A Railway Gazette Group White Paper

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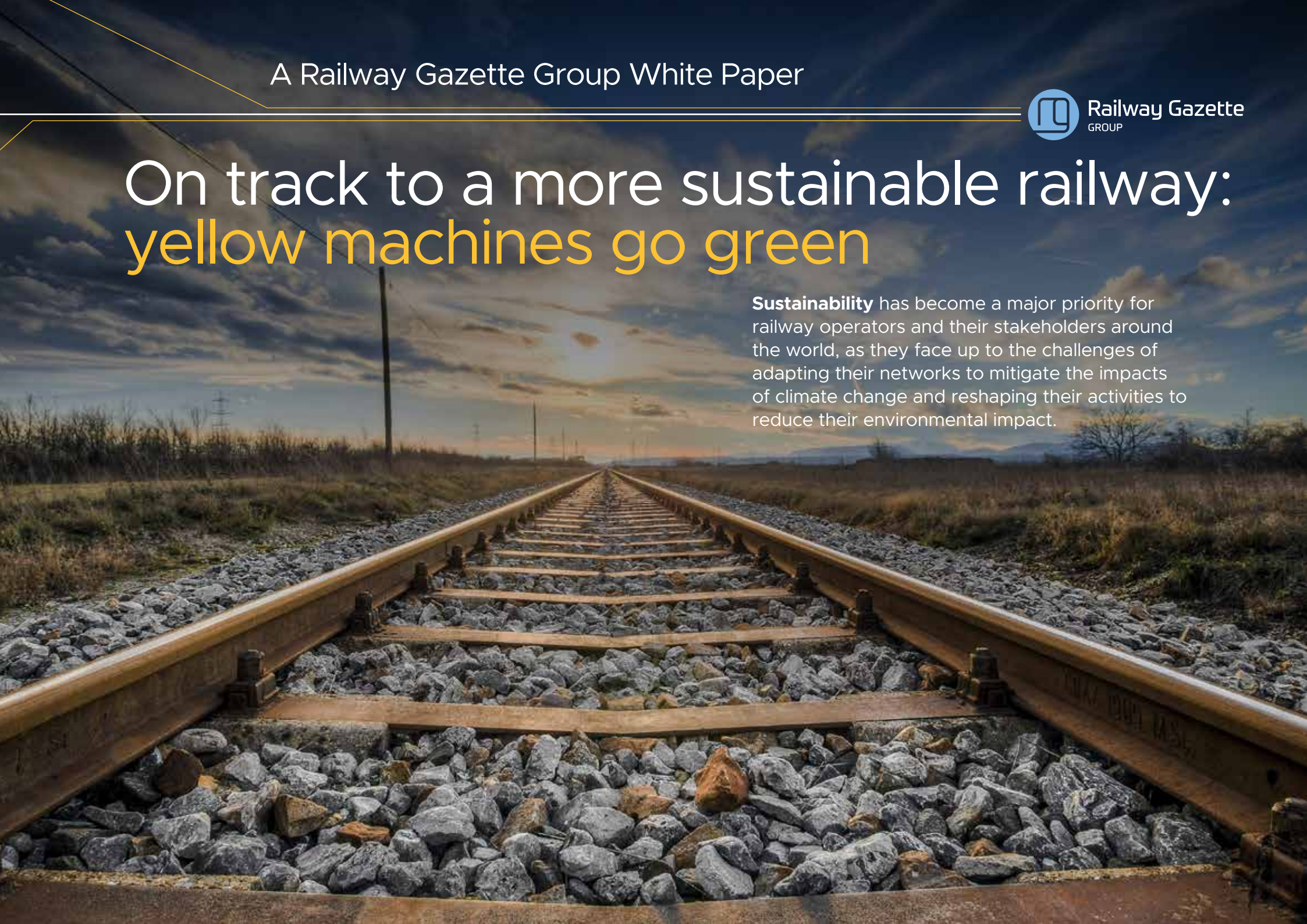
On track to a more sustainable railway: yellow machines go green



Sustainability has become a major priority for railway operators and their stakeholders around the world, as they face up to the challenges of adapting their networks to mitigate the impacts of climate change and reshaping their activities to reduce their environmental impact.

