Saft White Paper

Railways keep rolling with reliable onboard auxiliary batteries

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RAIL

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This white paper explains how rail operators rely on their onboard auxiliary batteries to ensure high levels of reliability, robustness and safety. It outlines the various applications for batteries such as engine starting, critical system backup, and emergency lighting, ventilation and door control.

It then explores some of the key questions to consider when specifying a rail battery :

- How do you achieve the optimum balance of performance, reliability and lifetime costs?
- What does a battery cost?
- Why are nickel-cadmium (Ni-Cd) batteries growing in popularity over traditional lead-acid batteries?

The need for reliable onboard back-up power

Rechargeable batteries perform several roles in onboard rail applications, including emergency backup (both for critical onboard systems and for passenger comfort and safety), engine starting, and supplementary traction power (e.g. depot operations on battery power). Reliable operation in such applications requires specially designed batteries that can tolerate the heavy shocks and vibration, wide temperature fluctuations and the general physical and electrical abuses that can destroy conventional batteries.

Power in an emergency

Onboard batteries have two distinct emergency back-up roles in today's light rail vehicles (LRVs), metro, coaches, electric/diesel multiple units (EMUs/DMUs), locomotives and high-speed rail systems: to provide an emergency power supply for critical systems, and to back up the low-voltage onboard systems (typically 24 V to 110 V nominal).

These back-up duties include a mix of short, high-current discharge and longer low-current discharge patterns, which means the batteries must be able to operate under irregular cycling conditions.

Typical onboard emergency back-up applications include:

- Critical backup for operations like emergency braking and tilting systems in the event of main supply interruption
- Power supply for low-voltage systems including door operation, lighting, ventilation, communication and control functions. In the event of emergency shut-down of the high-voltage system or converter failure, this could call for batteries to provide 20 to 90 minutes of power

	Low rate	Medium rate	High rate
Discharge type	3 hours and longer	30 minutes to 3 hours	Less than 30 minutes
Applications	▪ Emergency lighting ▪ Telecommunications	▪ Lightning and control ▪ Ventilation ▪ Emergency lighting ▪ Door opening ▪ Communication ▪ Air conditioning	▪ Diesel locomotive starting ▪ Diesel railcars ▪ Inverters ▪ Emergency braking ▪ Tilting

- Buffer function – in a metro the battery often must meet sudden demands for power (peaks for emergency braking for example) or to compensate for high-voltage 'brown-outs' (especially during a change of section or a gap in the track).

London Underground

Saft SRM Ni-Cd batteries provide onboard backup power for Alstom's metro trains on the London Underground Northern Line.

The Northern Line is one of London's busiest tube lines carrying more than 250 million passengers per year. The onboard batteries deliver backup power for essential safety and passenger comfort systems including radio communications, train control, passenger announcement and CCTV systems.

Saft supplied the original batteries for 106 Northern Line '1995 Stock' trains. After 15-years of reliable service, Saft was awarded the contract to replace all the batteries with new SRM batteries that offer a long service life and extended service intervals, with topping up only required at two-year intervals.

Saft onboard batteries on Alstom's London Underground Northern Line metro trains

Reliable engine starting in any conditions

Starting a diesel engine calls for a reliable, high-current power source for a period of up to 60 seconds. The on-board batteries must be able to supply a constant current to the starter motor. They must be able to function over a wide temperature range (down to – 30°C) and to withstand heavy vibration.

In most applications, engines normally need to be started once a day. Once the engine is started, the battery is kept 'floating', that is, linked to a charger, so that full power is always available.

The batteries must function properly throughout their lifetime even under the most severe conditions, and in remote locations.

There is now a growing trend for operators to call for multiple start ability, so that engines can be stopped during breaks in daily operation, saving fuel and reducing noise and gas emissions. This type of high cycling duty is particularly demanding for onboard batteries.

In addition to engine starting, the on-board battery system on a DMU will also support the same low voltage control and communication functions as on an EMU.

