

The customer magazine of BorgWarner Turbo Systems



DREAM TEAM

*BorgWarner supplies turbochargers
for AMG V8 Biturbo engines*

10 years of gasoline VTG

From exclusive Porsche turbocharging systems to technology that covers a broad scope of applications

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Ready for testing!

The global testing network of Turbo Systems

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Dear readers,

We touched on the eBooster® in the last issue of TurboNews. The series launch of the world's first electric turbocharging system from BorgWarner is now just around the corner. With this issue, we therefore chose to provide a detailed examination of both the innovative technology employed and BorgWarner's innovation strategy. You can read about these in an interview with Dr. Hermann Breitbach (Vice President Global Engineering and Innovation) and Dr. Jürgen Adam (Business Director eBooster®).

Our article on Global Engineering Customer Services (GECS) focuses on innovations. The department is responsible for BorgWarner's global testing network and boasts test equipment that is unparalleled worldwide. This includes a bearing friction test bay, an impeller wheel test bay with electric drive that was developed in-house, as well as semi-anechoic chambers with an NVH cold-air test cell.

As for the latest turbocharging technologies, you can find a wide selection of BorgWarner solutions in this issue of our magazine. These range from waste gate turbochargers on the V8 biturbo engine in the Mercedes C63 AMG, through VTG turbochargers for gasoline engines, all the way up to the R2S system fitted in the Mercedes C 300 d 4MATIC, which recently set a new record time for diesel vehicles in the legendary Pikes Peak International Hill Climb in the US.



Günter Krämer
Director Marketing
BorgWarner

We hope you find the articles interesting and have fun reading. You can also find the online version of TurboNews at

www.turbos.bwauto.com/en/press/newsletter.aspx

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Reach for the sky

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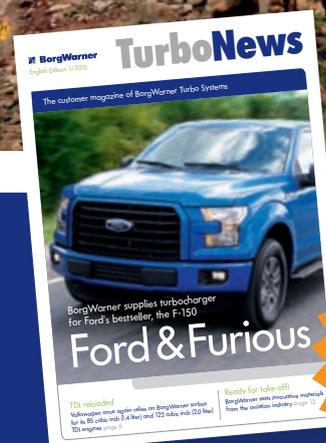
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Itatiba produces for Mercedes-Benz Actros

BorgWarner has been producing turbocharging systems for commercial vehicles in Brazil for 40 years. Additional capacities were recently established at the new Itatiba facility to produce S-Series turbochargers for Actros heavy-duty commercial vehicles from Mercedes-Benz. BorgWarner was presented with a Mercedes-Benz Brazil Supplier Award in the Innovation Technology category for the successful introduction of the turbo in the new Euro5 engines in South America.

Brazil transports most of its freight via road. However, the commercial vehicles used need to cope with extremely difficult road conditions and severe inclines. The turbochargers used in the vehicles need to be powerful and durable enough to handle both long-haul transport and construction applications. BorgWarner therefore equipped the S-Series turbochargers with forged and milled titanium impellers. These display better durability over impellers made of

aluminum during cyclical loads. Dual flow turbine casings, which can generate more power from the exhaust gas stream than single flow housings, ensure excellent response and fuel efficiency. With its local manufacturing operations in Itatiba, BorgWarner now supports the entire Euro5 range of engines that Mercedes-Benz produces in Brazil.



Big savings for small parts

Substantial savings are the fantastic result achieved by a team from the Tauber Institute at the University of Michigan in the US together with BorgWarner as project sponsor. The three-member team along with Stephan Altmeyer and Wolfgang Schneider from BorgWarner developed an intelligent solution to prevent small components from getting mixed up in turbocharger production operations.

They worked together to create new processes for the flow of materials and information associated with small parts. The problem they faced was that many components could not be efficiently tracked throughout the entire material flow. However, the new automated identification process has eliminated this problem. Since it now has excellent control over material flows, Turbo Systems can achieve important savings at all production locations and also increase its competitiveness.

The Tauber Institute is a joint venture between the University of Michigan and the College of Engineering, as well as 30 partners from the industry that provide the students with practical, real-world training. BorgWarner has collaborated with the Tauber Institute numerous times as one of these partners.



Scott Gallett, Vice President Marketing and Public Relations (on left) and Professor Fred Terry, Jr. from the Department of Electrical Engineering and Computer Science at the University of Michigan (on right) with the team from the Tauber Institute.

Congratulations! Fourth Safety Award for Oroszlány

Employees at the Oroszlány facility in Hungary set a shining example in terms of health and safety. Oroszlány is the first BorgWarner location to win the CEO's Safety Award for the fourth time in succession. The award was presented for reaching four million working hours without a reportable accident.



James R. Verrier, CEO at BorgWarner, took the opportunity to present the \$20,000 USD prize personally to the employees at the location during the celebration. The facility has decided to split the money and make equal donations to the fire service and outpatient clinic in Oroszlány, as well as the Benedek Elek Foundation, which looks after disabled children.



The team in Oroszlány during the distribution of the donations.



YS Yew, SCM Manager, Turbo run champion in PyongTaek (l.) and Michael Dougherty, GM Turbo, hand over the donation to JA Lee, Vice President of the Korean Incurable Disease Association (r.)

Generous and heartfelt donation

SeohanWarner Turbo Systems, joint venture partner of BorgWarner in PyongTaek, South Korea, initiated a fundraising campaign for children in need in the form of the TurboRun Charity Fund. Around \$44,000 USD was collected at the fundraising event held last year. This was then presented to a young patient with a rare type of leukemia on November 24, 2015 to help with her to continue her treatment.



Success story:

Ten years of Ningbo

BorgWarner's Ningbo facility has every reason to be proud: in 2015, the location in China celebrated its 10-year anniversary and also received its third CEO's Safety Award in succession. Numerous guests appeared for the celebrations, including customers, suppliers and political representatives.

The successful development of the facility speaks for itself, as it recorded a hundred-fold increase in sales revenue between 2005 and 2015. Staff numbers have also grown just as significantly. While it all began with only one product being produced for just one OEM on one production line, Ningbo today manufactures numerous products on new lines for 25 different customers. Since the Ningbo Engineering Center (NEC) was opened in 2011, products can also be refined, tested and validated on site. Employees of the NEC also support other BorgWarner locations in Asia. The CEO's Safety Award provided another reason to celebrate: in 2015, the facility received the award for reaching three million working hours without a reportable accident. Ningbo donated the prize money to two local elementary schools.

