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The MTU 16-cylinder Series 4000 natural gas engine for commercial marine applications

Power. Passion. Partnership.

MTUreport

The magazine of the MTU and MTU Onsite Energy brands | Rolls-Royce Power Systems Brands
Issue 01|2018 | www.mtu-report.com

Electrifying the diesel
Diesel is no longer alone: Hybrid drives for off-highway mobility

Go! Service
Digital offerings enhance the service experience

Pleasure on tap
CHP plants generate beer brewing power

Power. Passion. Partnership.

Andreas Schell is CEO of Rolls-Royce Power Systems AG and Chairman of the Board of Directors of its subsidiary MTU in Friedrichshafen.

At MTU, the future's electric

Dear Readers,
Yes, you read that correctly: MTU – which has spent more than 100 years pioneering technology that graces the internal combustion engine – is now making electrical power the lead topic in its customer magazine. We are doing this to make a clear statement: MTU is about more than diesel. We're on the move, transforming from a diesel engine maker to a provider of solutions.

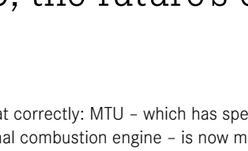
My vision is one where you tell us broadly what you need from your power delivery or power generation system, and we give you exactly the right solution to this need. This solution might be a diesel or natural gas engine, but could equally be a hybrid or even an electric-only system. In future, you might pay us not for the power delivery system itself, but for the benefit it gives you. In short, therefore: you are free to concentrate your mind on your ferry, train or haul truck – and we deliver the power it needs.

This edition of MTU Report will show you how far down this road we've already come. In an interview on pages 14 to 33, our Head of Engineering Development Studies, Dr. Peter Riegger, explains what we're doing in the field of electrification. Our hybrid drive system for rail cars is already mature enough to go into full production, and next year will see us present our initial marine hybrid prototypes. We are also going to be teaming our power generation and management systems with different power sources, allowing us to offer you intelligent microgrids. In fact, we're building the first microgrid pilots as I write.

We are making great strides in service, too. Our aim is to give customers up-time guarantees for their MTU products. To this end, our newly created Digital Solutions team is busy developing tools to help us track the operation of your power delivery systems. We'll be able to analyze this data and use the results to give you valuable tips on how to improve the way you use your systems. You can read more about this in our “GO! Service” article on pages 34 to 37.

As you can see, we're very much on the move. But naturally – and I think this is very important – we are not about to forget the trusty diesel engine. When it comes to diesel, we're up there in the Champions' League, and we intend to stay there. But the world of propulsion and drive power is changing around us, and we want to be well armed for a future which, without doubt, is set to be more electric and more digital.

Sincerely,
Andreas Schell



Electrification

Keep up with MTU!

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Register here for MTU eReport: www.mtureport.com/newsletter

CROSSMEDIA

Electrifying diesels
We are electrifying the diesel engine. Behind the vibrations and waves on the front cover of MTU Report, our electrification strategy provides the focus for this issue of our magazine.

Service in record time

MTU technicians have succeeded in servicing in record time two of the four Series 8000 engines installed in the largest high-speed ferry in the world: the trimaran *Benchijigua Express*. The assignment was exceptional because the 20-cylinder engines were overhauled in-situ in 15 days, with overhaul of the other two units planned to take place in January 2019. The high-speed ferry Benchijigua Express serves the Canary Islands routes between La Gomera, Tenerife and La Palma.

"This was the biggest service assignment I have ever taken on," said Selahatin Tiryaki, chief of operations and site manager. "We worked three shifts over 15 days, overhauling the engines on the ship and fitting spare parts in the ship workshop. Thanks to fantastic teamwork by our colleagues and perfect coordination with the ferry operator team, we were able to guarantee the customer a hitch-free performance."

For ship owners, having an engine serviced in-situ saves a lot of precious time. For MTU it presents very special challenges. Normally, the engine is removed, taken to a factory workshop, disassembled and the components, where necessary, overhauled. However, the Fred. Olsen company had decided to have the engine disassembled while on the vessel. Any components in need of repair were overhauled in the ship's garage, where new parts were also fitted.

Ivan Fernandez, technical manager at Fred. Olsen said: "We are highly satisfied with the smooth execution and the great support given on site in coordination with our superintendents and crewmembers. Our trust in the service and expertise of MTU goes back 12 years, since vessel delivery, and our experiences with them have always been positive. A QL4 on two engines with the amount of parts and technicians involved plus a limited working area and limited movement resources need to be planned more than 12 months in advance, and it is very satisfactory for all parties when everything goes according to the plan."

Whether QL4 maintenance can be realized with the engine in-situ largely depends on whether the main bearings can be replaced without having to tilt the engine. This is the case with Series 8000 units, so an overhaul can be carried out with them in place on the vessel. Engines from other MTU series can also undergo QL4 maintenance on the ship if the conditions are right for replacing the main bearings. ■

Read the full story here: **www.mtureport.com/recordservice**

Picture: Selahattin Tiryaki

Reaching the summit

The new aerial cable car line that carries visitors to the German Zugspitze mountain can claim a clutch of world records. Covering more than 3,200 meters from base support pylon to summit, the Zugspitze cableway traverses a greater single-span distance than any other aerial cable system. It also boasts the world's tallest steel support pylon (127 meters) and over its total length of 4.5 kilometers, the cable cars overcome a difference of around 2,000 meters in altitude.

To enable it to master these impressive distances, the cable car system has its own medium-voltage power grid that is also fed by a cogeneration station. And two diesel engines from MTU are always at the ready to deal with possible power outages. The 18-cylinder Series 2000 units form the heart of two generators from genset manufacturer POLYMA Energy Systems GmbH, which supplied the overall package to the Bavarian Zugspitzbahn company. The generators each deliver 1,250 kVA of electricity and can ramp up to peak performance inside 15 seconds. "If the power were to fail, the cableway would come to a brief stop. But as soon as the MTU engines were running, it would start up again to resume normal service," explained Matthias Ferchl, Rail Operations Manager responsible for power supply systems at Bavarian Zugspitzbahn. The generators can also operate in parallel with the medium-voltage grid – so that the monthly test run can take place without interrupting operations, for example.

Each cable car can carry 120 passengers, with the system transporting up to 580 people an hour. But with scenic superlatives like those available at the Zugspitze, few tourists will be studying the technical details. After the car leaves the base station, the alpine panorama that unfolds before visitors becomes more majestic with each meter they ascend. ■

Picture: Bayerische Zugspitzbahn Bergbahn AG/ Max Prechtel

Dr. Daniel Chatterjee is Head of the Green & High-Tech programme at MTU and also responsible for the project management of MTU's large and classic engines and engines in the lower output range.

Right on course

Greenhouse gas emissions in international shipping are to be reduced by at least 50% by 2050 compared with 2008 levels. This has now been decided by the Marine Environment Protection Committee of the International Maritime Organization (IMO). How is the decision viewed by the manufacturers of ship propulsion systems? We put the question to Dr. Daniel Chatterjee, Head of the Green & High-Tech programme at MTU.

Dr. Chatterjee, what do you think of this decision?
The decision taken by the IMO is a clear affirmation that international shipping is also committed to achieving the climate goals. Establishing global uniform rules with clear targets and concrete actions is important for us. It will result in innovative propulsion technologies being employed and funded.

What must be done to ensure that this radical maritime energy turnaround is successful?
What is absolutely essential for the success of the maritime energy turnaround, however, will be retrofitting ships with new, more fuel-efficient propulsion systems. New, state-of-the-art HFO-free diesel engines are already delivering significant improvements. The step forward will be achieved through electrification, the use of LNG as a fuel and, in the long term, the use of P2X fuels, and subsequently the coupling of the transport and power generation sectors.

Is MTU prepared for this?
Very much so! In 2015, we launched our Green & High-Tech programme. This is a programme with which we make targeted investments in environmentally sound solutions for the future that are designed to lower the emissions of pollutants and reduce the consumption of energy and raw materials. We focus on exhaust gas aftertreatment, alternative fuels, electrification, digitalisation and total systems capability. This means we have an overall view of the entire propulsion system down to the energy generation systems. As early as the end of 2017, we delivered the first of our new mobile MTU gas engines for two Dutch ferries. Compared with a diesel engine with no exhaust gas aftertreatment, the gas engine emits no soot particles and no sulfur oxides, 90% less NOx and 5 to 10% less greenhouse gas. It thus meets the IMO III emission standards in force since 2016 with no additional exhaust gas aftertreatment. When developing new systems, we always include electrical components in the design as optional equipment. This is an area where we see an increasing demand for hybrid propulsion systems in the near future. Besides marine applications, these systems will also be relevant for use in other applications, such as rail or in the form of battery-based energy storage systems for microgrids for the supply of electric power.

As a manufacturer of complete propulsion and energy solutions, we have to think beyond the engine. We are currently in the process of launching a joint project dealing with the entire chain, from P2X generation down to the end use.

The mobile gas engine once more demonstrated its exceptional performance on the test stand.

Mobile gas engines ready for series production

The first pre-production units in MTU's new gas engine series have successfully completed functional tests and are currently being fitted in two ferries in Vietnam. MTU had presented its new marine propulsion units for the first time at the SMM International Maritime Trade Fair in September 2016. The engines have meanwhile completed well over 5,000 hours on the test bench. Paul Melles, Managing Director of Rederij Doeksen, said: "We are very happy with the test run. All the key engine parameters, such as the extremely dynamic acceleration behaviour, have now been verified by MTU."

As the year 2017 comes to a close, MTU has delivered the first two of a total of four 16-cylinder Series 4000 gas engines, each with an output of 1,492 kW, for two new catamarans. From 2018, the two aluminium vessels will operate ferry services on the Dutch Wadden Sea. They are currently being built by Strategic Marine's shipyard in Vietnam for the Dutch shipping company Doeksen. The new 16-cylinder gas engine from MTU will be available as of 2018 as a certified series production engine covering a power range from around 1,500 to 2,000 kW. An 8-cylinder version will follow with a rated output of approximately 750 to 1,000 kW. The new gas engine is ideally suited to tugboats, ferries, push boats and special purpo se vessels such as research vessels. By comparison with a diesel engine without exhaust gas aftertreatment, the gas engine emits no soot particles and no sulphur oxides, 90% less NO_x and 5 – 10% less greenhouse gas. It thus meets the IMO III emission standards in force since 2016 with no additional exhaust gas aftertreatment.

A film on Factory Acceptance Test:
www.mtureport.com/gas-mobile

MTI and Force Motors will be joining forces in Chakan near Pune (India) to build Series 1600 diesel engines and electrical gensets based on Series 1600 units.

Joint Venture with Force Motors

MTU parent company Rolls-Royce Power Systems and Pune-based vehicle manufacturer Force Motors today signed an agreement on a Joint Venture in which Force Motors will hold a 51% and Rolls-Royce Power Systems a 49% stake. The new joint venture will be named 'Force MTU Power Systems Pvt. Ltd.' and is to produce MTU's renowned 10- and 12-cylinder Series 1600 units with power outputs from 545 to 1050 HP (400 to 800 KWm). Series 1600 engines are particularly suitable for power generation and rail underfloor applications. Besides manufacturing Series 1600 units, the JV will also build Series 1600 generator sets for the Indian and global markets.

In brief:

First engine ready

MTU Yuchai Power, a joint venture set up between Rolls-Royce Power Systems and the Chinese diesel engine manufacturer Guangxi Yuchai Machinery Company, is preparing for the start of series production of MTU Series 4000 engines. In April, Yan Ping, Chairman of Guangxi Yuchai Machinery Company, together with Andreas Schell, President of Rolls-Royce Power Systems, unveiled the first MTU Series 4000 engine manufactured in Yulin.

On course for success

Rolls-Royce Power Systems delivered a strong performance in the last financial year and held its ground well against the competition. The MTU parent company achieved a turnaround in terms of revenue, profit and order intake. For more figures, see www.mtureport.com/figures2017.

CEO Andreas Schell (right) and CFO Marcus A. Wassenberg (left) announced the annual figures for Rolls-Royce Power Systems at a press conference.

Woodward acquires L'Orange

MTU parent company Rolls-Rolls-Royce has sold L'Orange, the sister company of its subsidiary MTU. The new owner is the American company Woodward. L'Orange supplies injection systems to several of the world's leading manufacturers of special-purpose diesel engines, including MTU. Close collaboration between MTU and L'Orange is to be continued following the sale.

Seven of the world's ten most powerful megayachts have MTU engines on board. One of them is 'Indian Empress'.

The mighty ones prefer MTU

Number one is 180 m long, and in its engine room houses over 70 kW of drive power – it's indisputably the most powerful mega-yacht in the world. Number two, the 138-m Rising Sun, is capable of delivering half of that output, so has no need to hide. Place no. 9 in the rankings is occupied by Indian Empress, 95m long and boasting three 20-cylinder MTU units that deliver a whole 22,074 kW for acceleration up to 25 knots. At the end of the day, mega-yachts are all about superlatives: on the deck, luxury knows no limits, and down in the engine room, horsepower craziness reigns.

The specialist journal 'Boote Exklusiv' ('Exclusive Boats') has issued a ranking of the ten most powerful mega-yachts. Seven of them have MTU in their engine room. The propulsion concepts behind them are as varied as the yachts themselves. Some are straightforward and consist of MTU's biggest and most powerful engine (the 20V 8000), that delivers 10,000 kW. In others, a combined solution with diesel engines and gas turbines has been chosen. These offer the advantage of fuel economy over long distances or during cruising, when just the diesel engine is brought on stream. When high speeds are needed, the gas turbine can be switched in. These system packages include propulsion and automation, and are tailored by MTU to meet the customer's specific needs.

Tier 4-certified locomotives from US manufacturer Knoxville Locomotive Works are powered by MTU Series 2000 and 4000 engines.

Tier 4 locos with MTU

MTU will deliver Series 4000 and Series 2000 engines to Knoxville Locomotive Works (KLW), an original equipment manufacturer of switcher and road-switcher diesel locomotives. The Series 4000 and Series 2000 MTU engines will power KLW's SE Series four- and six-axle locomotive designs, which were recently awarded EPA Tier 4 emissions certifications. The engines are produced at the MTU America facility in Aiken, South Carolina. Each KLW model uses a single-engine drive train system consisting of either an MTU Series 4000 or Series 2000 high-speed engine powering a traditional intermediate speed AR-10 Series alternator. KLW is the only freight diesel locomotive manufacturer to achieve Tier 4 switch and line-haul certifications with single-engine prime-movers rated at 1,050 to 3,218 horsepower (783 – 2,400 kW).

Patrol vessels for the Philippines

MTU France is delivering ten engines to the French shipyard OCEA.