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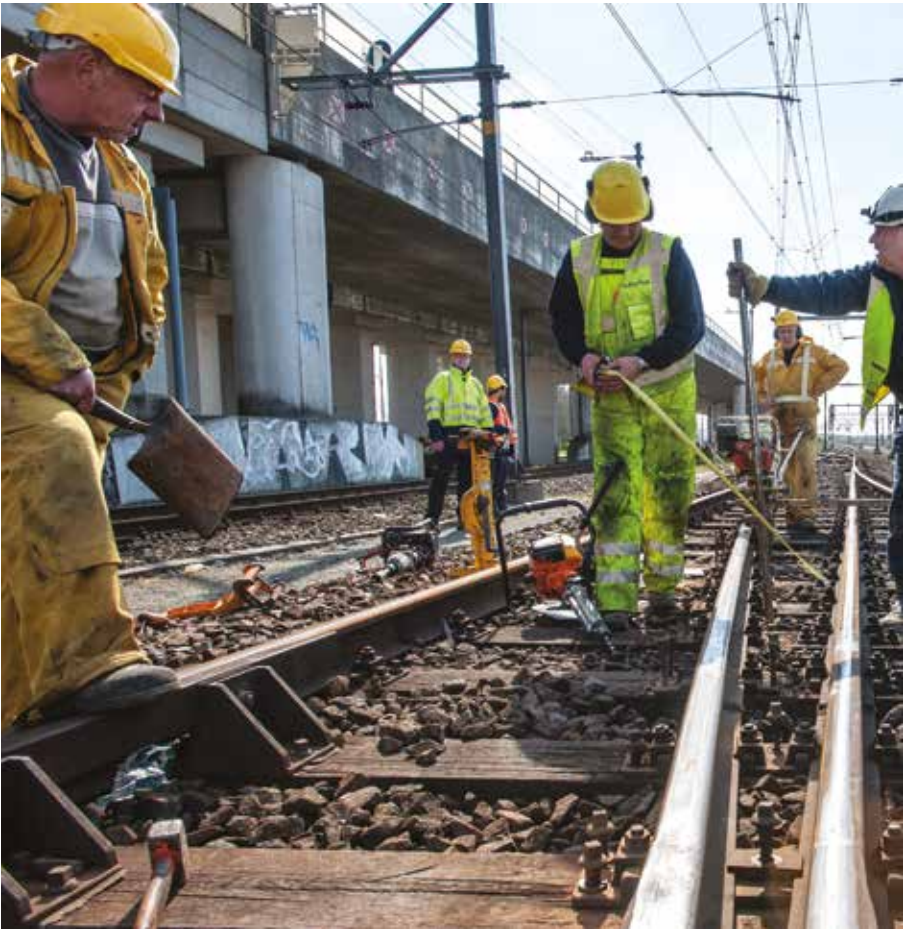
Today, transport accounts for around one third of all greenhouse gas emissions, and there is a growing recognition of the need for rapid decarbonisation. Rail is already one of the most sustainable modes of transport, and proponents have made much of the 'quick wins' that could be achieved through shifting the movement of both passengers and freight from other more polluting modes. That would require investment to increase the attractiveness of rail, and also to provide the necessary capacity to accommodate a significant increase in traffic volumes on busy routes that are anything up to two centuries old.

However, the rail sector cannot simply stand on its laurels and trumpet its position as the greenest transport mode. With much political and public attention focused on other modes and significant sums being allocated for research into ways of reducing their environmental impact — such as the development of electric road vehicles and 'sustainable' aviation fuels — railways must demonstrate that they too are working to improve their environmental credentials.

Work is underway to improve many different aspects of railway operations and maintenance. In terms of traction, railways as far apart as the USA, Australia and Latin America are turning to batteries and fuel cells as potential alternatives to diesel. Others are harnessing renewable energy supplies to feed their electrified networks — India and France are among those investing heavily in solar power, while Germany and Scandinavia are banking on wind and hydroelectric generation, for example. Recycling and the circular economy are growing importance, with asset managers looking to make better use of materials for both rolling stock and infrastructure, backed up by smarter maintenance techniques.



USING POSSESSIONS SMARTER

The over-riding demand for rail to carry much more traffic on existing networks poses huge challenges for infrastructure managers and maintenance contractors. More frequent and heavier trains increase the wear and tear on the track, which needs to be kept in good condition to handle the traffic reliably. Conversely, the operation of more and more trains leaves less time for maintenance. That means working smarter to make best possible use of the available track time and to ensure the infrastructure is kept in optimum condition.

The increasing digitalisation of almost all aspects of railway operations, together with the expansion of real-time condition monitoring, offer significant opportunities in terms of asset management. Never before have railways had access to so much data about the condition of their infrastructure, while digital tools and smart algorithms can provide trending information, helping to predict deterioration rates and determine where and when maintenance interventions will be required.

Maintenance equipment specialist Plasser & Theurer is harnessing these advances in the digitalisation of asset management and condition monitoring to support the automation of infrastructure maintenance. It has been developing 'assembly line' techniques for track maintenance and renewals, aimed at speeding up the work and making best use of the available possessions. At the same time, maintenance has been transformed by combining multiple functions into fewer machines, simplifying access requirements and optimising the work cycles.

Such an 'end-to-end' approach groups the various measuring and maintenance functions — either by deploying a group of machines which can exchange data in real time or by using multi-functional equipment. As well as the environmental benefits, this new way of working is expected to improve worksite safety and make better use of staff and resources.