Kirchheimbolanden facility certified for high environmental standards

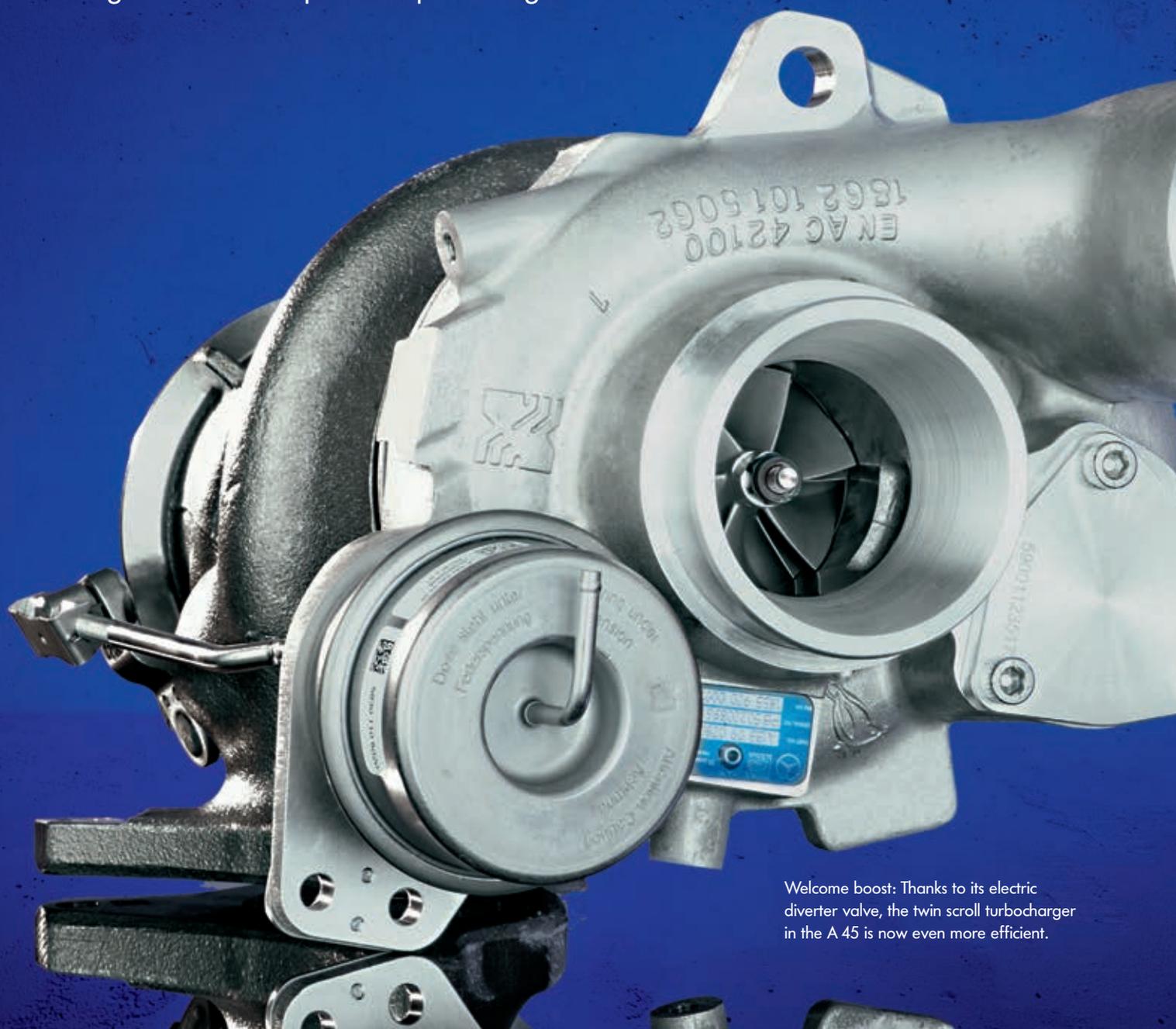
Reducing the consumption of both energy and resources represents an important component of BorgWarner's business operations. The company therefore also pursues a sustainable energy policy. The Turbo Systems facility in Kirchheimbolanden, Germany had its energy management system certified to ISO 50001:2011 at the end of 2015. The certificate applies to the areas of development, production and sales.

Back in 2013, management decided to implement an energy policy that would meet the strictest efficiency benchmarks and to commit to the standards as per ISO 50001. In 2014, an energy team was then tasked with driving forward implementation of the ISO standard and training all employees at the location. Thanks to the excellent work of the team and the great cooperation of all employees, it was possible to perform the certification audit as early as September 2015. The certification was then ultimately awarded on December 21. Even after receiving the certification, staff at the location are still keen to further improve efficiency at the facility. For example, a measuring point system for automated recording of energy consumption is to be introduced this year, and the company suggestion scheme is to be extended to include the topic of energy savings.



Dream team

BorgWarner has been supplying Mercedes' in-house tuner AMG with turbocharging systems for high-performance engines since 2001. While work initially focused on 12-cylinder engines fired by BorgWarner turbos, the 4-cylinder engine in the A 45 AMG also joined the party in 2014 and was then followed by the 8-cylinder unit in the C 63 one year later in 2015. Both of these drive units represent the absolute pinnacle in their respective segment and provide impressive evidence of what the developers at AMG and BorgWarner are capable of producing.



Welcome boost: Thanks to its electric diverter valve, the twin scroll turbocharger in the A 45 is now even more efficient.



Eight cylinders, 244 cubic inches (4 liters) of displacement and two B03 turbochargers: The new C 63 S from AMG offers all the power you will ever need.

Two-Time Engine of the Year

When AMG presented the sporty A-Class, its turbocharged engine outperformed even the most powerful supercars with an incredible power density of 3 hp per cubic inch of displacement (181 hp per liter). A BorgWarner twin scroll turbocharger delivers a maximum of 1.8 bar boost pressure to the four combustion chambers of the state-of-the-art engine. The amazing performance potential makes the AMG engine's standard fuel economy of 34 mpg US (41 mpg UK) and particularly low exhaust emissions all the more impressive. The reward for the ambitious work of the developers included an Engine of the Year Award in 2014 – followed by the same award the subsequent year.

With the facelift of the A-Class, AMG chose to revise the drive of the A 45, which is also available as the CLA 45 Coupé and CLA 45 Shooting Brake. Power increased from 355 hp (265 kW) to 375 hp (280 kW), while torque was up 18 lb-ft to 350 lb-ft (475 Nm). To this end, the engineers at BorgWarner modified the twin scroll turbocharger to include an electric diverter valve. This keeps the impeller wheel of the turbo spinning at high speeds even when the driver backs off the gas pedal, allowing full boost pressure to be available more quickly when the pedal is depressed again. The improvement in boost efficiency achieved in this way can be felt quite clearly through improved dynamic performance.

New V8 engines with biturbo

The completely new 8-cylinder engines from AMG, which celebrated their premiere in the 2015 Mercedes C 63 and C 63 S, are even more impressive. The power unit with the designation M177 is a V8 biturbo engine with a displacement of 244 cubic inches (4 liters) that delivers up to 503 hp (375 kW) and maxi-

mum torque of 516 lb-ft (700 Nm) in the Mercedes C 63 S. BorgWarner supplies two B03 MonoScroll waste gate turbochargers, which are identical on the left and right-hand side. In addition to reduced part diversity, this also reduces costs, which offers significant competitive advantages – particularly for small and medium production series. The turbocharging system went through BorgWarner's "Design for Value" process and, thanks to the highly motivated team at the Kirchheimbolanden location, it was possible to launch series production with a fault rate of zero ppm.

Another special characteristic of the M177 is the positioning of the turbos inside the hot space of the engine's V with wet sump lubrication. This places extremely tough demands on the temperature resistance of the B03 turbos. The two engines in the C 63 and C 63 S are largely identical to Mercedes' own M178 biturbos, which help the AMG GT and GT-S models achieve breathtaking performance. However, the M178 versions employ dry sump lubrication, which led to a rather unusual engine compartment design. To ensure optimum ventilation, the BorgWarner turbos were put on show – like a partially skeletonized Swiss watch.

Optimum values achieved in terms of fuel economy and emissions

As is always the case with AMG, the new C 63 and C 63 S models impress drivers with their incredible dynamic driving performance. However, the high-performance vehicles also boast low emissions and the best consumption figures in the segment. The latest model in the Mercedes AMG BlueDIRECT range of engines sets standards with its fuel economy (NEDC combined) of 28.5 mpg US (34.5 mpg UK) and thereby marks another milestone in the longstanding and successful collaboration between AMG and BorgWarner.

Excellent throttle response with better fuel economy and lower exhaust emissions: With the eBooster[®], BorgWarner has created an electric-driven turbocharging system that significantly improves the potential for combustion engines.

Dr. Hermann Breitbach, Vice President Global Engineering and Innovation and Dr. Jürgen Adam, Business Director eBooster[®], tell us more about the new turbocharging technology and the innovation strategy of the turbocharger pioneer in an interview.

“With the
to drive th

INNOVATING
FUTURE
MOBILITY



eBooster[®], we are continuing the engine downsizing trend."

Dr. Breitbach, you recently assumed the role of Vice President Global Engineering and Innovation. What are your duties?

Dr. Breitbach: I hold global responsibility both for our generic product development and for technical application development. I am also responsible for continuously filling our product pipeline with innovation. We develop our products generically up to application maturity, often working together with a small selection of key customers. After this, we regularly get a large number of customers on board in parallel for the application development phase of series production projects. Our new eBooster[®] is a good example of this. Two customers were involved in the generic development early on, which helped us transition the eBooster[®] to the application development phase quickly and now develop further series production projects with a good degree of product maturity.

On the topic of the eBooster[®]: What are the advantages of this turbocharging system and why is this the next important step for BorgWarner?

Dr. Breitbach: Electrification is playing an increasingly important part in motor vehicles. The electrical infrastructure is being expanded, thereby boosting the total electrical power available. This paves the way for our eBooster[®], which is an electric-driven turbocharging system that facilitates excellent drive response and efficiently eliminates turbo lag. With this development, we have been able to further advance the engine downsizing trend, which in turn offers important benefits with regard to fuel economy and exhaust emissions.

