

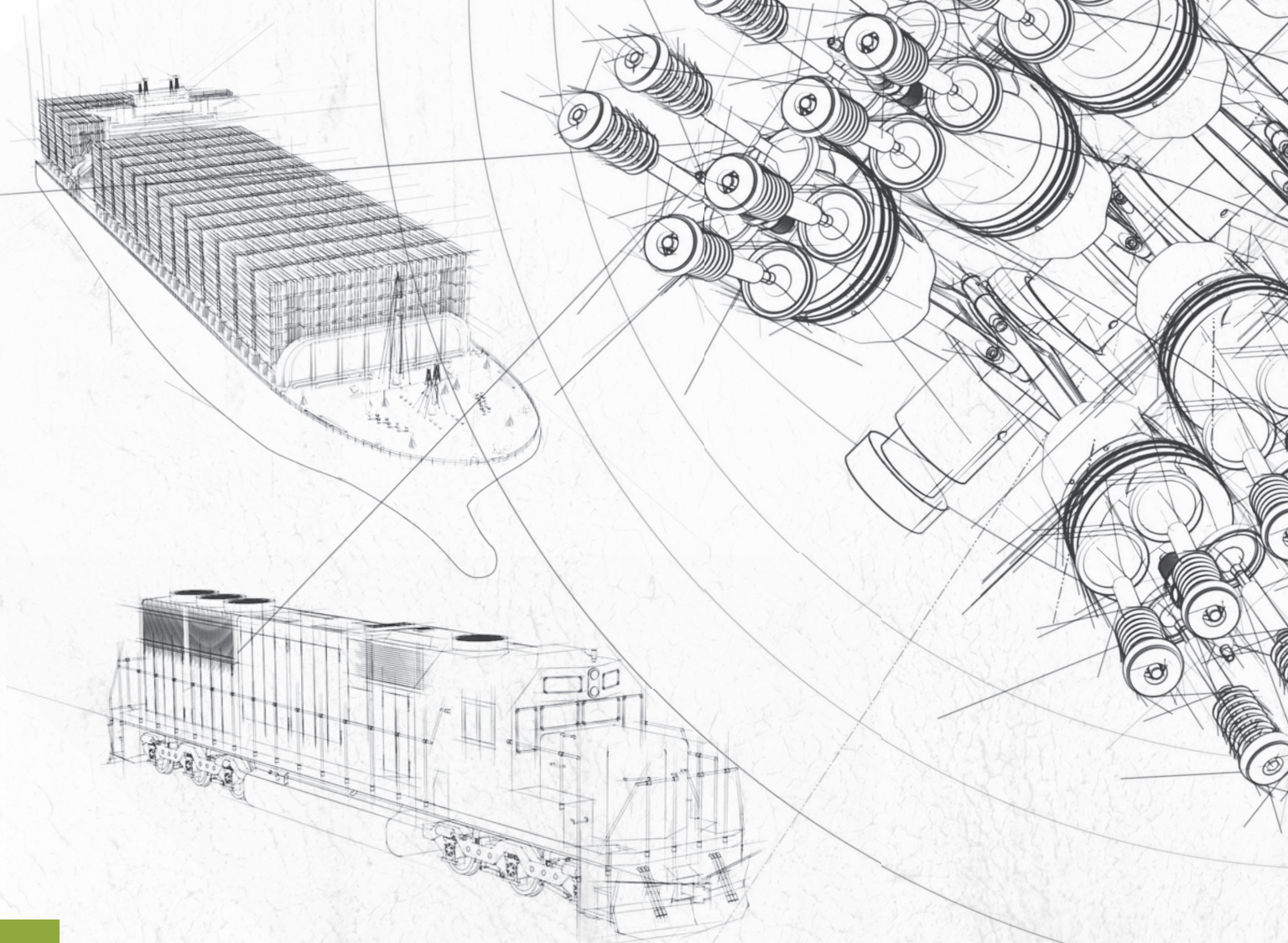


Powertrain XXL

Cutting-edge Technologies for Large Bore Engines

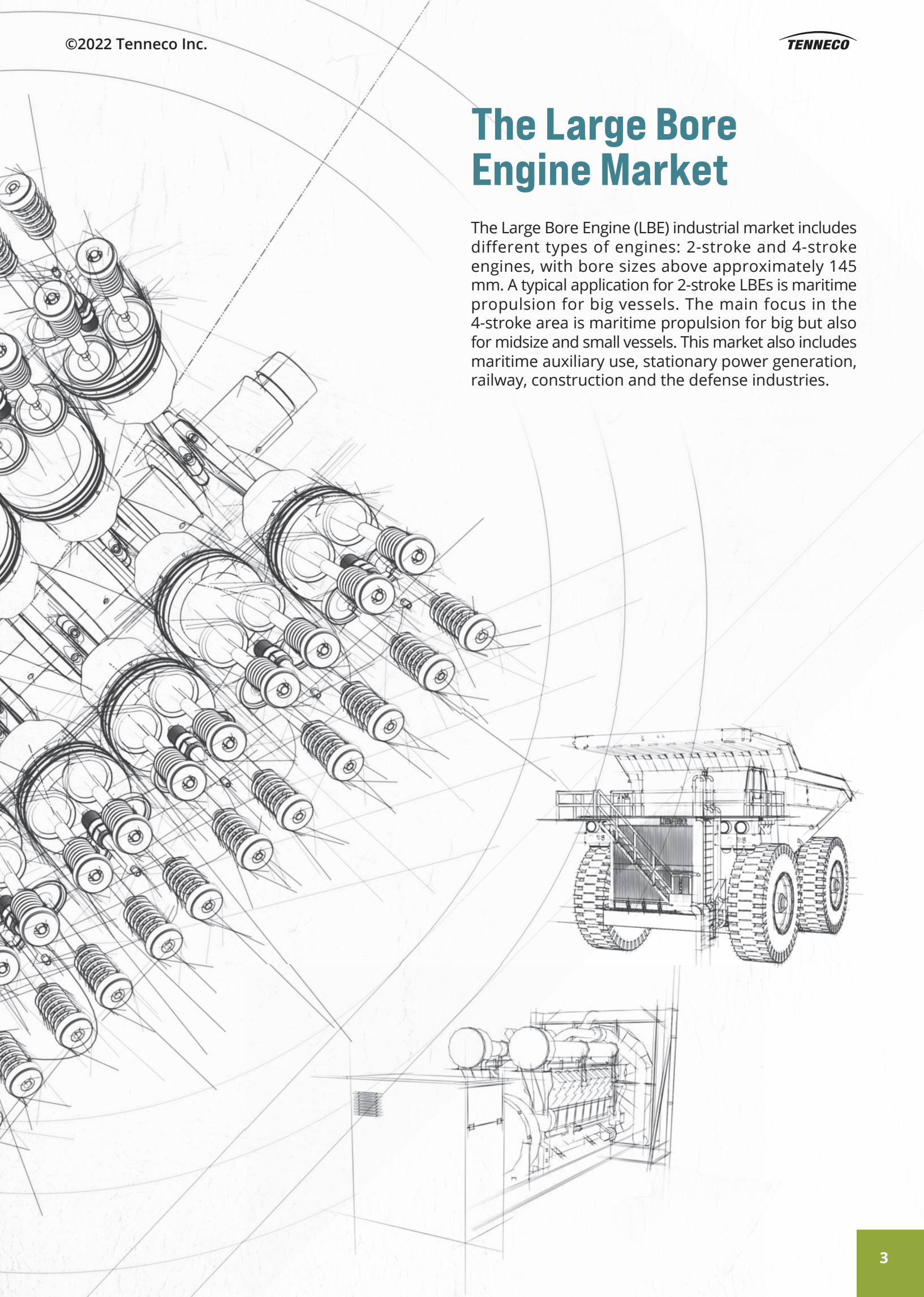
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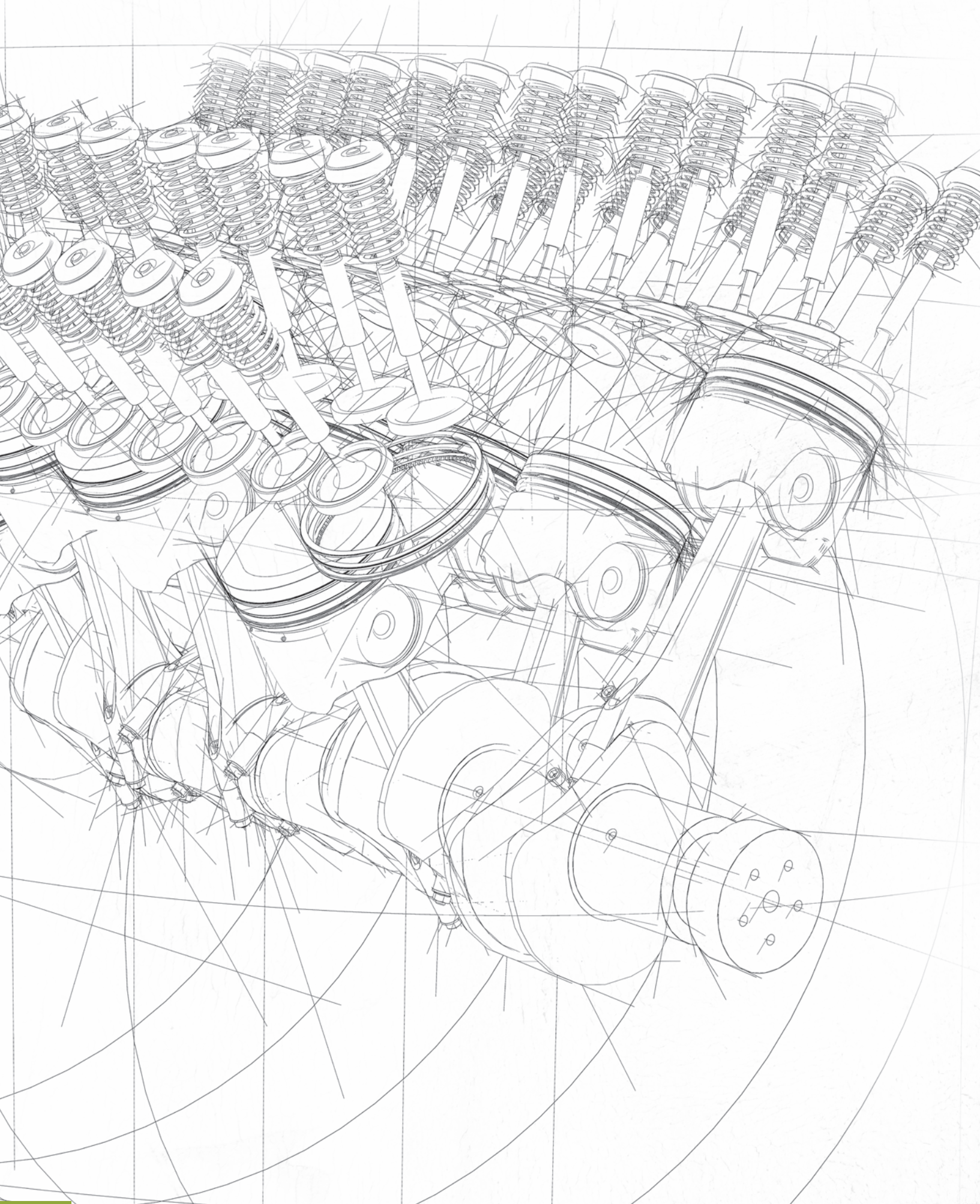
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The Large Bore Engine Market

The Large Bore Engine (LBE) industrial market includes different types of engines: 2-stroke and 4-stroke engines, with bore sizes above approximately 145 mm. A typical application for 2-stroke LBEs is maritime propulsion for big vessels. The main focus in the 4-stroke area is maritime propulsion for big but also for midsize and small vessels. This market also includes maritime auxiliary use, stationary power generation, railway, construction and the defense industries.





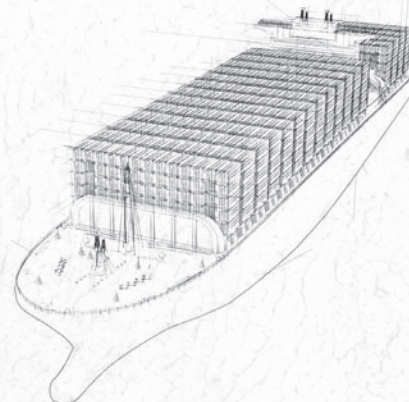
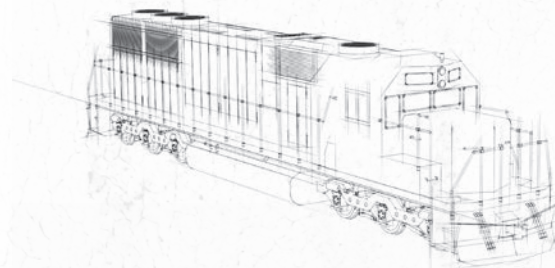
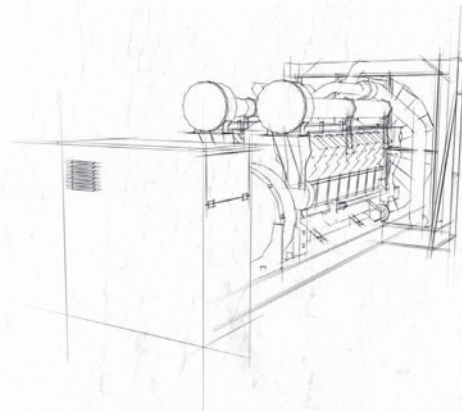
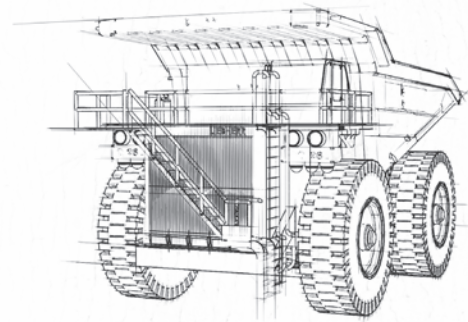
Tenneco's Powertrain Business Group

High Efficiency Components for Tomorrow's Large Bore Engines

The technical challenges facing LBEs are greater now than at any point in the last hundred years. Every industrial application sector—from marine and rail to construction and power generation—requires each new engine generation to take ever larger steps in reducing emissions, fuel and oil consumption, downtime and running costs. That means optimizing every critical component to ensure it is as efficient as it possibly can be—not only in its specification, but also in the way it interacts with the complete engine system and the environment. Calling on a skill set that ranges from in-depth knowledge in materials and coatings to precision manufacturing, the result is a Tenneco portfolio of award-winning technologies that help achieve design goals more quickly and cost-effectively.