MTU will power the future flagship of the Philippine Coast Guard: MTU France is delivering a total of ten engines of Series 4000 and 2000 to the French shipyard OCEA, which will build five new patrol vessels for the Philippine Coast Guard. Among those is a 84 m long Offshore Patrol Vessel – the largest ship that OCEA has ever built. It is powered by two 16V 4000 M73 engines. MTU is also supplying the automation system Blue Vision New Generation for the vessel. OCEA convinced the customer with a competitive and environmentally friendly concept: Thanks to efficient engines and an aluminum hull, the OPV will emit 40% less CO_2 than comparable vessels.

In brief:

MTU powers Significant Boats

Every year, WorkBoat magazine chooses ten Significant Boats– newly built commercial vessels that "stand out as models for the industry." In 2017, three of the boats named to the prestigious list are powered by MTU: the Cleveland and Gladys B tugboats, along with the Hydrus ferry.

Of the ten most significant US ships, three are fitted with an MTU engine.

Delivery of Stage V industrial engines commences

The first series-production MTU Series 1000, 1100, 1300 and 1500 engines have now been delivered. Based on commercial vehicle engines from Daimler and covering the 115 kW to 480 kW power range, the units are specifically designed for applications in the agriculture and construction sectors and are Stage V-compliant.

IMO Tier III certificated

The latest generation of MTU's Series 4000 engines equipped with the SCR system for ships has successfully completed the IMO Tier III certification tests. Representatives of the ABS, BV, DNVGL, KR, NK, LR and RS certification bodies initially tested the 20-cylinder version, which was awarded approval as being representative of the remaining versions.

MTU Series 4000 marine engines have achieved IMO III certification.

Claas Tractors break records with MTU

On the test course in Nebraska, Claas tractors proved that they are the most powerful in their class.

Before a new tractor model can be approved for operation in the field in North or South America, it has to successfully complete test runs at the Tractor Test Laboratory in Nebraska. The latest test participants are MTU-powered Xerion Series tractors from Claas. These brand-new Claas Xerion 5000 and 4500 models had to prove themselves in direct competition with competitors in the 450-500 PS class. At around 7.6 meters in length, Xerion 5000 and 4500 are among the biggest in sector. The vehicles boast innovative function features like all-wheel steering, GPS capability and a rotating cab as an option. Sophisticated technology also underlies the vehicles' powerful 6-cylinder MTU Series 1300 (OM 471) engines that meet Tier 4 final emissions regulations without the need for particulate filter exhaust gas aftertreatment. At the test lab in Nebraska, the Xerion tractors broke the records for fuel consumption, pull-to-weight ratio and low cab noise. The Xerion 4500 is now the record holder for lowest fuel consumption in its class. Xerion 5000 and 4500 models set a new record for maximum low-end torque, beating their nearest rivals for engine pulling power by a long chalk. Under ballast conditions in the tests, the Xerion 4500 broke the 25-year record for pull-to-weight ratio for all-wheel-drive tractors.

Save with MTU Onsite Energy

MTU Onsite Energy will deliver two gas-fueled combined cooling, heating and power (CCHP) trigeneration systems to Richmond University Medical Center, a Level I trauma center in Staten Island, New York (USA). The target is a US $1.6 million annual reduction in the hospital's operating costs. The trigeneration project is being managed by developer Innovative Energy Strategies (IES) and is part of a multimillion dollar facility expansion adding a substantial increase in treatment capacity. "After we evaluated the equipment, installation and maintenance requirements for the project, IES selected MTU because of the fuel conversion efficiency and the extended maintenance periods that significantly reduce the total cost of ownership," said Marty Borruso, principal at IES. "Another major factor was the ability of the MTU engines to operate on low-pressure gas. This feature is desirable in densely populated urban areas like New York City." Rated at 1,500 kWe each and guaranteeing performance under high ambient conditions, the CCHP units will provide clean and efficient continuous power to the 114-year-old trauma center.

Two trigeneration plants for heat, power and cooling are to help reduce energy costs in a hospital in the US by 1.6 million dollars.

CHP of the year

The 'Energie & Management' trade journal named the co-generation plant at Master Butchers Ponnath 'CHP Plant of the Year 2017'.

Electricity to cover baseload, steam for meat and sausage production, and refrigeration power for foodstuffs: The combined cooling, heat and power (CCHP) system which has been in operation at Master Butchers Ponnath meat processing plant in Kemnath, northern Bavaria is meeting all expectations very efficiently. That was the verdict reached by German CHP trade association Bundesverband Kraft-Wärme-Kopplung e.V. and trade journal Energie & Management who named the installation "CHP Plant of the Year 2017". At the heart of the co-generation plant is a natural-gas-fired CHP installation supplied by MTU Onsite Energy. Powered by a V12 MTU Series 4000 engine, it delivers 1,287 kWh of power, covering the meat factory's baseload energy needs. Meat producer Ponnath manufactures around 120 metric tons of meat and sausage products per day. Now, not even a power outage is capable of stopping production at the autonomous facility. The installation also uses a waste heat steam boiler to produce 760 kg of saturated steam per hour at 8.5 bars of pressure. This is used in the manufacture of the company's sausage specialties. The built-in absorption chiller also generates up to 550 kW of refrigeration power, which is used to chill foodstuffs down to -10°C. "With an eye to economic feasibility, the people who constructed this year's CHP Plant of the Year exploited the full depth of technical possibilities," said the five-member panel of judges, explaining its decision. The panel was especially impressed by the plant's flexible power delivery capability. "With its high efficiency, this plant is not only set to deliver lower energy bills long-term, it's also incredibly efficient from an environmental point of view," said Gabi Markert, a member of the trade association's board of management. The power plant is reducing CO_2 emissions by around 1,800 metric tons per year, equivalent to a 30% saving over conventional generation.

#Electro

The future is electric

The electric power star is definitely rising. For over a century, the internal combustion engine reigned supreme, powering everything from huge ocean-going vessels to the monster machinery used in mining and construction. But now there is a new contender – the electric motor. But while it has proven its mettle in E-formula racing cars, the use of a straightforward electric drive in an off-highway vehicle remains the absolute exception – the power density gap between diesel fuel and a battery is simply too wide. The solution lies in the hybrid drive, which takes the electric motor and all the virtues it undeniably possesses and offers the best of both worlds. The trend towards electric is very much in evidence inside the diesel engine too – in the form of electric turbocharging.

#Electro

Electrifying the diesel

Electric motors are the future – a mantra we hear everywhere. When is MTU's last internal combustion engine going to roll off the production line?
It is going to be a very, very long time until then. I have no doubt at all that the combustion engine has a major role to play for a considerable time to come. But you'll begin to see it being teamed with other power sources as part of a system solution. We're going to be supplying more and more of our engines in combination with electrical components. For example, under our Green & High Tech initiative we've already developed – and are in the process of developing – products such as hybrid drives and microgrids. But in most cases there will still be no getting away from the internal combustion engine. After all, you can use overhead power lines to drive trains, but they're not much use for yachts or most haul trucks. Currently and in the foreseeable future, the energy density of batteries is much too low to allow us to think in terms of completely dispensing with combustion engines in all applications any time soon.

The head of Bosch, Dr. Volkmar Denner, is saying that, thanks to electrification, the best days of the internal combustion engine are still to come. Can you sign up to that?
Definitely. When it comes to development, electrification is opening up a whole raft of possibilities we simply haven't had before. Just look at our emergency power gensets. These generating sets have to start up at the drop of a hat, something we do a huge amount of development work on. It's also possible to add a small electric motor and battery, and then simplify the engine design. Electrification means we no longer have to design technology to cover the entire span of requirements, but rather it gives us much more freedom to make our combustion engines more robust, more efficient, cleaner and more economical.

Dr Peter Riegger, Director Research & Technology at MTU, on the future of off-highway drive technology.

What kind of drive systems are hybrids especially suited to?
Hybrids really come into their own where you have a highly intermittent load profile, with frequent shifts between low and peak loads. A classic example of this is the hybrid train propulsion, with trains entering and leaving stations under electric power, then using a combination of diesel engines and electric motors to accelerate, running economically on level track sections under diesel-only, and converting braking energy into battery power. The peak load can be borne in this instance by the electric motor. But, in my opinion, yachts are also perfect candidates for hybrid propulsion, albeit for reasons of comfort rather than economy, allowing skippers to turn off their diesels – say in scenic coves or anchorages – and maneuver quietly under electrical power. The battery can also be used to cover the high electrical power draw which a modern yacht has.

And what about agricultural machinery?
You'll see hybrids moving in here too, albeit not immediately. In agri applications, electrical power can be shared very simply among various consumers. I'm thinking here of large combine-harvesters, for example, which have a multitude of hydraulic systems that – bit by bit – are going to be electrified. But this market is much more cost-intensive than rail or marine, and for that reason this trend will take a while to get going.

« **ELECTRIFICATION** gives us much more freedom to make our **COMBUSTION ENGINES** more robust, more efficient and more economical. »

Small-scale grids are the latest trend

The energy scene is shifting. The range of distributed power generation sources, such as solar cells, wind turbines and cogeneration plants, is growing constantly. And it is happening in tandem with the dynamics of a digitalization process that has already rocked some industries to the core. The combination of these two phenomena has led to the emergence of small-scale power networks or 'microgrids' – soon to be available from MTU as package solutions complete with battery and control system.

Photovoltaic systems, wind turbines, hydro-electric plants, diesel gensets and combined heat and power (CHP) modules – whether operating separately or in concert – can all be included in a microgrid. They are not new. In 2017, more than 500 gigawatts of installed wind power capacity and around 400 gigawatts of installed photovoltaic power capacity were already available. By comparison, global nuclear power capacity was just 391 gigawatts. So far, however, the major challenge has always been how to store that power and then release it just when it is needed. CHP plants and diesel-powered gensets are always available, but compared with regenerative energy sources, they are not always economical to run.

Microgrids now provide a solution by combining both types of power generation and including batteries and a control system to integrate all the elements in a smart system. "Microgrids combine cost-efficient and ecologically friendly regenerative energy sources with the reliability of our gensets to create a concept for the future of power generation," declared Alexander Patt, who heads MTU's microgrid development team.

Battery containers from MTU
MTU is currently developing a battery container that incorporates 154 modules and 3,388 lithium-ion cells. Together, these elements can store around 1,000 kWh of electrical energy, that is about 14 times as much as a Tesla Model X. MTU's battery container also boasts around 2,000 kW of electrical power and a capacity of 1,095 ampere-hours. A transformer adapts the output voltage of the MTU battery container to match the connected power grid. "The battery container will have a modular design to maximize flexibility for adaptation to our customers' power needs," said Patt.

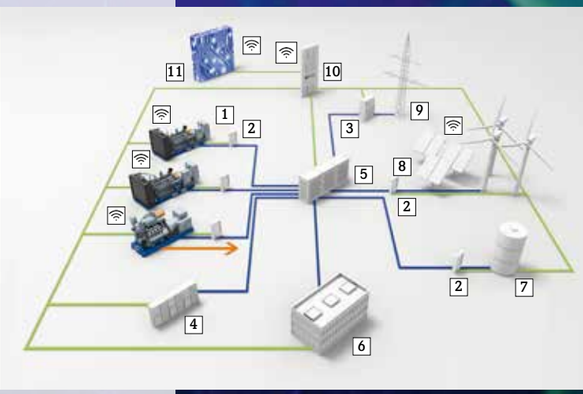
Control at the core
Whatever else is involved, the critical component in a microgrid is the control system. "It has to be predictive, smart and self-teaching, and it has to deliver exactly the right energy mix for the customer's needs," said Armin Fürderer, Team Leader for Electrical Systems, PowerGen at MTU. To enable the control system to decide which power sources to use, the customer has to specify the key parameters: Is his priority cheap power generation or is 'green' power from regenerative sources more important? Or is availability the key factor? Based on these parameters, the control system calculates which energy sources to use and when and whether to feed consumers or charge the batteries. This is where artificial intelligence also comes into play. "A modern microgrid control concept must be smart enough to accurately predict which energy sources will be needed to deliver the perfect energy mix. We are not going to achieve that with classical software architecture. We need to think outside the box here," said Fürderer. The first stages on the journey to an MTU Microgrid will soon take visible shape. The MTU battery container constructed at the company's Ruhstorf location will provide the first element for a planned new Microgrid Validation Center at the Friedrichshafen facility, where it will store power from the photovoltaic installation for supply to the MTU production section when needed. Several CHP modules from MTU Onsite Energy are available to take over when the battery container has been discharged.

« We know how distributed **POWER GENERATION WORKS.** Just like our **CHP PLANTS** and **GENSETS,** our **MICROGRIDS** will be synonymous with **RELIABILITY** and **MAXIMUM AVAILABILITY.** »
Alexander Patt, MTU engineer

MEMO

Microgrids are the solution...

... for electrification in remote regions
... for municipal power authorities
... for grid distribution operators
... for customers who already have a CHP facility and want to use renewables to expand their system
... for customers who already operate with renewables and want to increase their supply capability
... for industrial concerns that want to generate their own power cost-effectively, reliably and sustainably



1 Genset **2** Circuit Breaker **3** Main Breaker **4** Uninterrupted Power Supply **5** Switch gear **6** Load **7** Energy Storage **8** Renewables **9** Main Supply **10** Master/Microgrid Controller **11** Intelligent System
Wireless Communication ■ Power ■ Data ■ Heat

Power without overhead lines

Use the brakes to cut fuel by up to 25% and protect the environment. Accelerate faster and travel more quietly. That basically sums up the MTU Hybrid PowerPack.

« Depending on the routes involved, **AMORTIZATION** for the hybrid drive averages **THREE TO FIVE YEARS**. » Dragan Nedic, Key-Account Manager Rail at MTU

The MTU Hybrid PowerPack marries a conventional diesel engine with an electric unit that functions both as an electric motor and a generator. During braking, the unit acts as a regenerative braking system to recover energy initially generated by the diesel engine as kinetic energy. The energy recovered is fed to a battery, the MTU EnergyPack, where it is chemically stored, ready to power the vehicle whenever the train needs to travel quietly or accelerate quickly. MTU supplies both the hybrid drive system and MTU-tailored power electronics together with a highly sophisticated drive control system.

Flexible installation and application
Versatile installation characteristics and compact design mean the Hybrid PowerPack is ideal for newly developed vehicles as well as for repowering existing units. In conjunction with a current collector, the Hybrid PowerPack can also be used to create a trimodal drive system because the electric drive and motor are already in place. This extends the range of possibilities available to operators and enhances vehicle value retention as electrification programs are rolled out.