Dr. Adam, you are responsible for transitioning the eBooster[®] into series production. What is the greatest challenge here?



Dr. Jürgen Adam and Dr. Hermann Breitbach

Dr. Adam: The eBooster[®] is a mechatronic assembly that combines tough mechanics with complex electronics in a very compact space. This only works when both the mechanical and electrical components are developed to their full potential. To this end, the first task was to bring together experts that previously had little interaction with one another to create an efficient team. We therefore collaborated early on with colleagues from BorgWarner Emissions Systems in Ludwigsburg, where we now have a dedicated team with electronics expertise. This networking worked very well. Indeed, we were even presented with the BorgWarner Innovation Award in the Collaboration category for our efforts.

Is the idea behind the eBooster[®] completely new?

Dr. Breitbach: BorgWarner has been working on electrically supported turbocharging since around 2003, fueled by the desire to optimize throttle response. Back then, we were restricted by the limited performance of the on-board electrical system. However, on-board power supply systems and power electronics have enjoyed further development, meaning that we are now able to implement the eBooster[®] efficiently with a significant improvement in throttle response,

which is always one of the core development objectives.

What kind of market potential can you see for the eBooster[®]?

Dr. Adam: At the start of 2017, we will launch the first series production projects with two premium customers. Other manufacturers in the premium segment are also very interested in our product and submit concrete inquiries as to how our technology could be applied to their engine concepts. We therefore anticipate further series production projects for 2018/2019 and feel certain that we will be able to impress our customers in terms of technology, quality and costs. There is massive market potential here in the long term.

Will the eBooster[®] also be available in more affordable vehicle classes?

Dr. Adam: We are currently working hard on this. We have initially presented a product that can meet the strictest technical requirements. The next stage of development now focuses on 12 V on-board power supply system applications. We will show that the eBooster[®] technology is also well suited to small and mid-sized engines.

Other companies are also working on electrical turbo technology. Where do you see yourself relative to the competition?

Dr. Breitbach: We have been the market leader in multi-stage turbocharging for years and sell more systems than any of our competitors. The eBooster® is also a multi-stage system that is combined with a conventional turbocharger. We are a full system supplier that understands the entire air supply system on modern engines.

“Our eBooster® is also well suited to small and mid-sized engines.”

Dr. Jürgen Adam

In addition to this, however, we also cover the electronic side, which requires on-board power supply system expertise. Our collaboration with colleagues from BorgWarner Emissions Systems and also the acquisition of Remy in December 2015 really help us in this regard. We have gained a great deal of expertise regarding the electrical side of the impeller from these two BorgWarner divisions.

What is the relationship between your “Design for Value” initiative and the development and optimization of products such as the eBooster®?

Dr. Adam: Design for Value is a higher-level strategy, which we are also pursuing with the eBooster®. With this turbocharging system, we currently offer a technology that actually exceeds customer requirements in certain areas. Within the scope of Design for Value, the key now is to strike the right balance between performance and quality on the one hand, and costs

on the other. In Design for Value workshops, we are already working on optimizing the next generation of eBooster® on the cost side without compromising performance or quality.

Dr. Breitbach: Design for Value is now a permanent component of our development and industrialization strategy. Each product passes through this process. We perform analyses to determine precisely where we can either improve on or dispense with a function. We also constantly analyze costs. With the eBooster®, for example, we check whether we have already reached the optimum in terms of the electronic and mechanical elements. We will then also align the eBooster® with various customer requirements. Our first customers are using it in a 48 V on-board power supply system. This allows us to offer peak power of 5 to 6 kW, compared with just 2 to 2.5 kW for customers using a 12 V on-board power supply system.

What are the current trends in engine development?

Dr. Breitbach: In terms of turbochargers: improved throttle response, greater throughput spread, higher boost pressure and greater efficiency are important topics for all vehicle manufacturers. Dethrottling of gasoline engines, and the turbocharging systems optimized specifically for this, is another key topic at the moment. In terms of diesel engines, the original concept of downsizing has given way to “rightsizing” as a way of creating both economical and low-emission engines. The turbocharger systems must deliver the best possible efficiency here and therefore often employ two-stage or multi-stage boost. All engines – including those with new combustion concepts – require excellent turbocharger response. Optimizing the turbocharger will therefore remain a central objective of our development operations in the future.

We have now heard about the eBooster®. So what other new technologies does BorgWarner have in the pipeline?

Dr. Breitbach: We have the most diverse portfolio in the market and will continue to develop this product spectrum in the same way that we are now driving forward development of the eBooster® and already working on the eTurbo. For example, we offer turbochargers with segment turbines, the so-called DualVolute for gasoline engines. This was developed according to the Design for Value principle and represents a highly cost-effective solution that delivers excellent response. We are also further refining variable turbines for gasoline engines and have been supplying Porsche with series production units for high-performance applications for some time. Several of our customers are now keen to implement more conventional applications. We are happy to oblige by adapting our technology. In terms of diesel engines, we are currently in the process of further improving our variable turbines. We are now launching the sixth generation with improved aerodynamics – and have already received a great deal of positive feedback from many customers. After all, we are achieving levels of efficiency that would have been considered inconceivable just a few years ago. We also have better testing methods and can develop products in a faster and more targeted approach thanks to the use of simulations. Within our development operations, we also established the Core Science department. This department holds central responsibility for fundamental concepts such as simulation, aerodynamics or materials. Core Science supports both our passenger vehicle and commercial vehicle development operations. We are keen to combine the expertise from both fields to drive forward early, computer-aided development.



Dr. Jürgen Adam began his career as a development engineer at ABB Reaktor GmbH. He then performed various duties at Bosch as a group leader and departmental head, most recently as Head of Production Fuel Injection Systems. In 2009 he began his career with BorgWarner Turbo Systems and assumed the position of Technical Director, initially responsible for Manufacturing Engineering and later for Operations. At the start of 2015, Dr. Jürgen Adam was appointed Business Director eBooster® and assumed responsibility for the industrialization and series production of BorgWarner's latest innovation.



Dr. Hermann Breitbach has held the position of Vice President Global Engineering and Innovation at BorgWarner Turbo Systems since September 2015. He began his career as a research associate at the Aachen University of Applied Sciences (RWTH Aachen) and the University of California in San Diego. After this, he held various development and management positions at Delphi Automotive in Luxembourg and most recently worked as Chief Engineer in England. From 2004, he worked as a department head at Daimler in Stuttgart, where he was responsible for preliminary development of diesel engines and later for series production development of injection and turbocharging systems, as well as operating supplies. Dr. Hermann Breitbach joined BorgWarner as Director Global Product Development Passenger Car Turbo Systems at the start of 2014.

So you have plenty of new concepts for the passenger vehicle sector.

What about the commercial vehicle segment?

Dr. Breitbach: We are obviously still refining conventional turbocharging systems with regard to efficiency and Design for Value. However, eBooster® and eTurbo will also form part of our commercial vehicle portfolio. For commercial vehicles, we are talking about electrical power of 15 to 20 kW. In fact, commercial vehicle applications may actually hold the key to establishing the eTurbo, as electrical energy can be recovered by the turbo during long-haul transport with heavy loads.

“Proximity to and close development collaboration with customers represents one of our key strengths.”

Dr. Hermann Breitbach

This should then deliver significant fuel savings. In addition, we aim to recover energy from exhaust gas heat in a further new development, the so-called Organic Rankine Cycle expander. Through initial research projects, we have shown that this allows fuel savings of up to 5% to be achieved. We are also working hard on electrically-supported turbocharger systems on the commercial vehicle side.

Is BorgWarner’s organization strong enough to roll out a large number of new and improved products across the globe?

Dr. Breitbach: Yes, we have a very wide footprint when it comes to development and production – with five Turbo Systems locations in Europe, six locations in Asia and three locations in North and South

America. Proximity to and close development collaboration with customers represents one of our key strengths. However, our developers obviously need to communicate effectively with one another within this worldwide network. We therefore ensure that our teams throughout the world operate to the same high level of expertise and are capable of successfully developing our latest technologies to series production maturity with the customer.

Dr. Adam: The eBooster® is an excellent example of this. We offer this turbocharging system in all markets worldwide from the Kirchheimbolanden location and

then provide local support together with our local facilities. We have already received extremely positive feedback from our customers regarding this approach. The manufacturing is also split across a network. The electronics for the eBooster® are produced in Portugal, while Kirchheimbolanden is responsible for the mechanics, as well as final

assembly and final testing. Production planning and execution are performed using the same concepts. To this end, the facilities collaborate closely with one another and each use the experience and expertise of the other location.