Leveraging our extensive expertise and capabilities as a leading global supplier of engine components for automotive and a host of other sectors, we can help address design issues before they become barriers to innovation. For example, with Tenneco's range of enabling technologies, consideration of the impact on components and systems of harsh environments and new combustion strategies with higher temperatures and pressures is just one of the areas that we have explored. We also understand that the nature of the LBE market requires engines to have the longest possible product life cycle, with clever design refreshes keeping each engine family competitive. Our engineers can help here too, with technologies that reduce weight and friction, improve combustion efficiency or are maintenance-free; all achieved with incremental component-level changes that can be introduced without a major system redesign.

This brochure introduces our technologies for 2-stroke and 4-stroke engines with bore sizes above 145 mm, including high-performance pistons and piston rings, bearings, valvetrain components and ignition products. Each one is the result of substantial research and development, utilizing state-of-the-art analysis, simulation and physical testing capabilities, focused on supporting our customers to meet their next LBE design goals.



Large Bore Engine Piston Rings

Technologies to Meet a Full Range of LBE Piston Ring Requirements

Piston ring design for LBEs is increasingly driven by the desire to minimize environmental impact through reduced oil consumption and emissions, and the pressure to cut operating costs by fuel economy and extending Time Between Overhauls (TBO).

As engine manufacturers increase efficiency and specific power output, LBE rings must also function reliably when facing rising combustion temperatures and pressures. In addition, they need to resist the corrosion that can occur due to many engines being operated with heavy fuel oil.

With its sector-leading expertise and an extensive range of piston rings, Tenneco satisfies these specific demands in the 2- and 4-stroke LBE market with ring geometries that optimize contact conditions with the cylinder bore, and through the use of wear-resistant materials and coatings that promote longer life.

While some of Tenneco's technologies are suitable for a wide range of applications, others are directed at specific sectors, such as the patented oil control LKZ-Ring® for 4-stroke engines.

The LKZ-Ring® uses a stepped and tapered profile to provide optimal downward scraping action with minimal upward scraping. This allows the ring tension to be reduced, which cuts friction while minimizing oil consumption of 4-stroke engines.

Industrial Sealing Rings

In addition to its broad range of piston rings for LBE applications, Tenneco also offers smaller industrial sealing rings for radial and axial movement with diameters from 10 to 1,000 mm. Dynamically sealing the working chamber of pistons and sealing-off rotating shafts against the environment, sealing rings are used in a broad range of sectors: for gearboxes, pumps, hydraulic systems, gas compressors and vacuum pumps. Higher load collectives, ecological and economic targets require continued optimization of sealing rings, and a growing number of applications can no longer be effectively served by standard products. Building on the extensive experience of the company's automotive business, including precision manufacturing, we can develop an optimized blend of technologies and product properties depending on the application, helping our customers to reduce total cost of ownership, meeting the latest environmental requirements, increasing efficiency and generating sustained business growth.



GOETZE® and DAROS®

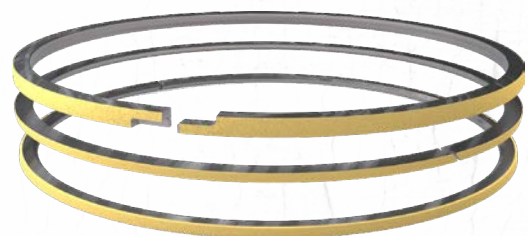
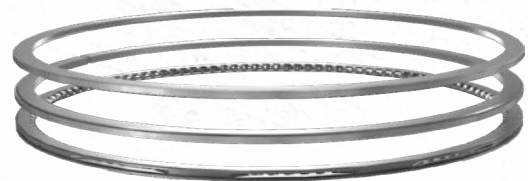