Precision calculation of life-cycle costs
"Depending on the routes involved, amortization for the hybrid drive averages three to five years," said Dragan Nedic, MTU Rail Sales specialist. MTU can pinpoint the exact number of years for each scenario using simulation tools and a hardware-in-the-loop test stand. The technology allows MTU engineers to run the MTU Hybrid PowerPack using real timetables and actual routes reflecting real topography. As a result, data on the vehicle and route profiles can be used to calculate life-cycle costs and identify the concept best suited to the operator's needs in advance. The MTU Hybrid PowerPack has already demonstrated its practical benefits on the test stand, and these were confirmed under actual working conditions when a Hybrid PowerPack test unit completed trials over 15,000 kilometers in a Deutsche Bahn Type VT 642 railcar. The trials were initially run by Deutsche Bahn and later taken over by MTU. "The trials verified that operators can make fuel savings of up to 25% with our hybrid drive," said Nedic.

Complete and balanced concept
Going forward, the Hybrid PowerPack clearly provides a future-oriented version of the MTU PowerPack that has established its credentials for success over the last 20 years. These are compact drive systems incorporating both engine and power transmission units as well as all the subsidiary systems, from cooling to exhaust aftertreatment, needed to operate the vehicle. 20 years ago, MTU was the first provider worldwide to develop the concept. Since then, more than 6,500 PowerPacks have gone into operation with rail customers around the globe.

MEMO

The benefits at a glance

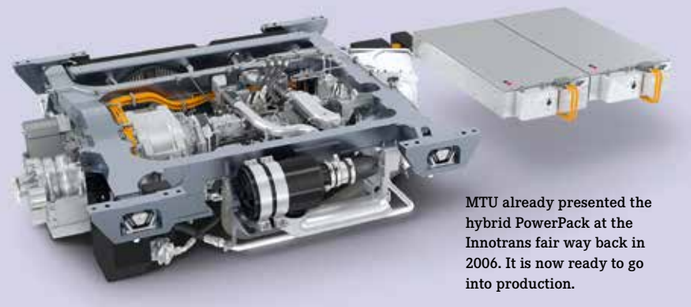
Fuel savings thanks to recovery of braking energy
The recovery of braking energy can achieve diesel fuel savings of up to 25%. The technology has proved especially efficient and effective on local routes with lots of stops involving frequent braking and acceleration.

Reduced emissions due to balanced diesel engine operation
The electric motor and battery mean that during low-load operation, the diesel engine can be run at a more efficient speed or switched off. This also achieves significant reductions in consumption and emissions.

Faster acceleration in boost mode
The supplementary electric motor makes faster acceleration easier than with the diesel engine alone. As a result, delays can be made good and tight timetables are easier to meet.

Less noise
The diesel engine can be switched off during travel through residential areas and tunnels or during stops at stations. Using the electric motor as the main drive unit can reduce the train's noise emissions by up to 21 decibels.

Simple retrofitting and versatile application range
The Hybrid PowerPack offers vehicle manufacturers and operators maximum flexibility when it comes to design and applications. Installation space requirements are the same as for conventional MTU PowerPacks, and units can be adapted by MTU on a modular basis to meet customer requirements. Batteries can be accommodated at various locations in the vehicle. The combined drive concept means that vehicles can switch between electrified and non-electrified routes without interruption so that operators are no longer dependent on decisions and schedules for electrification.



MTU already presented the hybrid PowerPack at the Innotrans fair way back in 2006. It is now ready to go into production.

Will MTU be supplying a fully hybrid system?
Yes, we're going to be offering customers a range of clever all-round solutions in future, featuring not just an engine, but an entire package incorporating advice and guidance, a power delivery system and a long-term maintenance agreement. For customers, this is going to be easier, smarter and more economical overall than self-designed systems where they have to buy, integrate and maintain all the discrete components themselves.

It will soon be 20 years since Toyota unveiled the Prius. Why are hybrids still so few and far between in off-highway applications?
It's true, hybrid cars and buses have been around for a long time now. Indeed, we started delving into this as early as 2006, and we first put a hybrid train on the tracks back in 2012. On the seas, you'll find the first hybrid ships – powered by MTU. However, until now, economy and ecology have not been great bedfellows, but we're slowly getting to the point where hybrids are paying real dividends. Battery storage capacity is coming down in price all the time, and – as developers – we've learned a lot in recent years and are now in a position where we're able to offer customers a truly winning proposition.

What's the number one challenge in getting MTU hybrids into full production?
We've already got rail hybrids ready to roll off the production line and are well on our way when it comes to yachts and microgrids – we're just honing the cost model a bit. Interestingly, it's not the tech that's our greatest challenge – a diesel engine is far more complex to develop than a hybrid system – but most of our time recently has been spent getting to grips with how customers want to use our systems, with a view to packaging together all the features and functionality they need. And now we've arrived at the point where we're able to offer them a menu of smart, reliable total solutions for microgrids, propulsion and drive systems, and on-board electrical power generation. Now, it's all about putting ourselves on the radar with reference installations, and convincing customers of the benefits these solutions offer.

« Given the **ENERGY DENSITY** of the **DIESEL,** these engines are going to play a key part in our systems for a long time to come. »

Video excerpts from the interview: **www.mtureport.com/futureoffhighway**

Where does the diesel come into this system approach?
A system is only as good as its components, and given the energy density of diesel, these engines are going to play a key part in our systems for a long time to come. We're going to continue refining our diesels, keeping them at the forefront of technology. One of the major parts of the development work we are doing involves designing the engine proficiently into the overall system.

Is hybrid technology a stepping stone to all-electric off-highway mobility – or is it here to stay?
The term 'bridging technology' is sometimes misunderstood. The actual function of a bridge is to connect two sides. In this case, the conventional side and the electrical side are involved. I assume that hybrid systems will fit just a few individual applications and will provide a single-purpose, one-way bridge to purely electrically powered transport – on ferries, for example. We're already seeing the first all-electric ferries in Norway. They have large battery banks and comparatively low power draws because of the short routes, and their timetables take account of the time required to charge the batteries, or swap them

over. This is no longer an engineering challenge – it's more a commercial one. In practically all other applications, its feasibility is fairly borderline. Some day, we might see trains bridging unelectrified track sections using on-board electrical power only, but that will still be no general replacement for the internal combustion engine in railcars. That said, we're going to be keeping a weather eye on all the factors involved, to see if they develop along the lines we're predicting – and to see whether, perhaps, any totally different emerging technology comes along to change the ball game.

MTU has been designing combustion engines for over 100 years now – its engineers may be the crème de la crème, but can they 'go electric' just like that?
It's not as if the whole e-issue has hit us out of the blue. We've been doing grid connection calculations for gensets for a long time now – something that calls for considerable electrical engineering skills – and diesel-electric drives have been part of our proposition for a long time in the form of MTU PowerPacks, which are underfloor railcar engines complete with generators and power transmission technology. And we've been fitting hybrid systems to yachts as well. But of course there's always room to grow. The trick will be to modularize our existing hybrid systems, making them easier to integrate. We want to cater for a wide range of variants, load profiles and operating conditions while minimizing the effort involved. That is not to say we're going to have a single standard product. Far from it – our aim is to develop an entire modular family which allows us to meet even special customer requirements simply and economically. Ideally, our sales engineer is going to click his way through the configurator software – I can even see a customer doing this on an app – putting together a power delivery system, which triggers the corresponding production order. That is the goal we're not going to lose sight of.

So where does digitalization come into this?
Electrification offers us a vast array of new possibilities. However, to master these possibilities we have to understand how customers are going to use our new systems. Not everything can be simulated. To make our systems even more efficient, we have to collect data and focus our expertise on analyzing it properly.

Any illustrative examples of this?
Let's take battery life. We can design systems with big batteries to reduce wear and tear on the cells and make them last longer. But that's a pretty expensive option. It's more economical to use a smaller battery and make it work harder – but this lowers its lifetime. Sure, we can run simulations to see which option is preferable, but detailed operational experience is a huge help in areas like this. Analyzing past data, and using present-day knowledge to predict what's going to happen in the future – I think that's going to be the great benefit of digitalization.

We've been talking a lot about electrified propulsion and drive systems. What other tech do you see coming over the horizon?
There are some big developments we've got our sights on. A very important one is alternative fuels, which are set to gradually replace diesel fossil fuel. Natural gas is just one of these, and we're also looking at synthetic fuels. The jury's

« We want to **MODULARIZE OUR EXISTING HYBRID SYSTEMS,** making them **EASIER** to integrate. »

A modular hybrid

International shipping has to clean up its act: by 2050 carbon emission levels have to be half those recorded in 2008. That is the goal formulated by the 170 member states of the IMO, the International Maritime Organization. Hybrid marine propulsion systems will indeed be the answer, but their lower carbon emissions are only half the story.

Say 'hybrid drive' and what comes to mind for most people is regenerative braking, where energy given off during braking is captured and used to help power an electric drive system – something which is difficult, if not practically impossible, to make work on board ships. Even so, hooking a ship's diesel up to an electric motor and a battery bank has a lot of things going for it. An electric motor in a tugboat, for example, assists high-precision maneuvering, and its lower operating costs make it an attractive proposition to operators. On a yacht, a diesel-electric setup enables high-power propulsion plus the extra comfort thanks to the lack of noise and low vibration levels. On patrol boats and other applications with highly intermittent load profiles and where the propulsion system is powered up and down very regularly, hybrid drives also offer cost benefits and extra power capability.

MTU hybrid expertise
MTU now has several vessels under its belt that it has equipped with hybrid propulsion exactly suited to the customer's needs. The largest sailing yacht in the world – sailing yacht 'A' – is equipped with a diesel-electric propulsion system capable of seven different drive modes. That means that high speeds are as possible as smooth, silent, fuel-efficient cruising. In the 'Nova Hybrid' project being realized by Heesen shipyard in the Netherlands, customers are offered a 50-m fast displacement yacht with twin MTU 12V 2000M61 diesel engines delivering 1,200 kW and two 110-kW electric motors. The full aluminum vessel can attain up to nine knots running on the electric drives alone, making for completely silent travel.

Modular hybrids
At MTU, we are currently using our experience gained from these custom solutions to develop a standard set of modular hybrid building blocks which can be mixed and matched as required. Each hybrid system will basically comprise an MTU Series 2000 or 4000 engine, an intermediate gear with up to four electric motors or optionally a mechanical gearbox, and one or more batteries. "Using our system integration experience, the building block configuration will enable us to assemble a custom-built hybrid propulsion system depending on the application and customer needs," explained Bastian Hornig from MTU's Offshore Application Engineering unit. A customer who interested in having a lot of electrical power, can incorporate several electric motors into the system. But if he wants to cruise over very long distances on the electric drives alone, he can simply add a few batteries. "The matching system automation and interfaces will already be available, so putting together the modules to create a hybrid system will be a very simple business," said Hornig.

Next year, the first yachts equipped with MTU's new hybrid system will go out for trials. Launching of series production is planned a year later in 2020.

Built by the Dutch Heesen yard, the yacht 'Home' has two 1,200 kW MTU diesel engines and two 110 kW electric motors on board.

Converting electricity into fuel

How could surplus electrical power – generated for example using solar energy or wind – be stored and used on demand? That's one of the challenges of the energy turnaround. How could a diesel engine be run efficiently without using oil in the medium and long-term? That's one of the challenges of off-highway mobility. The answer in both cases is the same: Power-to-X. In this version of Power-to-X, electricity is converted into fuel.

The basic idea behind all Power-to-X processes is easy to grasp: Renewable energy sources such as the wind or the sun are by their nature inconstant, which can result in surplus electrical power being produced. In the Power-to-X process, this power can be transformed – into hydrogen, for example, which can then be either combusted directly or converted onwards into methane or synthetic fuel. So fuel is won from electricity.

« As a solutions provider for COMPLETE DRIVE SYSTEMS AND POWER GENERATION PLANTS we have to think BEYOND THE ENGINE. »

Daniel Chatterjee, leader of the MTU Green and High-Tech program

The essential point is that if the electricity has come from a renewable resource, the fuel subsequently produced will be classed as climate-neutral. Furthermore, this fuel can be stored cheaply and securely and transported with the help of existing infrastructures. It can also be used to power an internal combustion engine, scoring extra ecological points for sustainability and cost-efficiency along the way. The concept is still in its infancy, but carries huge potential.

Natural gas - the bridging technology on the way to Power-to-X

As part of its Green and High-Tech initiative, MTU is developing new gas gensets for use in power plants. These gas gensets are capable of coming on stream as quickly and as flexibly as diesel gensets and likewise boast high overall efficiency. "The ultimate aim is to use gas as operating reserve," explained Dr Daniel Chatterjee, who leads the Green and High-Tech program. Another significant development is MTU's first gas engine for marine applications, which offers the same performance and characteristics as its diesel engine and is about to be approved for series production. This gas engine currently runs on liquid or compressed natural gas (LNG/CNG), but in the next stage these fossil fuels could be replaced by synthetic fuels produced in the 'Power-to-Liquid' process. The same approach would be plausible for diesel fuels. "Synthetic diesel fuel is cleaner to combust than diesel fuel based on crude oil," explained Chatterjee. Exhaust gas aftertreatment would still be necessary, because emissions directives are becoming ever stricter, but the system will enjoy a longer service life because combustion is simply cleaner.

No energy turnaround without Power-to-X

Some Power-to-X projects are already at the pilot stage. German car manufacturer Audi for example has been operating a plant for five years now in which hydrogen derived from green electricity using electrolysis is converted into methane. The cost-effectiveness of the process still needs to be worked on, however. In a study published jointly in late 2017 by the Deutsche Energie-Agentur (German energy agency) and energy consultancy Ludwig Bölkow Systemtechnik, the price of a Power-to-X fuel equivalent to a diesel fuel would be up to 4.5 euros per liter. Looking ahead to the future, Chatterjee said, "As a solutions provider for complete drive systems and power generation plant, we have to think beyond the engine. That's why we're currently launching a collaborative research project dealing with Power-to-X technology along the entire chain – from the renewable energy source through to generation of the Power-to-X product and how it is finally used." Of one thing Chatterjee is absolutely convinced: "Without Power-to-X, we won't be able to make a success of the energy turnaround."

still out on which one is going to win the day – be it methanol or so-called OME fuels, or maybe even something completely different. The production of such fuels – thinking of power-to-x – is one key issue we're looking into. How can we use renewable energies to obtain clean, CO_2-free fuels? Hydrogen springs to mind, however, combustion can be tricky. But using hydrogen to produce all kinds of synthetic fuels is an interesting proposition. We're undertaking studies and analysis on this. This summer we're launching a government-assisted project to cast more light on alternative fuels and on the combustion of hydrogen in our engines.