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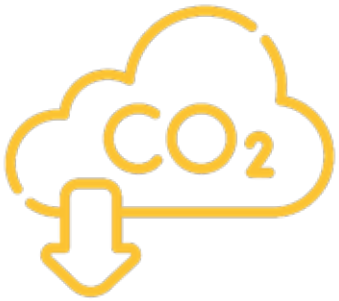


ELECTRIC AND HYBRID DRIVES

While the majority of infrastructure maintenance equipment in use around the world is still powered by diesel engines, the benefits of transitioning to electric drives or alternative power sources apply just as much to maintenance as they do to revenue operations. This is particularly relevant at a time of rising fuel prices and stricter environmental protection requirements, while railways are increasingly favouring green working methods in the tendering of maintenance contracts.

Changing from diesel to hybrid and all-electric drives not only reduces fossil fuel use and greenhouse gas emissions, but can also reduce overall noise pollution, making it less intrusive to carry out essential works in populated areas or at night. It also reduces the machine maintenance costs significantly.

In 2021, the Institute of Railway Engineering & Transport Economy at Graz Technical University published the results of a study undertaken with Plasser & Theurer, examining the potential for achieving zero direct emissions during railway maintenance and renewal works. Using data from Austrian Federal Railways, the university estimated that work on the ÖBB network generated 9 600 tonnes of CO2e per year — considering energy consumption for the movement of machinery and materials as well as the actual maintenance operations.

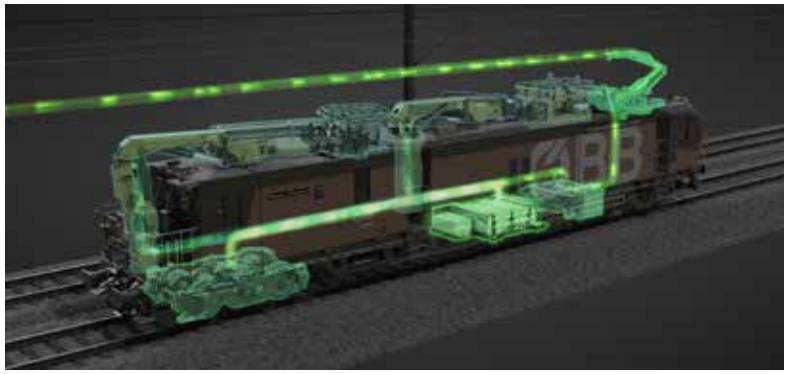
The Fossil Free Future for Track Work Machinery (FFF) study looked at the development of alternative drives in other transport modes and the construction industry, to assess their applicability for railway maintenance where there is no overhead electrification or it cannot be used. The study also evaluated the institutional and regulatory landscape, and considered the potential incentives that could be expected at a political level.

The cross-industry analysis found that the development of alternative drives had made most progress in the road sector, but some powertrain and transmission concepts being developed in the

Table 1 Overview of alternative powered track maintenance equipment (various suppliers)

Machines	
Catenary tower wagon	battery or catenary
Road-rail service vehicle with crane	diesel-battery
Utility track vehicle	catenary-battery
Rail milling train	fuel cell
Ballast regulator	diesel-catenary
Dynamic tamping machine	diesel-catenary
Catenary tower wagon	diesel-battery
Continuous-action dynamic tamper	diesel-catenary
Multipurpose switch tamper	diesel-catenary
Multi-purpose vehicle	battery
Rail transport wagon	(battery or fuel cell)
Tools	
Portable tamper	battery
Abrasive rail saw	battery
Rail drilling machine	battery
Rail band saw	battery
Impact wrench	battery
Vertical tamper	battery
Rail cutter	battery
Rail loading system	supercapacitor

Source: Graz Technical University, FFF study



construction sector might also be applicable. Battery technology was more established in the construction sector, whereas hydrogen fuel cells were still at an early stage of development, with the exception of forklifts. In rail, pure battery drives were essentially limited to small plant and hand-held tools, while larger machines were trending towards diesel-battery hybrids **(Table 1)**.

TU Graz used its CalCAS tool (Calculation of Comparison for Alternative Solutions), to look at the key parameters informing the choice of fossil-fuel alternative drives **(Table 2)**. The study suggested battery should be the preferred technology for applications that required less than 300 kWh, while fuel cells were better suited to applications requiring more than 800 kWh. Between those figures there was a range of options.

However, the authors emphasised that the benefits of alternative drives, such as reduced greenhouse gas and noise emissions or higher efficiency, did not automatically equate to fossil-free or emission-free. Both battery and hydrogen technologies would ultimately depend on the electricity mix, as well as on the production process and the end-of-life of their components.

Table 2 User-specific input data required for the calculation of different scenarios in CalCAS

Parameter	Notes
Charging time [h]	In the case of battery operation or hybrid usage, this value defines the desired charging time of the battery.
Shift multiplier	Converts working hours to standard 8 h shifts
FC workload	Desirable continuous workload for highest efficiency of fuel cells.
Time share of battery-only mode	Defines battery capacity in cases of hybrid operation
Battery factor [1/h]	Defines the proportion of fuel cell power to battery capacity in the case of FC only mode.
Battery type	Look-up table of different battery types with properties such as volumetric and gravimetric energy density.
FC type	CalCAS assumes the use of Proton Exchange Membrane fuel cells, as these are the dominant type used in transport applications.