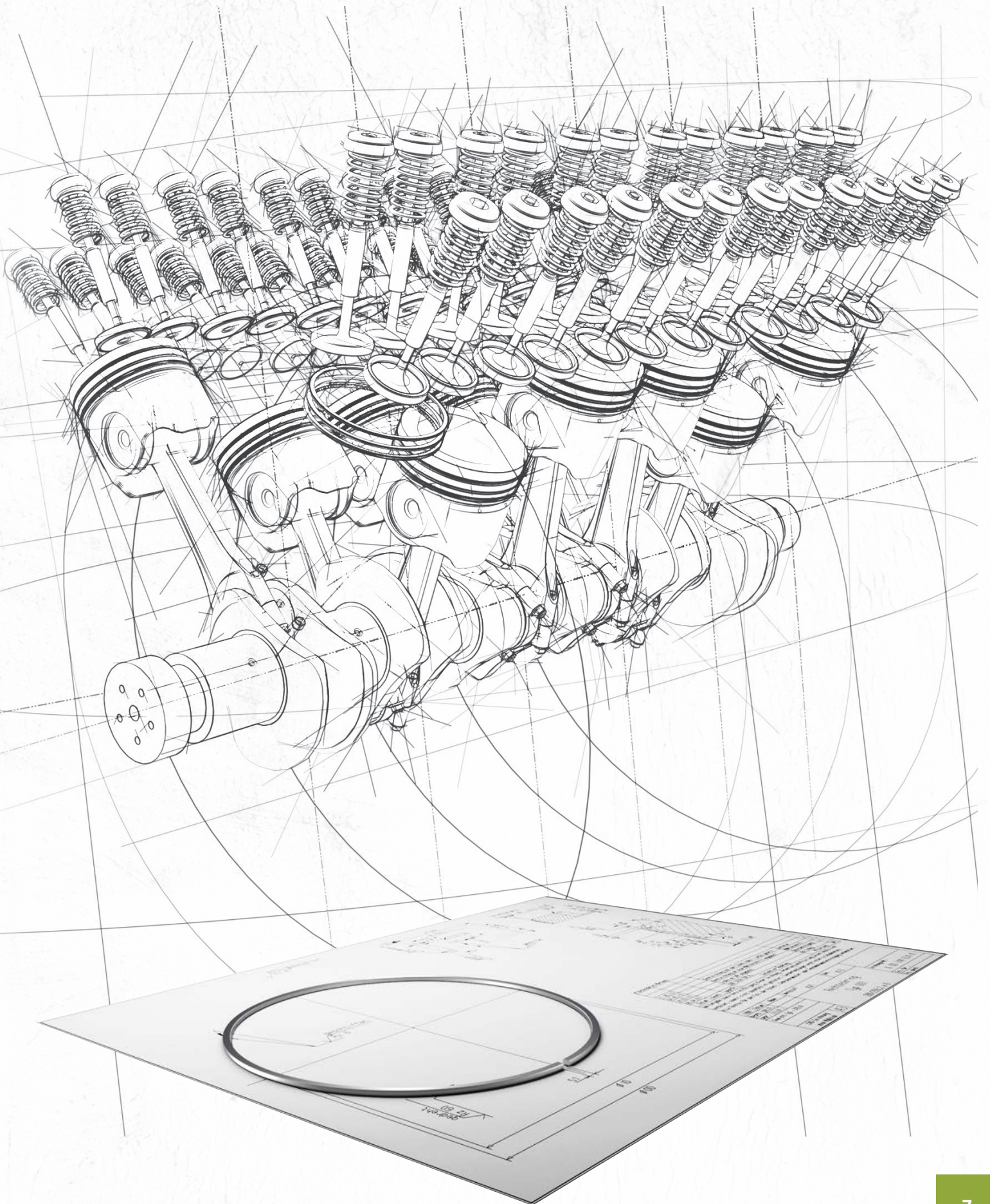
GOETZE®

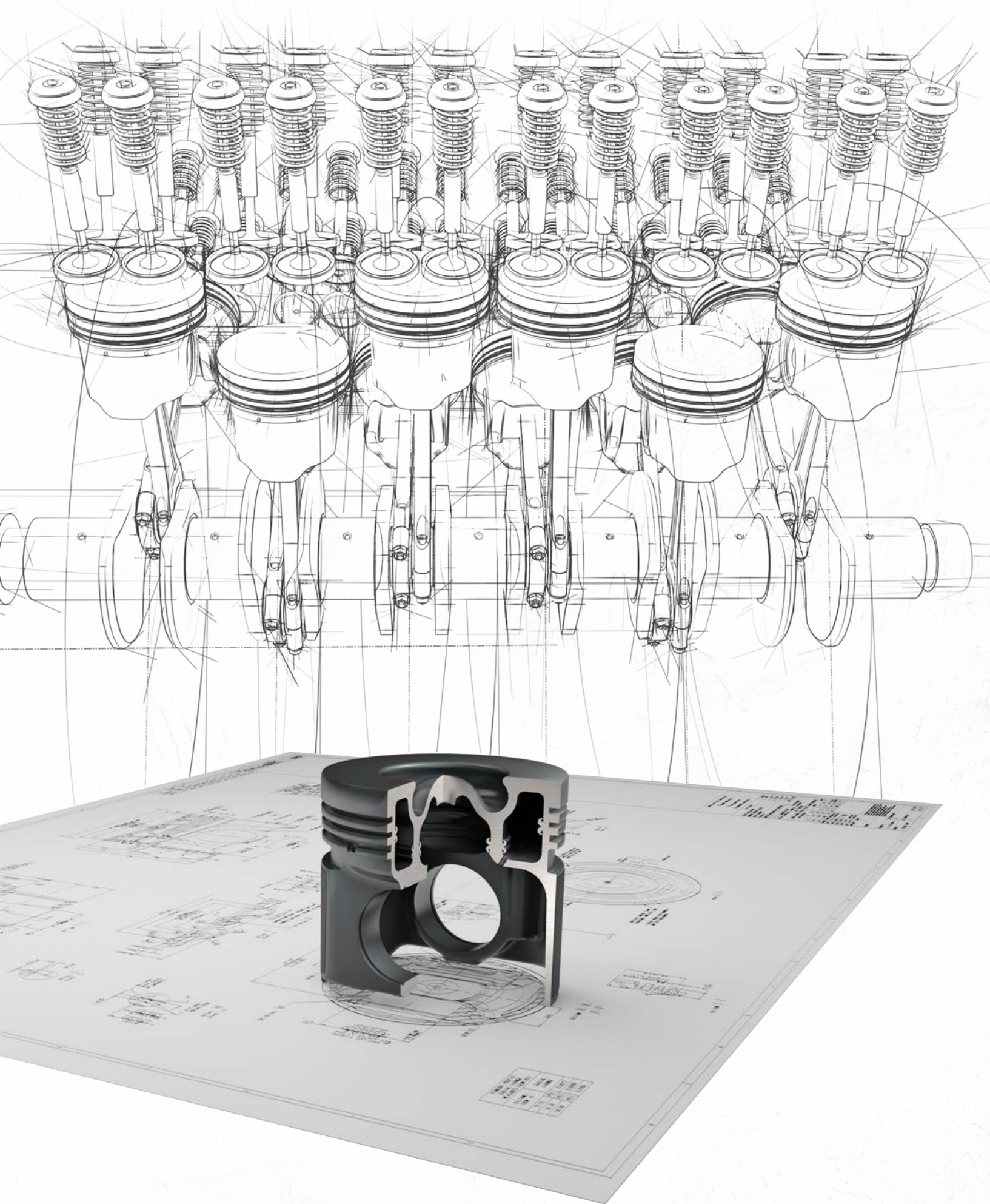


DAROS

Under the two well-known brands GOETZE® – for bores from 145 to 640 mm – and DAROS® – for bores between 260 and 980 mm – the company offers galvanic coatings, such as GDC® (Goetze Diamond Coating) and CKS® (Chrome Ceramic Coating). These highly efficient layers can promote a longer lifecycle by significantly reducing the wear rate of piston rings and cylinder liners. The wide range of galvanic, thermal spray coatings and electric arc processes enables selection of the optimal coating for each individual application.







Large Bore Engine Pistons

Advanced Aluminum and Steel Piston Technologies

Development of Large Bore Engines is mainly driven by endurance, reliability, total cost of ownership, suitability for different fuel options, general performance and low emissions. The latest LBEs are also required to operate with increased cylinder pressure and temperatures, which could reduce endurance and reliability in the absence of an emerging technology that compensates for harsher operating conditions.

That is exactly where Tenneco is leading with advanced piston technology, successfully expanding its capability with new aluminum and steel pistons.

For higher peak cylinder pressures and longest life expectation, Tenneco has successfully introduced the Monosteel® piston—a design concept, friction welded from two steel forgings into a one-piece steel piston. There is no risk of loosening bolts or wear and fretting at the abutment surfaces that can occur on bolted two-piece designs.

At the same time large piston galleries can be achieved with very high cooling efficiency or alternatively with a dual gallery. Optional laser groove hardening results in high wear resistance for variation in fuel type and quality, including heavy fuel oil (HFO).

Being very cost effective compared to composite pistons, Monosteel®, for which EcoTough®-D low friction skirt coating is available, has secured a significant share in the LBE market of pistons with up to 220 mm diameter.

For engines with moderately high peak cylinder pressures, we are offering aluminum pistons up to around 170 mm diameter size. Aluminum pistons are highly cost effective and, with the introduction of new features, offer performance and durability advantages for challenging engine applications.

Our exclusive horizontal casting process enables the use of innovative material alloys such as Duraform® G91 as well as flexible designs, including insert rings and cooling galleries to optimize the pistons for a wide range of bowl designs and fuels. The casting process is safeguarded using leading-edge nondestructive analysis tools, eddy current and ultrasonic inspection technology, where Tenneco is the industry benchmark for aluminum pistons. Our award-winning skirt graphite coating, EcoTough®-D sets the industry standard for low friction and wear/scuff resistance.

With our most advanced DuraBowl® remelting process, which significantly improves the micro-structure, we are able to enhance the high temperature strength in the bowl rim area.

Tenneco's extensive experience enables the company to work with its customers to develop wide-ranging aluminum or steel piston solutions. Our team of advanced engineering experts and extensive R&D facilities is able to reduce development time and cost, accelerating the route to commercialization.



Large Bore Engine Bearings

Comprehensive Range of Metal and Polymer Bearing Solutions

Whether for automotive, off-highway or industrial applications, Tenneco's sliding bearing technologies deliver environmentally friendly solutions that combine high performance, reliability and an exceptional lifetime. Our ability to provide solutions uniquely matched to a variety of requirements supports customer's needs in diverse market sectors. This capability is enabled through the pioneering development of lead-free electro-coating technologies and our expertise in both metal and polymer bearing formulations as well as self-lubricating composite sliding materials.

Tenneco manufactures bearings under the GLYCO® brand and serves the LBE bearings market through a joint venture with Patel Brass Works (PBW). We are the only manufacturer to offer the full breadth of material and manufacturing technologies necessary to provide lead based and lead-free solutions for the entire global engine and transmission market. Applications include 4-stroke engines for marine, railway, power generation and off-highway. Our bearings and bushings can also be found in turbo chargers, pumps and compressors.