What excites you about working in the field of turbocharging and at BorgWarner in particular?

Dr. Adam: As an engineer, I am fascinated by innovative high technology. It is a fantastic challenge to push the envelope in development and bring new technologies to the top quality standard required for series production. This is probably what motivates me the most. BorgWarner also works to the “Local Accountability – Global Strength” business model, which defines clear responsibili-

ties while also providing enough freedom and scope for creative design. Despite our size, we have always remained a dynamic company with fast decision-making processes. I can incorporate and implement my own ideas, and this is what makes my work so exciting.

Dr. Breitbach: The automotive sector has always been one of the most dynamic industries. The development cycles are shorter than in many other high-tech industries, making it the ideal working environment for any full-blooded developer. Moreover, the turbo enjoys a very good image – as underlined by its use in everyday colloquial language – and is a key engine component. Turbochargers also allow engineers to apply everything that they have learned in a single product: materials science, component dynamics, thermomechanics, thermodynamics, aerodynamics with ultrasonic flows and much more. We can add power electronics and engines to this list for the eBooster® – which is capable of delivering 5 kW in the tightest of spaces and at high temperatures. This really is a fascinating field of work.

So what speaks for BorgWarner here?

Dr. Breitbach: The fact that we are very customer-oriented and collaborate with our customers at the design level. We actively seek communication and partnership with our customers. This not only benefits them, but also us. We also constantly ask ourselves the question of how we can get better. The fact that we are a global organization and thereby collaborate with international colleagues from various cultures is also important. We benefit from the intercultural exchange, as it brings us even closer to our customers.

Many thanks for the interesting discussion.

10 years of gasoline VTG – and we are just getting started!

BorgWarner's variable turbine geometry (VTG) technology celebrated its premiere in a gasoline engine ten years ago. In 2006, the Porsche 911 Turbo was the world's first gasoline engine vehicle with this innovative turbocharging technology to be built in large numbers. Fast forward to the present day and it is hard to imagine Porsche's top models without BorgWarner VTG technology. Yet thanks to alternative combustion processes and new materials, VTG turbochargers are no longer reserved just for no-compromise performance vehicles: they now also offer great potential for more conventional gasoline engines.



The gasoline engine version of VTG celebrated its premiere in the 2006 Porsche 911 Turbo.

BorgWarner's development of VTG turbochargers for Porsche began in 2002. The engineers faced a major challenge, as back then variable turbine geometry was the exclusive domain of diesel engines with their relatively low combustion temperatures. A VTG mechanism therefore had to be developed that could handle the significantly higher exhaust gas temperatures of up to 1,000°C encountered in gasoline engines. Beside a completely redesigned VTG cartridge, new materials from the aerospace sector were also used – in some cases for the first time ever in the automotive sector and turbocharger production.

Powerful performance thanks to biturbo with VTG

Following lots of preliminary testing and an intensive endurance test, four years later the product was ready. In 2006, Porsche began series production of an engine that boasted truly impressive performance figures thanks to its two BorgWarner BV50G turbos with electrical VTG actuation. This new 997 Top unit squeezed 470 bhp (353 kW) from its 219 cubic inches (3.6 liters) of displacement. The biturbo was capable of delivering its maximum torque of 457 lb-ft of torque (620 Nm) in a wide rev band from 1,950 to 5,000 rpm. Following its most recent modification in 2013 to celebrate the 50th anniversary of the legendary Porsche 911, the unit was also offered as a 3.8-liter boxer biturbo engine with direct gasoline injection, maximum power of 550 bhp (412 kW) and maximum torque of 516 lb-ft (700 Nm). The overboost function even allowed the engine to deliver torque of 553 lb-ft (750 Nm) for brief periods.

First VTG in a 4-cylinder boxer engine

The market launch of a first gasoline VTG with integrated waste gate

represented another important development step for BorgWarner in the use of VTG turbochargers for high-performance gasoline engines. Paired with a new 4-cylinder boxer engine, the new VTG turbocharger allows even better boost control. The vehicles equipped with this system offer a marked increase in performance, while also delivering better fuel consumption and emissions values.

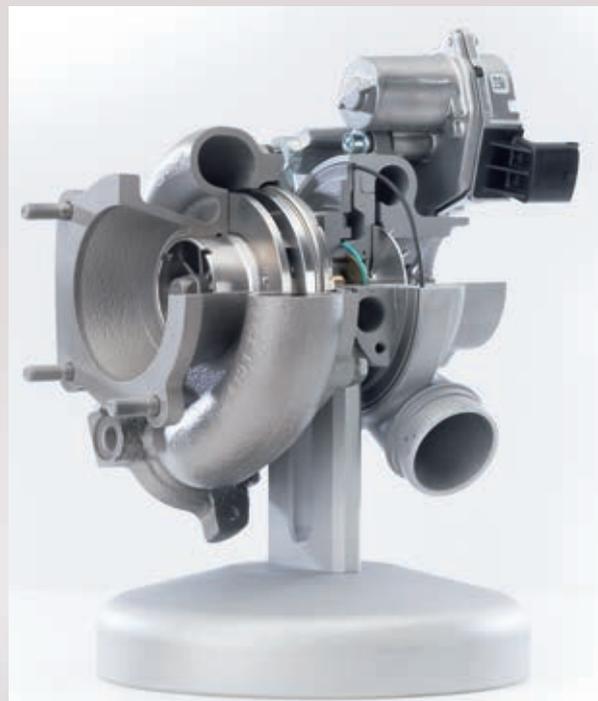
VTG turbocharged gasoline engines on the verge of a breakthrough

The use of gasoline VTG turbochargers for high-performance sports engines is just the start. With ever stricter requirements in terms of fuel economy and emissions, vehicle manufacturers are now displaying greater interest in rolling out this technology on a broader basis. BorgWarner is therefore working intensively on solutions to make gasoline engine VTG even more attractive. Combustion processes such as the Miller cycle, which operate at lower combustion temperatures, as well as new materials that are actually more economical despite offering greater resilience hold potential here. BorgWarner has now optimized the materials used to such an extent that the technology is also competitive in more affordable vehicle segments.

Beside material/cost optimization, focus is obviously also on thermodynamic optimization of the gasoline engine VTG for new combustion processes. The key here is to offer customers the best turbocharger for their specific requirements as a combination of performance and costs.

The turbocharger specialist is already working with a major European vehicle manufacturer on implementation of another gasoline engine with VTG turbocharger. Beside excellent response and smooth power delivery, this new unit also delivers excellent fuel consumption and particularly low emission values. BorgWarner sees massive market potential for the VTG technology in gasoline engines, not least due to the ever stricter fuel economy and emissions standards. The company is clearly keen to use its

many years of experience and leading position as a supplier of VTG turbochargers for gasoline engines.



The BV50G for Porsche was the world's first VTG turbocharger to be produced in large numbers for a gasoline engine.



With new materials and combustion processes, VTG technology also holds great potential for more conventional gasoline engines. Here a BorgWarner VTG turbocharger with waste gate.

Ready for testing!

Developing new testing procedures, expanding worldwide testing capacities and securing uniform global test results: these are just some of the duties of the Global Testing section within the Global Engineering Customer Services (GECS) department at BorgWarner Turbo Systems. The organization defines itself as an innovative service provider within the company that sets up testing facilities that are benchmark worldwide.

BorgWarner is the product and technological leader in the field of turbocharging and operates development centers in all of the world's important markets. Since testing and validation are key aspects when developing innovative high-tech products, all locations worldwide have high-performance testing facilities that are coordinated, supported and further improved by GECS.

The central development locations of GECS are the Development Centers in Asheville (USA) and Kirchheimbolanden (Germany). New testing methods and systems are primarily devised here. However, innovative ideas for improving existing processes or developing new processes come from all Turbo Systems Technical Centers worldwide. When establishing the global testing organization around four years ago, great emphasis was placed on collaboration and the exchange of best practices between the individual locations at BorgWarner.

