy storage. A rather valuable conclusion from the simulation results listed in Table 1 is the possibility to swap the 4.7% time saving for additional 18% energy saving, leading to remarkable 28% total energy savings.

6 km	Savings from energy storage	
4,5 kWh	Energy optimised	time optimised
Runtime Savings	0%	4,7%
Energy Savings	28%	10%

Table 1: Conversion of MITRAC Energy Saver benefits

Thanks to a long coasting not only high energy savings but also emission reductions of at least the same order are achievable. The emissions savings might be in the future at least as interesting as the energy savings. The rules of "emission trading" are heavily discussed at the moment. Additionally several railway operators took up the topic "reduction of emissions" in their strategic plans, e.g. the German railways DB announced a further 15% reduction of carbon dioxide until 2020.

The possible relative time savings thanks to "booster effect" are not as spectacular as the possible energy and fuel savings (see Table 1). However the financial benefits of time savings must be also relevant for the customers since very often high performance vehicles will be asked for.

Influence factors on the energy saving

The biggest influence factors on the achieved energy saving are the distance between station, the vehicle type, or more concrete the regeneration capabilities of the vehicle.

The shorter the distance between stations the more often the brake energy can be reused. If the top speed of the vehicle is in the same range, the energy saving effect due to reused energy remains independent of the distance, but the trains energy consumption is increased with distance between stops, therefore the relative energy saving is decreased with the stopping distance.

The biggest influence on energy saving effect is the distance between stops. Secondary effect on energy saving is gradients. Especially uphill, the energy storage gets empty at reduced distance and the diesel engines become the only remaining power source, this leads to reduced coasting effect and reduced energy savings. Gradients play also an important role in the dimensioning of the energy storage. On uphill tracks the braking energy is reduced. Assuming that the energy storage is dimensioned that at least in the majority of cases the energy storage gets fully recharged by braking the train, the maximum gradient sets with its available braking energy the limit for the energy storage size.

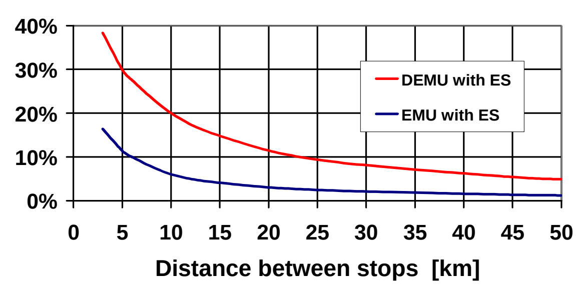


Fig. 16: Energy savings of the energy storage in function of the stopping distance for a Diesel Multiple Unit DEMU and a Electric Multiple Unit (EMU) in case of no regeneration

The energy saving effect is considerable bigger on a Diesel Electric Multiple Unit (DEMU) compared to an Electrical Multiple Unit (EMU). The main difference is that the EMU typically is more powerful and the diesel engines do not limit the available power. Therefore the booster effect is not relevant for EMUs, since there is enough power available from the line. As a consequence the energy saving effect due higher acceleration and coasting can only improve the energy saving in DEMUs. EMUs can only reuse the braking energy, which is otherwise wasted in the brake resistors. The potential energy savings of EMUs is therefore considerable below the potential of DEMUs. For EMUs the regeneration also effects the energy saving, the better the regeneration the less interesting the energy storage is. Therefore LRVs and metros with short stopping distances were focused on, but not on Main Line applications where the stopping distances are quite big and the regeneration could be quite good, e.g. in AC fed main lines.

Return on investment

In the case of the modeled three car DMU the initial investment in a MITRAC Energy Saver would be recovered in 2 to 4 years, depending on the way it is used. This estimate assumes that diesel costs between 0,6 and 0,95€/litre, and that passengers value their time saved by higher acceleration at 5€ per hour per passenger. As energy costs rise, the benefits of on train energy storage also go up.

