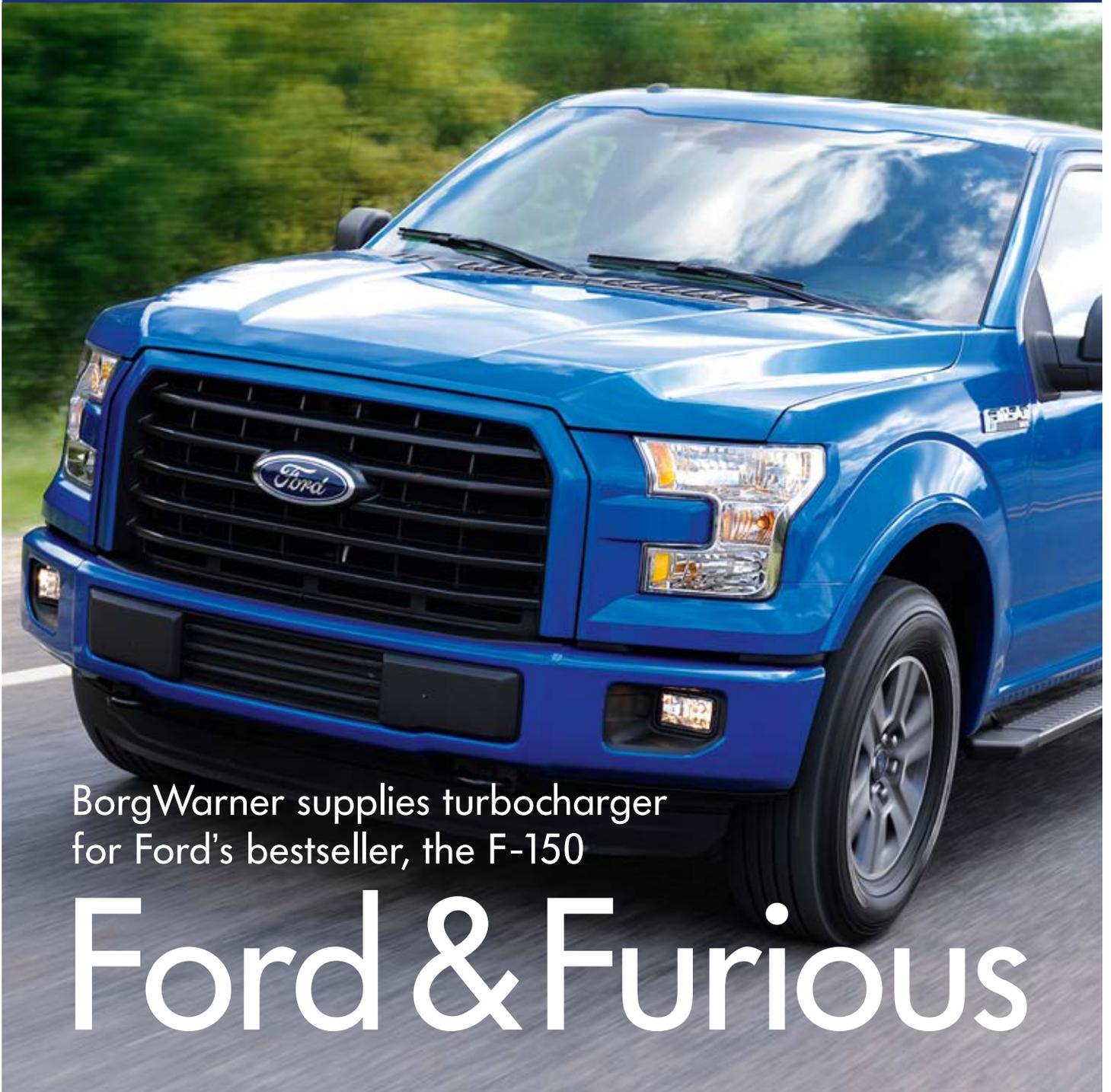


The customer magazine of BorgWarner Turbo Systems



BorgWarner supplies turbocharger
for Ford's bestseller, the F-150

Ford & Furious

TDI reloaded

Volkswagen once again relies on BorgWarner turbos
for its 85 cubic inch (1.4 liter) and 122 cubic inch (2.0 liter)
TDI engines page 6

Ready for take-off!

BorgWarner tests innovative materials
from the aviation industry page 12

Dear readers,

Whether new turbocharging technologies and new applications or new materials and new testing procedures: BorgWarner Turbo Systems is working at full speed in all departments to create innovative solutions that will help the company maintain the technological edge it enjoys in the field of turbocharging. Examples include the new flex-fuel turbocharger for use with ethanol in Brazil, as well as completely new turbocharging systems such as the eBooster® and eTurbo, which you can read more about in our current edition of TurboNews. These are complemented by ultra-modern aluminum-lithium alloys from the aviation industry, which BorgWarner is testing for use in turbocharging systems, and the new computer tomography material testing process, used by the turbocharger specialist to ensure the quality of its products.

However, challenges not only arise from continuously pushing the technical envelope, but also the company's continued strong growth presents management and employees with exciting tasks. BorgWarner therefore attaches great importance to training its junior engineers, as well as to expanding the capabilities of the individual locations. This approach is highlighted by the new research and development center in Itatiba and the new, highly flexible zero-error VTG production line in Bradford. Our interview with Henk Vanthournout (Vice President Global Sales, PM and Product Strategy Pass Car) and Wouter Nijenhuis (Vice President Global Engineering and Sales Commercial Vehicle) on page 8 also provides some interesting insights on what else BorgWarner is doing to stay ahead and meet future market and customer requirements.



Günter Krämer
Director Marketing
BorgWarner

We hope you have fun reading this newsletter and we would also like to invite you to test the special online edition of TurboNews at www.turbos.bwauto.com/en/press/newsletter.aspx

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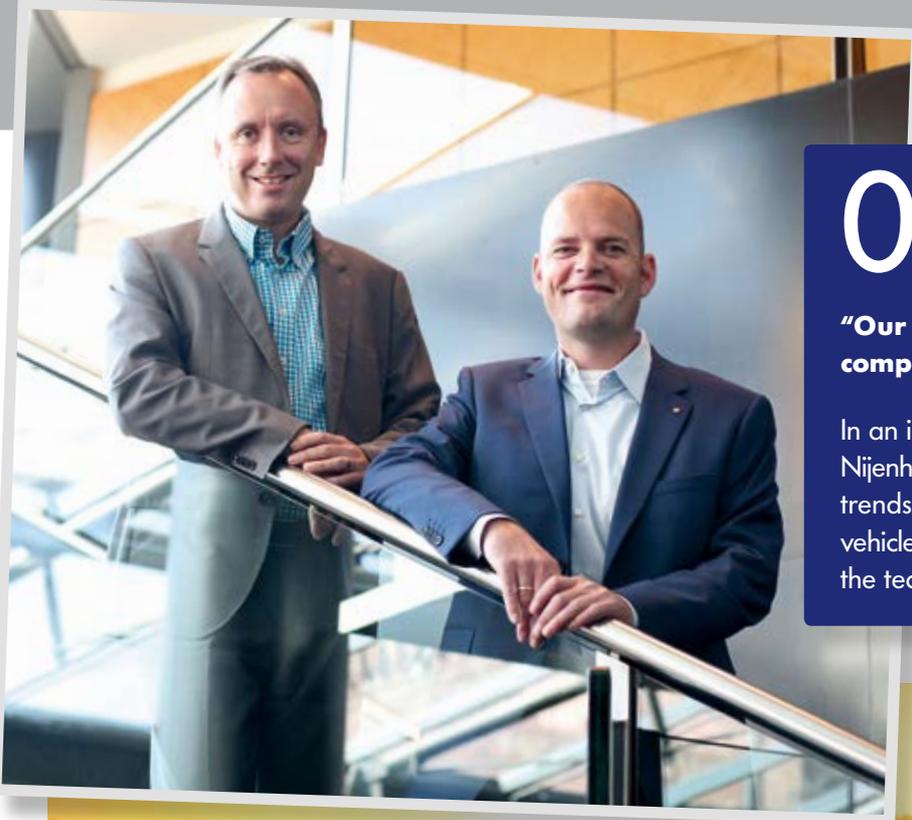
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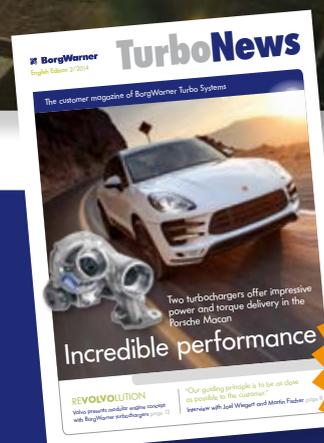
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With turbo to a master's degree

For many years, BorgWarner's Bradford facility has been offering students at the University of Huddersfield an opportunity to apply and build on their freshly learned technical expertise in practice within the scope of internships and research projects.