"Minding the gaps" with supplementary motive power

Some auxiliary batteries can provide supplementary motive power for LRVs and trams in areas where they need to run for very short periods without a power supply from rail or overhead catenaries, such as when maneuvering past obstacles.

A new generation of trams is now running that uses on-board traction batteries as an alternative source of motive power. This enables the vehicle to run autonomously when catenary power is interrupted or for short distances where the line is not electrified.

Basel trams

Saft is supplying Bombardier with the onboard battery systems for 61 FLEXITY trams for the Swiss city of Basel.

Emergency onboard backup power is needed to drive the tram for short periods when the external power supply from the catenary is interrupted.

0Each FLEXITY tram is fitted with two 24 V Saft MSX battery systems. If the main overhead catenary supply is interrupted the vehicle can travel on to a section where power is available. The batteries will also enable the tram to be driven for short distances in areas where there is no catenary, such as in the depot.

Basel's new Bombardier FLEXITY trams deliver reliable passenger services

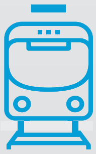
Shanghai Metro Lines 3 and 4

SATEE (Shanghai Alstom Transport Electrical Equipment) has installed Saft MSX battery systems to provide reliable emergency and traction backup power for the new trainsets on Shanghai Metro Lines 3 and 4. In addition to supporting critical onboard safety and passenger comfort systems the batteries support emergency traction in three scenarios:

- Failure of the power grid or pantograph - to move the train to the nearest station or rescue exit in the tunnel,
- Traversing a power-gap (or dead-section) in the main line
- For maneuvering trains where there are no high voltage catenaries, such as within the depot, or for metro lines which use the third-rail power mode.

The Shanghai Metro operator required powerful onboard batteries to support emergency traction functions

Such functions have also been extended to metros to allow operations in depots, where infrastructure electrification can then be reduced.



Rail battery design considerations

Perhaps the main consideration when evaluating batteries for onboard rail applications is striking a balance between reliability, performance and lifetime cost.

The cost of failure of the system is likely to be far greater than the cost of the system itself – whether the cost is measured as a financial loss or as a risk to human life. Nonetheless, in the real world, rail manufacturers need battery solutions that are cost-effective while still meeting the critical reliability and performance needs of the system.

Batteries are electrochemical devices, and each type has its own characteristics. The two most popular electro-chemistries – lead-acid and nickel-cadmium – have different characteristics and, even within these electro-chemistries, different designs and constructions offer different attributes.

It is vital to consider the different advantages and disadvantages of the two main technologies, to achieve the optimum balance of reliability, performance and lifetime cost for the onboard rail application.

Klang Valley Mass Rapid Transit

Saft MRX battery systems were selected by Siemens AG for the driverless metro trains on Malaysia's Klang Valley Mass Rapid Transit (KVMRT) project. The 51 kilometer Sungai Buloh – Kajang (SBK) Line project has 31 stations serving 1.2 million people, and is scheduled to be fully open in 2017.

The 58 KVMRT trains can carry around 300 passengers at a frequency of one train every 3.5 minutes during peak hours.

To maintain the high frequency of service, two 110 V, 100 Ah Saft MRX battery systems are installed on each trainset to deliver emergency backup and traction power if the main power supply is interrupted.

Smooth and reliable operation of Siemens' driverless Klang Valley metro trains in Malaysia