STORAGE TECHNOLOGY

To select the best suited storage technology the requirements form the application must be known. In Table 2 an overview on the requirements from applications already described in this paper is given, as well as the requirements for a mild hybrid car, as one example from automotive area. The important application requirements are proposed size of the energy storage, which is normally derived from the average available braking energy. For the Catenary Free LRV this is of course depending on the requirements of the catenary free section, such as length and gradient of the section. Another requirement which has to be considered is the power during braking, where the storage must be designed for, to reuse most of the braking energy. For Metros and LRVs the power during braking is relatively high and drives the selection of technology, especially when the peak power is taken into account. Another value to be considered is the expected load cycles over the lifetime of the energy storage, which will be a limit mainly for batteries. A load cycle is given by charging and recharging the storage, which happens before and after each station, but also when there is a temporary stop or a speed limitation. Examples for additional load cycles between stations are traffic lights, pedestrians crossing, speed limits in curves or during maintenance work on the track. Note that also a speed limit is influencing the load cycles considerably, since the kinetic energy goes with the square of the speed. To reflect the real occurring load cycles a factor between load cycles and start stop cycles is introduced, for LRVs this factor is higher, e.g. 1,7, since in city areas several unplanned stops can happen.

Batteries:

The main limitation for batteries for use in railway applications is the required load cycles, when aiming at energy saving due to brake energy storage. One extreme application is within LRV aiming at brake energy storage occurring each load cycle, even when only designed for 5 years 1 Mio load cycles are expected, which is too much for batteries, other storage technologies are preferred. The catenary free LRV, when using the energy storage only in the single catenary free section, is feasible with batteries. Designing the battery for 10 years lifetime this ends in 100’000 load cycles. When using a modern NiMH or Li-Ion traction battery the DoD has to be limited to about 10% (Depth of Discharge – the relation between “usable energy” and installed energy). That means that only 10% of the installed energy can be used. In automotive applications the situation is different, the limited number of load cycles is beneficial for the battery, on one hand the typical lifetime of a car which is between 8 to 12 years is less than the 30 years for railways, on the other hand the expected annual distance is considerable lower.

One relevant application where traction batteries for catenary free LRVs have been chosen is the project in Nice [14]. In this project an LRV is crossing 2 catenary free places of 400m, the power from the energy storage during discharging is limited to 200kW, while charging is only considered with even less power over long time while running under catenary on the rest of the track. The storage system weight is 1450kg. The lifetime is stated to be 5years. Please note that the storage consists of one single battery and not two redundant ones.

For catenary free applications with very tough requirements, as uphill or very long catenary free sections, the battery has the advantage that more energy can be used when allowing a shorter lifetime. Even when not preferred in standard catenary free LRV cases, since it does not allow brake energy storage and energy savings, it might be the only choice to keep the additional weight for the vehicle in acceptable limits.

The influence of upcoming Li-Ion batteries needs to be judged, when first systems in this size will be passing safety tests. The expected weight saving of more than 30% compared to NiMH is at least very interesting for Catenary free LRV applications.

typical values		LRV 30m, 60t Catenary free One section	LRV 30m, 60t brake energy storage	Metro 240t brake energy storage	Diesel 120t brake energy storage	automotive 1t Mild Hybrid
Proposed Energy	kWh	3,4 … 4,3 kWh	1, 4 kWh	9 kWh	4,4 kWh	0,02 kWh
Braking Energy	kWh	1...1,2 kWh	1...1,2 kWh	7,5...12 kWh	4...7 kWh	0,02...0,09 kWh
Brake Power (peak)	kW	600 kW	600 kW	3’000 kW	800 kW	20 kW
Braking time	sec	10 sec	10 sec	18 sec	38 sec	10 sec
Load Cycles	Cycles /year	10.000 Cycles/year	200.000 Cycles/year	165.000 Cycles/year	37.500 Cycles/year	5.000 Cycles/year
km/year	km/year	70.000	70.000	110.000	250.000	10.000
station distance	m	8.000	600	1.000	10.000	5.000
Load / stop cycle		1,1	1,7	1,5	1,5	2,5
Batteries		Possible, but reduced power no redundancy DoD 10...15% @ 8 years lifetime	No load cycles too high	No load cycles too high	No load cycles too high	Possible DoD ~20% @ 8 years lifetime
Flywheels		Yes but no redundancy safety concerns	Yes, but limited power safety concerns	No, power limited safety concerns	Yes, but limited power safety concerns	Not proposed ?
UltraCaps		Yes, but energy limited	Yes	Yes	Yes	Yes, but not for "pure electric"