Due to the ever growing demand for turbochargers and the increasing need for more young engineers, BorgWarner and the university have now further intensified their collaboration.

With the support of the turbocharger specialist, the renowned and multi award-winning university founded a dedicated Turbocharger Research Institute (TRI), which offers both short courses and the first MSc degree in mechanical engineering specifically for the field of turbocharging. Both courses are also available to engineers of all

BorgWarner locations as further training. Nine candidates, including eight BorgWarner employees, have already signed up for the master's course, which has been offered since the end of 2014.

BorgWarner and the university are also working together on a whole host of research projects, which are sponsored by the UK government's Regional Growth Fund. The common objective is to develop technical improvements for the turbocharger generations of the future.



The team from BorgWarner in Bradford honored the introduction of the MSc in turbocharging technology by organizing an indoor go-karting event.

China celebrates 5 plus 1 million

BorgWarner's manufacturing facility in Ningbo, China recently produced its five millionth turbocharger. Turbocharging systems for both passenger vehicles and commercial vehicles have been produced at this modern facility since 2005 to supply global and Chinese auto manufacturers.

The turbocharger specialist expects demand for passenger vehicle and light commercial vehicle turbochargers in China to more than double by 2019. Due to the increasingly strict emissions standards, local manufacturers are relying more and more on BorgWarner's fuel consumption-reducing and emissions-lowering turbocharging technologies.

The Ningbo facility has also set a new workplace safety record. Employees at the production site were recently presented with the BorgWarner CEO's Safety Excellence Award for one million accident-free working hours. The award comes with US\$20,000 in prize money, which the approximately 900 employees at the location decided to donate to two local elementary schools.



The Ningbo facility recently celebrated production of 5 million turbochargers and 1 million working hours without an accident.

Bradford wins third Safety Award



1 million
working hours
without a
single reportable
accident



Carefully designed to offer maximum workplace safety: The team in Bradford at the Safety Excellence Award presentation ceremony.

The health and safety of employees is extremely important at BorgWarner. This is something that the Bradford facility in particular regularly demonstrates. The location has now been presented with the BorgWarner CEO’s Safety Excellence Award for the third time. This is an award that BorgWarner presents to all facilities that have reached one million working hours without a single reportable accident.

BorgWarner CEO James Verrier celebrated this sensational success together with around 200 of the facility’s employees during a personal prize presentation ceremony. Employees at the site chose to share the prize money of US\$20,000, awarded to honor Bradford’s safety efforts, between two charities. Half of the money went to the Samantha Sykes Foundation Trust, which supports abused children, and the Wakefield Hospice, which provides care and support to dying patients.



Asheville plants trees

Environmental protection is an important topic for BorgWarner Turbo Systems – not least because the company’s products contribute to the reduction of both fuel consumption and exhaust emissions. BorgWarner in Asheville therefore also decided to do its bit by organizing a special event on Earth Day, which is now celebrated every year in more than 190 countries as a way of raising awareness for environmental protection. Together with third-graders from Avery’s Creek school, employees of the facility planted eight trees to add some natural beauty to the school premises. While planting the trees, the pupils also learned how to look after them and help protect birds.

Gorillas win robot competition



Today’s pupils with a passion for technology are tomorrow’s engineers. BorgWarner is therefore always happy to support and promote committed young talents, such as “The Gorillas”. High-School Robotics Team 1225 from Henderson County Public School recently won the North Carolina Regional Robotics Competition. The challenge during the competition was to build a robot that could stack as many containers on top of one another as possible in the shortest time. The Gorillas took first place – and thereby also the “Excellence in Engineering Award”, which was sponsored by Delphi.

TDI reloaded

For more than 20 years, the letters TDI have stood for powerful acceleration and sensationally low consumption in Volkswagen vehicles. Although the diesel engine has long since developed into a highly cultivated high-tech unit, today's turbodiesels still hold a great deal of optimization potential. The new 85 cubic inch (1.4 liter) and 122 cubic inch (2.0 liter) TDI engines from Volkswagen, which are equipped with ultra-modern BorgWarner turbocharging systems, represent the latest examples of this.

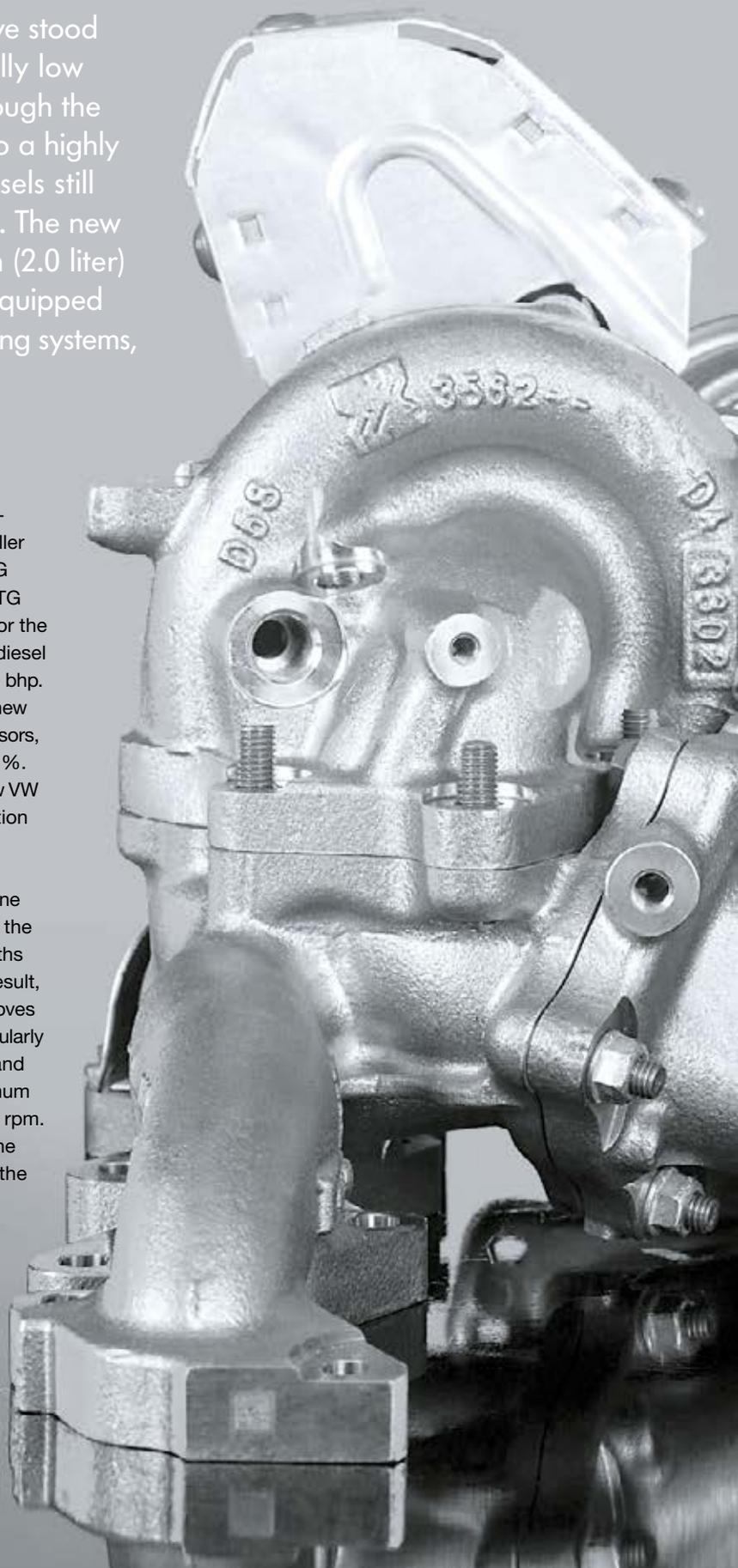
First VTG turbocharger in a 3-cylinder TDI

Volkswagen has been using the latest turbocharging technologies in its TDI engines for many years. Indeed, even the smaller engines come with innovative and technically sophisticated VTG turbochargers with variable turbine geometry. BorgWarner's VTG technology is now being used in a three-cylinder turbodiesel for the first time. The new, extremely efficient 85 cubic inch (1.4 liter) diesel unit is available in two versions: one with 75 bhp and one with 90 bhp. Both units comply with the Euro 6 emissions standard and set new records in terms of fuel efficiency. Compared with their predecessors, it has been possible to reduce fuel consumption by up to 21%. The 75 bhp turbodiesel is celebrating its premiere in the new VW Polo, where it impresses with average standard fuel consumption of 75 mpg US (91 mpg UK).