The factors that dictate battery reliability

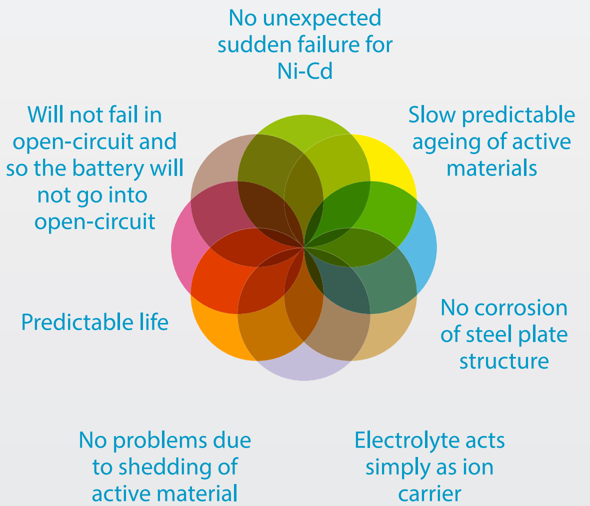
Reliability relates to the number of potential failure modes and their severity. It is a measure of the battery performance under the actual operating conditions, and a predictable failure mode is important for any controlled maintenance regime.

When it is vital for the battery to meet the discharge specification, it is probably more important for the battery to 'fail-safe' than not to fail at all: the battery should avoid sudden failure.

Ni-Cd technology is the most resistant of the main technologies to sudden failure. Due to its plate construction (either steel pocket plate or sintered/PBE), an individual cell cannot fail in open circuit, and the worst-case failure is a short circuit. The effect of a short circuit in a cell in a typical 110 V battery is to reduce the battery by one cell so, for example, an 84-cell battery becomes an 83-cell battery.

This translates into a loss of a little over one percent in the battery performance, which is far from a catastrophic situation. The battery will continue to perform at a slightly reduced rate, allowing time to take remedial action.

Ni-Cd failure mode



When it comes to lead-acid batteries, however, the plate structure and active material are lead, and open-circuit failure can arise from the natural corrosion of the lead plate structure which occurs during the electrochemical reactions. The effect of an open circuit cell in a lead-acid battery is to cause complete failure of the battery to deliver current. This is a catastrophic situation, and the only way to avoid it is to use parallel strings to provide system redundancy (and even then, the overall performance of the lead-acid battery system is reduced).

Other factors to consider are high-temperature operation and frequent cycling, which can both cause certain failure modes to become more prevalent and so reduce reliability. Lead-acid is particularly affected by high-temperature operation, and only certain lead-acid types are designed for cycling operation.

It is also important to consider tolerance to overcharge or over-discharge, and resistance to shock and vibration, as these can affect the reliability of the system and cause unexpected failure modes. Faulty or poorly configured charging systems can cause overcharge and over-discharge, which can both have serious consequences for some battery types.

Chengdu and Nanchang Metros

CNR Changchun, China's state-owned rolling stock manufacturer, specified 156 Saft SRM+ battery systems for metro trainset fleets for the cities of Chengdu and Nanchang.

Light rail and metro rail projects are a high priority for these Tier 2 cities to reduce the significant congestion and pollution issues that exist within these major population centers. Reliability and low running costs are key.

Saft's specialized SRM+ rail batteries provide up to 45 minutes of emergency backup power for critical onboard services, including lighting and ventilation. The batteries need no special attention between normal rolling stock maintenance examinations and topping up with water is only required at two-year intervals.

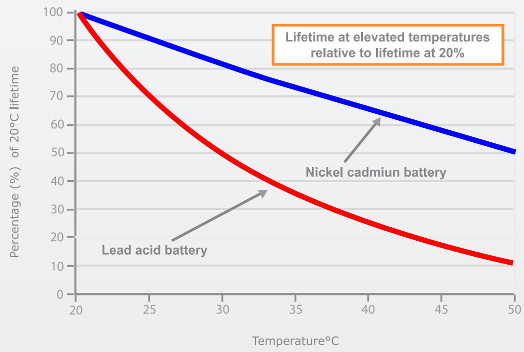
Reliable emergency backup power for rolling stock operating on new metro systems in the cities of Chengdu and Nanchang

Extreme temperatures influence both performance and life

Batteries with thin plates generally offer superior high-rate performance than those with thick plates. At the same time, lead-acid designs with thinner plates generally have shorter service lives. Since Ni-Cd batteries are not subject to corrosion or other deterioration of the underlying plate structure they can use thinner plates, without shortening their service life.