Complete the following sentences:

- **In my opinion, a modern power delivery system is ...** high-performance, reliable and environmentally-friendly – in other words, a perfect combination of combustion engines and electric drives!
- **Diesel engines are ...** cool!
- **MTU is in the process of ...** actively shaping the future of industrial drive systems.

Dr. Peter Riegger
Dr. Peter Riegger has been heading up MTU's Engineering Development Studies & New Technologies unit since January 2016. He graduated in physics at the University of Stuttgart and qualified as Ingénieur Généraliste in Paris. He began his career at Robert Bosch GmbH.

Interview: Lucie Maluck
Pictures: Robert Hack

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Dr. Peter Riegger sees the combustion engine occupying a place in the off-highway sector for a long time to come, although he expects it to be assisted by electrical components or powered by alternative fuels.

« We're undertaking STUDIES and ANALYSIS to cast more light on ALTERNATIVE FUELS, and on the COMBUSTION OF HYDROGEN in our engines. »

Electrically assisted turbocharging makes engines more agile

Goodbye turbo lag!

If you drive a turbocharged automobile, you probably know all about 'turbo lag'. You step on the gas at low revs and for a while – not much happens. In future, for MTU engines at least, this turbocharger design problem will be consigned to history, thanks to new technology that combines conventional turbochargers with an electric motor.

The two prototypes undergoing tests on the MTU test stand in Friedrichshafen look like nothing more than a couple of upturned cook pots, each with a round hole in the middle. But beneath the unremarkable-looking cover there lurks cutting-edge technology – possibly even the ultimate answer to some of the most complex questions ever faced by engine designers: How do we get rid of turbo lag? How do we meet increasingly strict emissions regulations without losing out on agility and consumption? And how can we get turbochargers to deliver maximum performance across the engine's entire operating range?

At MTU, the magic concept is electrically assisted turbocharging. And this is what is hidden beneath the two cook pot-type aluminum covers fitted in front of the turbocharger compressor on a 10-cylinder diesel engine. MTU has acquired exclusive rights to this new technology from the G+L innotec company, and the partners will now be jointly developing the product through to series maturity. Market debut for the first engines with electrically assisted turbocharging is scheduled for 2021.

"Electrically assisted turbocharging is a significant milestone on the road to hybridization," explained Dr Johannes Kech, Director, Turbocharging and Fluid Systems at MTU. "This technology will allow us to develop engines that deliver increased agility and lower consumption at the same time as enhancing ecological performance," he added. All this is made possible by using an electric motor to smooth out weaknesses in turbocharging systems.

Increased demands on turbochargers

Turbochargers are intended to increase performance and efficiency. They utilize the energy contained in engine exhaust gases to drive a turbine coupled with a compressor and deliver more oxygen to the combustion chambers in the diesel engine. However, the physical constraints of the technology mean that the additional performance only cuts in at higher engine speeds because at lower speeds, there is not enough exhaust gas to drive the turbine fast enough. Consequently, there is always a delay until the necessary speed is reached. In the past, designers tried to solve the problem with ever more complex (and therefore increasingly expensive) constructions, including sequential and alternating switching concepts and adjustable turbine blades.

Today, these technologies have just about reached their limits because the demands made on turbochargers are constantly increasing. Customers operating in more and more applications are demanding even greater acceleration across the operating spectrum. At the same time, turbochargers are increasingly expected to achieve reductions in emissions by helping to prevent the generation of diesel particulates and nitrogen oxides during the combustion process. Maximum performance across wider speed ranges with simultaneous suppression of emissions – expectations have now almost surpassed the possibilities open to conventional technology.

Electrically assisted turbocharger squares the circle

Turbocharging technology has now turned to electrification to square the circle. "With electrically assisted turbocharging we marry a conventional MTU turbocharger with an electric drive motor," explained Joachim Thiesemann, who is responsible at MTU for integrating the new system in the standard turbocharger landscape. It was as part of this process, that his coworkers mounted the 'cook pots' described earlier externally, in front of the compressor wheel. Each cook pot houses a permanent magnet, the rotor of the electrical unit, and the electrical winding that is integrated in the compressor casing. "The electric motor makes it possible to virtually decouple the operating point of the turbocharger from the speed of the diesel engine," explained Rudi Rappsilber, who is in charge of testing the new system at MTU. The result is that significant delays in performance ramp-up are now history, and optimum turbocharging can be achieved in almost every operating state. For development engineers and users alike, that represents the fulfillment of a dream. An additional advantage is that the technology can be implemented with existing turbochargers without excessive complications. The additional installation space required is limited.

On the test stand, Rappsilber and his coworkers completed a final check on the cabling for the measuring sensors before leaving the room. At the press of a button, the engine started up, and after a short idling run, the throttle was fully opened. The steep rise in the speed curve brought a smile of satisfaction to the faces of the engineers: "The engine is accelerating much faster than without electric support," reported Rappsilber, adding: "That promises to translate into a significant improvement in agility for operation in the field later on."

The new technology is expected to be available to owners and operators of ships, gensets and land-based vehicles from 2021. That said, Thiesemann, Rappsilber and their coworkers will still have to spend many hours at the drawing board and the test stand before their work with electrically assisted turbocharging reaches the point where emergency gensets in the field ramp up to full speed faster, motor yachts accelerate quicker and their engines power them up to top performance with less fuel and lower emissions. Nevertheless, the process is likely to involve increasingly frequent smiles of satisfaction.

Words: Rolf Behrens
Pictures: Roland Witsch, Robert Hack

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Linked to a conventional turbocharger, the electric motor ensures that extra fresh air is available whenever the engine needs it. As a result, delays in performance ramp-up are now a thing of the past.

Read more about electrically assisted turbocharging:
www.mtureport.com/electricturbocharging
(Link valid from September on)

Did you know?

#Electro

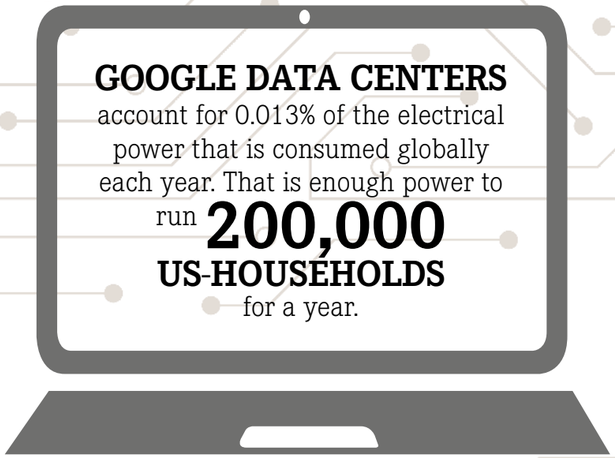
Electrification took off in 1879 when **Thomas Alva Edison** presented a light bulb to the public that could burn for almost 45 hours and was affordable for many. Electric lighting became available to the masses.

Over **1.4 Billion people** do not have access to electrical power. Most of them live in sub-Saharan **Africa** (589 million) and **Asia** (930 million).

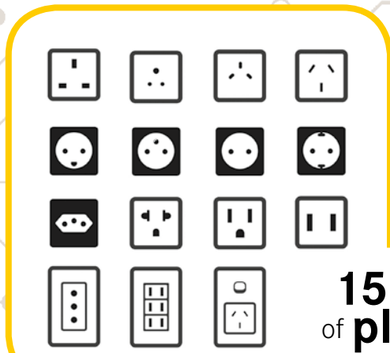
According to the CIA World Factbook, **21 billion kilowatt hours (kWh)** of **electrical power** are consumed worldwide each year.

Technically, it's a compelling concept: harnessing the energy of a bolt of **lightning** to produce electrical power. After all, a bolt of lightning strikes the earth with several **hundred million VOLTS AND UP TO 100,000 amps.** However, the third factor in an energy calculation is time, and that represents a problem here. Most of the electrical power is discharged within a 500 millionth of a second – far too short a space of time in which to harvest any significant amount of energy.

AC/DC is not only the English abbreviation for Alternating Current/Direct Current, but also the name of a famous Australian band. The two brothers who founded the band – Angus and Malcolm Young – decided to use the abbreviation after their sister noticed it on the back of her sewing machine.



GOOGLE DATA CENTERS account for 0.013% of the electrical power that is consumed globally each year. That is enough power to run **200,000 US-HOUSEHOLDS** for a year.



15 different types of **plug socket** are used around the **world.**

THE FIRST automobiles WERE ELECTRIC. Ironically, it was electronics – in the form of the electric starter – that paved the way for the internal combustion engine. It improved engine starting. And the increased range of gasoline-powered automobiles then led to the breakthrough.

'Electro' is the name of a supervillain appearing in an American comic published by Marvel. He was originally an electrician named Max Dillon who, having been struck by lightning in an accident, subsequently discovered that he was able to charge himself virtually endlessly with electricity and use it to create lightning.

The **WORLD'S FIRST Hybrid car** was not in fact the Toyota Prius but Porsche's Semper Vivus ('Always Alive') dating from 1901. On this vehicle, Ferdinand Porsche had added a petrol engine to the battery-powered wheel hub drive.

The sound of silence

#electro

Cars powered by electricity instead of petrol/gas, and eschewing a conventional circuit in favor of a course that cuts right through the city center: Jean Todt, President of the International Automobile Federation FIA, certainly provoked skeptics when he unveiled the world's first all-electric motorsport series back in 2013. One year later, during its inaugural season, Formula E was still attracting wry smiles from the motor racing fraternity. Today, its star is definitely rising, and present competitors Jaguar, Renault and Audi are to be joined over the next few years by teams from Nissan, BMW, Mercedes-Benz and Porsche. Quiet, carbon-free electric vehicles (EVs) have become a megatrend in their own right, and Formula E is a superb showcase for what EVs are capable of doing.

20 cars start the race together, yet all one hears is a humming and swishing sound. Their electric motors make Formula E cars very quiet compared to racing cars with combustion engines.

Two champions comparing notes: the Formula E champion Lucas di Grassi shows off his car to his F1 counterpart, Nico Rosberg.

With a top speed of 225 kph, racing cars can accelerate from 0 to 100 kph in 2.9 seconds.

20 racing cars are on the starting line when suddenly the lights change to green, and the air fills with: a humming sound. The cars sound like a large swarm of bees as they race round the Street Circuit at Berlin's former Tempelhof Airport, accelerating from zero to 100 kph in just 2.9 seconds. This compares favorably with a Formula 1 vehicle which is just a touch under 0.3 seconds quicker. Then the noise level rises, because on any in-city course the next corner is never far away, and the tires squeal around them – not a sound one is used to hearing on racetracks, as it is usually deafened out by the scream of engines. But Formula E is different. Emission-free, it is kicking over the traces – and leaving none in its wake.

"I certainly missed the sound of engines during the first few races," admitted Nick Heidfeld. He spent 11 years behind the wheel of a Formula 1 car and is now driving for Indian Formula E team Mahindra. "15 years ago, the F1 sound was wicked, and I miss it – but, having said that, today's F1 cars are a lot quieter," he added.

The race – staged at Berlin's mothballed Tempelhof airport – is the ninth event of the current Formula E season. The previous races have been held in Hong Kong, Marrakech, Santiago de Chile, Mexico City, Punta del Este, Rome and Paris: every one of them in-city courses where racing cars with combustion engines are (somewhat grudgingly) permitted in exceptional cases only – too much noise, too many fumes. But these races, with zero inner-city emissions, are allowed to be staged even by the pretty shores of Lake Zurich, or in New York's Brooklyn dockland. Formula E is all about sustainability, efficiency and engineering progress. Its intention is to offer the automotive industry a platform for driving the development of EV technology.

Open doors at Formula E: fans are welcome to stroll through the pit area before the race.

Trialing tech for street-legal vehicles

Manufacturers like Audi, Jaguar, Renault and Mahindra are already doing it, with BMW and Nissan coming on board next season, and Mercedes-Benz and Porsche the year after that. Even now, this is a bigger 'who's who' of the motor industry than in any other branch of motor sport. This championship sees them all testing and developing technologies under extreme conditions. This technology transfer has waned somewhat in Formula 1 as the similarity gap between racing cars and on-highway vehicles has widened.

All Formula E vehicles use a uniform chassis, the Spark SRT 01E. Each year, a Technical Roadmap sets out the parts and procedures on which manufacturers are allowed to get creative. Right now these include the gearbox, the inverter, the rear suspension and the motor. The motor is allowed to deliver no more than 200 kW, powering the car up to a maximum speed of 225 kph. This may sound a tad conservative for a racing car, but they rarely reach 200 kph as they hurtle down these winding in-city circuits. No improvements are permitted to car or motor during the year. This is intended to save cost. Another interesting feature is that every manufacturer is allowed to develop its own motors, but must then make them available to other teams at an acceptable price. At present, Chinese team Techeetah is availing itself of this opportunity, using a Renault power delivery system, though all other teams are doing their own development work. All these arrangements are in place to prevent an uncontrolled tech rush and ensure instead that Formula E remains exciting. Unlike Formula 1, it is not possible to say, before the race, who is in the running for a place on the podium.

In the Berlin race, Audi driver Daniel Abt put himself confidently in the lead. Behind him, drivers jostled for position, with constant overtaking. Braking errors are commonplace – it's hard to steer a vehicle with a 230 kg battery in the back. "Sometimes you can look like a bit of an amateur," said Mahindra driver Felix Rosenqvist before the race. At the time, he surely didn't think he would be referring to himself, but right in his first lap the young Swede made a braking error and slipped 10 places down the pack.

Pit stop and car change

It's a fairly common scene after 22 race laps: one by one, the drivers start coming into the pits. In Formula E, though, it's not to refuel or get new tires – they jump out of their cars and hop straight into new cars standing alongside. This maneuver takes just a few seconds – indeed the drivers train long and hard for it, because each tenth of a second saved is a tenth of second that does not have to be regained on the track. Battery capacity has still not reached a level permitting an entire race to be driven. "Our batteries come from Williams

Futuristic and powerful: the new Generation 2 Formula E racing car

Interviewed after the presentation, he stressed how impressed he was by the car's power: "I put my foot right down to the floor and hoped I would get the car back to the pits in one piece," he said after the race.

Gen 2 cars more powerful

The brand new second-generation Formula E car is due to replace existing vehicles at the end of 2018. It does not just have futuristic looks, but is also more powerful. Battery power is to double to 54 kWh, enabling the engine to produce more powerful bursts of energy – 50 kW more powerful, in fact, with a maximum power output of 250 kw (335 PS). This means the new cars with be able to accelerate all the way to 280 kph. The new car was shown to the public on a racetrack for the first time in Berlin – presented by Formula 1 champion Nico Rosberg. At the end of his five-lap circuit, he could barely conceal his enthusiasm: "It was a great feeling to sit in a racing car again. I really put my foot to the boards and just hoped I'd bring the car back safely," he said.