The VTG turbocharger with adjustable turbine vanes in the S-vane design makes a key contribution to the excellent efficiency of the new engine. The developers at BorgWarner went to great lengths to optimize the efficiency of the impellers and turbines. As a result, this turbocharging system from BorgWarner significantly improves the engine's response, while also increasing its efficiency (particularly in the low rev range), which leads to better fuel consumption and emissions figures. The compact 55 bhp engine delivers maximum torque of 155 lb-ft (210 Nm), which is available from just 1,500 rpm. The new turbodiesel is an important unit in the modular engine range of the Volkswagen Group. Following its deployment in the Polo, the engine will also be available in many other vehicles from Audi, Seat, Škoda and Volkswagen.

Power Passat with R2S system

While the 85 cubic inch (1.4 liter) engine represents the entry level model of the advanced TDI technology, the new 122 cubic inch (2.0 liter) turbodiesel from Volkswagen sits at the top end of the performance scale. Delivering 240 bhp and 368 lb-ft (500 Nm) of torque, the engineers at VW and BorgWarner were able to extract extremely impressive





Luxury liner: The powerful new TDI engine fits in perfectly with the dynamic and elegant lines of the new VW Passat.



Extreme economy: The new three-cylinder TDI engine makes the Polo a convenient and frugal companion.



With the new VTG turbocharger, BorgWarner's VTG technology is now also being used in a three-cylinder turbodiesel for the first time

performance from such a small displacement through use of the latest exhaust gas turbocharging technologies. With a top speed of 147 mph (238 kph) and a 0-60 mph time of just over 6 seconds, the new engine offers boundless driving pleasure in the new Passat 2.0 TDI SCR – together with exceptional fuel consumption of 44 mpg US (53 mpg UK). Of course, the 122 cubic inch (2.0 liter) TDI also complies with the Euro 6 emissions standard and produces just 140 grams of CO₂ per kilometer.

At the heart of the new engine sits a regulated two-stage turbocharging system (R2S), comprising one VTG turbocharger for the high-pressure stage and one larger, water-cooled B03 turbocharger for the low-pressure stage. BorgWarner employs a milled impeller wheel with a special protective coating in both turbochargers, so that they can handle the extreme loads and corrosive components associated with low-pressure exhaust gas recirculation more effectively. Controlled by an electrical actuator, the turbine vanes of the VTG turbocharger are adapted to the engine speed and the volume of exhaust gas available in a fraction of a second. This results in extremely fast boost pressure build-up for virtually lag-free acceleration. As the engine speed then increases, the B03 low-pressure stage begins to take effect, ultimately assuming all boost duties at high revs.

The two new 85 cubic inch (1.4 liter) and 122 cubic inch (2.0 liter) TDI engines from Volkswagen impressively complete the top and bottom end of the company's turbodiesel engine portfolio. For BorgWarner Turbo Systems, the drives represent an excellent opportunity to once again position itself as a qualified development partner to the well-known automotive manufacturer.

The R2S turbocharger system from BorgWarner makes the 122 cubic inch (2.0 liter) four-cylinder engine from VW the most powerful diesel unit in its class.

“Our huge advantage? We cover the complete spectrum of technologies.”

Price, performance, quality and service are the determining factors for customers seeking to place new projects. But what effects are the massive growth rates having? Where will the journey take us if the limits of what is technically feasible are getting ever tighter? In an interview, Henk Vanthournout and Wouter Nijenhuis chatted about cooperation with customers, trends in the passenger vehicle and commercial vehicle markets and the unique situation of holding the technological pole position.

Mr. Vanthournout, Mr. Nijenhuis, your responsibilities at BorgWarner Turbo Systems include worldwide sales. What issues/topics currently take up most of your time?

Henk Vanthournout: In the short-term, the challenge lies in achieving global growth. Asia and North America are currently recording the kind of growth rates we have rarely seen in the history of the automotive industry. To handle this, we need to ensure smooth product ramp-ups. In the long-term, we must remain technically and commercially competitive. There are new players in the market, and customer requirements are constantly on the rise. Emissions standards are also becoming ever stricter. This sometimes brings us and our customers close to the limits of what is technically possible. In other words, we must ensure the success of product ramp-ups, while at the same time strengthening our product portfolio in such a way that we can maintain our position as brand leader.

Wouter Nijenhuis: Emissions standards too, are becoming stricter and stricter in the commercial vehicle sector, and new competitors are entering the market. Costs also represent an important topic, particularly with regard to the total cost of ownership. When it comes to commercial vehicles, the fuel costs for end customers play a crucial role. Every single percentage point counts in terms of efficiency here.

Does this mean that innovations such as the eBooster® are extremely important?

Henk Vanthournout: Definitely. The eBooster®

has the potential to become a key technology in passenger vehicles. We are currently working very closely with all customers. In the next 12 to 18 months, we should have a clearer picture of the market potential offered by the eBooster®. To date, four contracts have been concluded with customers worldwide, two of which we were able to win. This means that the majority of orders is not yet being awarded, as we are still in the concept development stage.

What are the characteristics of the eBooster®?

Henk Vanthournout: On the one hand, it allows customers to improve the torque in particular at low revs. However, customers are understandably also keen to find ways of reducing CO₂ emissions, while also optimizing fuel consumption. We need to work together in specifying where and when the module can be used most effectively. In the next ten years, use of the eBooster® could potentially increase five or even ten times over. We are committed to investing in the eBooster®. To this end, we have established the requisite infrastructure and dedicated a large team. Together with customers we are keen to determine market potential in a targeted approach.

What is the competition doing?

Henk Vanthournout: At the moment, there is one main competitor from the field of electronics. We come from the turbocharger sector. The eBooster® is a combination of both. We are currently in the unique situation of enjoying a technological advantage.

But we are under no illusions about this and realize that other players will enter the market.

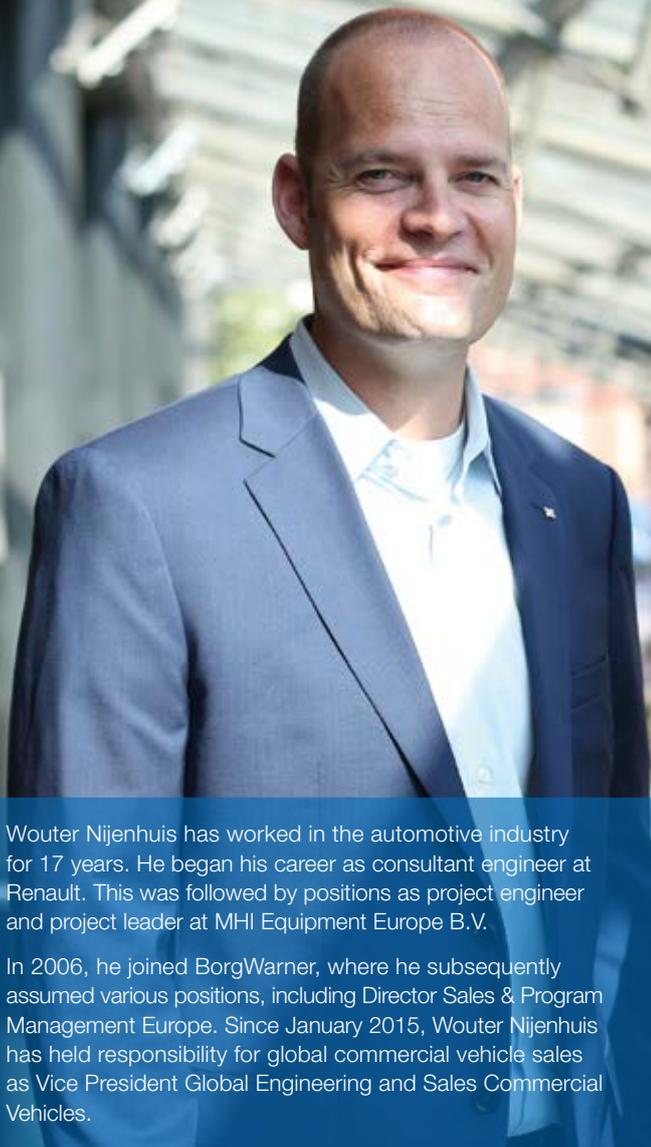
Is the eBooster® also of interest to you, Mr. Nijenhuis?

Wouter Nijenhuis: Yes, although we use it somewhat differently. Our customers for medium and heavy commercial vehicles wish

“We are continuously developing new technologies. Things never stand still.”