Today's LBE market is facing tremendous changes such as increased TBO, increased specific load, alternative fuels, and upcoming lead-free legislations (RoHS – Restriction of Hazardous Substances). To meet these challenges, we have developed solutions such as high strength materials, overlays with low wear rates, lead-free materials, polymer coatings such as IROX® as well as high performance bearings with a sputter overlay.

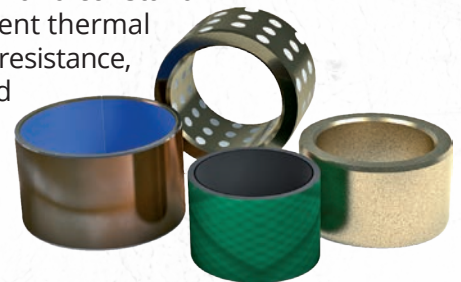
For critical fuels, such as heavy oil, land fill gas or biogas, with the risk of lead corrosion, customers can rely on our robust lead-free solutions. We have more than one decade of experience with those lead-free materials in the field.

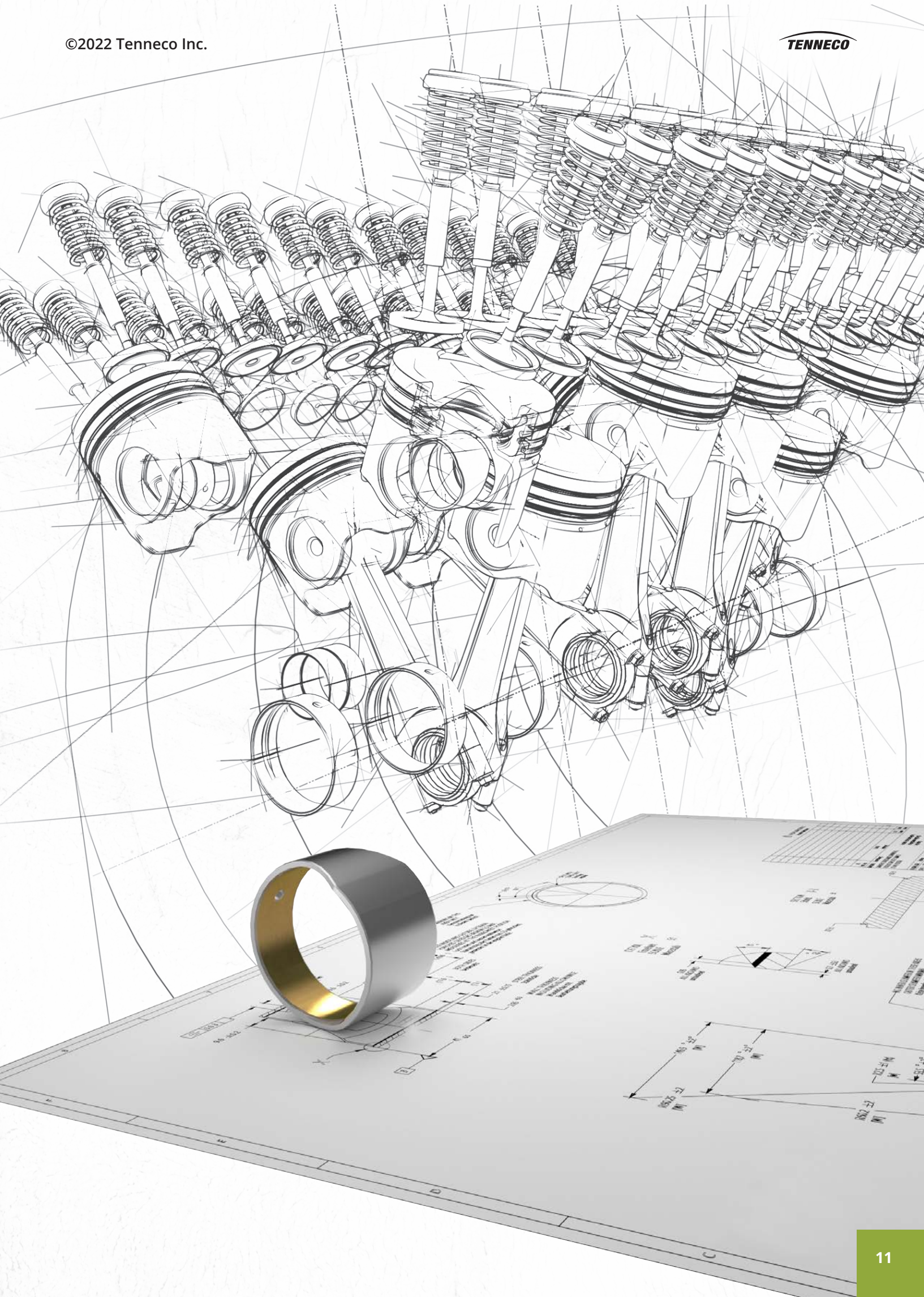
A comprehensive range of production processes gives us the opportunity to offer our customers an optimized manufacturing process matching their needs for either low or high volumes. Our portfolio of bearings and bushings covers a diameter range that spans from 8 mm to 350 mm and enables customers to work with one supplier for various requirements, e.g., for a larger main bearing, a highly loaded con-rod bearing or a corrosion resistant small end bush. We also offer bearing solutions for applications outside the crank drive, such as rocker arm bushes, camshaft bearings or oil pump bearings.