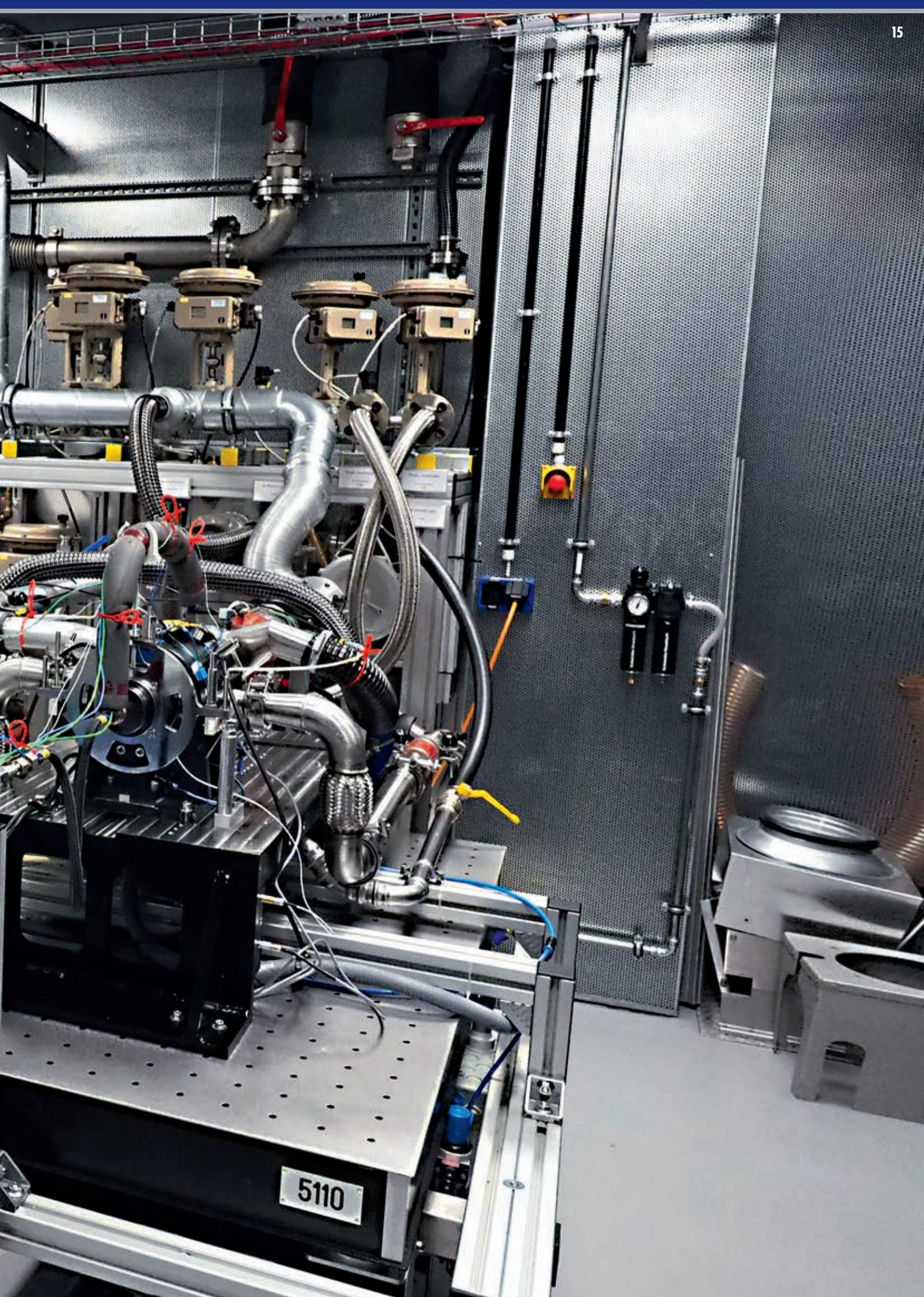
GECS therefore founded five Council Teams, comprising representatives from all Technical Centers

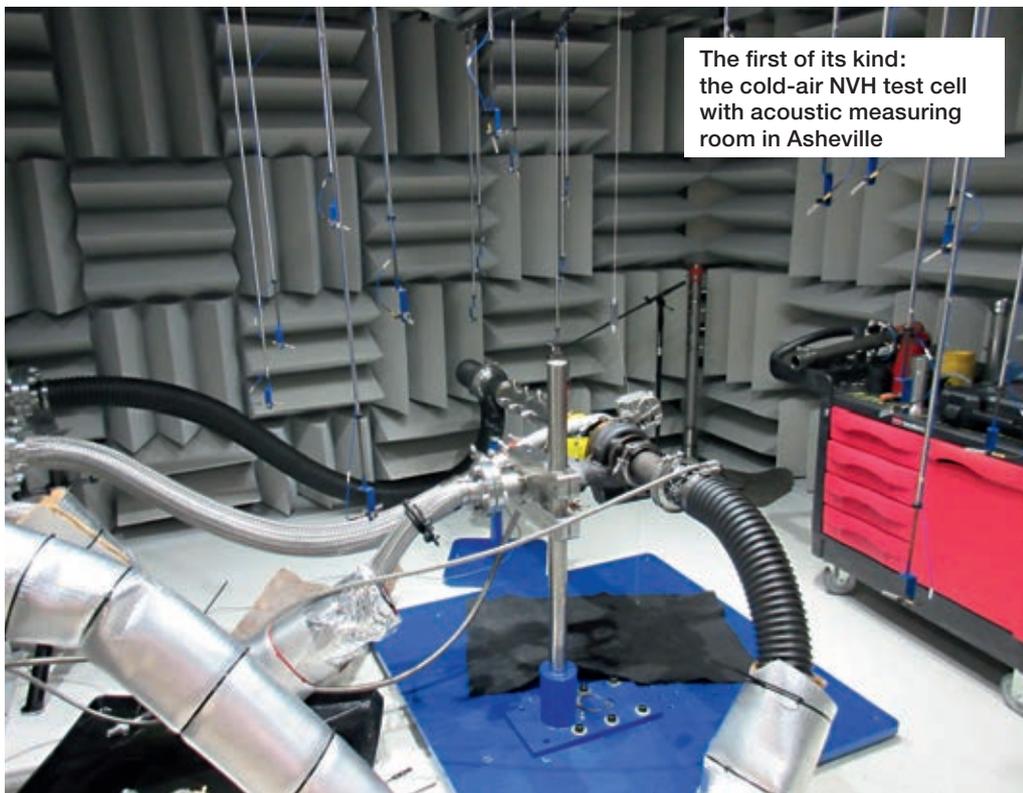
and responsible for various duties (please refer to the infobox). These include development and implementation of new testing methods, steering and expansion of the global test capacities, definition of test specifications for globally consistent and comparable test results and ultimately, the implementation of software solutions for seamless global cooperation of all testing experts.

Unique footprint

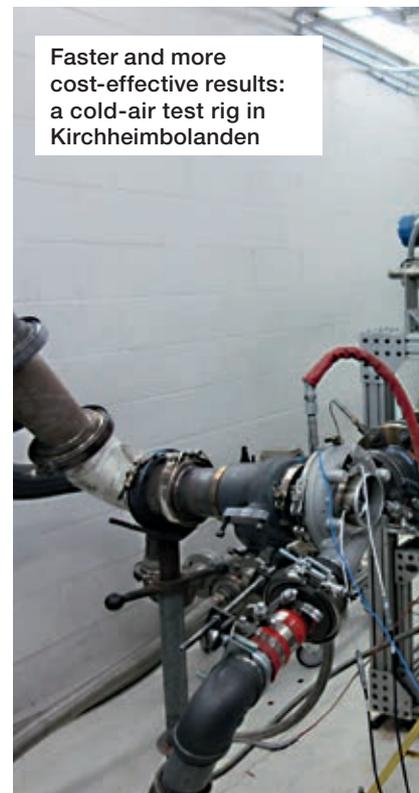
The global testing network is organized in accordance with BorgWarner's business model of "Local Accountability – Global Strength". The testing equipment at each individual facility is aligned to the respective requirements of local customers. This allows the locations to react quickly to requests and wishes from their local customers and provide solutions to any problems that may occur. The global strength of the network really comes to the fore when the capacities at one facility are not sufficient or if different testing methods are required at







The first of its kind: the cold-air NVH test cell with acoustic measuring room in Asheville



Faster and more cost-effective results: a cold-air test rig in Kirchheimbolanden

short notice. In this case, another location – as close as possible to the respective customer – steps in and provides additional capacity and equipment, all aligned with the specific customer requirements. This global testing footprint is unparalleled worldwide in the automotive supplier industry.