Wouter Nijenhuis

to run the eBooster® continuously, which makes a massive difference. There are also further developments in the direction of electrification, such as the eTurbo and eTurbo Compound. The eTurbo Compound is a turbine with generator that is driven by the exhaust gas, but which can be used to generate electricity for the engine and auxiliaries. This approach saves a lot of fuel, as energy that would otherwise be lost is recovered from the exhaust system. The eTurbo Compound makes a lot of sense for long distance travel, as a lot of electricity can then be generated. The eTurbo, which we are already developing, combines the advantages of both products. The unit uses an impeller, a turbine and the eMotor/generator. As such, it combines all functionalities in a single product. Electrification is something genuinely new, a real game-changer.



Wouter Nijenhuis has worked in the automotive industry for 17 years. He began his career as consultant engineer at Renault. This was followed by positions as project engineer and project leader at MHI Equipment Europe B.V.

In 2006, he joined BorgWarner, where he subsequently assumed various positions, including Director Sales & Program Management Europe. Since January 2015, Wouter Nijenhuis has held responsibility for global commercial vehicle sales as Vice President Global Engineering and Sales Commercial Vehicles.



Henk Vanthournout has been working in the automotive industry for 17 years. He began his career at Lear Corporation, where he initially held the position of platform manager and was subsequently responsible for sales and program management.

In 2011, Henk Vanthournout joined BorgWarner to assume the role of Director Sales & PM Pass Car Europe. Since May 2013, he has also held responsibility for worldwide sales of turbochargers for passenger vehicles as Vice President Global Sales, PM and Product Strategy Pass Car.

We are obviously continuing to develop our product portfolio, including the VTG for use in light commercial vehicles or in the CNG sector. The keywords here are efficiency, weight, material and temperature resistance.

“We currently enjoy a technological advantage in the shape of the eBooster®.” Henk Vanthournout

How do you differentiate yourselves from other competitors?

Henk Vanthournout: We cover the entire spectrum of technologies, from small turbos for gasoline engines, right through to large two-stage, three-stage and soon also four-stage diesel turbochargers. This gives us a great edge over the competition. Most new competitors are focusing on certain segments. This is something we cannot afford to do as market leader. Getting to this position was already tough enough, so maintaining

a sector with such strong growth is also extremely difficult from a technological perspective. If we do not continually improve all aspects by 10% to 15% over the next five years, we will lose this position. In order to strengthen our leading position we have started the new Management Excellence Initiative program.

What does this initiative involve?

Henk Vanthournout: We invest in our program managers more than ever before and are developing an entire skill set that will allow employees to gain even more qualifications and enjoy even better development opportunities. This will ultimately allow program ramp-ups to go more smoothly, which in turn should enable us to meet all aspects of our overall objectives.

Are there also other market trends beside electrification?

Henk Vanthournout: In terms of passenger vehicles, the main issues revolve around customers meeting their emissions standards, remaining competitive, and setting standards for attributes such as low-end torque or

driving pleasure. In addition to this, we have noticed that the requirements on turbochargers are increasing. We are now starting to approach the limit of what is technically feasible and are sensing enormous price pressure. Auto manufacturers are no longer able to pass on the costs of fuel-saving technologies to their customers. Well, they can technically still do this in the top segments, but not for the vast majority of vehicles.

What about commercial vehicles?

Wouter Nijenhuis: There is immense price pressure due to the high procurement costs of commercial vehicles. However, it is still possible to sell the concept of greater efficiency in our sector, as this has a direct influence on the total costs of owning and operating the vehicle. The situation is similar to passenger vehicles in that the product must not be too expensive and must also deliver excellent performance. In terms of commercial vehicles, all on-highway vehicles have a turbocharger. In the off-highway field, there is still a lot of untapped potential. This segment is growing at a fast pace, as is the market for gasoline engine turbocharging.

Is there a special sales strategy for overcoming these challenges?

Henk Vanthournout: Many factors are in play when customers reach purchase decisions. However, technology is perhaps the most important. If we offer the best product in terms of thermodynamics, we have an advantage. Yet customer requirements must also be met in terms of quality, delivery performance, warranty and costs.

So you offer more here?

Henk Vanthournout: In contrast to our competitors, we can look back over a long and rich history. This is often an advantage, although it can potentially also be a disadvantage in certain cases. A customer that is dealing for the first time with the topic of turbocharging is more likely to trust an established partner that has been producing millions of turbochargers per year for 40 years. Customers like this attach great importance to delivery reliability, quality

and warranty. In contrast, experienced OEMs are generally more willing to try out new market players. We recognize this, as these manufacturers offer technical solutions that are not bad, although they cannot really compete with us in terms of quality, warranty or delivery reliability.

Do you have any customers that went to the competitors, but then came back?

Henk Vanthournout: Yes. This happens when customers realize the importance of attributes such as delivery reliability, quality, warranty and stringent program management. We take the concept of customer satisfaction very seriously. We monitor and analyze it and then use the results to generate improvement measures. But setting this aside, we can totally understand the market situation from the customer's point of view. This massive market growth cannot be distributed among just three or four competitors.

Are there any interfaces where the passenger vehicle and commercial vehicle divisions meet? Can they learn from one another?

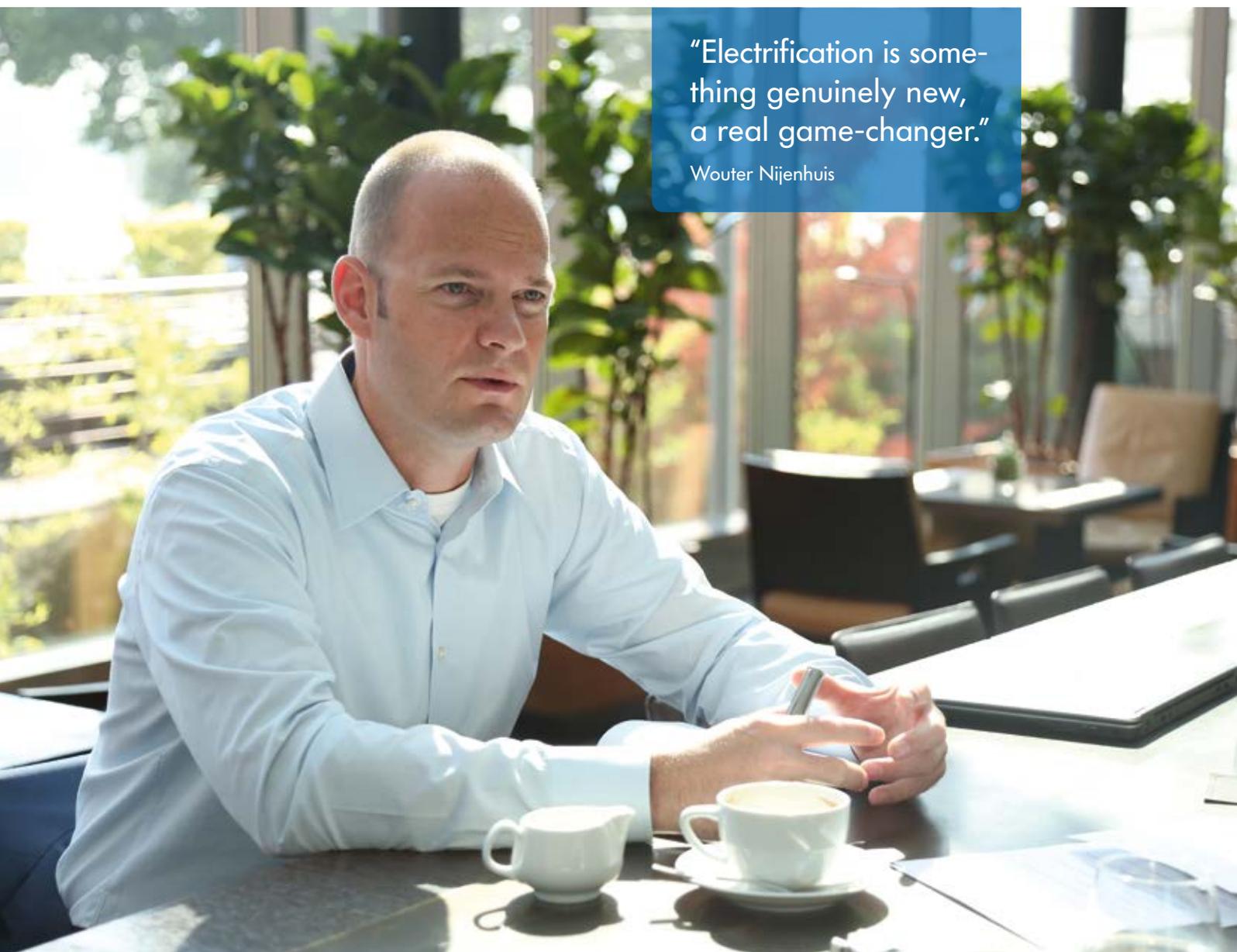
Wouter Nijenhuis: The eBooster® is a good example of this. In terms of on-road commercial vehicles, similar engine technologies are used as with passenger vehicles. For example, last year we developed a cross-over product for commercial vehicles from a small turbo used for passenger vehicles. Although we obviously had to adapt the unit, it is essentially the same turbo that we used for a 91.5 cubic inch (1.5-liter) diesel passenger vehicle. We will also attempt to release the passenger vehicle eBooster® for small commercial vehicle applications. Using these synergies helps us remain competitive.