Source: Graz Technical University, FFF study

Pictured left: Hybrid drive with power from the overhead contact line, battery-operated for the worksite; highest flexibility is ensured through the option to switch between the overhead contact line, battery, and diesel-electric power pack without interruption

Resource-friendly ballast management by using electrical energy from the overhead line

Plasser & Theurer's E³ family includes electro-diesel hybrids, diesel-electric-battery tri-modes and electric-battery variants

ENTER THE E³

The findings of the FFF study are supporting the ongoing development of Plasser & Theurer's E³ hybrid and zero-emission drive concept, which has been evolving steadily since it was launched a decade ago. Recognising the mounting concerns about costs, environmental impact and noise, Chief Executive Johannes Max-Theurer determined in 2013 that the Austrian firm should work to develop cleaner, greener products.

Work began in November 2013 on the development of the E³ concept, which was branded to emphasis the potential benefits in three aspects: Economics, Ecology and Ergonomics. The E³ family uses electric drives for both travelling and working functions. Machines can be powered from the overhead contact wire, but an onboard diesel engine is generally retained for use on non-electrified routes or where the power is turned off.

The traditional diesel powerpack was initially replaced by a dual-mode power module, but the range has subsequently expanded to include battery options, facilitating electric operation even where no external power supply is available. Today, the E³ family includes electro-diesel hybrids, diesel-electric-battery tri-modes and electric-battery variants, depending on the application.

The first E³ machines were unveiled in mid-2015, ahead of that year's ÖVG convention in Salzburg. In-house contracting arm Franz Plasser Vermietung von Bahnbaumaschinen GmbH, took delivery of an 09-4X Dynamic Tamping Express E³ continuous-action tamper and a BDS 2000 E³ ballast distribution system for use on contracts for ÖBB Infrastruktur, while a Unimat 09-32/4S Dynamic E³ multi-functional tamper was delivered to Swiss contractor Krebs the following year.

Key to the development of the E³ range was a switch from using hydraulic actuation of the tamping, lifting, lining and levelling systems to electric drives. Early applications reportedly delivered an 80% reduction in the amount of hydraulic oil used, while later machines have continued to evolve towards an all-electric drive.

As part of the development process, Plasser & Theurer subjected one of its all-electric tamping units to an extensive endurance test. Mounted on a specially developed test rig, the unit was put through 1 million tamping cycles over four months, with the appropriate tine pressure to simulate the relevant ballast forces. This corresponded to an average of around 20,000 tamping cycles per day, with the unit operating for up to 14 h at a time. All of the major parameters were monitored throughout the trial, with particular attention to the bearing temperatures. Following the completion of the test, the unit was dismantled and thoroughly inspected to confirm that the various components were still in good condition.

More and more infrastructure managers and contractors are now adopting E³ technology. In March 2023, Baneservice AS ordered the first zero-emission track maintenance machine for the Scandinavian region. The ETCS-equipped Unimat 09-2X-4x4/4S Dynamic E³ tamper will be deployed across Norway's 4 200 track-km network.

E³ on track since 2015: the first development carrier was an Dynamic Tamping Express 09-4X E³


by Plasser & Theurer
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UNIMAT 09-32/4S DYNAMIC E³

THE ULTIMATE E³?

One of the latest additions to the E³ family is the Unimat 09-8x4/4S BR Dynamic E³ track and turnout tamping machine, which was unveiled at the iaf 2022 trade fair in Münster and subsequently put into operation with Franz Plasser in Austria. The company anticipates that infrastructure managers and contractors looking to making best use of short possessions will increasingly favour universal tamping machines that are able to treat both turnouts and plain track in a single intervention.

A single machine combining the ballasting, tamping, profiling, stabilising, surveying, and post-measuring functions comes into its own for periodic track maintenance, undertaking a full sequence of work from pre-measuring of the track geometry, through tamping, lining and levelling of the track and stabilising the ballast bed with a built-in DGS dynamic stabilising unit and post-measurement of the finished geometry. This can offer significant cost savings compared to deploying a series of separate machines in convoy.

The Unimat 09-8x4/4S BR Dynamic E³ has been designed as the successor to the Unimat 09-475/4S N-Dynamic. The 8x4 tamping satellite has eight independent heads with tiltable tines. It normally operates as a continuous-action two-sleeper tamping machine, but can be switched to single-sleeper mode when working on turnouts, where the rail geometry is constantly altering, and attention must be paid to movable crossing noses or point machines located in hollow sleepers.

Another innovation is a new operating concept, where the machine only has one work cab for both the tamping and co-tamping operators. This improves co-ordination and communication, increases working comfort and enhances safety. The co-tamping operator sits on the continuously moving part of the machine, controlling the lifting and lining unit using 24 high-resolution cameras to give an optimal view of the work units on six digital screens.

Fully electric drive technology for emission-free tamping of plane line track and turnouts

MODULAR GREEN FLEET

While the initial focus of the E³ development was the larger machines, the range has expanded to include multifunctional inspection and maintenance units for track, structures and overhead lines. The first machine to incorporate a battery power pack, for example, was the HTW 100 E³ hybrid tower car for overhead line work.