High temperatures influence the life of batteries – increasing temperatures above the +20°C to +25°C range reduces their life, and temperatures above +40°C have a significant impact.

Battery lifetime versus temperature



- The lifetime of the lead acid battery reduces 50% for every 10°C increase in temperature
- The lifetime of the Ni-Cd battery reduces 20% for every 10°C increase in temperature

The effect is greater on lead-acid batteries than on Ni-Cd batteries but is applicable to all electrochemical systems. At lower temperatures, below around +20°C, there is a slowing of the chemical reaction in a cell, resulting in a reversible loss of performance. This means that, if the battery is required to give its full performance at low temperatures, it will need to be 'oversized' at normal temperatures. Again, this has a greater impact with lead-acid batteries than with Ni-Cd batteries.

Tallinn LRV

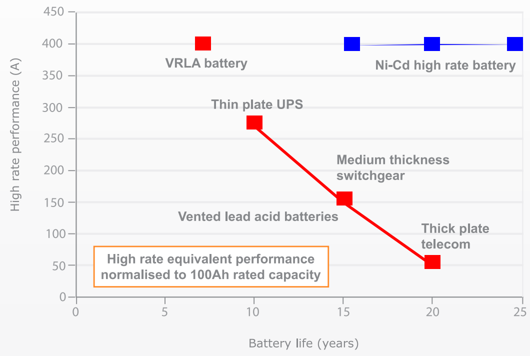
CAF, Spain's largest rolling stock manufacturer, has fitted Saft's SRA LT (Low Temperature) Ni-Cd battery systems to 16 Urbos AXL trams now in operation in Tallinn, the capital of Estonia.

The onboard batteries are required to support critical control and safety functions in extreme winter conditions where temperatures can fall to –50°C.

The SRA LT batteries deliver totally reliable backup power for the Tram auxiliary systems with a design that also offers a more compact and lighter weight battery capable of supporting the required load profile.

CAF's Urbos trams running smoothly throughout Estonia's winter

Battery performance versus expected lifetime



China Railway Corporation EMUs

Saft has supplied MRX battery systems for Project 807 EMUs under construction for the China Railway Corporation (CRC).

Bombardier Sifang (Qingdao) Transportation Ltd (BST), one of China's leading manufacturers of railway passenger cars and rolling stock, is building 20 new-generation 'Project 807' EMUs for CRC's 250 km/h rail services. Onboard backup power is vital to ensure passenger safety and comfort.

Saft's Zhuhai facility in China supplied 100 MRX fully integrated onboard battery systems.

Bombardier Sifang Transportation's trains running on time on China's high speed rail services

Life time drives the choice of the electrochemical technology - even in normal temperature conditions

In practice, unless the application is for discharges longer than three hours, does not involve any cycling, is in a temperature-controlled environment (at 20°C to 25°C), and does not have any special requirements, it is unlikely that the same kWh of battery support would be calculated for the different technologies and plate types. It is therefore important that battery sizing conforms to a recognized standard, the most well-known of which are those produced by the CENELEC, IEC or IEEE, covering industrial valve-regulated lead-acid (VRLA), vented lead-acid and Ni-Cd batteries.

What does a battery cost?

In rail applications, where locomotives and rolling stock are likely to be in service for several decades, it is vital to consider the lifetime cost, or total cost of ownership (TCO), of the battery system.

A two-year lifetime is perfectly acceptable in terms of reliability, as long as the battery is replaced every two years. However, the design life and warranty life quoted by some manufacturers often bear little relation to real-life performance, and it is important to determine the actual service life under normal operation conditions.

For example, as temperature increases, the electrochemical activity of the battery increases and so does the rate of ageing of active materials in lead-acid batteries. By contrast, a higher temperature does not affect the structural components of the electrode assembly of nickel-cadmium cells, which maintain their long-life characteristics.

There is about a 20 percent reduction in the life of Ni-Cd batteries for every 10°C increase in temperature, while lead-acid batteries experience around a 50 percent reduction in life for each 10°C rise in temperature.