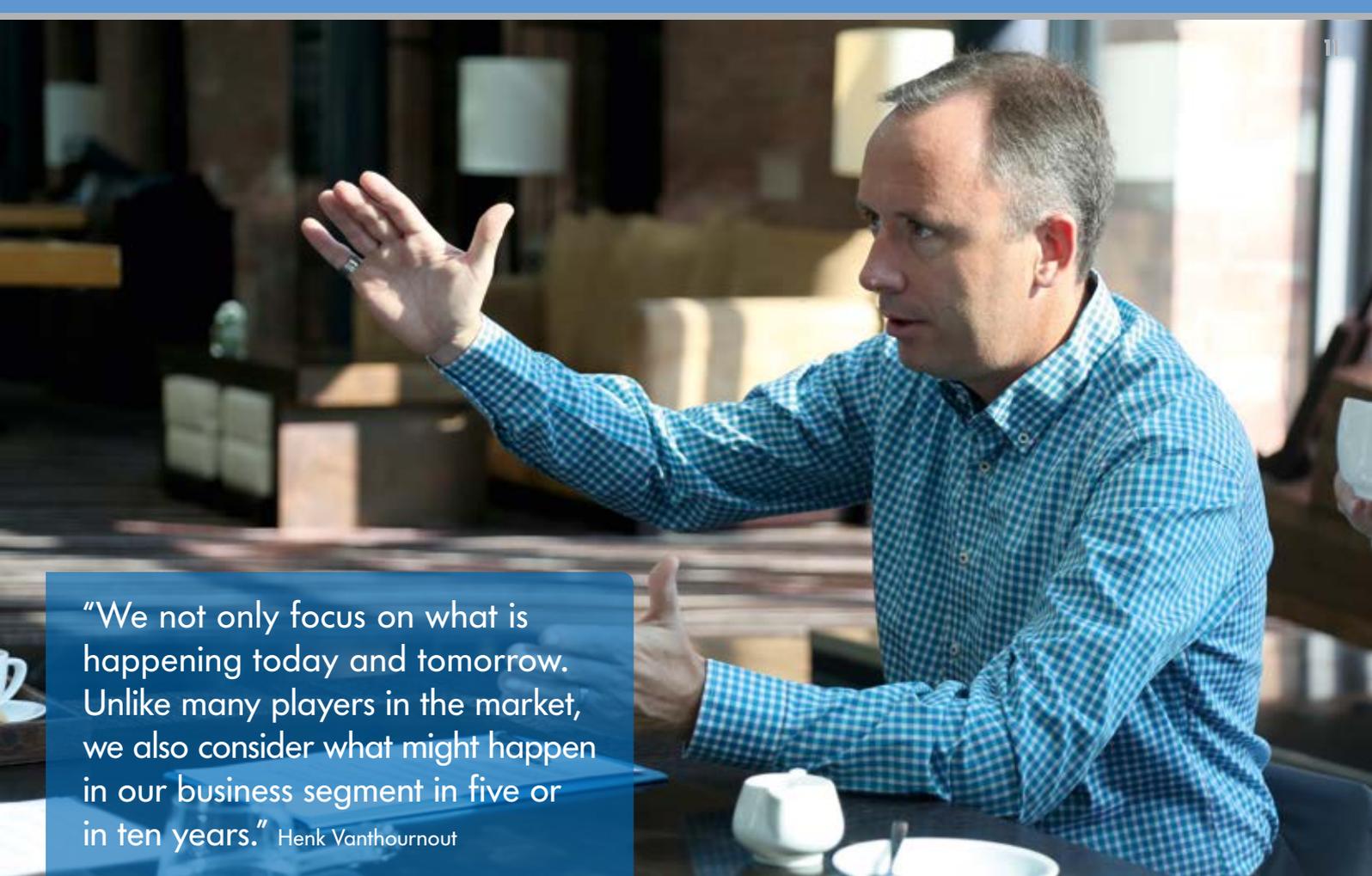
Is globalization still a topic for you?

Henk Vanthournout: Not in the passenger vehicle sector. This is where BorgWarner Turbo Systems has its strongest worldwide

“Electrification is something genuinely new, a real game-changer.”

Wouter Nijenhuis





“We not only focus on what is happening today and tomorrow. Unlike many players in the market, we also consider what might happen in our business segment in five or in ten years.” Henk Vanthournout

presence with locations in South and North America, Europa, China, Korea and now also Japan. We are currently also planning to expand in Thailand. In terms of capacity, we are ideally positioned for the next ten years. Compared with other market members, we can stand proud and tell customers that we are fully equipped to handle the step-by-step expansion of their operations.

Is this also the case in the commercial vehicle sector?

Wouter Nijenhuis: We are right in the middle of the globalization process here. More and more customers are getting together to found joint ventures. The project landscape also shows that operations are becoming increasingly global. We are adapting to this and support this trend. Of course, we enjoy the benefit of being able to rely on our infrastructure from the passenger vehicle sector. After all, we share the same locations and all BorgWarner Turbo Systems facilities produce units for both commercial and passenger vehicles.

You have already mentioned the massive growth, which obviously also leads to a growing number of customer projects. How can you be sure to deliver on schedule and maintain consistently high quality when working with almost exponential growth of this kind?

Henk Vanthournout: In the past, we coordinated many projects centrally from Kirchheimbolanden. However, today we enter the various regions with our “Local Accountability, Global Strength (LAGS)” business model, which allows us to handle projects autonomously at each location. In other words, we have established a corresponding infrastructure and staffing level has grown regionally over the years.

You see a lot of the BorgWarner turbo world. What impresses you the most?

Wouter Nijenhuis: Although there are regional differences, it really does not matter which BorgWarner facility you visit worldwide. You will quickly notice that it is a BorgWarner enterprise. We live by the same culture, the employees are all highly motivated and everyone works effectively in a team. This not only impresses me, it also makes me very proud.

This is made even more amazing if we consider that BorgWarner Turbo Systems has not been around very long in its present form.

Henk Vanthournout: Absolutely. We should also not forget that we merged the passenger vehicle and commercial vehicle sectors only two years ago. This was a major challenge, although one which we mastered very effectively and which provided us with many synergies in the fields

of engineering and production. I am also fascinated by the growth in Asia and Mexico, where we were able to establish an excellent infrastructure within just a few years. The new facilities got up to speed and were producing at the highest level very quickly in terms of quality, delivery performance and profitability. It is amazing to see just how well the global cooperation works. Over the years, a huge pool of experience has been amassed in Europe. This is now being shared with the regions.

What else makes BorgWarner different from other companies?

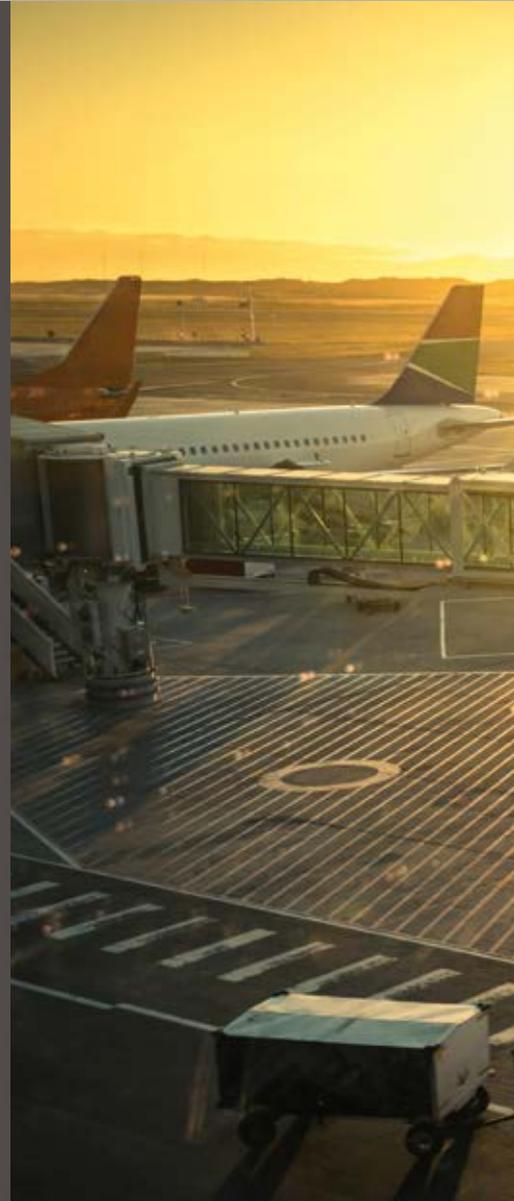
Henk Vanthournout: We not only focus on what is happening today and tomorrow, but also consider what might happen next month or in ten years. In this respect, we differentiate ourselves from many of our competitors in the market. The 10-year strategy is aligned with our company philosophy. We do not simply talk about it, we actually live by it.