Thanks to the development of battery power as a viable option, Plasser & Theurer is currently delivering 56 modular maintenance vehicles to ÖBB Infrastruktur, under a contract which includes an option for a further 46. Described as the largest single order in the company's 70-year history, this contract will enable the infrastructure manager to renew its entire maintenance vehicle fleet. All of the new units will have an E³ tri-mode drive with the flexibility to switch seamlessly between the overhead contact line, battery, and diesel-electric power.

Further developed from the HTW 100 E³ prototype, the customised vehicles have been purpose-designed to meet ÖBB Infrastruktur's specifications. A standard carrier vehicle suitable for 120 km/h operation is used to carry different working modules, aligned to the infrastructure manager's working processes. This will reduce the number of vehicle types in the fleet from 12 to three, simplifying the maintenance regime and reducing the level of staff training required.

There are 29 CatenaryCrafter 15.4 E³ units in two variants — one with a three-part elevating work platform and crane for overhead line construction and one with a freely moving work platform for inspection and maintenance. The 21 Type 3 MultiCrafter 15.4 E³ units are equipped with a loading bed and crane for various types of superstructure work. These will be all backed up by six TransportUnit 14.2 vehicles.

The first Type 1 CatenaryCrafter and a TransportUnit are now being tested in Austria, while the first of the Type 2 CatenaryCrafter

Eco-Retrofit is an attractive way to reduce noise and emission for existing fleets green

and Type 3 MultiCrafter units are being commissioned. Series production in Freilassing is scheduled to start at the end of August, with deliveries to be completed within the next five years.

The tri-mode machines will be primarily powered from the catenary while travelling to and from the worksites, and from battery during operation. Battery technology has improved over recent years, and the batteries are expected to be able to supply sufficient energy for an entire shift, being charged via the overhead contact line using a pantograph or via regenerative braking. The diesel-electric powerpack has essentially been provided as a back-up, but even so this has been designed to use synthetic e-fuel to ensure carbon-neutral operation.

ECO-RETROFITS AS WELL

Building on its experience with electrically powered tamping units for new machines, Plasser & Theurer is developing options for retrofitting electric drives to older tampers. The company feels such 'eco-retrofits' could offer significant cost-efficiency and environmental benefits, even without a switch to external electric power.

The conversion involves replacing the hydraulic drive to the tamping unit vibration shaft by an electric motor, which is powered from a hydraulically operated generator. This allows the diesel engine to be run in a more economical speed range, which is around 500 rev/min lower than the former peak, making maximum use of the available torque.

Last year, a 2004-built Unimat 08-4x4/4S, operated by Swietelsky in the UK under contract to Network Rail was rebuilt at Maidenhead over 13 weeks. Following commissioning and testing, the machine returned to regular operation in early 2023.

Meanwhile, a Unimat 08-475/4S of a similar vintage operated by Strukton was converted by Plasser Robel Services at its Opladen maintenance workshop in Germany, where the machine had been sent for accident repairs. Following display at iaf 2022, this retrofitted machine was trialled on Strukton's test track at Zutphen in the Netherlands and returned to regular use. In September 2022, approval was granted for it to operate in Germany, Belgium, and Sweden.

Tests with these two machines demonstrated fuel savings of up to 40% or 30 litres/h thanks to the lower engine speed when working and idling. Noise emissions decreased by an average of 7 dB, while the switch from a hydraulic to electric drive also reduced the amount of heat created during operation.

The overall efficiency of the machines was improved by an estimated 30%, which is attributed in part to the better response time of the electric motors. Wear on the tamping head was reduced because of a higher rotational speed during penetration, which is expected to lead to a reduction in maintenance requirements.

SYNTHETIC FUELS

Meanwhile, a further transitional technology is under development. Recognising that diesel generators will still be needed as an alternative to electric operation — particularly for large 'assembly line' machines where batteries are not feasible from a technical perspective or where no overhead power is available, Plasser & Theurer has been researching the potential for using synthetic fuels as an alternative to conventional fossil fuel. It has been investigating a range of options include hydrogenated and hydrotreated vegetable oils, e-fuels, and gas-to-liquid fuels.

The company is currently working with partners such as Deutsche Bahn to test the use of synthetic fuels in various machines. Freight operator DB Cargo is already using a second-generation biofuel to power diesel locomotives in Germany, and expects to save around 30,000 of CO2 emissions per year by replacing 10 million litres of diesel fuel with HVO.

Plasser & Theurer is in working with various engine manufacturers

to ensure that all of its new machines can be delivered compatible with synthetic fuels, although the company recognises that the use of such fuels on older vehicles would require a case-by-case assessment.