Testing with the latest methods

BorgWarner can also offer several special features in terms of technical standards and equipment. For example, the turbocharger specialist is the only producer to have a modern bearing friction test bay – an in-house development of GECS. This equipment is indispensable for development of future bearing systems. It allows the effects of all relevant parameters on frictional losses to be determined and thereby makes a key contribution to improving simulation models and design principles for bearings. The test bay ultimately allows developers to create new bearing systems within a short period of time to improve the efficiency of the turbocharger and thereby also reduce the respective engine's fuel consumption.

Another example is the E-Drive impeller wheel test bay – also an in-house development of GECS. Unlike conventional systems, with this setup the impeller wheel being tested is not driven by a turbine, but rather by an electric motor. The test bay also provides precise measurement results with very low air mass flow rates and low compres-

sion ratios that go beyond the capabilities of combustion chamber test bays. This is extremely important for vehicle manufacturers, since most operating points of real-world driving cycles are outside the measurement ranges of combustion chambers. Yet it is precisely these operating points that have a major influence on emissions, fuel consumption and dynamic driving performance, which make them essential for engine simulations.

The NVH test cells with acoustic measuring room are also key at BorgWarner. These are used to accurately record and measure noise, vibration and harshness. The NVH cold-air test cell at the Development Center in Asheville is already in operation, while a second NVH combustion chamber test bay in Kirchheimbolanden has almost been completed. The test bays make it possible for the engineers at BorgWarner to detect and eliminate any undesirable resonances early on during the development phase of a turbocharger. To this end, the corresponding components are tested in combination with vehicle-specific acoustic data from the customer. Vehicle acoustics are playing an increasingly important part for auto manufacturers, so there is great demand for reliable NVH testing systems.

In terms of classic turbocharger testing facilities, BorgWarner is increasingly investing in cold-air test rigs to accompany its hot air testing systems. These allow a simpler test setup in smaller test cells. The engineers and developers can then

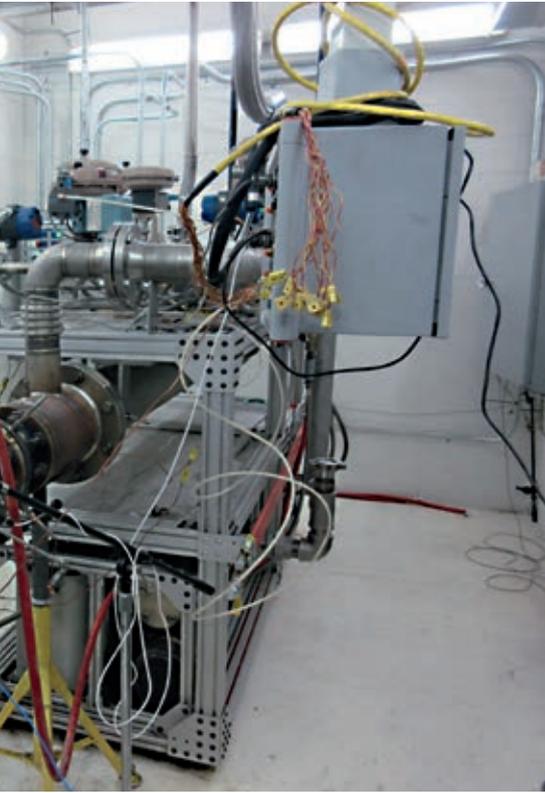
react significantly faster to customer requests and provide DoE (design of experiment) results for lower costs.

Uniform results worldwide

The most important objective of GECS is to provide vehicle manufacturers with accurate and uniform results for thermodynamic mapping, regardless of region or location. BorgWarner has therefore been working intensely for years on maximizing the consistency of the various testing facilities for passenger vehicles and commercial vehicles worldwide. The turbocharger specialist performs testing to many strict criteria, such as those stipulated by the SAE J-1826 specification for drafting turbine and compressor maps. The Society for Automobile Engineers has also recognized the need for more defined stipulations. As part of an SAE Council, the GECS experts at BorgWarner are therefore playing a key role in helping improve the specifications. This will in future also allow better comparability of the turbocharging systems from various manufacturers.

Strong partner to developers

Within BorgWarner Turbo Systems, GECS regards itself as a strong partner to the developers – from preliminary development, through generic development, all the way up to application development. The depart-



ment makes a key contribution to improving products in the sense of 'design for value', guaranteeing smooth series production start-ups and securing high product quality.

The five Council Teams of the Global Engineering Customer Service

1

The **"Test Development & Implementation Team"** identifies necessary testing methods, develops its own equipment if it is not available in the market and integrates testing equipment at the individual locations.

2

The **"Global Capacity & Utilization Team"** ensures optimum utilization of the testing capacities available worldwide and establishes new capacities at corresponding locations on the basis of long range planning (LRP).

3

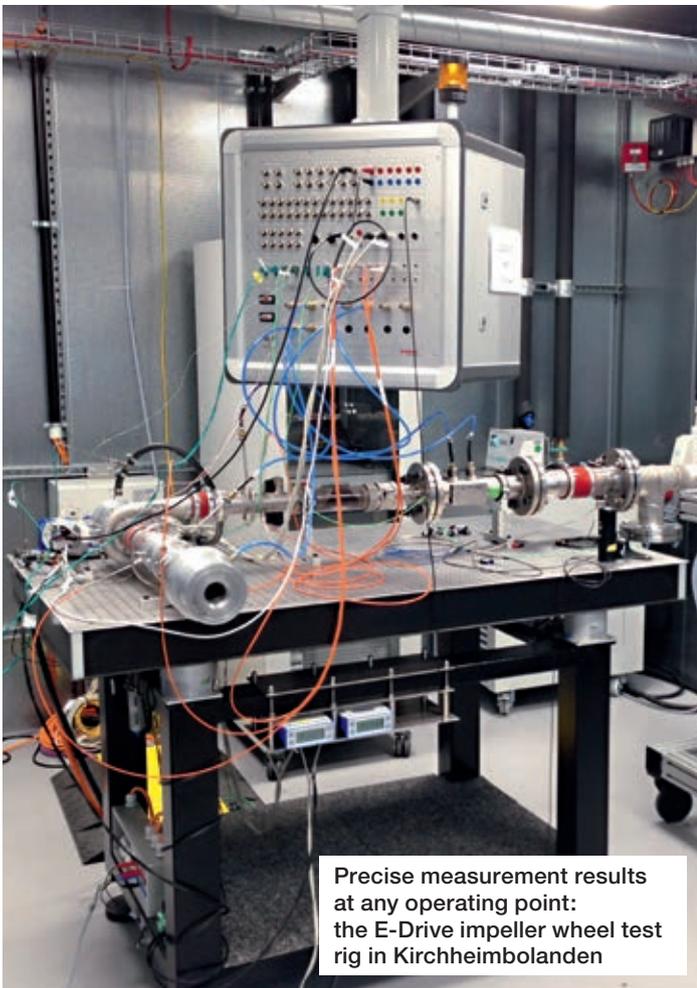
The **"Global Correlation Team"** is responsible to ensure that consistent and comparable results are produced by all testing facilities worldwide, documents this in specifications and thereby guarantees sustainable quality of the test results.

4

The **"Work Process Team"** implements global software solutions, so that all locations can use uniform tools and processes, collaborate more efficiently and share best practices with one another.

5

The **"Common Test Specifications Team"** draws up common methods, as well as documentation and test specifications, so that these can be used uniformly across the globe.



Precise measurement results at any operating point: the E-Drive impeller wheel test rig in Kirchheimbolanden



Unparalleled worldwide: the bearing friction test rig at BorgWarner in Kirchheimbolanden

Reach for the sky

How would you like experience driving on a race track of just under 12.5 miles with 156 corners and a total elevation change of more than 4,700 feet? This was the challenge faced by a virtually stock standard Mercedes C 300 d 4MATIC at the legendary Pikes Peak International Hill Climb in Colorado in mid-2015. The C Class, equipped with a BorgWarner R2S system, set a new record time for diesel vehicles.

Test driver, Uwe Nittel, raced the Mercedes to the summit of Pikes Peak in just 11 minutes and 37 seconds. This is an impressive achievement, since the air at an altitude of 14,000 feet is particularly tough on diesel engines. Nittel comes from the rally sport world. Besides many other championships, he was vice world champion in Group N (1996) and member of the team that won the FIA European Truck Racing Championship (2011).