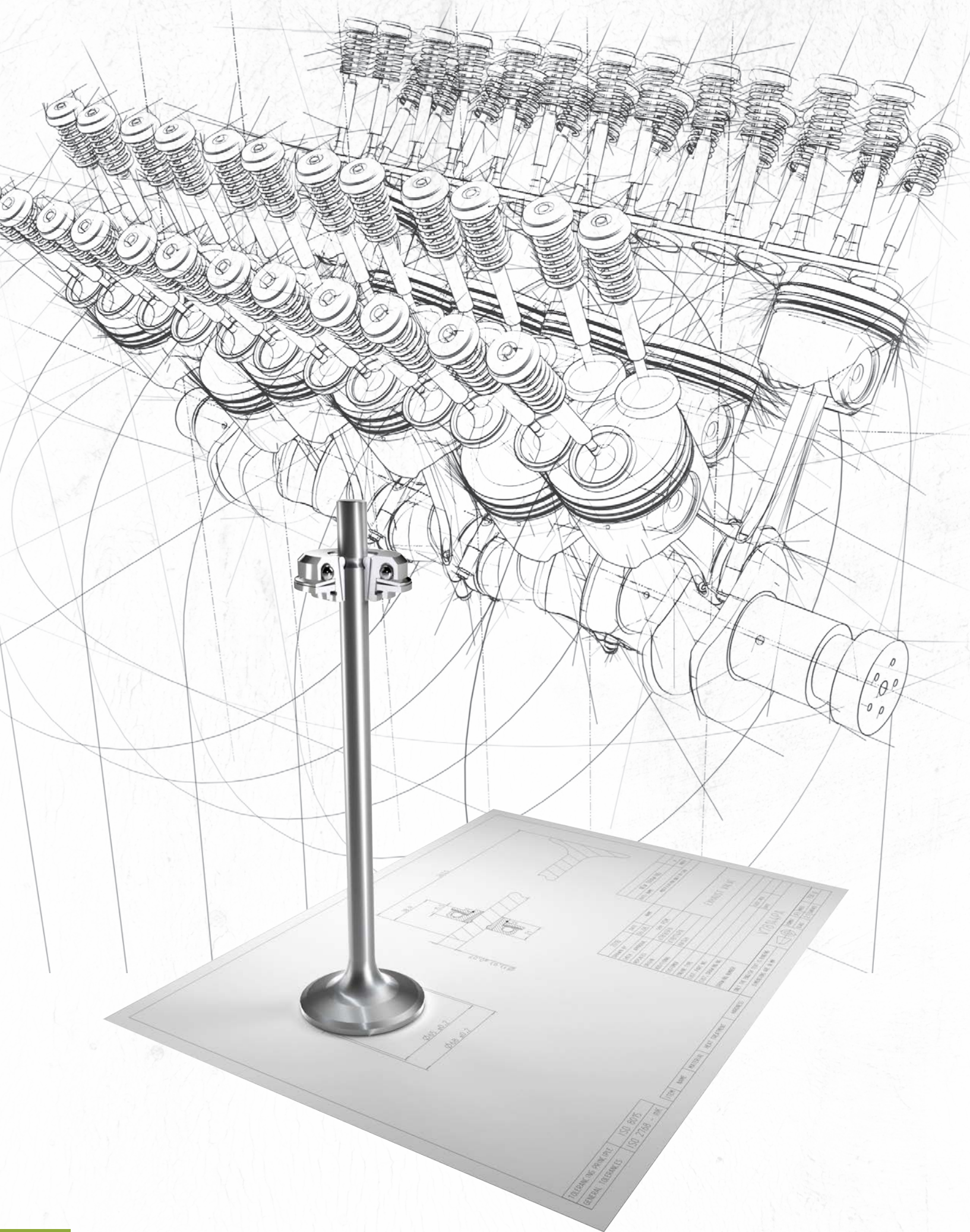
Tenneco has a strict focus on customer requirements and the necessary capability to address specific needs. We are working closely together with our customers to develop bearings that are optimized for utilization in extreme conditions across a range of industrial applications. Our comprehensive service offer spans from bearing design over rigid and elastic hydro dynamic simulation (RHD, EHD), material development, up to tool design and production. This all is supported by Tenneco's development centers located in Europe, North America and Asia which enable regional relationships with us as a global company.

DEVA® Self-lubricating Bearings

Tenneco's LBE bearings offer is complemented by its DEVA® brand self-lubricating, maintenance-free bearings. These are suitable for extreme conditions such as high temperatures, underwater, high edge loads and shock loads, which make them ideal for a wide range of industrial applications: marine, offshore, railway, power plants, steam turbines, gas turbines and heavy-duty. The comprehensive range of high-performance bearings feature high wear resistance, low and constant friction, excellent thermal and corrosion resistance, durability and immunity to abrasive particles.







Large Bore Engine Valves & Valvetrain Components

Technologies for Increased Valvetrain Lifetime

Tenneco develops and manufactures engine valves and valvetrain components, such as valve cotters, valve rotators and spring retainers. We supply our products for the LBE market to 4-stroke engine manufacturers for use in ships, propulsion and auxiliary, as well as for power plants and off-road applications, e.g., railway or mining.

Inlet and exhaust valves are among the most highly stressed components of internal combustion engines. They are precision components used for sealing the combustion chamber and controlling the gas exchange process and have to work reliably under severe mechanical, corrosive and high thermal load conditions. Basic valve designs are monometallic, bimetallic and hollow valve type. The biggest LBE valves reach dimensions up to a maximum length of 1,000 mm, a stem diameter of 38 mm and a head diameter of 180 mm. The latest engine developments due to emission regulations, e.g., from International Maritime Organization (IMO) and Emission Control Area (ECA), result in increased temperatures and combustion pressures. To optimize operating costs, one measure is to extend service intervals.

We enable this by using high alloy materials and materials which can meet the high variance of working conditions of modern engines encountering fuel and gas quality variance. Valve rotators, such as Rotocap® and Rotocoil, are designed to provide a defined rotation of the valve to create homogeneous surface contact and to prevent the forming of deposits on the valve seat and seat ring. The rotation results in optimized sealing and increased valve lifetime. Rotators can be top or bottom mounted and work with both single and double valve springs. Our Rotocap® portfolio covers an outer diameter range starting at 22 mm up to approximately 200 mm with respective spring forces of 250 N up to more than 20,000 N, respectively. Rotocoil ranges start from an outer diameter of 20 mm up to 113 mm. Current challenges for rotators result in new creative designs based on reduced packaging space but increased valve spring forces within the valvetrain, a consequence of increased operating temperatures and combustion pressures of modern engine designs. Tenneco's advanced rotators ensure a reliable operation and controlled rotation of the valves.

Valve cotters are the joining element connecting the valve spring retainer or the rotator with the valve stem, holding the valve in the required position. We offer a choice of application-dependent solutions: a single-groove cotter (fix connection) or multi-groove type (allowing free valve rotation). Our portfolio includes valve cotters for all kinds of engine types and in the range of inner diameters from 5 mm up to approximately 100 mm depending on cotter type.

Tenneco continues to work closely with its customers to engineer customized valvetrain component solutions for rapidly evolving Large Bore Engine challenges. Our complete in-house design, development, validation and manufacturing capacity ensures that our customers benefit from the latest technologies, materials and manufacturing techniques to remain at the forefront of the LBE industry.



Large Bore Engine Valve Seats and Guides

Powder Metal Technology for Superior Wear Resistance

Tenneco's Valve Seats and Guides (VSG) product line develops valve seat inserts (VSI) as well as valve guides (VG). About 300 million units respectively per year are manufactured in its production plants in Europe, North America, China and India, utilizing powder metal (PM) technology for applications up to 65 mm VSI outer diameter and 25 mm VG outer diameter. PM technology has a long history in automotive applications and replaced cast VSI and VG in numerous commercial truck and off-highway diesel and gasoline applications in the recent years. PM is a near-net shape primary shaping technology with efficiency advantages compared to casting.

Thanks to their superior wear resistance based on tailored mechanical and tribological properties, and the oil-impregnated PM intrinsic porosities providing liquid lubrication under all running conditions, PM valve guides are already in use with several LBE customers.