The depth and frequency of discharges can limit the service life of the battery, so that it is less than the lifetime to be expected under normal float conditions. Again, this is related to the technology and in a cycling application care must be taken to choose a product designed for cycling applications and not simple float applications. This is reflected for example in the EN 50547 standard.

Once a battery has been correctly sized, the only accurate way to compare alternative battery types is to perform a lifecycle cost analysis. This considers all the costs associated with battery ownership over a defined period. These costs include purchasing and administrative costs, battery cost (initial and replacement, if applicable), transportation, installation, commissioning, routine surveillance, discharge testing to verify operability and predict end of life, decommissioning and removal (if applicable), downtime cost of system shutdown during battery replacement, and recycling.

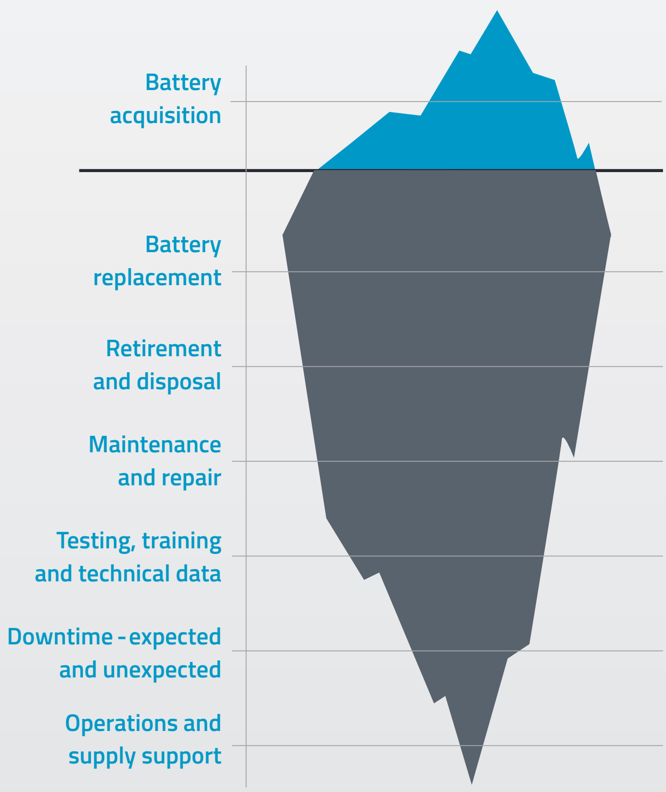
Most of these costs can be quantified with some accuracy. The lifecycle economic analysis includes the cost of sudden and catastrophic battery failure, and this is no less important than the predictable costs.

Battery maintenance can have a significant effect on the economics of a battery system, particularly when a remote or difficult site is involved and so should be simple and not time-consuming. Maintenance might include water additions (if applicable), voltage readings, specific gravity checks, internal ohmic measurements, and connection maintenance.

In open cells the excess electrical energy absorbed by a lead-acid or a Ni-Cd battery on float charge is converted to chemical energy through the breakdown of water (electrolysis). In VRLA batteries, the products of electrolysis are recombined to minimize water consumption and eliminate water additions. However, this benefit comes at the expense of battery life and reliability. In vented batteries, water must be added at periods ranging from every few months to up to three years to compensate for losses due to electrolysis and evaporation.

The watering interval varies by battery type and should be considered in maintenance calculations.

Total cost visibility – the iceberg effect



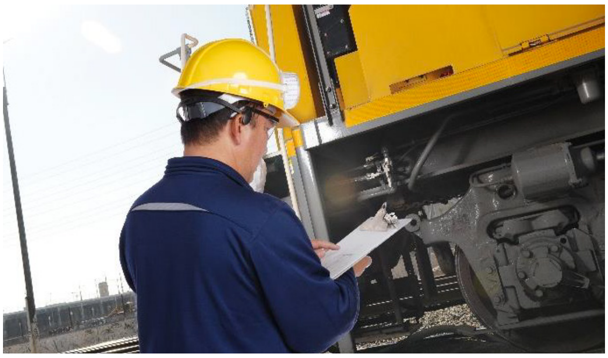
Thus, operators often decide to replace the lead-acid batteries supplied as original equipment on their rolling stock with by Ni-Cd batteries that offer a better life cycle cost.