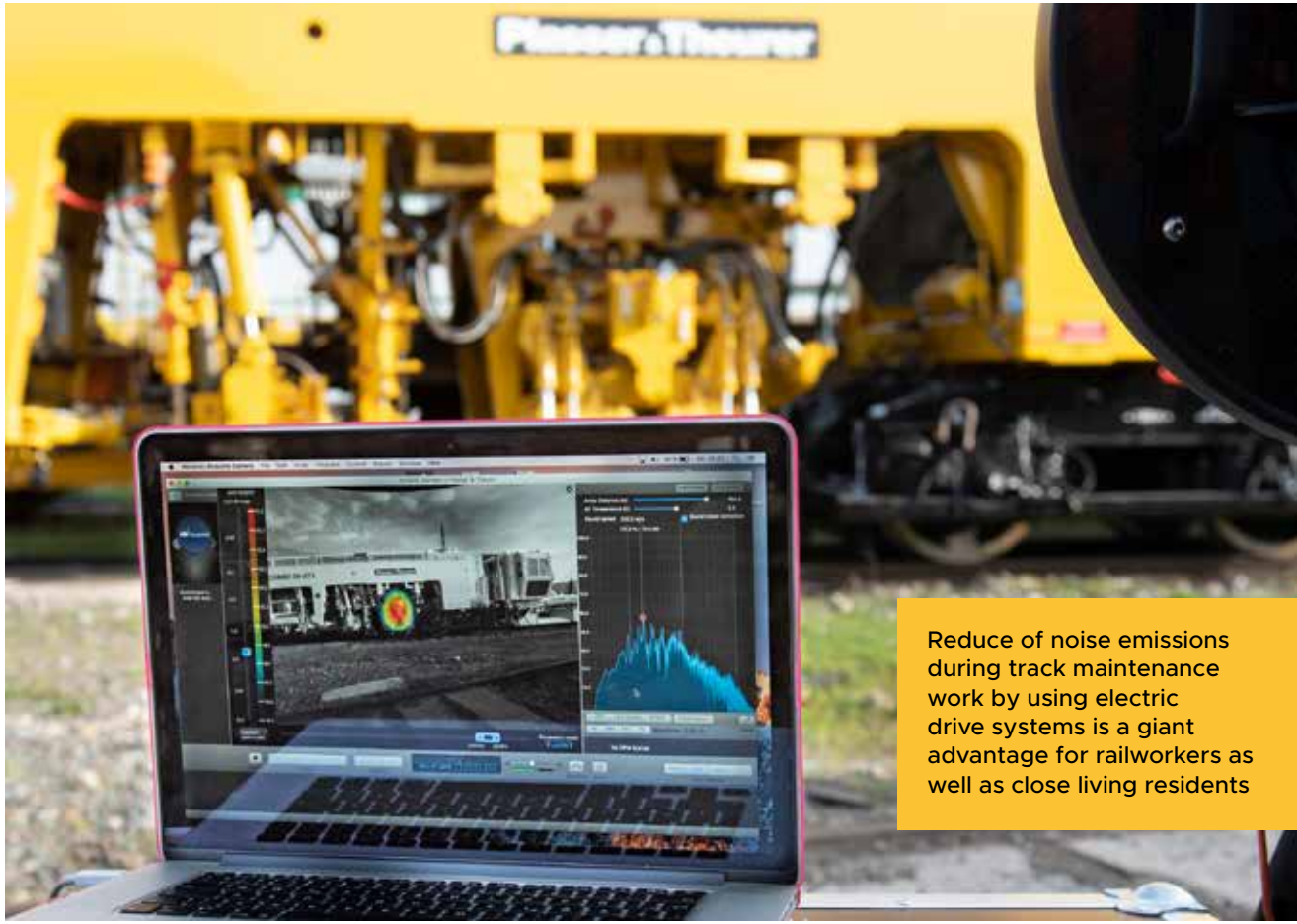
NOISE REDUCTION

As well as cutting greenhouse gas emissions, the transition to electric drives has helped to reduce the noise of infrastructure maintenance. Plasser & Theurer has been working for many years to reduce the noise emitted by its machines, including lateral shielding of the tamping and stabilising units, for example. However, the company reports that the switch to electric and hybrid drive systems has brought a significant reduction in overall noise levels.

In 2018, comparative measurements were undertaken with two vehicle types, a Unimat 09-4x4/4S E^3 tamper and an HTW 100 E^3 overhead line unit. In both cases, the sound measurements were undertaken in a tunnel to exclude extraneous ambient noises. The tests confirmed that the E^3 series machines offered noise reductions of more than 20 dB(A) compared with their diesel-engined equivalents.

In testing, the power car of the Unimat 09-4x4/4S E^3 tamping machine emitted 13 dB(A) less noise than that of an equivalent diesel-hydraulic machine. Meanwhile, the noise emitted by the electrically powered tamping unit was more than 20 dB(A) less than the hydraulic drive. The noise measured in idle mode was around 62 dBA, which is comparable to a normal conversation in an office.

The HTW 100 E^3 catenary renewal and installation machine similarly recorded noise levels more than 20 dB(A) less than an equivalent diesel-engined MTW, with the researchers commenting that sometimes the loudest noise coming from the machine was the staff talking on the working platforms. In working mode, the battery-powered HTW 100 E^3 never exceeded the 80 dB(A) exposure limit requiring the use of hearing protection.