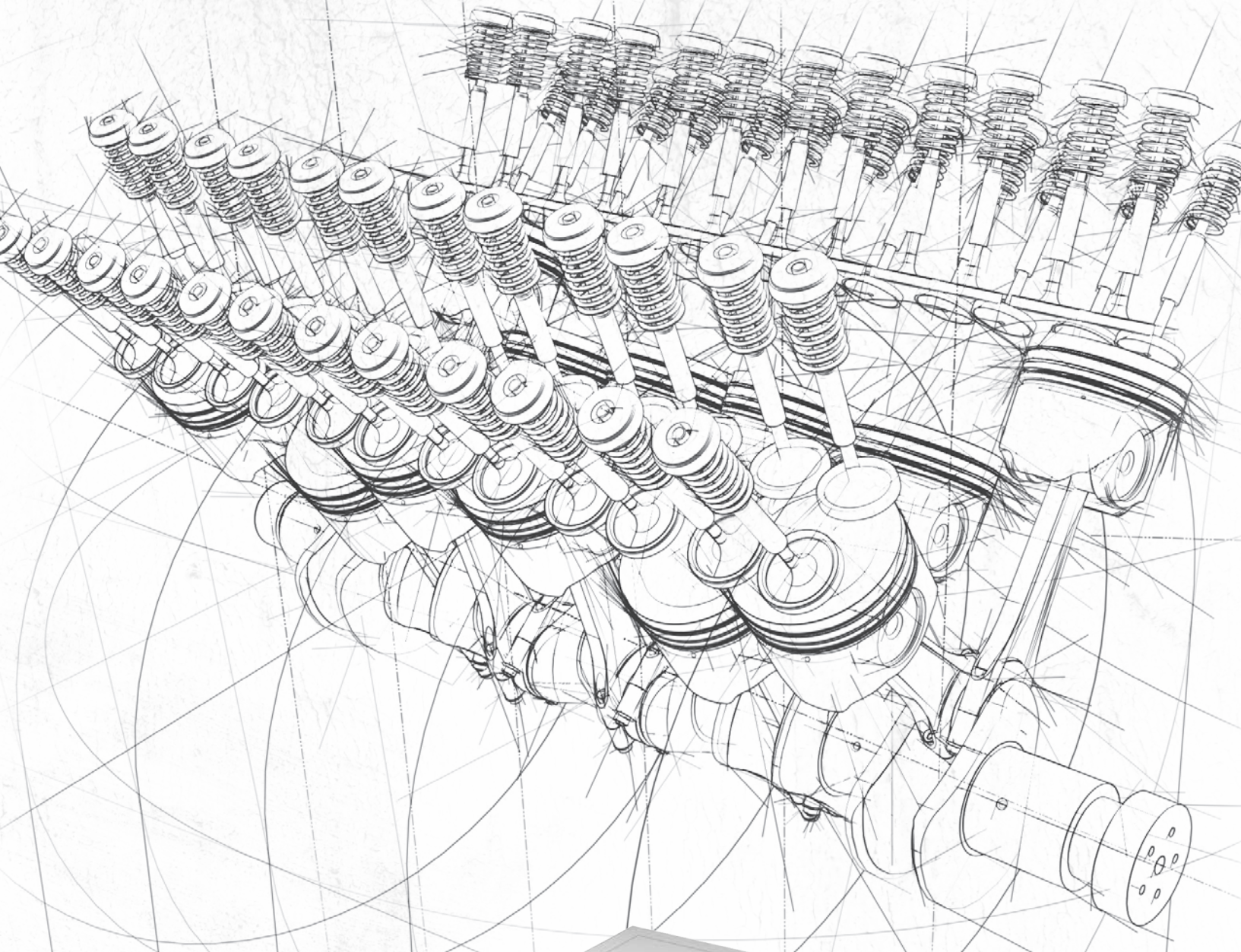
Tenneco's PM VSI achieve a thermal conductivity in the range of 40 W/m K by filling the PM porosity with copper and hence reducing VSI and valve temperature significantly compared to cast VSI applications. To reduce the component's temperatures even more, Tenneco's thermal interface coating can be applied to the VSI surface. Mechanical properties, such as density, hardness and compressive proof stress, are at least on the same level as cast material.

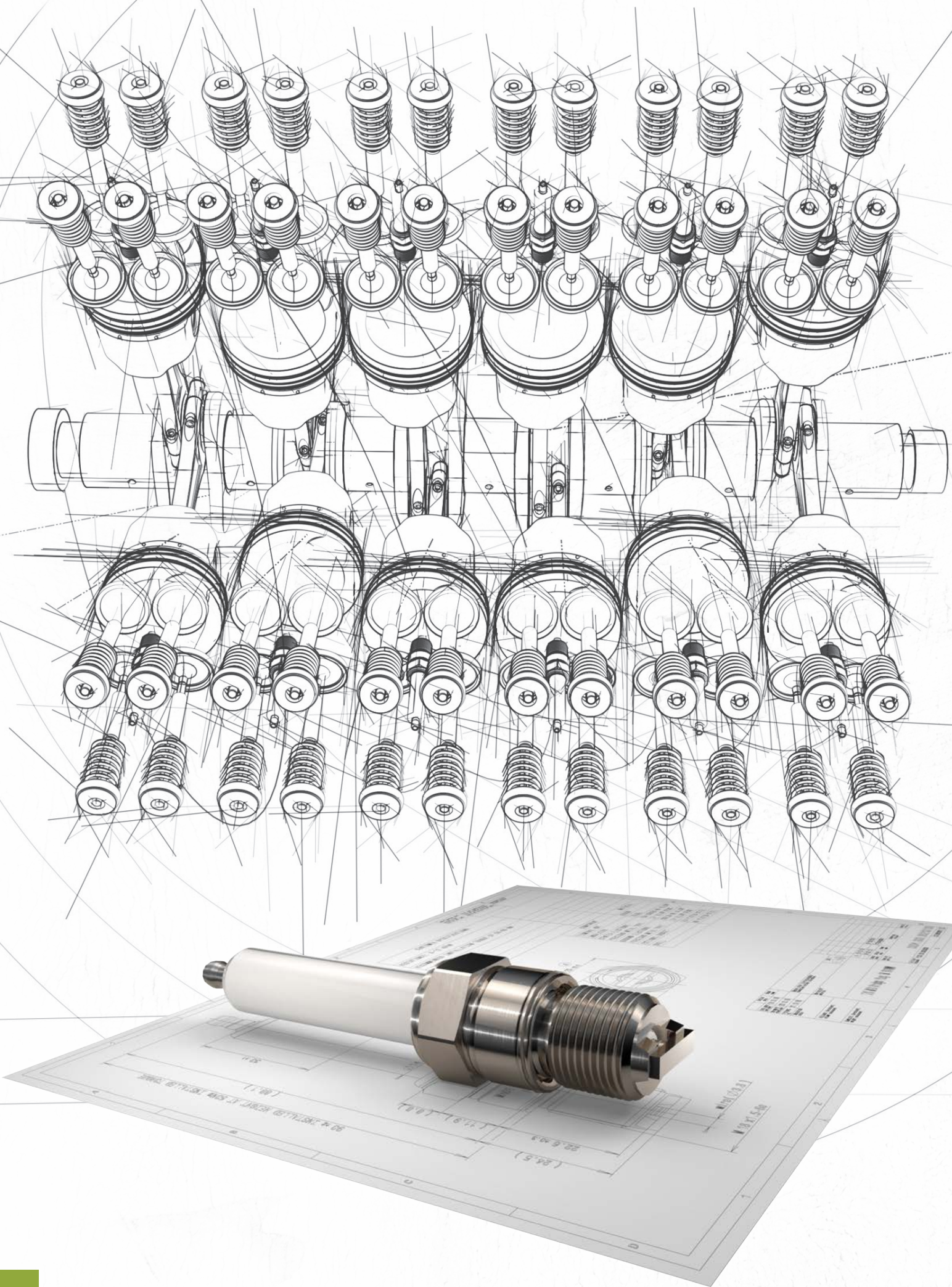
Tenneco's material portfolio for VG and VSI covers a wide range from cost-efficient, lower-alloyed materials up to highly alloyed grades including machinability enhancers, solid lubricants, hard phases, and hard particles. The portfolio also includes densified materials for outstanding mechanical properties and highly corrosion-resistant alloys.

PM production technology enables for a so-called dual-layer VSI design, which consists of an optimized back layer material with high mechanical strength against plastic deformation under high thermal and mechanical load, and relaxation properties on par with or above cast materials. The top layer material is optimized for low wear and tailored tribological properties in combination with the mating valve head material.