SNCF's French fleet of TER trains

Saft is helping SNCF to migrate its entire fleet of over 200 TER 2N NG (double-decker new generation) trainsets from lead-acid batteries to state-of-the-art MRX batteries. The on-board batteries play a critical role for SNCF by providing the backup power to support the train's control, safety and communications functions should the main power supply be interrupted.

The switch to MRX batteries is delivering many performance and reliability advantages for SNCF. Primarily, unlike lead-acid batteries, the MRX design does not suffer from 'sudden death'. Furthermore, its compact, lightweight design has enabled each battery system to be reduced in weight by 90 kg – the average weight of a single passenger.

As well as the MRX's reduced maintenance requirements, an important advantage for SNCF is the integrated water filling systems that makes topping-up fast and simple.



SNCF is replacing lead-acid batteries on its TER 2N NG trainsets with Saft MRX batteries

Service ensures a productive working life

One very important factor that affects all aspects of battery reliability, performance and lifetime cost is service, ranging from sizing, installation and commissioning, through to ongoing maintenance, training, spares management, decommissioning and recycling.

In recent years, there have been major changes in the rail battery supply chain as OEMs are now seen increasingly as vehicle integrators and providers of aftermarket services. So rather than seeking a cell or battery supplier, many OEMs want to form relationships with a reduced number of partners who can supply fully integrated, customized systems that are ready to 'plug and play'.

In response, battery suppliers are being called on to enlarge their scope of supply to fully integrate the on-board energy storage function around their traditional core business, the battery. This requires battery system supplier expertise in the integration of energy, mechanical and monitoring functions as well as design, manufacturing, project management, qualification to all relevant international standards, logistics and local after-sales service. The growing importance of environmental concerns has also led to the creation of a comprehensive recycling service to manage collection and disposal of batteries at the end of their life.

Saft's COMM Batt remote monitoring service provides real-time remote monitoring of on-board, N-Cd rail batteries so that maintenance can be performed when needed. This helps extend the battery's service life as well as keeping costs down. It also provides the basis for operators to adopt an optimized Conditioned Based Maintenance (CBM regime, rather than a preventive or corrective routines.

COMM Batt collects real-time operational data from batteries and processes the information with advanced modeling algorithms to provide an accurate picture of battery status, making management, diagnostics, maintenance and service more efficient.

UK High Speed 1 (HS1) EMUs

Saft is providing scheduled servicing of its batteries on board Hitachi's fleet of Class 395 EMUs operating on the UK's High Speed 1 (HS1) line between London and the Channel Tunnel.

Hitachi demands high reliability from all the systems and components on board its high-speed trains to ensure a predictable and consistent service for passengers.

From its depot in Ashford, Kent, Hitachi is overseeing the planned maintenance of its fleet of 29 Class 395 trains, which have been in operation since 2009.

Each Class 395 EMU is fitted with three sets of Saft MRX batteries, which provide the power for traction and auxiliary systems in neutral sections on the electrified rail service as well as backup power. To ensure that they remain in optimum condition, the batteries are overhauled by Saft every five years.

Refurbishment services keep Hitachi's Class 395 batteries in perfect conditions

Conclusion

Rail manufacturers and operators are naturally looking for the best return on investment for their onboard equipment. But as part of this calculation, it is important to consider the total cost of ownership of a battery is much higher than the initial purchase cost.

What is more, the choice of battery technology should be made having considered the key reliability and performance requirements of the application. There is no single battery type that is appropriate for ALL applications, and choosing the wrong battery can have potentially disastrous results in the case of failure.