Reduce of noise emissions during track maintenance work by using electric drive systems is a giant advantage for railworkers as well as close living residents

Integrated hopper units during track maintenance are a contribution to the goal of major railways: to achieve a closed loop economy

Pictured right: Re-distribution of existing material on the spot help to avoid unneccesary costs and emissions for transport and logistics

USING BALLAST BETTER

Ballast remains a fundamental component of the track structure, being used both to support the track and to ensure adequate drainage — an increasing concern given the recent rise in extreme weather events. The higher temperatures being experienced around the world are increasing thermal stresses in the rails, and this in turn is putting increased pressure on the ballast bed. One response has been to increase the cross-section of the ballast shoulder at the sleeper ends, in order to strengthen the track structure and protect against the risk of buckling in the extreme heat.

As part of their drive to greater sustainability, various railways — particularly in Europe — have committed to increase the level of recycling across all their activities, as a contribution to the developing circular economy. This is expected to reduce their Scope 3 carbon emissions, as Austrian Federal Railways explained in its 2022 annual report.

ÖBB procures around 700,000 tonnes of new ballast each year, as well as 60,000 tonnes of concrete sleepers and 30,000 tonnes of rail, and says it is placing a greater emphasis on recycling these materials at the end of their working life. In Germany, DB Netz reported that it used around 3.5 million tonnes of ballast in 2022, of which almost 400,000 tonnes was recycled — either back into the track or for other purposes. The infrastructure manager said it wanted to increase the proportion of recycled material being used to around 40% by 2030.

Recognising the rising cost of ballast and the need to minimise the use of natural resources, several railways and academic partners from France to North America are undertaking extensive research into the life of traditional stone ballast. Given that double-track main line railways typically use between 3,000 and 5,000 m3 of ballast per route-km, there could be scope for substantial savings.

One study now underway is looking to assess the degradation of individual ballast particles following repeated tamping and any loss of structural integrity of the ballast bed as a result of rounding. Early results suggest that ballast life on high speed lines could potentially be extended from around 30 to as much as 100 tamping cycles before the need for reballasting. Meanwhile, another study is looking at the proportion of used ballast that can be recovered during ballast cleaning operations, in order to reduce the requirement for new stone.

Plasser & Theurer has long been working in this field, having developed its BDS 2000 ballast distribution system to capture and reuse excess ballast. The ballast regulator is typically deployed as part of scheduled maintenance or in conjunction with track renewals, recovering any surplus ballast in a continuous movement and depositing it where required. It is perhaps not surprising that it was amongst the first machines to be selected for the application of hybrid powerpacks under the E^3 programme.

The BDS 2000 is configured as two units, which can operate separately if necessary for shunting or worksite logistics. The rear unit carries the ballast sweeper units and is fitted with a pick-up conveyor belt, which collects the surplus ballast. This is then passed to the front unit, which incorporates an integrated ballast hopper

with a 40 tonne capacity and two slewing conveyor belts for redistribution. The design facilitates the inclusion of additional MFS hopper wagons to increase the storage capacity when necessary – the traction packages on the two units have sufficient power to haul the extra vehicles.

ÖBB has been using the BDS 2000 for around 15 years, and reports a significant reduction in the amount of new ballast required.

BRINGING EVERYTHING TOGETHER

In order to demonstrate the benefits of integrated maintenance and the scope for automation, Plasser & Theurer recently participated in a trial of 'end-to-end' working on eight selected sections of line in Sweden. This was mainly focused on detecting the condition of the ballast and the track geometry against a fixed-point measuring system, but also demonstrated the complete maintenance process from pre-measuring through semi-automated interventions to post-measuring and creation of the acceptance reports.

The track geometry was initially surveyed using the tamping machine itself. Combining data from an inertial measurement unit with a fixed-point measuring system determined both the relative and absolute track geometry with a high level of accuracy, which is particularly important for high speed lines. 'Sensing' tines were able to detect the condition of the ballast during the tamping runs, and the data was then used to update existing records, being verified through trial excavations.

Many of these concepts are reflected in the company's vision of the 'tamping process of the future', which was demonstrated by Director of Technology & Innovation Florian Auer at the iaf trade fair in May 2022. Using a Unimat 09-4x4/4S E^3 hybrid machine, he explained how the tamping assistant technology could be used to automate all the steps involved in turnout tamping.

The machine is fitted with an integrated measuring system using stereo cameras, which initially records the track geometry at a speed of up to 100 km/h, using QR markers mounted on the catenary masts to ensure precise localisation. The machine also creates a 3D image of the track section using laser scanning. A built-in Artificial Intelligence tool then calculates specific suggestions for the tamping cycles based on this model and the pre-measurement track data. All the operator needs to do is confirm these suggestions and initiate the tamping run.