First ultra-low emissions vehicle with diesel engine

The reason for taking part in the Broadmoor Pikes Peak International Hill Climb, one of the most spectacular and challenging hill climbs in the world, was to present the new C Class with OM 651 diesel engine at the Detroit Motor Show. The vehicle is produced by Daimler in the US and equipped with sophisticated exhaust gas treatment technology specifically for the US market.

With a combination of SCR catalytic converter (selective catalytic reduction) and low-pressure exhaust gas recirculation (EGR), the new C 300 d is the first diesel vehicle to

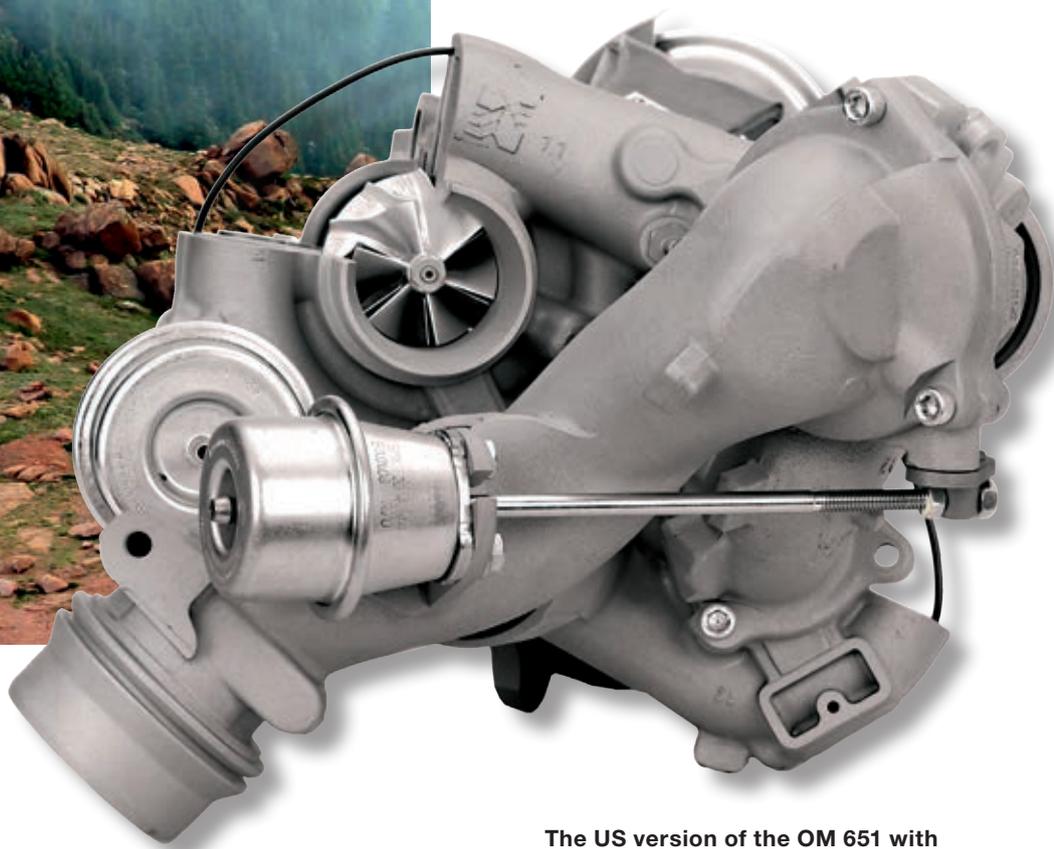
comply with the strict American ULEV-70 emissions limits (ultra low emissions vehicle).

Efficient and dynamic thanks to R2S

However, the environmentally friendly diesel offers impressive dynamic driving performance to ensure the kind of experience drivers expect from a Mercedes. The four-cylinder diesel unit with common-rail direct injection delivers 201 hp (150 kW) and maximum torque of 368 lb-ft (500 Nm), which drivers can enjoy from just 1,600 rpm. The engine is boosted by a regulated two-stage turbocharging system (R2S) from BorgWarner, comprising one B01 high-pressure turbo-



Reached the summit in just 11 minutes and 37 seconds: the Mercedes C 300 d 4MATIC at the Pikes Peak International Hill Climb in the US.



The US version of the OM 651 with low-pressure EGR employs an R2S system with coated impeller wheels.

charger with waste gate, as well as one K04 low-pressure turbocharger, which is also fitted with a waste gate. Both turbocharging systems employ milled impellers that differ from the European versions of the R2S system through their special coatings. This was necessary to ensure long-term protection of the impellers from aggressive exhaust gas components when using the low-pressure EGR.

Thanks to its advanced turbocharging systems, the Mercedes C 300 d 4MATIC sprints from 0 to 60 mph in under seven seconds and reaches top speeds of over 150 mph. This technology becomes even more impressive if we consider the

combined fuel consumption of over 47 mpg US (56 mpg UK) and CO₂ emissions of around 130 g/km. The new C 300 d therefore represents another milestone in the successful collaboration between Daimler and BorgWarner. At the Pikes Peak International Hill Climb, the vehicle impressively demonstrated the power reserves of the latest environmentally friendly diesel technology.

Development progressing at Japanese location

The automotive industry ranks among Japan's key industries. Although the figures have declined somewhat in recent months, the almost nine million vehicles produced in 2015 underline the massive market potential for BorgWarner Turbo Systems. This is why the turbocharger specialist began marketing its turbocharging systems in Japan back in 2006. The latest important step in growth is the ultra-modern prototype shop, which opened at the start of 2016.

Around
9,000,000
cars were produced
in Japan in 2015.

In 2015, the Japanese
automotive industry
employed
5.5 million
people.

Another milestone followed just one year after the launch of sales activities in Japan. In October 2007, BorgWarner Morse TEC Japan Tokyo Turbo was founded with five employees. Two years later, this new BorgWarner Turbo Systems facility relocated to Yokohama, Japan's second largest city.

BorgWarner scored its first project success with Nissan when the turbocharger specialist was selected as turbocharger supplier for a 152 cubic inch (2.5 liter) diesel engine. Series production of a fourth generation BV45 turbocharger with electric actuator was launched for this engine for the first time in PyongTaek, South Korea. In 2013, BorgWarner Turbo Systems commenced its first series production operations for Nissan in Ramos, Mexico. More recently, the location was able to impress Honda and win the order to supply the turbochargers for its new 61 cubic inch (1.0 liter) gasoline engines.

Milestone: new prototype shop

BorgWarner is keen to secure a market share of 30% by 2020 with five Japanese OEMs in the land of the rising sun. It aims to achieve this through technology leadership, reliable project management, on-time series production launches and perfect quality. To support this objective, in 2015, the facility relocated from an old office building to the German Industry Park in Shin-Yokohama. It was here that BorgWarner opened its prototype shop in February 2016, equipped with the

latest technology. This is an important benefit for the location, as it allows the company to assemble and test turbocharger prototypes directly in Japan, from initial performance samples all the way up to series maturity. With this local responsibility, BorgWarner will be able to react even more quickly to customer requirements in the future.

The International team is ready to go

Sixteen employees from five nations – Japan, Korea, Brazil, France and Germany – today work at the Shin-Yokohama location. Three application groups and one sales and project management group work on site, focusing on achieving the greatest possible customer satisfaction. As per the BorgWarner business model "Local Accountability, Global Strength" (LAGS), the employees are in close communication with other worldwide development centers and project teams. In addition to this, they hold responsibility for customer projects in Ningbo (China), Ramos (Mexico), Itatiba (Brazil), PyongTaek (Korea) and Rayong (Thailand). Further employees are to be hired in the areas of program management and engineering by the end of 2016.

Source: Wikipedia and Foreign Office

Japan is the world's third largest economy. In 2015, the country generated per capita GDP of USD 32,481. The East Asian state in the Pacific is made up of 6852 islands, only 425 of which are actually inhabited. Some 98% of the 127 million residents live on the four main islands of Hokkaido, Honshu, Kyushu and Shikoku. With just under 9 million residents, Tokyo is the country's largest city and capital, followed by Yokohama with around 6.7 million residents.



Assembly, actuator setting, laser marking, final quality control



Assembly of core group and housing



The BorgWarner team from Yokohama and Ningbo

Together with Kawasaki, the two cities form the world's largest metropolitan region.