Racing cars old and new – a comparison

	Generation 1 (2014 – 2018)	Generation 2 (from Fall 2018)
Manufacturer	Dallara/Spark	Dallara/Spark
Wheels	Michelin, 18-inch	Michelin, 18-inch
Length	5,000 mm	5,160 mm
Weight (incl. driver)	880 kg	900 kg
Battery producer	Williams Advanced Engineering	McLaren Applied Technologies
Useable battery power	28 kWh	54 kWh
Maximum power output	200 kW	250 kW
Battery weight	230 kg	385 kg
Acceleration (0 to 100 kph)	2.9 seconds	2.8 seconds
Top speed	225 kph	280 kph

Cheers galore: Audi driver Daniel Abt notches up a home win in Berlin.

MEMO

Is quiet really quiet?

People always talk of the electric Formula E cars being quiet. The lack of engine noise is a big issue. Yes, Formula E racing cars are quiet if you compare them with F1 cars. The V6 hybrid turbo engines they have been using since 2014 are stated to have a sound pressure level of 128 decibels as opposed to the 80 dB produced by their Formula E counterparts. When you consider that an increase of 10 dB represents a doubling of perceived volume – as psycho-acousticians tell us – Formula E really is quiet. However, these vehicles are still twice as loud as conventional cars, which emit 70 decibels.

MEMO

It's green power all the way

Any electric drive system can only be described as environmentally-friendly if the power for its lithium ion batteries is produced in an ecological manner. Here, Formula E has teamed up with UK company Aquafuel Research. They have adapted diesel generators to produce electricity with zero harmful emissions using glycerol. This also produces a liquid by-product which is drinkable and tastes like honey. Glycerol can also be produced using salt water plants. Experts expect this to be economically viable in 3 to 5 years' time.

Advanced Engineering and have a capacity of 28 kilowatt hours," said Gerry Hughes, head of Chinese team NIO. And minimizing the load on this battery is one of the decisive factors in the race.

Battery management wins the race

"Keeping your foot to the floor is easy for anyone, but we've constantly got to keep an eye on battery capacity if we're to finish the race with some to spare," said Felix Rosenqvist, pinpointing a key factor that differentiates Formula E. Great Britain's Oliver Turvey experienced this firsthand in Berlin: even at the start of the race he was using a lot of battery power, which caused him to head for the pits one lap before the others to switch cars. During the second half – having started the race in second place – he was forced to save power and ended up being fifth over the finishing line.

But it's not all about saving battery power. Drivers are allowed to recover up to 150 kW from the energy released during braking. Precisely when they choose to do this is up to them. They have the option to brake heavily, or less heavily, before a corner, and can also use switches on the steering wheel to select different energy recovery levels. Using a special paddle on the wheel, drivers can also recover energy without using the footbrake. The electric motor then applies braking to the rear wheels, and allows the driver to use the energy so produced during the course of the race. Reigning Formula E champion Lucas di Grassi explains the tactical options available to the driver: "Where to use full acceleration, and where to go a bit easier and save power? Where to take your foot off the accelerator when entering a corner, and how to recover energy? When you're battling it out with another driver, it's better to save power until such time as he doesn't have much left. If you're defending your position, though, you've got to make intelligent use of the power available so the other guy can't tget past. That's why I always say it's like playing chess at 200 kilometers an hour."

Formula fun for all the family

It's not just the drivers that get a thrill out of this chess game. It may not yet have reached mass popularity like Formula 1 has – attracting, as it does, 60 - 70 million spectators and viewers – but, even so, the races are all sold out. And they attract a different breed of person, with families, city-dwellers and techies all flocking to the events. They don't just get a ringside seat for the race – before it starts, they're also able to visit the pits and talk to the drivers, giving a whole extra depth of involvement in the event. Also, the Fanboost feature allows them to use Twitter (the official Formula E app) or a website feature to fast-track an extra 100 kilojoules of oomph to their favorite driver who can then use it during the second half of the race. The Fanboost winners in Berlin were Daniel Abt, Sebastien Buemi and Felix Rosenqvist.

"The thing we just love about Formula E is that it's different from other series. Here, we're reaching people who may well be looking to buy an EV of their own soon," said Toto Wolff, Head of Mercedes Motorsport. He, too, attended the Berlin event as a guest or, as he put it, "as a fan". Sitting with other fans, he saw his German competitor Audi's Daniel Abt and Lucas di Grassi quietly cross the finish line to win the race, leaving jubilant fans significantly less quiet! Many had indeed hoped for a German home win, but the chances did not look so good before the event. The race won, everyone rushed towards the podium to congratulate the winners. Trackside, there was scarcely any noise, the motors now humming peaceably, and the tires once again slumbering into silence.

Words: Lucie Maluck; Pictures: Lucie Maluck, FIA

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What if all drivers 'went electric'?

by Vince Ebert

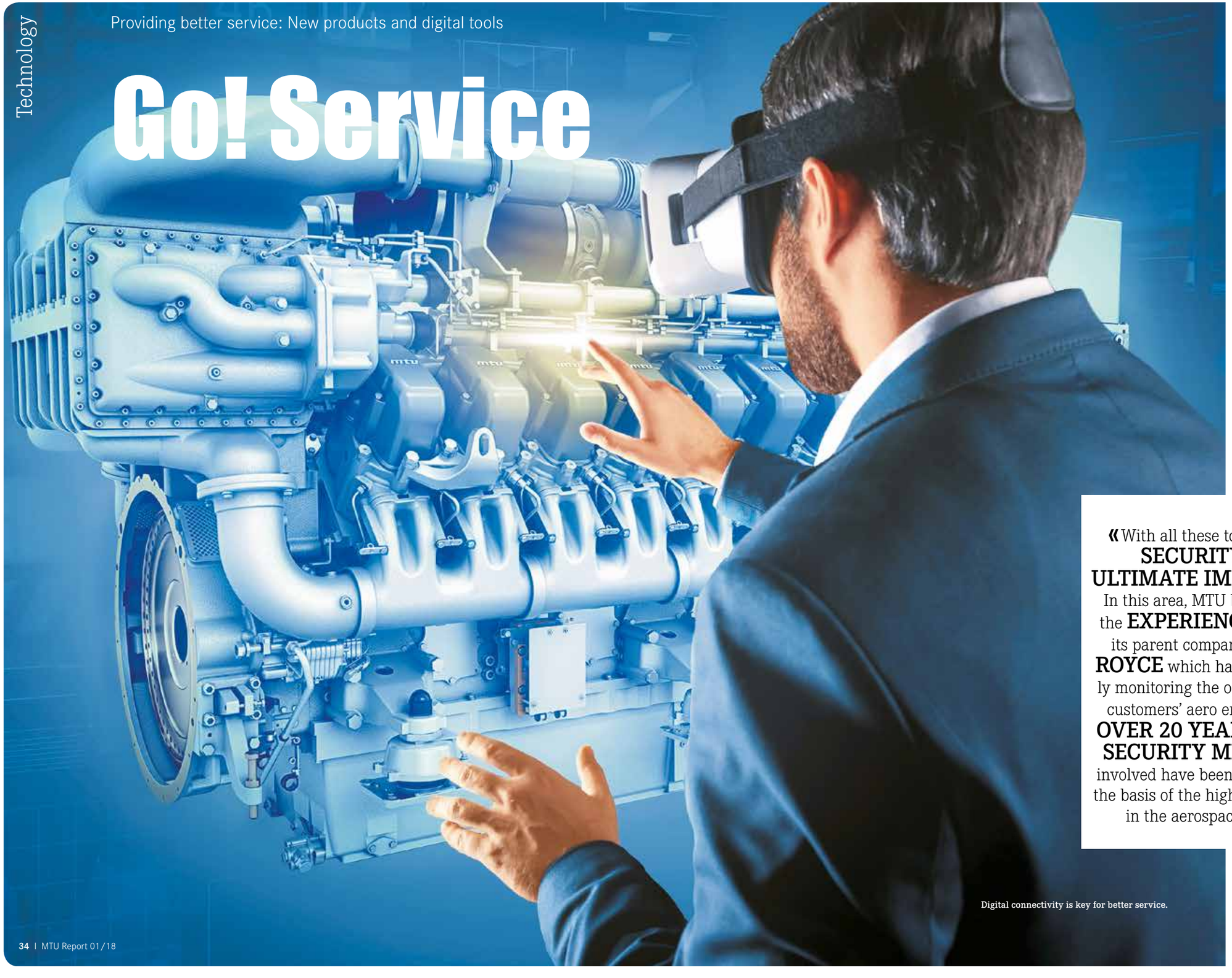
The world is getting greener and expects everyone to do their duty. But wait: without nuclear power stations, how are we going to drive all those wind turbines? And is it true that leaving your kitchen's icebox wide open will help combat global warming? And hey, how can a Tesla's battery catch fire if its designers are so picky about internal combustion? Well, whatever the answers to those questions – the political powers that be have decided those nasty particulate-producing diesels are going to be classified as major health hazards. They conveniently fail to mention all the particulate victims we have during the lead-up to Christmas. Any four-candle advent wreath worth its salt has no trouble exceeding the current nitrous oxide limits. And while we're on the subject, one great imponderable in all this is precisely at which point any given quantity actually becomes a health hazard. Imagine, if you will, 10,000 people crossing a 10-foot-deep river, and 100 end up drowning. Following this logic, does the idea that a one-inch stream is going to kill one person strike you as a reasonable conclusion? Of course not. Yet that's exactly the kind of calculation that's used when specifying these limits. Now, of course, the electric vehicle (or 'EV' to its friends) is supposedly set to vanquish all our energy and environmental problems in one fell swoop. The government here has promised to put all the wherewithal in place by 2030 to allow us all to 'go electric'. Hang on a minute! Let's not forget, this is the government that decided Berlin needed a new airport and is now 12 years into a 6-year building project …

If we really were to replace all Germany's internal combustion engines with EVs, we'd need nigh on 140 extra power stations, or 220,000 more wind turbines, or a solar farm the size of Luxembourg, to cater for the extra demand. Now I know a lot of people might be quite happy to see Luxembourg disappear beneath a sea of panels in the interests of powering the European dream of having EVs in every household, but that's another story. The politicians are suggesting that EVs are clean and place no burden on the environment. But moving an EV from A to B takes a certain amount of energy, right? And that energy has to come from somewhere – whether it be electricity, gas, petrol or muscle power. Replacing gas-powered automobiles with EVs simply shifts the resource burden and the environmental burden someplace down the road. There is no such thing as usable energy free of charge. It always comes at a price. The sun may not send out invoices, but the solar power supplier certainly does. I, for my part, am healthily skeptical of all these eco panaceas being bandied about. Only yesterday, the BBQ ran out of charcoal, necessitating a mercy dash in my diesel SUV. Took a long time in first gear, I can tell you! And when I go on a men's night out, I always leave the lights on. I like to come home well lit.

Vince Ebert has a degree in physics and a career in satirical stand-up. His stage shows, talks and books cast light on matters scientific through the universal medium of humor.

Providing better service: New products and digital tools

Go! Service



Digital connectivity is key for better service.

“Your engine is down? We’ll fix it.” Once upon a time, that was what service meant. Today, customers are more likely to hear: “Our platform is telling us your system needs a new injector. A replacement is already on its way to you. When can we fit it?” That is Service 4.0: predictive, customer-friendly, digital – with electronic monitoring, apps and Customer Care Centers.

Anyone researching the smart factory revolution on Google will come up with many millions of results for the search term ‘Industry 4.0’. Searching ‘Service 4.0’ will produce only a few hundred thousand. Nevertheless, digitalization is definitely transforming the service sector. “Digital products mean we can now use our systems to link up far more effectively than before to help our customers operate their products better and avoid incidents,” said Jörn Lindstädt, Director Global Customer Service at MTU, explaining the benefits of Service 4.0.

ValueCare Agreements secure availability

There is just one overriding aim: engines, plant facilities and power generation systems must work – either all the time or whenever the customer wants them to. That is the only way for them to make money. “That’s why we offer our customers standardized maintenance contracts – our ValueCare Agreements,” said product manager Nadja Lang, adding that the agreements come in three levels: Bronze, Silver and Gold. Whilst the Bronze version mainly aims to make sure that guaranteed spares are always on hand for scheduled servicing work, the Gold version is almost like an insurance policy with MTU providing a guarantee that the system will always be available. “Our Gold version comes very close to achieving our ultimate vision. What the customer buys from us is the availability of his power generation plant or his drive system. We look after everything else,” declared Lang.

Connectivity: The key to better service

To be able to offer services like these, MTU needs to know how and where the systems operate. “Connectivity is the critical element in Service 4.0,” said Lang. This is what enables MTU specialists to remotely monitor customers’ systems, to plan servicing operations and spares availability, and to analyze operator data and develop recommended actions. Dataloggers transmit the relevant data to a ‘Go!’ platform that has been newly developed by MTU. Here, the information is processed as needed so it can be utilized by customers and MTU specialists alike. “The new platform combines field data with all the other additional data needed like maintenance schedules and technical documentation,” explained Hubert

> « With all these tools, **DATA SECURITY** is the **ULTIMATE IMPERATIVE.** In this area, MTU benefits from the **EXPERIENCE** gained by its parent company **ROLLS-ROYCE** which has been remotely monitoring the operation of its customers’ aero engines **FOR OVER 20 YEARS.** All of the **SECURITY MEASURES** involved have been developed on the basis of the high standards set in the aerospace sector. »

Maier from the MTU Digital Team. Depending on the application involved, operators and fleet managers can access the data for their assignments and plan action accordingly.

Apps as platforms for MTU systems

'MTU Go! Manage' is a presentation platform for operating data for MTU products. It primarily targets users such as fleet managers, operators and MTU service personnel, and can be accessed online with terminal devices like laptops and tablets. By analyzing specifically selected data, users are then able to improve plant operation, process fault messages, plan maintenance schedules well in advance and monitor the health of their fleets. Based on the expectations and needs of numerous customers, MTU's digital development engineers have specifically designed data presentation to match customer applications. For example, ferry fleet operators can see exactly where their vessels are located and how many hours of operation the engines have logged up. Genset operators can use the platform to check total output from their units at any given time and find out what the daily power load on the gensets is. Until now, fleet managers could get this data only by asking operating staff to log it manually. They then had to manually compare the information with maintenance schedules. 'MTU Go! Manage' frees up fleet managers by taking that workload off their shoulders.