Wouter Nijenhuis: This fits in with our very open culture and short decision-making chains. When something is detected, we are able to react very quickly and work in a specific direction. This agility is a key characteristic of BorgWarner.

Gentlemen, many thanks for the interesting discussion.

Ready for take-Off!

Whether ever stricter emissions and consumption guidelines or increasingly exacting requirements with regard to power density and service life – exhaust gas turbocharging today faces tough requirements in terms of the materials used. BorgWarner is now also addressing this technological challenge through use of innovative aluminum alloys from the aviation industry.



Alloy 2618 is a modern material that has established itself as a standard alloy for milled aluminum impellers in the last few years and also proven its value at BorgWarner in many turbocharging systems. Despite this, the company engages in a continual and intensive search for new, still stronger materials for future, even more technologically challenging applications.

From the aircraft to the turbocharger

The ultra-modern aluminum-lithium alloys 2055 and 2099, produced by Alcoa, caught the attention of the developers here. They were originally developed to reduce the weight of wings and fuselages in aircraft, as well as to improve the fatigue strength of the wings. This was achieved by reducing the material density, while also increasing the ductility, modulus of elasticity and high-temperature resistance. The two new materials have been approved for use in aircraft

since 2013 and have been aptitude tested at BorgWarner for use in the automotive sector – specifically in exhaust gas turbocharging.

To turbocharge future passenger car engines, for example, the company is looking for a material that permits greater circumferential speeds of the impeller wheel. While the maximum speed is currently around 560 m/sec, the engineers at BorgWarner are keen to increase this further. For this to work, the wheel must offer increased resistance to cyclical loads (LCF). In addition to this, improved media resistance is required for applications with low-pressure exhaust gas recirculation. The focus here is on increased mechanical resistance to erosion caused by water particles or droplet erosion, improved chemical resistance to corrosion caused by water and exhaust gas condensates (weak acid with pH values between 2 and 3), and greater resistance to solid particles up to 200 µm in size.

Tested and rated as very good

The developers at BorgWarner subjected impellers made of alloy 2055 and alloy 2099 to intensive corrosion tests and were able to determine a significant improvement in corrosion resistance over standard wheels made of alloy 2618.

Warm tension tests also display an increase in mechanical strength. The yield point and yield strength of the Al-Li alloys are significantly higher at 200°C when compared with alloy 2618. The Wöhler curves, with whose help the vibration resistance of the

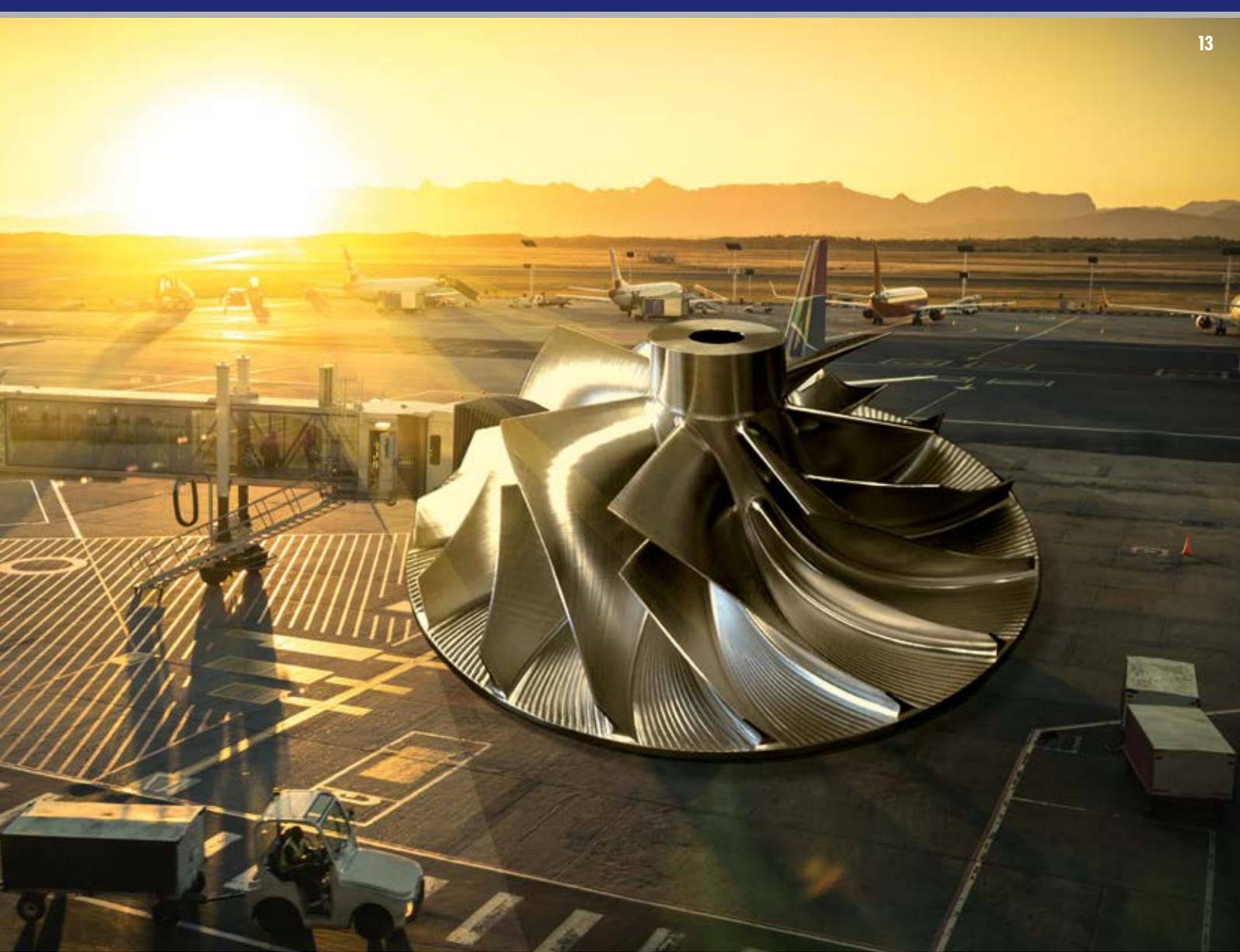
In the corrosion test (350 hours of outdoor exposure in the NaCl/MgCl/CaCl medium), the new alloy 2099 (on the right) displays significantly improved corrosion resistance over alloy 2618 (on the left).



VR – Material: Alloy 2618



VR – Material: Alloy 2099



new alloys 2055 and 2099 are measured, also display improvements over the previous standard series material, alloy 2618, with regard to service life. As such, the new aluminum alloys are ideal materials for meeting the strict technological requirements of future engine generations and will therefore be used in new BorgWarner turbochargers.

Yet beside new materials, the turbo specialist is also looking for innovative machining processes to improve the performance and service life of its turbochargers. In this vein, the impellers made of the new alloys, as well as those made of alloy 2618, are soon also to be subjected to a controlled shot-peening process. Based on the experience of the developers, this surface processing of the impeller wheel leads to another significant increase in service life. Surface treatments such as oxidation to Al_{2O_3} or application of a polymer sealer are also being investigated. The objectives here are to

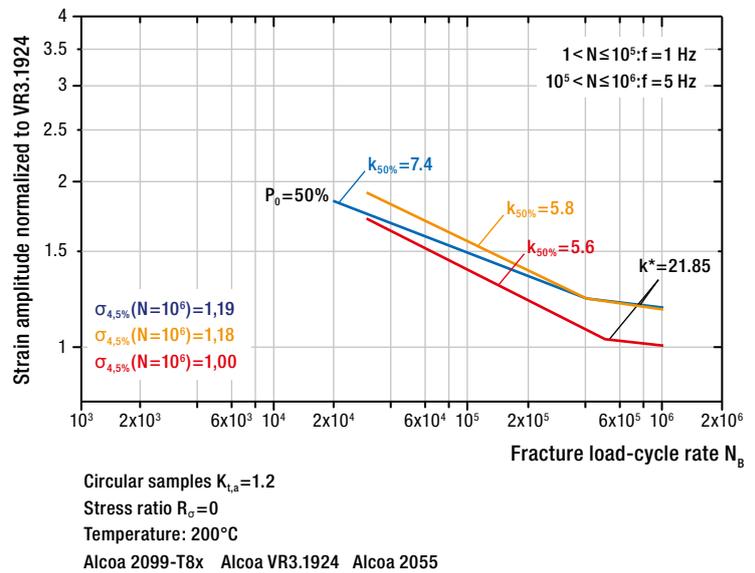
further improve the media resistance and resistance to particle bombardment of the impeller wheel and to equip the wheel optimally for use in combination with low-pressure exhaust gas recirculation.