Table 2: Application requirements and preferred storage technology

Flywheels

For storage applications on board of railway vehicles high speed flywheels are still under development, see also [15]. Compared to the flywheel versions used in substation the speed was increased to 20’000…25’000 rpm, resulting in considerably increased energy density. The increase of speed is needed to reduce the size of the flywheel system to fit them on the roof of vehicles and leads to additional safety efforts and development work. The “hard” characteristics of the PM motor designed for high speeds required higher efforts within the power electronics. As an example taking a 4 pole motor with 500kW power at 20’000 rpm requires an inverter, which is capable to generate this power at a fundamental frequency of 667 Hz with limited harmonics to reduce motor losses. Adaptations in energy, power or voltage require therefore considerable efforts in developments. The limited power of flywheels under development, which are close to a product, are often too low for brake energy storage. The high speed flywheels seem to have also some open safety issues.

The only noticeable relevant application of flywheels on board of railway vehicles is the field trial in Rotterdam [14]. After some initial test in summer 2006 the status seems to be back to under development.

UltraCaps, SuperCaps or Double Layer Capacitors

For most of the onboard energy storage applications UltraCaps are the best choice. UltraCaps are much better in power capability than other technologies and allow also high load cycles. The expected lifetime even for LRV applications is up to 15 years, with as much as 3 Mio load cycles.

For some applications like the single section catenary free LRV, the energy density might be seen as a limitation, but typically it is compensated by good redundancy and power. Compared to batteries the UltraCaps allow also energy saving and several catenary free sections.

The relevant application of UltraCap based energy storage vehicles is the prototype in Mannheim, which achieved 4 years in revenue service.

Bombardier Transportation is preferring UltraCap based energy storage. Only in a few pure catenary free applications a NiMH Battery was preferred. Anyhow all technologies are followed up very carefully.

CONCLUSIONS

Compared to conventional modern Light Rail or Metro vehicles, which are already using regeneration into the line, a train using a propulsion system with onboard energy storage results in further energy savings up to 30% and a reduction of the peak power demand by up to 50%.

With the prototype Light Rail in Mannheim the benefits have been proven in daily passenger operation, the world first application in passenger service, still unique in this application field. With the good experience in 4 years daily passenger operation the new Bombardier *MITRAC* Energy Saver can be considered as a reliable proven technology. The now placed order for energy storage LRVs from RNV for the city of Heidelberg is the best confirmation of the good results achieved in 4 years field experience.

In addition to the energy savings several cost benefits due to reduced power demand on the infrastructure can be taken into account case by case. The example presented in this paper allowed a reduction from 8 to 6 substations on the presented line, thus leading to very good Return of Investment scenario.

Furthermore the on board energy storage allows an autonomous operation. Also without external power supply or even without a catenary or a 3rd rail a short distance operation can be maintained which leads to further system advantages, such as rescue in tunnels but also for the so called Catenary Free Operation. The main aspired benefit is the possibility to avoid overhead wires in some selected areas for esthetical reasons. Even several km long catenary free areas can be served by on board storage and recharging in stopping stations.

The new *MITRAC* Energy Saver is an important contribution for a more sustainable transport system, boosting the already established environmental advantage of public rail transport.

The proven energy savings of 30% by the LRV prototype and the corresponding emission reduction is in line with various local and global energy saving programs set up by e.g. European Union and major railway operators. Therefore the on board energy storage is one of the main future technologies for rail operation.

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