'MTU Go! Act' is a native app for smartphones. That means it works without an Internet connection – in the engine room of a ship, for example. It alerts the customer's operating personnel to issues occurring on plant facilities and helps them to quickly verify and clear them. Additionally, any issues and relevant information can be reported to the fleet manager for collation at a single location. That simplifies communication between operating staff and fleet managers as well as accelerating incident identification and clearance.

MEMO

Hitachi demonstrates confidence in digitally supported service from MTU

Rolls-Royce Power Systems is currently supplying a total of 360 MTU PowerPacks for 122 Hitachi trains for the British International Express Program. Under the terms of a ValueCare Agreement, MTU guarantees the availability of these drive units for the next 27.5 years. The PowerPacks are equipped with dataloggers that allow MTU and train manufacturer Hitachi to jointly monitor the performance of the engines. Teams from MTU UK maintain and service the PowerPacks in Hitachi depots using current sensor data in order to prevent unscheduled downtime.

"These new products are a whole lot more than just remote fault reporting systems. They safeguard communication between operators, service staff and specialists, consolidate information at a single location and help customers and our company to optimize product operation," emphasized Jürgen Winterholler, who heads MTU's Digital Solutions section.

Customer Care Centers for rapid solutions

The data collected is not only invaluable for customers. MTU experts and network partners can also access and analyze them in order to provide additional customer support. For example, MTU service staff can efficiently plan preventive maintenance schedules and adapt maintenance intervals in order to further guarantee the reliability and availability of engines and systems. And if an issue should nevertheless arise, MTU experts at three Customer Care Centers are ready to provide rapid-response solutions. These Customer Care Centers have specialists from Sales, Service, Quality, Development, Applications and Logistics who can work together to solve the customers' concerns as fast as possible. The Customer Care Center teams are located in different global time zones in Friedrichshafen, Novi and Singapore, so they are always available 24/7 on a 'follow-the-sun' basis. At the same time, fault and feedback reports are analyzed and evaluated by quality specialists who pass the results on to the Product Development section.

"Along with our digital solutions, the new maintenance contracts and global Customer Care Centers are permanently transforming our service capabilities. There is a world of difference between yesterday's service structures and the new ones we offer today. Our customers are reaping the benefits," said MTU's Director of Global Customer Service, Jörn Lindstädt.

Words: Lucie Maluck
Pictures: Isobar, Klaus Schmieder

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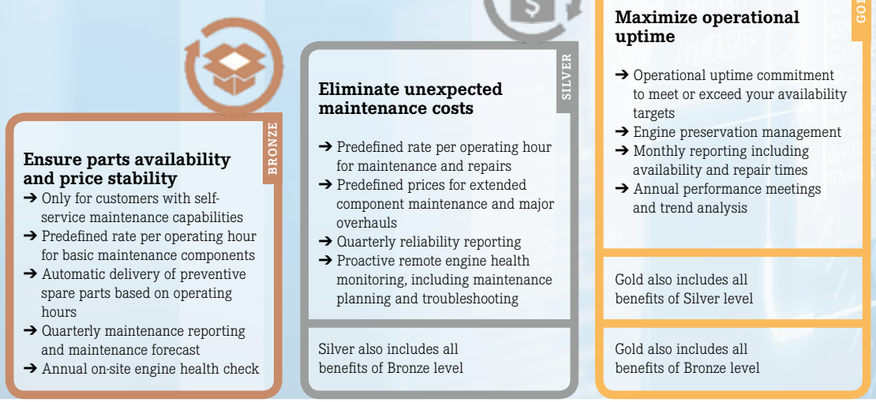

Mark Kugel founded a startup before joining MTU with the aim of introducing the startup mentality to the company.

The new offices reflect a new approach to working: Workspaces are open and furniture is mobile. There are no fixed desks, but plenty of opportunities to visualize concepts.

Our start-up

Brightly-colored stools for workstations, writable walls, Post-it Notes on the windows and a cozy coffee kitchen in the middle of the room – definitely a creative working environment. And working creatively is what MTU's Digital Solutions Team is all about. Founded in April 2017, the team is no longer brand new, but for a company like MTU that was founded 109 years ago, the way it works is definitely novel: agile, with a horizontal organizational structure and a culture that makes mistakes in order to learn from them. Two of those involved in developing this new way of working are Mark Kugel (27) and Thomas Schladt (57).

"Entrepreneurship is like jumping off a cliff and building an airplane on the way down," said Mark Kugel. "You just have to take the plunge, soak up knowledge as fast as you can and hit the ground running." It was this approach that Kugel hoped to introduce in the company when he joined the Digital Solutions team at MTU in summer 2017. As a successful startup founder he knows what he is talking about. His first encounter with the startup spirit came in a postgraduate course on digital entrepreneurship, where he learned how to transform a raw concept into a marketable product in the shortest possible time. Together with two colleagues he founded his own company 'useley GmbH', that provided an online platform where users could hire products like cameras, drills or drones from third parties. "We went through the entire startup learning curve. With all the highs and definitely with plenty of lows," Kugel recalled. He had to find investors and coworkers – and he had to learn how to take lots of knocks. Along with his co-founders, he invested blood, sweat and tears as well as a great deal of time in the project, but the enthusiasm is still clearly there when he recounts his experiences. He radiates the feeling that he lives for his job and identifies completely with what he does.

«START-UPS ARE NOT JUST COOL, FANCY AND FUN. BY THE SAME TOKEN, NOT EVERYTHING IN A COMPANY IS SIMPLY BORING, STRUCTURED AND HIERARCHICAL.»

MARK KUGEL,
MTU DIGITAL SOLUTIONS

Still open-minded and inquisitive 30 years on

At first glance, Thomas Schladt seems to have very little to do with startups. After graduating from the Technical University in Darmstadt, he began his career at MTU – and he has remained there right up to the present. Although he has had no experience at other companies, he has always been open to new challenges. In 30 years at the company he has had eight different jobs, the last of which was in Controlling. Nevertheless, true to form, he decided he wanted to do something completely new before retiring – something that would make a difference. "Even after 30 years of professional experience, I still think it is important to stay open and inquisitive," he declared. So now he is responsible for data management in the Digital team, i.e. for making sure all the data needed is available. "What annoyed me most at first was not having a fixed place to work from," he smiled, recalling the switch to his new team. No one in the Digital team has his/her own desk. People work where they can work best at any given time whether it is on the sofa, at the counter in the kitchen or at a desk.

Visualizing concepts is one way of working in the Digital Solutions team at MTU.

Agile working for rapid results
After selling ‘useley GmbH’ Kugel joined MTU, intent on putting his ideas into practice on a global scale as soon as possible. The aim of the Digital Solutions section is to develop digital products and services for customers. “We want to use digital tools to strengthen our links with our customers so we can provide much more effective service support,” said Kugel. “If we can effectively analyze our customers’ data, we can enhance the product development process and improve the quality of our products even more,” added Thomas Schladt, outlining another major benefit of digitalization.

The team currently has around 40 members, and that number could increase to as many as 70. The way they work resembles a startup company: fast, agile and customer-oriented. However, agile working does not mean noting the customer’s requirements and then disappearing into the cellar for six years before emerging with a finished product. “We hold intensive discussions with our customers because we need to understand what they actually need,” explained Kugel. During a series of ‘sprint’ phases usually lasting for a defined period of a few weeks, the team then creates a prototype relatively quickly before gathering feedback from the customer once more. The actual product development process does not start until a number of feedback loops have been completed to verify whether the product concept created really matches the customer’s needs.

Based on this approach, the team has developed digital products like ‘MTU Go! Act’ and ‘MTU Go! Manage’. These facilitate and safeguard communication between the operator of an MTU product, the MTU service organization and the MTU specialist. They also collate the data collected at a single location and help both the customer and our company to operate products more effectively.

«IF YOU’RE NOT EMBARRASSED BY THE FIRST VERSION OF YOUR PRODUCT, YOU’VE LAUNCHED TOO LATE.»
REID HOFFMAN, CO-FOUNDER OF LINKEDIN.

Agility is not a universal panacea
“Our people here have an extremely positive mindset. Everyone is out to change something,” said Kugel, describing motivation within the group. The teams form themselves depending on the task in hand and the few hierarchies that exist are horizontal. “That doesn’t mean that agility can solve everything,” he acknowledged. For example, it would not be possible to completely develop a new energy system just in ‘sprints’. Nevertheless, the rapid feedback involved is especially useful for digital products. Once a design has been developed, the next task is to get all the other departments in the company involved, because the team needs the expertise available in the other specialist departments to develop the actual product. “We have an infrastructure that has grown up over decades. The big challenge is to harness it effectively,” said Schladt. Considering how infectious the enthusiasm of these two digitalists is, that should not prove too difficult.

Words Miriam Jesenik
Pictures: Robert Hack

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Thomas Schladt has been at MTU for 30 years. He wanted to do something new again before retiring, and is now a data manager in MTU’s Digital Solutions team.

The Dragon rides the rails

Mention transport technology capable of transforming entire countries, and people immediately think of artificial intelligence, flying taxis and driverless cars, not locomotives, freight cars, sheet metal and steel. But that is exactly what China is also exporting. And by doing so, the Middle Kingdom is getting the economy on track in countries like Argentina, South Africa and Madagascar.

The Dragon rides the rails: China's rise as a global rail technology player.

Orders for rail technology from Australia (left) and New Zealand (right) marked a breakthrough in the western marketplace for Chinese manufacturer CRRC.

Chinese rail company CRRC has supplied freight locomotives to Argentina since 2016. Locomotives from China have been in service in Madagascar for 10 years (photo, left).

MTU HAS ALREADY SOLD **500 ENGINES** TO **CRRC.**

When China and MTU started out in Madagascar, there was a single working locomotive and a ramshackle rail system to work with. In 2008, the local operator Marda Rail received five locomotives for its modernization program and delivery of the Chinese locomotives marked a turning point for the African island nation. According to the World Bank that assisted with financial arrangements, the project played a major role in revitalizing freight transport.

China has already completed its own rail modernization program. Today, the country has around 124,000 kilometers of track and the world's biggest express network. The Chinese market is saturated, and the country is now exporting its modern rail technology. China Railway Rolling Stock Corporation (CRRC) is the biggest rail company in the world – half as big again as the combined rail divisions of its competitors Alstom, Bombardier and Siemens. In 2015, this huge concern earned around 11% of its €32 billion revenues from foreign transactions. Its customers are located right around the globe, from New Zealand to Madagascar, South Africa and Argentina.

CHINA PLANS TO INVEST **$1,000 BILLION** IN THE **"NEW SILK ROAD"** PROJECT.

And cooperation with the Chinese state is excellent: CRRC delivers the equipment, and the state supports customers financially by making favorable credit available.

Investment in Argentina

Argentina is a case in point. At one time, the country's rail system ranked among the world's best and the breathtaking classical-style Retiro Station in Buenos Aires still provides a reminder of that era. But by the start of the 21st century, the once-famous rail network had deteriorated to the point where trains were limited to 5 kph over wide areas. In 2010, the Argentine government announced a rail rejuvenation program – with assistance from China. The Middle Kingdom made $10 billion of low-interest credit available over a 19-year period for various projects.

The Argentine government invested the funds in trains from China, and in 2013, CNR Corporation, a predecessor of CRRC, delivered 20 locomotives for Argentina's passenger trains. At the same time, the state-owned construction and engineering concern China Machinery and Engineering Corp (CMEC) took on a contract worth $2.4 billion to commence work on repairing almost 5,000 kilometers of track on the Belgrano freight rail system in northern Argentina. During the course of the project CMEC increased the finance involved by a further $2.4 billion as part of a contract that also covered the supply of 100 new diesel locomotives from CRRC. The entire fleet, powered by 2,200 kW engines from MTU, will be in service by mid-2018 and modernization of the Belgrano routes will be completed in 2019. That means a huge boost for Argentina's agriculture sector. Currently, 96% of cereal crops transported within the country are carried by truck. Rail transport is almost four times more energy-efficient and is therefore much cheaper.

MEMO

Cooperation: MTU and CRRC

At the end of 2017, MTU and CRRC further consolidated their successful cooperation by signing a strategic partnership agreement. The document confirms that in future CRRC will continue to consider MTU engines as drive solutions for diesel railcars and locomotives. The two companies also expressed their intention to work jointly on future drive solutions such as hybrid drives and gas engines. Over recent years, CRRC has already placed orders for 500 MTU Series 4000 engines. "An MTU engine costs CRRC more than an engine from the competition," said Tony Chan who heads engine sales for China at MTU. "But the MTU engine is lighter and smaller it uses less fuel. And the customers are full of praise for the quality of our customer service," he added.

Trains for industrial transformation

CRRC's first customer west of China was the New Zealand rail operator KiwiRail. During the 1980s, New Zealand set out on the path from an agriculture-based structure to a modern market economy. Alongside tourism, the export of milk, timber and other products like goat meat, lamb and butter played a significant role. For its transport system, the island state in the Pacific opted for a 10-year plan to modernize its ailing rail network. In 2009, KiwiRail purchased 20 diesel locomotives from CRRC predecessor CNR Dalian. Follow-up orders in 2013, 2015 and 2017 increased the number of vehicles ordered to 63, and with new trains in service, in 2016 KiwiRail was able to transport in excess of 100 million tons of freight.

China's breakthrough in the western marketplace

Shortly after the conclusion of the first contract with KiwiRail, Chinese manufacturer CSR Ziyang, a CRRC subsidiary, won an order worth around €12.7 million to supply trains to Australian company SCT Logistics. Powered by 20-cylinder MTU Series 4000 engines each delivering 3,000 kW, these trains have been in service hauling heavy freight and ore in Australia since 2012. For CRRC, this order represented the definitive breakthrough in the western marketplace and it was followed by further rail contracts with various Australian operators like Bradken, Pacific National and Qube.

The new 'Silk Road': China to Europe by rail

And Chinese 'Rail Mania' continues to flourish. With its 'New Silk Road' project, Beijing has launched a logistics initiative costing billions and intended to create giant new railroads linking China with Europe. By investing in a range of construction projects involving highways, rail tracks, pipelines, power plants, telecommunications networks, harbors and airports, China plans to connect the land and water masses of Europe and Asia. An 11,000-kilometer rail link already connects the Chinese city of Chongqing with the German logistics center in Duisburg, where 25 trains from China now arrive every week. The newly completed rail link costs only half as much as airfreight and is twice as fast as sea freight, making it ideal both for time-sensitive cargo like promotional goods and for high-end products like automobile parts and electronics.