The Unimat 09-4x4/4S E^3 is fitted with electric tamping units that require less energy to perform the filling and compaction cycles under automatic control, ensuring a sustainable track geometry. During the tamping run, the same camera and measuring systems are used to make a record of the new geometry, compiling this data into a fully-documented report that is uploaded to the cloud for storage and future reference.

Because the machine performs its own geometry measurements both before and after the intervention, there is no need to take additional possessions for this work.

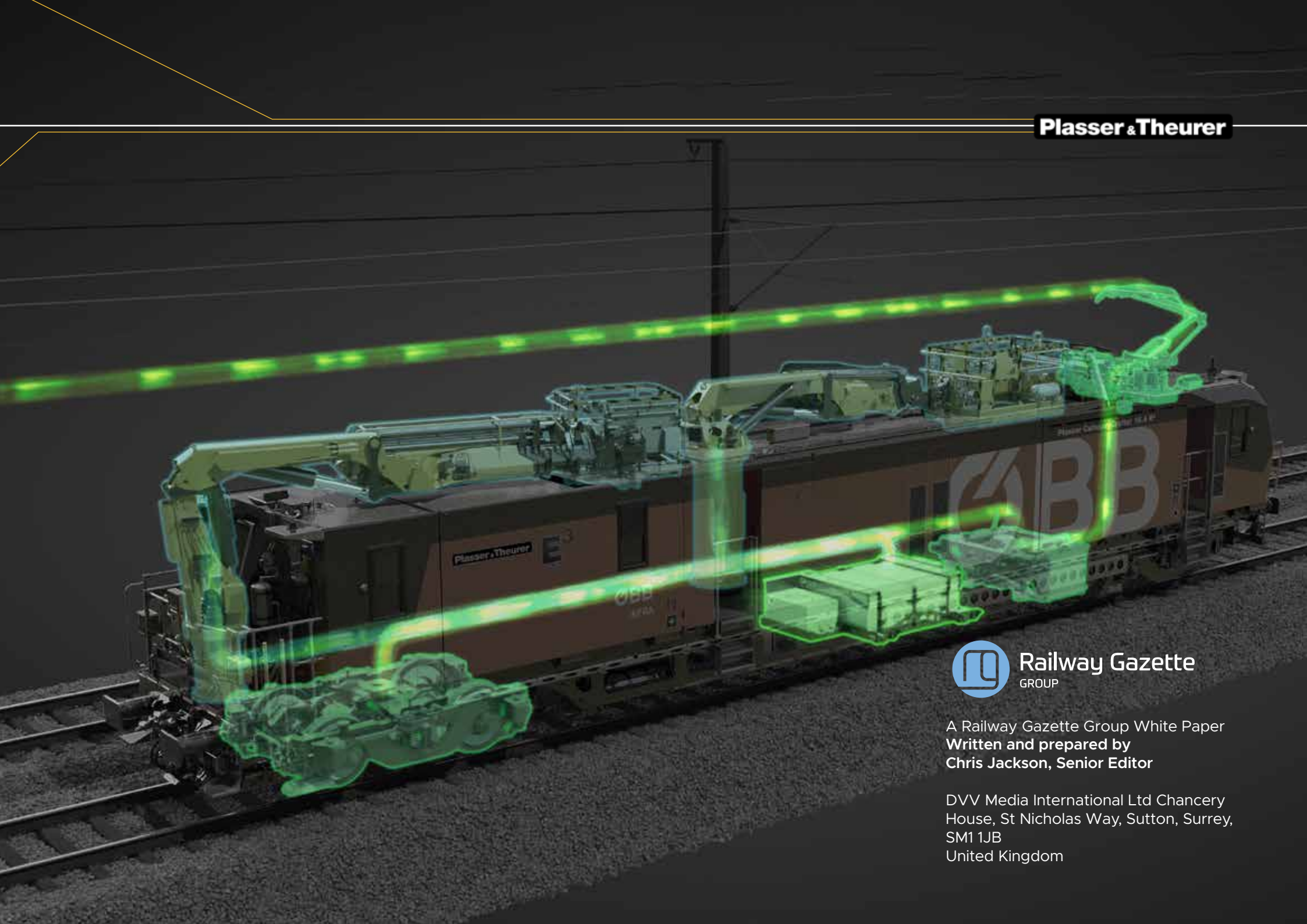
CHALLENGE AND OPPORTUNITY

While the urgency of climate change mitigation and the need to harden railway assets against extreme weather events pose a growing challenge for infrastructure managers, technical innovation is providing the necessary tools for the task. Digitalisation, automation and the increasing use of zero-emission power sources are combining to improve the efficiency of maintenance and renewal activities, while reducing the amount of time that track has to be taken out of service for attention.

As well as the environmental advantages of working smarter, other benefits include reduced noise emissions, a need for fewer specialist staff and improved safety for all concerned. Raw material use can be reduced and the level of recycling improved to contribute to a wider circular economy. All of which adds up to a better performing railway that is greener and cleaner, and ready to support a more sustainable global economy for the years ahead. ■

The hybrid and zero-emission drives of the E^3 family was designed to support environmental sustainability

Plasser & Theurer



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