Intensive materials research

So that BorgWarner can rely on high-performance materials for future turbocharger applications and their strict technological requirements, the company has intensified its materials research and significantly extended its materials development activities. The experts at BorgWarner are also collaborating intensively with external suppliers in this endeavor as a way of tapping the potential of innovative new materials for the field of exhaust gas turbocharging.

The primary focus here is on finding materials that further improve the performance, reliability and efficiency of future turbocharger generations.

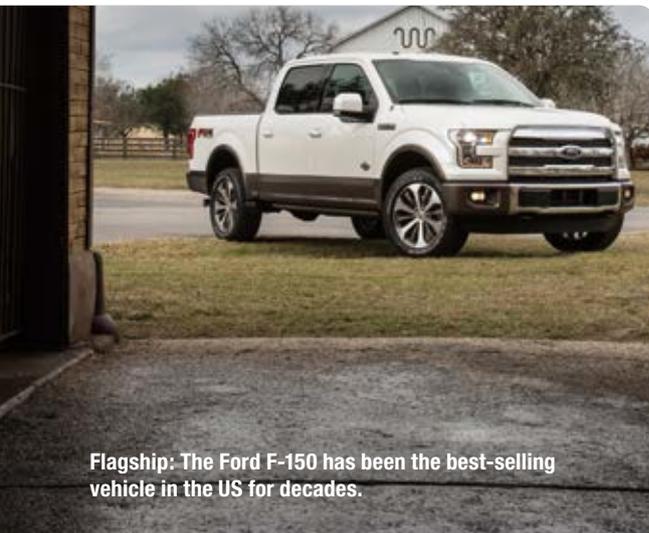
Fatigue strength tests show a significant extension in service life over the previous standard material.





Ford & Furious

Ford F – for lovers of rugged vehicles with high load capacity, this letter represents the epitome of the American pick-up. The 13th generation of Ford's successful model was therefore eagerly anticipated. BorgWarner supplies two turbochargers for the brand new 165 cubic inch (2.7 liter) EcoBoost engine in the F-150 model.



Flagship: The Ford F-150 has been the best-selling vehicle in the US for decades.

Ford has been producing its F models since 1948. The pick-up has been the best-selling vehicle in the US for more than three decades and is number 2 in the worldwide list of most produced vehicles. Fans of Ford's F models not only appreciate the outstanding transport capacity they offer, but also the seemingly inexhaustible torque delivered by their large-displacement V6 and V8 engines. When developing the latest generation of the popular pick-up, which has been available since the end of 2014, Ford was therefore adamant that the engines must meet the high expectations of the discerning group of buyers in full.

High performance, low fuel consumption

The 165 cubic inch (2.7 liter) EcoBoost engine with 6 cylinders is a true innovation. In keeping with the downsizing trend, this new unit boasts less displacement. However it still offers the kind of impressive performance drivers expect from a V6, while also delivering significantly improved fuel consumption and emissions figures. Compared with the predecessor generation, the engineers at Ford were able to improve fuel efficiency by between 5% and 29%, depending on the model. The new V6 engine generates 325 bhp and maxi-



Not one but two modern BorgWarner waste gate turbochargers help the Ford F-150 deliver impressive performance and consumption figures.

mum torque of 276 lb-ft (375 Nm), which is available from 3,000 rpm. Despite weighing over 2 tons, the pick-up delivers an impressive average consumption figure of 22 mpg US (26 mpg UK) and sets new standards in this vehicle class. The new model thereby continues the success story of its predecessors: The 213 cubic inch (3.5 liter) V6 EcoBoost engine, which Ford still offers and is also equipped with BorgWarner turbocharging systems, is today considered the pioneer of downsizing in the pick-up segment.

Powerful thanks to bi-turbo

The excellent performance figures of the new EcoBoost drive are in no small part thanks to an innovative BorgWarner waste gate turbocharger with vacuum pneumatic actuator. Not one but two turbocharging systems of this type ensure optimum pressure. When defining its requirements specifications for the developers at BorgWarner, Ford listed high effi-

ciency and spontaneous response as the top priorities. The engineers at the turbocharger specialist therefore worked intensively on achieving optimum thermodynamics of the impeller and turbine to meet Ford's strict requirements. The results are impressive: The new 165 cubic inch (2.7 liter) EcoBoost engine impresses drivers from very low revs thanks to its excellent response and power delivery.

With the advanced turbocharger for the F-150, BorgWarner has once again successfully underlined its role as Ford's most important technology partner in developing highly efficient EcoBoost engines. Just like many other turbochargers for Ford in North America, the turbocharging system is produced at BorgWarner's ultra-modern facility in Ramos (Mexico).



BorgWarner implements highly flexible production line

Flexibility and quality in the manufacture of turbochargers have always been key strengths of BorgWarner in Bradford. The facility is now demonstrating this once again with its new, highly flexible production line for commercial vehicle VTG turbochargers.

With a zero-defect rate and significantly reduced set-up times, the new VTG production line in Bradford sets standards in terms of both quality and flexibility.

0

zero-defect rate

In designing and implementing the line, the team in Bradford received the support of experts from BorgWarner in Asheville, who already have a great deal of experience in the manufacture of VTG turbochargers. This led to the Bradford facility installing an ultra-modern production line which, thanks to the principles of kaizen, poka yoke, lean production and a high degree of process ergonomics, greatly surpasses the original line.

Around 30 integrated safety checks are performed, among other things to ensure compliance with the desired zero-defect rate.

The new VTG production line was originally set up to produce BV55 turbochargers for construction equipment manufacturer JCB. However, the team at the location designed the line flexibly from the very outset, so that other VTG turbos can also be manufactured.

Alongside five different BV55 versions for JCB, BV70 versions are now also being produced for two further well-known European customers. This was all made possible by optimizing the set-up time in line with the SMED method (single minute exchange of die), which allows the previous standard set-up times to be significantly reduced.



Material testing 2.0

How can you see through a turbocharger – without breaking it down into its components or even destroying it? BorgWarner is answering this exciting question in Poland with an innovative technology that many people will know from the field of medicine. The Rzeszów facility uses a computer tomography system for effective component and material testing.

Aluminum or titanium impellers, cast iron or stainless steel turbine casings ... – the most diverse of materials and components are used in the production of turbocharging systems. To ensure that BorgWarner can guarantee a high degree of reliability and durability of all components, including those developed in collaboration with suppliers, they are subjected to extensive materials testing and installation monitoring. Only then are they released for series production. However, turbocharging systems still in development must also go through these inspections before having their thermomechanical resilience and durability tested in the engine testing bay.

Optimum replacement for previous testing procedures

Like elsewhere, materials testing at the Rzeszów Technical Center (RTC) used to involve sawing apart specimen casings/prototypes and then investigating them using a CMM (coordinate measuring machine). However, this required often costly prototypes and pilot series models to be 'wasted'. The fact that the components being destroyed were not identical to the actual products used in practical tests represented an additional problem.

BorgWarner therefore decided to acquire an ultra-modern high-power computer tomography machine for material and component testing. The CT system operates at a voltage of 450 kV and is capable of penetrating

extremely dense materials, such as those used in turbocharger production. This means that the inner material characteristics of the turbine casing and also the integrity when fitting components that have been welded together can be checked non-destructively.

CT analysis provides more information

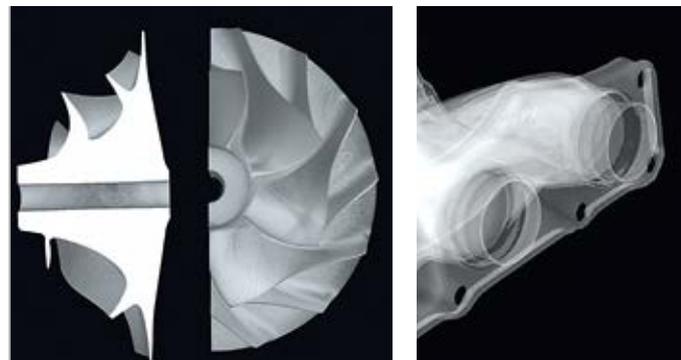
Turbine casings can, for example, be very easily and reliably tested for porosity and material inclusions, while also checking for cracks and cavities. In addition to this, the investigation provides reliable conclusions as to whether any material failure has been caused by the type or quality of the material used or the design/production process. A fully fitted bearing housing, on the other hand, can be tested to determine whether all intended individual parts have been fitted correctly and completely. A precise test can also be performed to determine the porosity and mechanical integrity of the connection between turbine wheel and shaft. This is a test that would simply not be possible visually.