Words: Lucie Maluck
Pictures: Shutterstock, MTU Archive

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3,700 TRAINS CURRENTLY COVER THE ROUTE FROM **CHINA** TO **EUROPE.** BY **2020,** THE NUMBER WILL RISE TO **5,000.**

The Chinese Dragon is expected to maintain its momentum. China's 'New Silk Road' project underlines the country's aspiration to rail technology leadership.

Read a report on rail transport in Argentina at: **www.mtureport.de/Argentina**

At home in the engine room

Chief field-service technician Selahattin Tiryaki (left) in the engine room aboard the ferry 'Al Riyadh' with Marco Saliba from service dealer Melita, Malta.

Selahattin Tiryaki in discussion in the workshop.

Whether he is working in the engine room of a fast ferry or a megayacht, in a locomotive or on a genset, chief field-service technician Selahattin Tiryaki is equally at home. In the age of globalization, the 37-year-old (married with two children) is a modern-day working nomad who has been jetting around the world from job to job for the last 15 years. In his view: "There couldn't be a more varied job." Nevertheless, it is a task that demands immense resilience and flexibility – both from him and from his family.

He is often the first to arrive at work in the morning and the last to leave at night. And that work could take him anywhere – to Sydney, Usedom or Cape Town, to a hotel, a customer's workshop or the engine room of a ship. Known to his coworkers as Sella, Tiryaki learned his trade from scratch and has an expert command of all the major MTU maintenance operations from simple repairs through to the most complex maintenance levels (QL4). And, for him, the icing on the professional cake is that his position as 'site supervisor' allows him to build close, working relations with customers and their staff.

Every assignment is different

Unlike technicians who assemble engines at the production facilities and specialize in individual sub-assemblies, field-service technicians deal with the engine as a complete system. They have to dismantle, inspect, exchange and rework parts and then reassemble them and test the engine before handover to the customer. They are just as familiar with the complex interplay between mechanical and electronic elements as they are with the internal workings of the various sub-assemblies that make up the cooling, lubrication and fuel systems. "Out in the field is where you learn most," Tiryaki says. "Every assignment is different and each job makes different demands on individuals and teams alike. That's how teams are built." During his career, Sella has worked on lots of smaller 'sites' both at home and abroad, but his focus gradually concentrated more and more on propulsion systems on large ferries and naval vessels with multi-engine plants, and in particular, on Series 8000 engines. That included service assignments on some of the world's biggest and most glamorous megayachts.

Assignment planning meeting in Egypt.

The laptop: Mobile reference source for all types of engine data.

In 2010, he experienced one of the key events of his professional career when an assignment took him aboard the 126-meter fast trimaran ferry, the 'Benchijigua Express' in the Canaries. A long-term service contract with the vessel's operator presented the chance to spend several years based on La Palma, and this was where he became a chief field-service technician and site supervisor. This year also saw him working on a Series 8000 assignment – this time aboard an 88-meter Egyptian fast ferry, the 'Al Riyadh', operating between Egypt and Saudi Arabia. The job involved a total of 18 service technicians and the overhaul of four Series 8000 engines.

Projects like this go far beyond routine filter changes, and they are possible only with perfectly coordinated teams. Sella is part of a field service unit that specializes in exactly this type of assignment. The team of 110 highly qualified service technicians is permanently engaged on a number of different major projects, jetting out as 'flying doctors' from their base in Friedrichshafen

In March 2018, a team of service technicians overhauled the Egyptian fast ferry 'Al Riyadh'.

Hans Fairhurst / Marinetraffic.com

to locations around the world. No one gets closer to the customer than that – and it is just how Sella likes it.

Work and family – how do you cope?

The two most important things in this chief technician's life are his job and his family, and he candidly admits: "Combining the two is not easy." Coming home after a long period away is always a cause for great celebration. Sella: "When I'm back in Germany on the A81 autobahn from Stuttgart and catch sight of Lake Constance again for the first time, my heart beats faster and I think: Soon be home again!" That is when the family is really able to appreciate what being together actually means.

But despite all that, he would still find it a little difficult to stay at home indefinitely. When it comes to successfully reconciling job satisfaction and family bliss, Sella and his wife do not see the stereotype regular daily routine as essential. When they met 13 years ago, Gülsüm was the youngest branch manager working for a German supermarket chain and had already carved out a solid position in life. For her too, having the family as the sole focus of existence would not have been enough. Nevertheless, the six years they spent on La Palma were "Heaven-sent – for the whole family." It gave Sella the opportunity to live together with his family and work on the 'Benchijigua Express' at the same time. Now five years old, the couple's son, Melih Halim, was born on La Palma where he learned to speak Spanish without an accent and got to know every nook and cranny of the 'Benchijigua Express'. He was four when the family returned to Germany and was amazed to discover that MTU existed in Friedrichshafen as well as in the Canaries. Now, he speaks Spanish, German and Turkish, just like his eight-year-old sister Tusem. But what will happen as the children grow up and the challenges of family life grow with them? Sella still finds it hard to confront such issues, but he can be confident that his employer is supportive of flexible solutions that would allow him to work at home more often.

Sella has obviously been fortunate. A German of Turkish extraction, he grew up in the idyllic holiday location of Eriskirch on Lake Constance. Highly talented, both technically and mathematically, he first attended the Technical College for Electronics in Tettnang before completing an apprenticeship in industrial electronics at MTU in Friedrichshafen. It was not long before his ambition to work directly on-site with customers as a field-service technician took root.

Not everyone's cup of tea

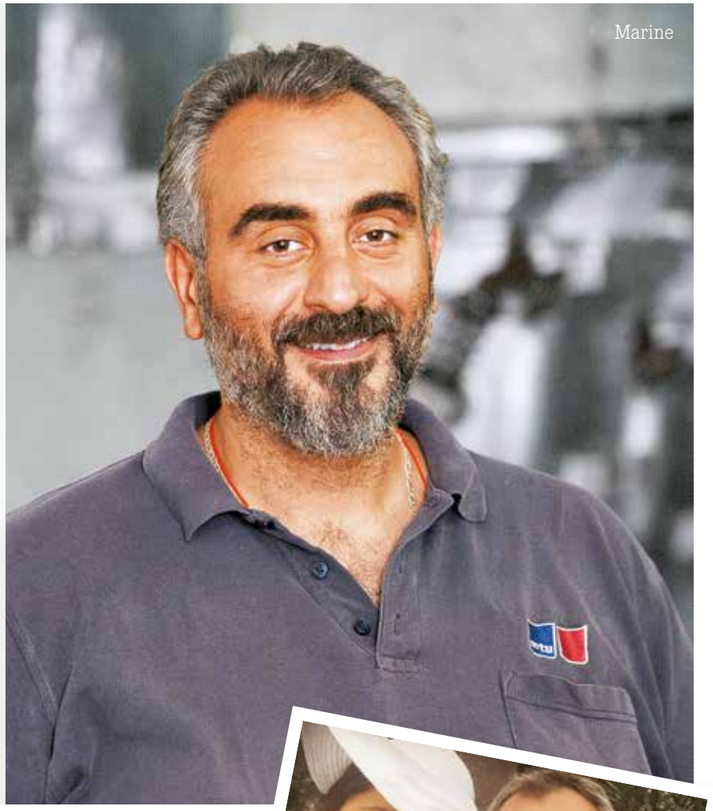
Since then, he has had 15 years of professional experience. And his opinion so far? "You couldn't find a more varied job. But it's not everyone's cup of tea." The five-week service assignment on the twin-hulled Egyptian fast ferry 'Al Riyadh' in March and April of this year, for example, was particularly long and taxing. Four 20V Series 8000 engines had to be overhauled. Whilst thousands of tourists from around the world enjoyed diving and beach vacations on the Red Sea, the 18 service technicians were constantly traveling the 30 kilometers between their hotel and the vessel's berth – working a 2-shift rotation from 08:00h to 20:00h and 20:00h to 08:00h, six days a week with a single day off on Fridays. A noisy power generator was in non-stop operation in one of the engine rooms, so that work was possible only wearing ear protectors.

In tandem with its sister ship the 'Alkahera', the 88-meter fast ferry has been plying the Red Sea route between Safaga in Egypt and Saudi Arabia for ten years, carrying a quarter of a million passengers a year. "In all those years, not a single trip was canceled due to propulsion issues," stressed Mohamed Ismail Saad, Technical Manager at state-owned operator Alkahera. This high-level availability is due in large part to the MTU Service Organization with Maltese MTU Service Dealer Melita, supported as necessary by service technicians from Friedrichshafen.

Quality has many facets

As always, in his role as 'site supervisor', chief field-service technician Sella was responsible for running the lines of communication between customer, coworkers, service dealers, company HQ and the spare parts center. In effect, that meant an email or phone-call every five minutes, several meetings with the customer's technical manager every day and constant discussions with coworkers on-site. Every day brings fresh surprises, and when others have long since thrown in the towel, Sella is still able to keep his cool and carry on. He calmly explains: "The unexpected happens because every engine is subject to quite specific operating conditions like climate, length of time in operation, skippers' individual styles, maximum acceleration and duty cycles and so on." That is why wear parts are subject to different load rates and why it is not always clear whether a component should be exchanged or can be reworked on-site. Where there is doubt, signs of wear and other changes in surface condition are analyzed in the company's lab in Friedrichshafen, where they can be assessed by development engineers.

Quality also involves assigning the right person to the right task. Different jobs need to be allocated to different technicians with great care. "Some people prefer direct hands-on assignments. Others have organizational skills," Sella says. Basically, Sella sees himself less as someone who is there only to give orders and more as one of the team: "We often decide things together." Relations with the customer are also part of the multi-faceted quality issue. In Egypt, Sella was in daily contact with Technical Manager Mohamed Ismail Saad and Safety Manager Nabil Nada. "We need to know exactly which standards have been specified by our customers and the relevant authorities – and the customer needs to be informed



The field-service specialist has been jetting around the world for 15 years.

Family photo: Traditional 'Los Indianosa' carnival in La Palma.

about our routines," he says. Talking to customers is one of Sella's great strengths and he was able to explain why: His father's delicatessen in Friedrichshafen was "the most important key experience of his childhood" and at the age of 13 he worked in the store selling spices and groceries. "That's where I learned that there is nothing better than providing satisfaction and making a customer happy," he says. "And that still holds true today."

Words: Wolfgang Stolba; Pictures: Robert Hack

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BREWING GROWS WITH THE FLOW

Every year, the Oettinger brewing group produces around 9.3 million hectoliters (1.8 billion bottles) of beer at its four locations in Germany. The process is intensively automated and employs a highly efficient energy management concept.

During brewing, the wort is produced by mashing barley malt and wheat malt.

No one passing through the picturesque town of Oettingen can fail to notice that beer brewing is a major activity here.

Visitors to the Bavarian community of Oettingen (population 5,000) can hardly fail to notice the Oettinger facilities. The town is home to the company's headquarters and it is hard to overlook the fact. Approaching the town from the west, the first thing you see is a traffic circle displaying a copper brewing kettle. Coming from the south, you get a clear picture of the new brewery facility with its giant fermenting vats and from the east, the view is of the old brewery. Even underground, you could hardly miss Oettinger because the company runs a subterranean beer pipeline from the brewing plant in the north to the bottling plant in the south.

OETTINGER PRODUCES APPROXIMATELY **9.3 MILLION HECTOLITERS OF BEER** AT ITS FOUR LOCATIONS.

The brewery seems able to effortlessly reconcile apparent contradictions. It is both a family-run business and large-scale company. It combines ultramodern, automated production with tradition. It places great value on environmental awareness as well as pursuing attractive pricing policies.

Technical Director Ludwig Metz heads the brewing facilities at the Oettinger HQ. Originally from the German region of Franconia, Metz has been with the company for 28 years. It is where he learned his craft as master brewer and he even remembers working there with traditional copper brewing vats. Since 1991, he has watched the brewery gradually expand into a major company and pursued his own successful career path to become Technical Director. He knows the company like the back of his hand and it is not hard to imagine him in rubber boots and apron standing at a copper vat and inspecting the brew in the mash tun. "The only place we still brew like that today is at our traditional family location, the Forstquell Brewery in Fürnheim," explained Metz. Everything at Oettingen and the other locations in Brunswick, Gotha and Mönchengladbach is highly automated.

At the new, state-of-the-art brewing plants, the only indication that beer is being brewed is the aroma of the simmering wort. Virtually nothing else remains to be seen of the process. Four huge stainless steel vats have been erected in the southern brewing plant that was constructed in 2002. "We start ten 1,000-hectoliter batches here every day," explained Metz. The contents of the vats, whether malt mash or hops boiling in the wort, are now only visible through a small inspection port. Shiny stainless steel vats and pipelines are everywhere. This where the industrial production facility shows itself from its most modern side. Operating staff are few and far between. "We have two brewing assistants and a master brewer on duty in the brewery round the clock. That is all the staff we need here," added Metz. And this operating crew oversees everything including plant technology systems such as the combined heat and power (CHP) module from MTU Onsite Energy and the absorption chilling plant.

A brew is born

Trucks deliver malt to the breweries where it is stored in silos until it is needed for processing. Unseen by any observer, the malt is ground in the malt-mill before being fed through pipelines to the mash tun and mixed with water to create the actual mash. As it is heated in consecutive stages, the mash releases its vital ingredients to determine the character of the beer to be produced – dark or light or with a stronger flavor. "It's not just the quality of the malt that is critical here. Water quality is also crucial," explained Metz. The mashing process takes around two hours. The brew then flows to the lauter tun where the solids from the malt are separated from the liquor. The remaining spent grain or 'draff' is drawn off through pipelines and at this point, visitors can catch a rare glimpse of the process as the draff is loaded onto trucks to be used in agricultural animal fodder or to produce bread or distillery products. The remaining wort flows through other stainless steel lines to the wort copper where it is mixed with hops and boiled for around an hour and a half. The brew is then cooled in the wort cooler before yeast is added and alcohol forms in the fermentation tank. When its work is done, the yeast is extracted and the beer is left to rest in a storage vat before the final stage in the process decides whether the beer is to be filtered to

Technical Director Ludwig Metz heads the Oettinger brewing facilities.

Beer brewing is a modern industrial process: The brewing process in the copper vats is computer-controlled and each temperature change is precisely programmed.

WITH ITS **TWO CHP PLANTS** IN OETTINGEN AND MÖNCHENGLADBACH, OETTINGER SAVES **7,800 TONS CO_2 A YEAR.**

Oettinger produces 1.8 billion bottles of beer every year.

EVERY YEAR, THE TWO CHP PLANTS GENERATE AROUND **26 MILLION KWH OF ELECTRICITY** FOR BOTH LOCATIONS.

Two combined heat and power (CHP) plants from MTU Onsite Energy generate the power needed for brewing beer.