Where reliability and life cycle costs are key, Ni-Cd batteries offer considerable advantages to the rail industry compared with lead-acid batteries.

About the author

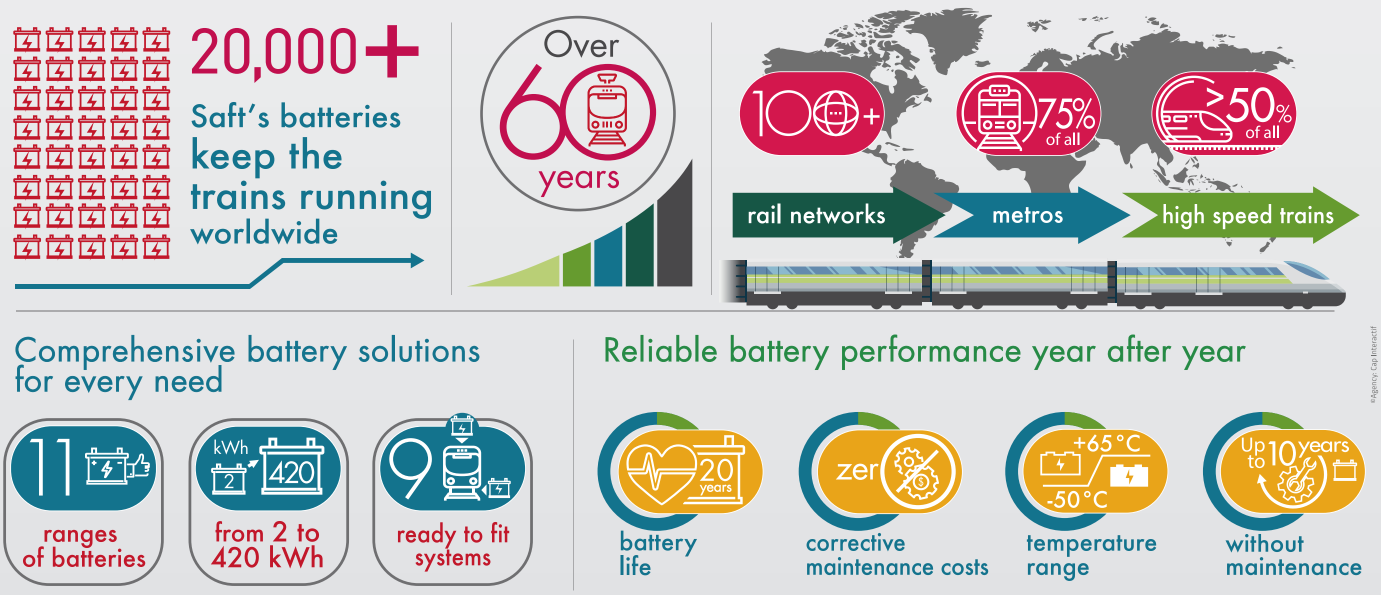
Pierre Prenleloup is the railway market manager at Saft. He has been involved in the European projects that demonstrated the capability of the Li-ion onboard ESS for rolling stock (Railenergy, CleanER-D, OSIRIS), and in the deployment of Saft solutions in the rail market as a railway application expert. He is now supporting the introduction of these technologies to various users and participating in the IEC TC9 committees responsible for establishing the standards covering them at international level.

Meeting rail onboard backup needs around the world

Saft has supplied batteries to the rail industry for a wide variety of onboard applications in more than 150 rail networks and mass transit systems worldwide for over a century.

The company has developed four specialized ranges of advanced rechargeable Ni-Cd batteries based on sintered/PBE construction – MRX, MSX, SRA, SRX and SRM+ – and offers several standard batteries suitable for rail applications. A fully integrated system approach means Saft can act as a total service provider to take global responsibility for battery systems.

Battery expertise that powers reliable rail networks



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To go further, Saft contact:

www.saftbatteries.com

mailto : ttg_sales@saftbatteries.com

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