As such, CT-based component and material inspection offers BorgWarner a large number of crucial advantages. For example, the prototypes tested in the engine test bays are the exact same units that were previously scanned. The powerful CT system also facilitates many more extensive analyses and measurements – delivering significantly



The computer tomography system allows reliable and non-destructive testing of components and material quality.

more data. The latest software allows the tested components to be compared with the CAD model or reference sample, either in the form of a direct comparison or via GD&T analysis (geometric dimensioning and tolerancing). Ultimately, CT analysis also reduces costs, since the components inspected can be re-used for further tests.



The system that sees it all: Both impellers and turbine casings can be reliably checked without any issues.



Further development

At the start of 2013, BorgWarner opened an ultra-modern new facility in Brazil. The Itatiba location, which replaced the Campinas production site, now also has a dedicated development center.

Local accountability, global strength: In keeping with this business model, leading global automotive supplier BorgWarner is increasingly expanding the capabilities and independence of its individual locations as a way of supporting customers in local markets with comprehensive local expertise. The new Itatiba facility, which now also has an advanced research and development center, is perhaps the best example of this.

Sufficient capacities for development and testing

Since the start of 2015, a dedicated team of engineers has been working in an area with total floor space of 21,500 square feet (2,000 m²) to create innovative technologies for the rapidly growing Brazilian vehicle mar-

ket. One of the first projects to be handled by the specialists at BorgWarner was development of turbocharging systems specifically for use in flex-fuel engines (see also article opposite: Fit for flex-fuel). To this end, the development center has two engine test bays, which can be used to test and validate new technologies under ideal conditions. The testing capacity can also be expanded to include further test bays in future.

Innovations in demand

BorgWarner is anticipating further significant increases in demand for modern turbocharging systems. After all, environmentally friendly powertrain technologies that allow fuel consumption and exhaust emissions to be reduced while improving

performance are also extremely popular among Brazilian auto manufacturers. This is due to Inovar Auto, a program initiated by the Brazilian government which both encourages and requires investment and innovation in the local automotive industry. With its new development center, BorgWarner is supporting local customers in reacting quickly to changed market conditions and bringing new technologies to series maturity in a short space of time that allow individual local requirements to be optimally met.

The new development center therefore makes the Itatiba production site, with total indoor floor space in excess of 225,000 square feet (21,000 m²), one of the most powerful development and supply partners to the Brazilian automotive industry.

Over the course of the last ten years, Brazil has developed into the world's fourth largest automobile market – ahead of Germany.



The new development center in Itatiba: Some 21,500 square feet of space are dedicated to producing innovative technologies for the growing Brazilian vehicle market.

Fit for flex-fuel

In Brazil, so-called flex-fuel vehicles with gasoline engines burn a mix of gasoline and ethanol. The ethanol content in the tank of these vehicles can range from 25% all the way up to 100%. At its new location in Itatiba City, BorgWarner developed the first flex-fuel turbocharger to be produced in Brazil for the growing domestic passenger vehicle market.

Turbocharged gasoline engines with reduced displacement represent an important development trend in Brazil. BorgWarner is anticipating a considerable increase in demand for modern downsizing engines and is keen to make a significant contribution to reducing both fuel consumption and exhaust gas emissions with the new flex-fuel turbocharger technology. The turbocharger specialist is thereby supporting auto manufacturers in complying with the requirements of the Brazilian Inovar Auto program, which aims to drive forward technological developments in the domestic market.

Optimized for ethanol use

The local team of developers was supported by the development center in Kirchheimbolanden in creating the flex-fuel turbocharger.

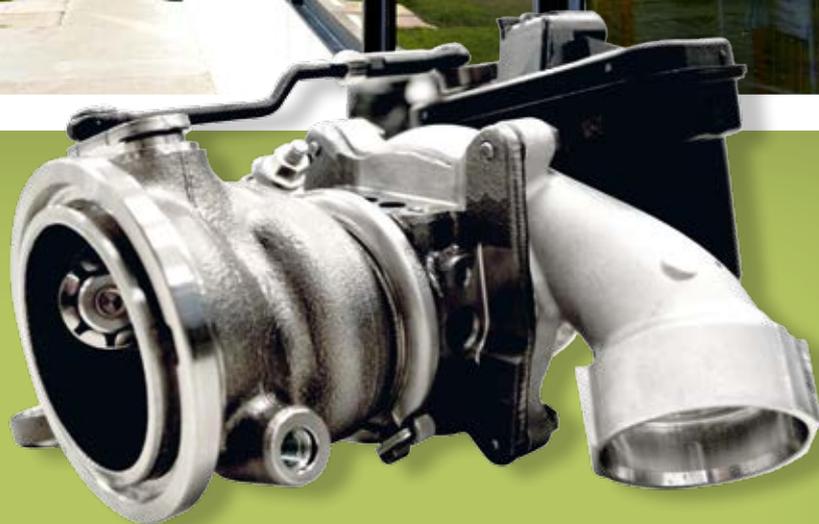
The primary challenge to overcome here was setting up the turbocharging system for use with the ethanol biofuel. In comparison with conventional fuels, combustion of ethanol leads to greater corrosion rates and increased oil thinning, which can potentially compromise the durability of the turbocharging system. The engineers employed several tactics to solve this problem, including selection of optimized materials. This resulted in excellent durability of the new turbocharger when operated with pure ethanol.

The new flex-fuel turbocharger in the B01 range excels through its particularly compact design. It employs a milled compressor wheel, an optimized bearing system and a wastegate that is controlled by an electric actuator. The experts at BorgWarner designed the turbocharger in such a way that it can be fitted

directly to the exhaust manifold, which is integrated in the cylinder head. This allows an extremely compact overall engine size. The new flex-fuel turbochargers are designed for gasoline engines with displacements from 49 to 98 cubic inches (0.8 to 1.6 liters). They have been in use at a large global auto manufacturer since mid-2015.

Flex-fuel turbos expand the passenger vehicle business

BorgWarner has already been producing turbochargers for light and heavy-duty commercial vehicles in Brazil for 40 years. With the new flex-fuel turbochargers, the company is now expanding its business to include turbocharging systems for passenger vehicles with gasoline engines and impressively demonstrating its local development expertise.



Compact, robust and ethanol-compatible: the B01 flex-fuel turbocharger from BorgWarner.

Bradford receives award for promoting young talent

Everyone is talking about how hard it is to find skilled staff. BorgWarner in Bradford is doing something about this. For seven years, the location has been supporting the Engineering Education Scheme in Great Britain – a sponsorship program with the aim of conveying technical knowledge to pupils and getting them excited about the prospect of a career in engineering.



At the end of April, the two teams of pupils from Greenhead College sponsored by BorgWarner presented their project results.

The EES was established 30 years ago by the non-profit organization Engineering Development Trust. More than 30,000 young people – including more than 9,000 girls – have now taken part in the program, slipping into the role of engineers. The EES brings engineering companies together with local schools. For eight months, an engineer from the company, a teacher from the school and four 16 to 17-year-old pupils work together in a team on a project specified by the company. The pupils are assigned a task, draw up a solution, develop and test prototypes and then use these to derive a recommendation for the company. Finally, the junior engineers present their project to a jury, which is made up of industry representatives.

Study projects with practical benefit

BorgWarner in Bradford has been involved with the program for seven years and sponsors two project teams at Greenhead College in Huddersfield. The pupils at the

renowned college have already worked on a large number of turbocharger projects, addressing assembly, design and construction issues. Several of the concepts created have even flowed into series production.

The 14 BorgWarner engineers who have been involved to date and supported the trainees have worked in Design, Manufacturing Engineering, Simulations and Applications Engineering. One of these trainees – Tony Allen – subsequently went on to become Plant Manager in Bradford. This emphasizes just how much importance BorgWarner places on the EES projects.

A true win-win situation

At the presentation ceremony held in April, where this year's students presented their project results, the Bradford facility also received an award for its longstanding support of the Engineering Education Scheme. For BorgWarner, this commitment benefits everyone involved. After all, assu-

ming responsibility for the common good – which includes promoting young talent – is a key component in the automotive supplier's corporate values. Yet there are also other reasons for the company's participation in the EES. For example, the program provides a good opportunity for young engineers at BorgWarner to gain some valuable management experience. In addition to this, the company can identify and promote potential junior staff early on. Ultimately, the projects often also produce solutions that deliver genuine benefits for BorgWarner's business. In other words: a win-win situation for everyone involved.