Oettinger brews 26 different types of beer.

produce pilsener-type products or clear, light beer types. For naturally cloudy beers, the filtration process is bypassed and the product is directly bottled or filled into kegs in the filling plant.

IT TAKES **300-400 LITERS OF WATER** TO PRODUCE **100 LITERS OF BEER.**

Background processes keep things flowing

Brewing is an energy-intensive business. 300-400 liters of water are needed to produce just 100 liters of beer. Generating the necessary electricity, heat and cooling power also generates costs and negatively influences the environment. Oettinger investigated a range of possibilities to ensure its operations run at maximum efficiency and decided that the best solution was a combined heat and power (CHP) plant with an absorption chilling unit. “At our company we set great store by regional identity and brand awareness. That is why we commissioned a firm of consulting engineers from this area and why we opted for a top-brand CHP solution from MTU Onsite Energy in Augsburg using engines that are built in the region,” declared Metz. The ‘Moroschan’ engineering consultancy designed the facilities for the Oettingen location as well as for the brewery in Mönchengladbach and stipulated 5,000 hours of CHP plant operation a year. Downtime was to be scheduled outside brewing operations and 100% of the power generated was to be available for use by the relevant production facility. On this basis, the choice went in favor of an MTU 16V 4000 gas engine delivering 2,000 kW of electrical energy. Oettinger utilizes thermal energy discharged from the engine to heat the brewing water and in Oettingen, the exhaust is used to generate steam. “In Mönchengladbach we use the exhaust to heat water for the mash house,” explained Metz. In Oettingen, the engine’s thermal base load is sufficient to run an absorption chiller unit for cooling the storage tanks, for example. The absorption chiller unit alone accounts for 20% of requirements. Nevertheless, the natural gas CHP module is not the sole element in the company’s cogeneration concept. Beer production and the filling equipment needed to wash bottles and kegs use a lot of water and Oettinger cleans that water in its own two-stage treatment plant. In Oettingen, the biogas generated in the treatment plant is used to fuel the boiler house, for example, and is thus also utilized in the heating process.

Whether they are light lager-type beers, shandies and soda/beer mixes, wheat beers or naturally cloudy German-style Kellerbier, all of the brews produced are bottled or filled into kegs in the company’s own filling plants for distribution. “We deliver our products direct to trade outlets and that helps keep prices down,” said Metz. Oettinger also operates its own logistics service. Around 70 company-owned trucks leave Oettingen every day headed for the A6 autobahn. Of course, their route takes them past the traffic circle with the copper brewing kettle that once played its own role in the history of the company.

Words: Katrin Auernhammer
Pictures: Robert Hack, Oettinger

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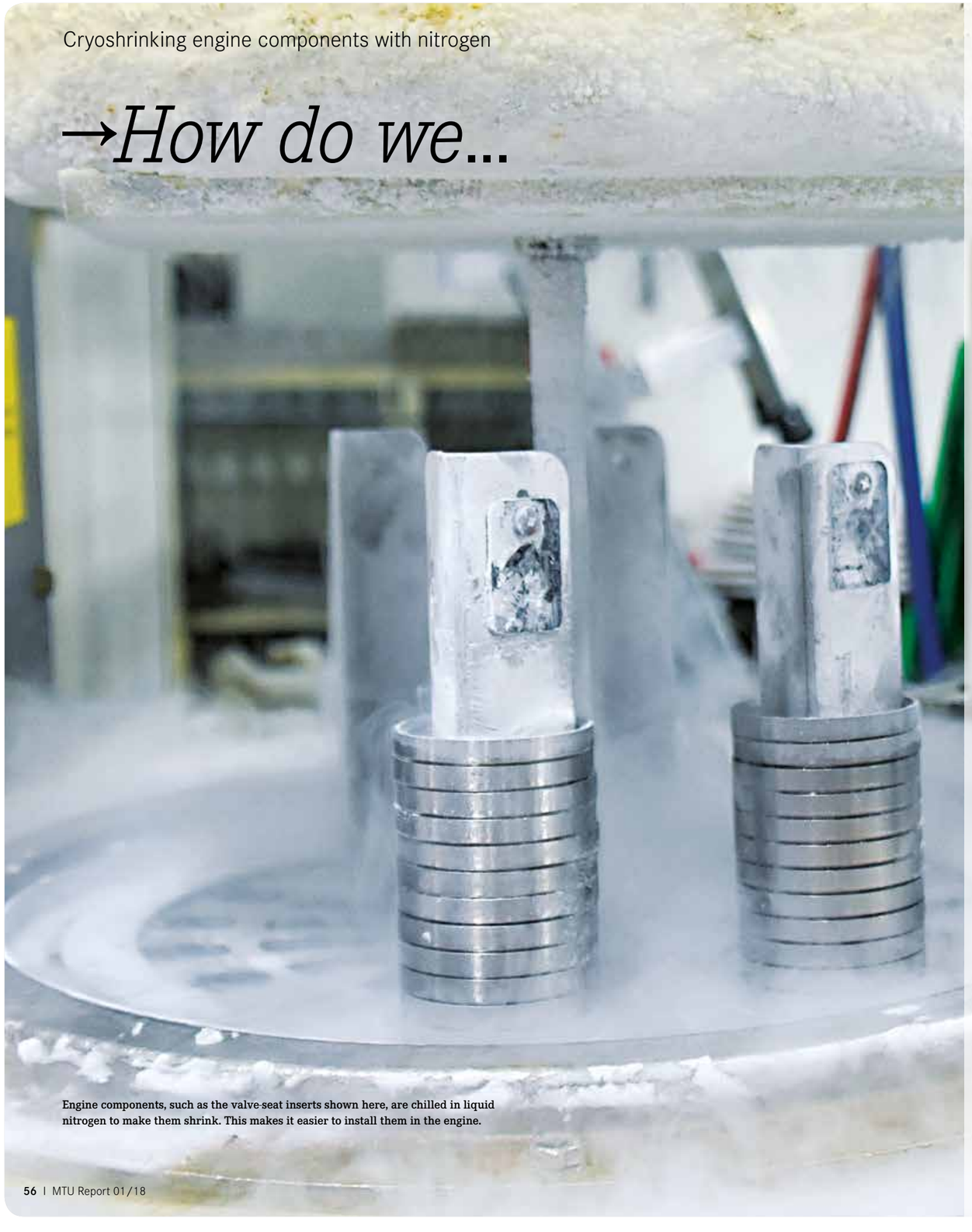
→*How do we...*

...make parts smaller?



Engine components, such as the valve-seat inserts shown here, are chilled in liquid nitrogen to make them shrink. This makes it easier to install them in the engine.

In Alice in Wonderland, Alice was much too big to fit through the tiny door that led to the Queen of Hearts' garden. Thanks to a bottle labeled "Drink Me," she shrank down to 10 inches in size and continued her adventures. Here in the real world, when machinists want to shrink an engine part, they don't have magical potions at their disposal. However, they do have a few tricks up their sleeves to get the job done.

The process of machining is defined as forming and cutting a piece of metal into a desired shape and size by machine tools. Travis Blystone, Machining Supervisor at the MTU Aiken Plant, likens the facility's machine shop to a butcher's shop. "A butcher takes a whole beef loin and makes tenderloins, T-bones, all sorts of different cuts. In machining, we start with a raw casting. Then we meticulously cut away the unwanted material—the fat and trimmings. The end product is lean, clean and high-quality," says Blystone.

Machining and assembly require strict attention to detail. Incorrect dimensions can lead to big problems. Every part must be perfectly snug. On the cylinder head and cubical part assembly line at Aiken, valve guides, valve seats and bearings must be "press fit" into their corresponding mating parts. Extreme cooling with liquid nitrogen ensures the perfect fit quickly and efficiently.

Here's a quick physics lesson: When temperatures are cold, the kinetic energy of a solid object is decreased, causing atoms to take up less space. As a result, the material contracts in size. Machinists use this principle to join parts every day. At the MTU Aiken Plant, the technique is utilized to assemble components for Series 2000, Series 4000 and Series 883 engines. For example, on Aiken's cubical part assembly line, when a bearing is set into a portable tank of liquid nitrogen, it can reach a temperature of -320°F (-196°C) in less than 5 minutes. The bearing can shrink more than 100 microns in size.

This reduction in size enables a machinist to place it into the flywheel housing quickly and easily. "They will pick up the bearing with an installation tool that lines it up, and drop it into the part," says Blystone. "When it comes up to room temperature, the bearing expands larger than the hole, so it makes a tight fit. If you need to get the bearing out, you have to get a hydraulic ram and press it out, physically."

Ensuring strong connection is crucial to engine quality. Only after the part passes a close visual inspection can it move down the line. Any imperfection can lead to costly waste and production delays. "On the equipment rack, if we had a bearing that was a little bit loose, then pretty much the whole engine would have to be torn down," says Blystone. "If we had a valve guide or a valve seat that came out, you'd have a cylinder head failure. It's not good for the company, and definitely not good for the customer."

Words: Chuck Mahnken
Pictures: Amber Chafin

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The operative immerses a bearing bushing in a vessel filled with liquid nitrogen with the aid of a jig. The bearing bushing contracts when chilled...

...and can be inserted more easily in the equipment carrier where it then gradually expands.

Afterthoughts

Lucie Maluck and Robert Hack in their quest to find the right way to make electricity visual.

Visualizing electricity

Have you ever tried to express electricity in a visual? Neither had I, and if I'd known how tricky it is ... ah well, that probably wouldn't have made any difference. But at least I'd have been forewarned. Designing the front page and deciding the main theme is always the key to each edition of MTU Report. We soon discovered it was going to be a bit of a challenge this time, though. A bolt of lightning, we thought – but it was too threatening, too unpredictable. So we tried drawing an electrical circuit – yet it just didn't work somehow. Searching for inspiration, we popped into the electricians' workshop, where our photographer started making eyes at all the plugs and cables – but it wasn't exactly high-tech. You've no idea the sense of relief that washed over me when our graphic artist suggested simply 'drawing electricity', and our photographer/illustrator came up with the work of art that now graces the cover. It uses electrical waves and vibrations to symbolize how we electrify diesel engines into veritable powerhouses. And, sure enough, he couldn't resist putting in a small bolt of lightning for good measure. Thank you, Robert, for your patience and skill!

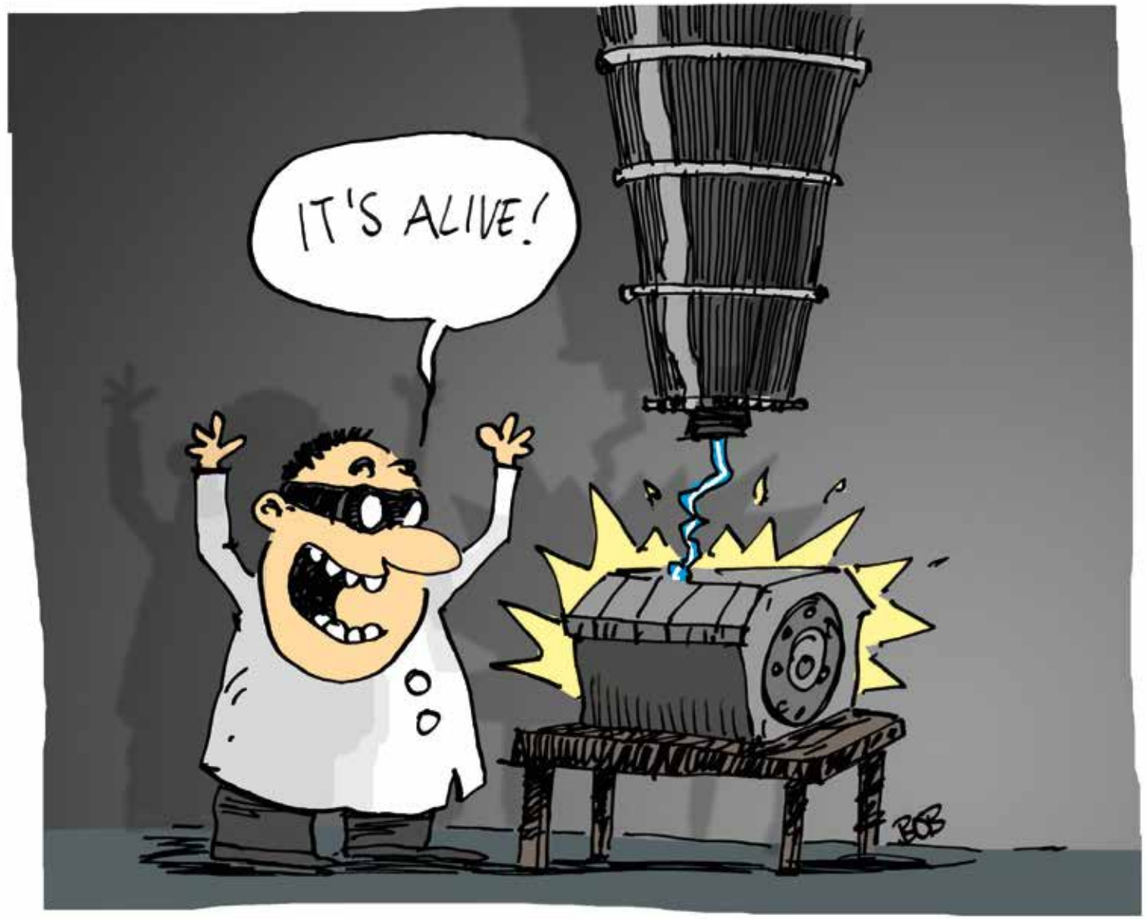
Wolfgang Stolba and Robert Hack visited Egypt – not on vacation, but on the job alongside our MTU service nomads.

Jealous? Think again!

While our colleagues in Friedrichshafen were using their lunch breaks in March to engage in a spot of ice-fishing on Lake Constance (the ultimate chill-out, I'm told), Robert and I flew off to the sunny climes of Egypt. Jealous? Well, admittedly we did have around half an hour on our first day to go to the beach and see the fiery sun sink into the horizon, smell the saltiness of the slumbering sea, and feel the waves of ancient legend and the distinctly comfortable coolness as night approaches on tiptoe. What a fabulous half hour it was .... Then ... Cut! The next three days were spent in the bowels of the fast ferry 'Al Riyadh' for 12 hours at a time plus 30-minute commuting transfers through the best dust the desert could throw at us. Alongside us in the vessel were colleagues from Service, coolly dismantling huge bits of Series 8000, conducting analysis and diagnostics, re-working the parts and re-assembling them with utmost precision. As we wiped the sweat from our brows, what impressed us most was not the legendary sun the tourists love, but the legendary skill of our colleagues.

Talking of...

...electrification



See pages 14 to 33 for more on the subject of electrification.

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