Japan's capital Tokyo

Efficiency in focus

How can the fuel consumption and emissions of agricultural machines be effectively reduced, while also complying with increasingly strict emissions regulations? Everything revolved around this central question during BorgWarner's appearance at the Agritechnica trade fair at the end of 2015. The automotive supplier presented its latest products for the off-highway sector at the world's largest international trade fair for agricultural machinery and equipment.



The fair attracted around 450,000 visitors from 115 countries. More than 2,900 manufacturers showed off their products, following the exhibition motto of "People, Technology, Innovations – The Future of Agricultural Machinery". While the focus with agricultural machines used to be primarily on performance and robustness in the toughest of deployment conditions, the topics of energy efficiency and environmental friendliness have become increasingly important over the last few years.

The latest turbocharging technologies

BorgWarner therefore presented a whole range of innovative solutions from its various business units. For example, Turbo Systems showed off its R2S® two-stage regulated turbocharger technology, which has won multiple awards. With this unit, two turbos of different sizes are arranged in a series and provide excellent response, while also improving fuel consumption and reducing emissions. R2S® systems deliver maximum exhaust gas recirculation rates, even under full load conditions, while simultaneously significantly reducing emissions and thereby fulfilling the requirements of advanced engine concepts.

The turbocharger specialist also presented its latest turbochargers with variable turbine geometry (VTG) and turbocharging systems with improved efficiency.

Lower emissions thanks to EGR

The Emissions Systems division presented advanced diesel cold-start technologies and exhaust gas recirculation modules (EGR modules). Ultra-modern EGR systems are one of the most effective methods for reducing NOX emissions. The EGR modules from BorgWarner combine an EGR radiator, an EGR valve and a bypass valve in a compact unit. The recirculation and cooling of the exhaust gases reduces the level of emissions, while increasing both reliability and efficiency.





At Agritechnica, BorgWarner presented innovative products in the area of turbocharging, exhaust gas recirculation and cooling.

Custom cooling

In addition to this, the visitors were able to take a close look at precise fan solutions, such as Visctronic® fan drives, electronically controlled compact variable coolant pumps and dual-mode coolant pumps (with electrical and mechanical drive). The electronically controlled Visctronic fan drives from BorgWarner are automatically engaged as and when needed. Depending on load conditions, this can improve fuel efficiency by up to 1.4% when compared with conventional fan drives and by up to 4% over fan solutions without speed control. In addition to this, the system reacts immediately to the cooling requirements of the engine and thereby increases perfor-

mance while simultaneously reducing fuel consumption and emissions. Further benefits include the maintenance-free design and increased passenger comfort thanks to improved NVH behavior (noise, vibration, harshness).

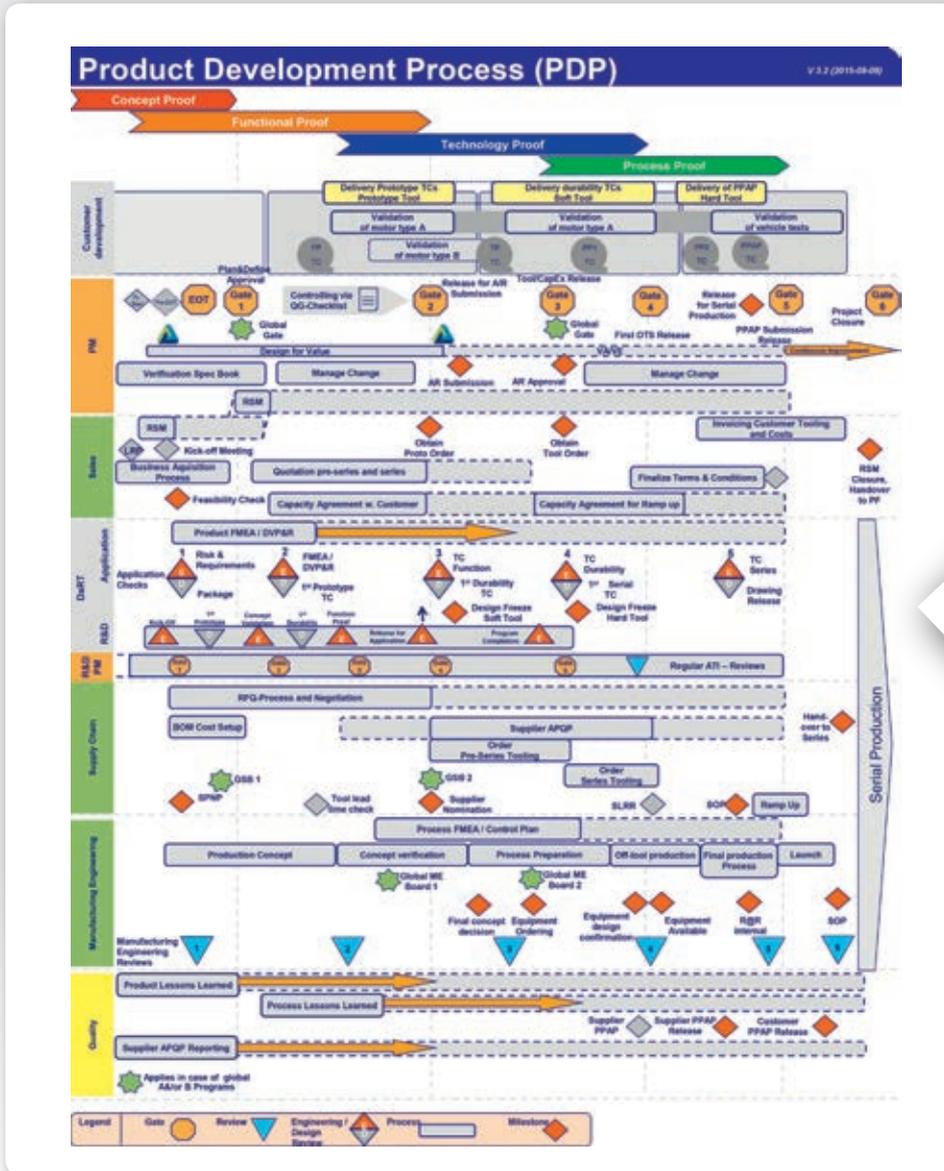
Aftermarket solutions

Beside the latest technologies for OEM customers, BorgWarner also presented its current EXCHANGE program for the aftermarket. This includes reconditioned turbochargers for a wide range of passenger vehicles, commercial vehicles, buses, construction machinery and agricultural applications. The target group is customers looking for an affordable repair solution.



xPro – the development turbo

With more and more development projects, shorter development cycles, increasingly globalized project teams and growing cost pressure, application development is today a massive challenge for everyone involved. This places even greater emphasis on efficient project management that provides optimum support for the development process. BorgWarner Turbo Systems therefore introduced a modern IT tool for global program management: xPro.



level of knowledge. No matter where in the world and at which point in the process. The system has now been implemented worldwide and proven itself in practice.

Efficient project management

Changing market conditions provided the impetus for the introduction of the tool. Not only are quality standards rising, but more and more global series production launches also have to be successfully managed. Cross-functional

With direct links to important project details, the xPro project overview ensures that everyone involved is always up-to-date with the latest information.

and cross-location cooperation is therefore becoming increasingly important. xPro is tailored specifically to meet these requirements. The global transfer of information facilitates highly efficient project management, provides smooth processes and procedures and supports on-time production. It merges information and makes it accessible in a way that allows global cooperation to be simplified and therefore intensified at the development level. A dedicated xPro cloud is used to synchronize the data.

XPro is a system that globally networks all departments at BorgWarner Turbo Systems that are involved in development, while also controlling, monitoring and documenting all development steps up to series production. It secures a seamless flow of information and cooperation, also ensuring that specifications are met equally reliably by customers throughout the world.

xPro meets the high expectations

The objectives for the new project and planning management tool were clear when work began back in 2013: to reduce superfluous data to the absolutely necessary and establish an information basis for all employees – to which everyone with the necessary rights could also add information to improve and complete the general

The system's user-friendly interface makes handling easy. The respective process status is continually updated, the following project steps are communicated and any documents that may be needed are requested. Since xPro was implemented at all locations of BorgWarner Turbo Systems, the processes and procedures have become noticeably more efficient – for a development process without turbo lag.