Tenneco combines all of its valve-related product lines together in one unit, thus providing customers a technically optimized and well-matched mechanical and tribological system consisting of valves, rotation devices and cotters, as well as VSI and VG components from one source.







Large Bore Engine Industrial Ignition Products

Spark Plug Technologies for Spark-Ignited Gaseous Applications

Tenneco's spark plug technologies for spark-ignited gaseous applications within the industrial Large Bore Engine market focus on enabling engine manufactures to enhance main operating areas including combustion performance, thermal efficiency, reduced emissions and fuel consumption, as well as increased durability and service life. Together, these help drive improved overall engine efficiency and reduced total cost of ownership. Depending on the engine structure, the market segment applied and intended usage profile, we have tailored ignition product designs and manufacturing solutions that ensure these key areas are addressed.

For open (combustion) chamber type engines, Tenneco has developed and is currently supplying into the market pre-chamber spark plug technologies which consist of a patented ring electrode design inside of nickel dome-shaped, enclosed capsule. While the general technology is not new to the market, we stand out from other manufactures as a "one-stop shop" that offers analysis-led design via CFD and FEM models to simulate and predict combustion performance/thermal efficiency, a full range of bench and application testing capabilities, and full component/assembly design and manufacturing at prototype and production levels.

Through design optimization of central-based ignition, our pre-chamber spark plug technologies have been proven to enable engines to increase air-fuel lambda ratios up to 1.9, while also speeding up combustion resulting in improved engine efficiency.



For fuel-fed pre (combustion) chamber type engines, Tenneco offers two unique technologies—Bridge Plug and Cold Plug—which are designed specifically to manage the hot combustion environment conditions thermally within the pre-combustion chamber. Specialized electrode shapes made of highly engineered, thermally conductive nickel alloys maximize heat extraction, keeping electrode surface temperatures at low levels to ensure consistent combustion of cycle and prolong service life. In combination with the electrode design, we have established innovative welding techniques giving ultra-high accuracy and precision at material joints.

The welding processes applied generate deep penetration and an innovative "stitching" feature, resulting in a robust weld capable of managing severe thermal shock conditions inherent to extreme temperature variations and/or application run profiles, which the engine loads are constantly varying.

For open- or fuel-fed pre-combustion chamber type LBEs, Tenneco offers a leading range of ignition components that are vital for many engine manufacturers. Our "one-stop shop" offers a comprehensive portfolio of products that helps provide our customers with a crucial competitive advantage when seeking to optimize combustion cycle and emissions control.

CHAMPION® and GOETZE®



Formed in 1907, the Champion® spark plug brand has long been associated with reliability and performance. As a world leader in the manufacture of spark plugs for every kind of combustion engine, the Champion® brand is known and trusted by end-users worldwide.

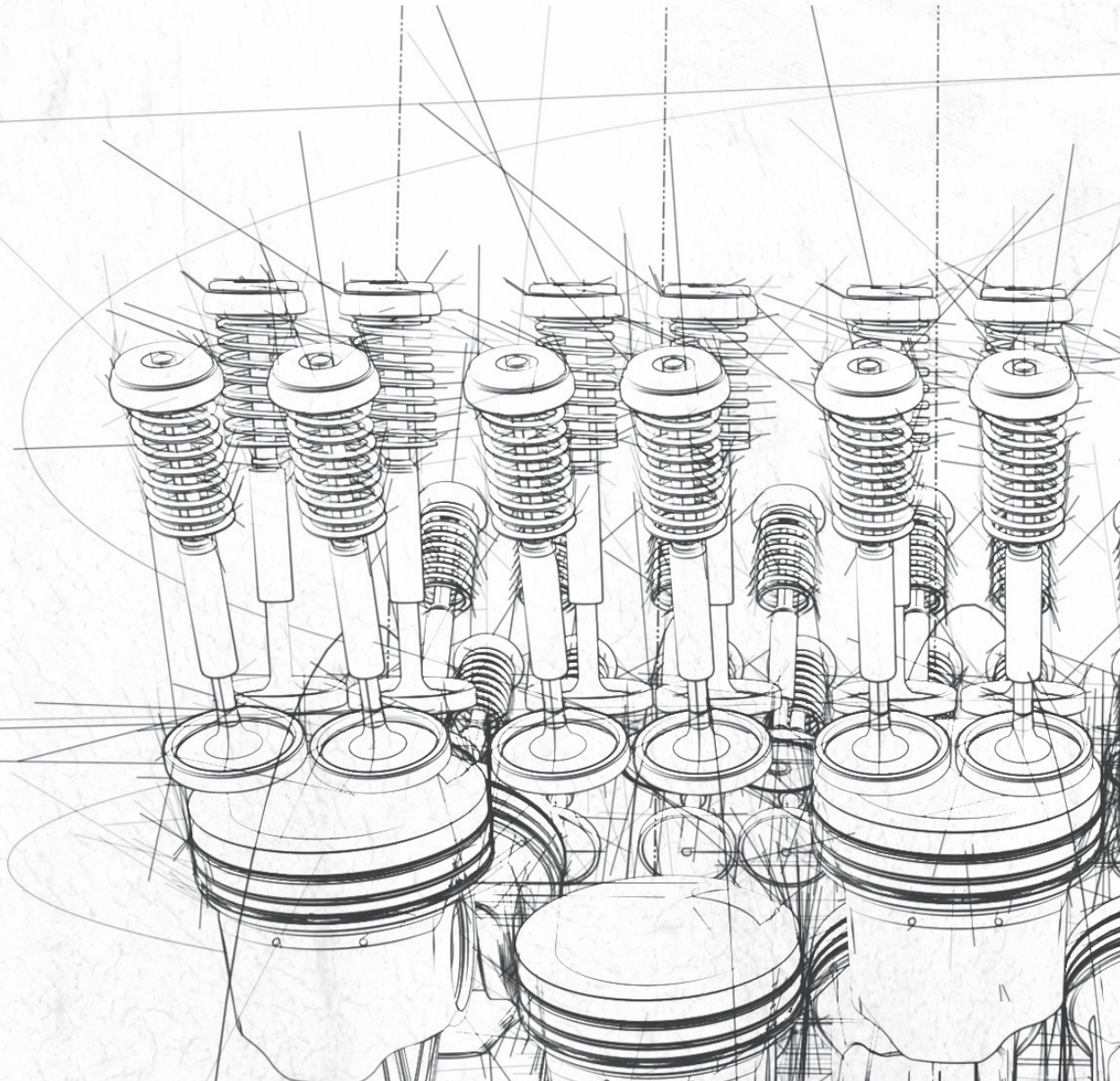


A brand long known in the industrial market, Tenneco has launched a range of new GOETZE® branded industrial spark plugs, designed for industrial gas engines. With proven durability for these challenging industrial applications, GOETZE® spark plugs are designed and manufactured for robust, reliable service.

About Tenneco

Tenneco is one of the world's leading designers, manufacturers and marketers of automotive products for original equipment and aftermarket customers. Through our four business groups, Motorparts, Performance Solutions, Clean Air and Powertrain, Tenneco is driving advancements in global mobility by delivering technology solutions for diversified global markets, including light vehicle, commercial truck, off-highway, industrial, motorsport and the aftermarket.

Tenneco's Powertrain business group designs, develops and manufactures original equipment components and innovative technologies that support engine designers to meet increasingly demanding customer, regulatory and market requirements in every region of the world. Whether for gasoline, diesel, alternative fuel or electric and hybrid applications, across every sector, the company's advanced components and systems, specialized coatings and proprietary manufacturing processes help to reduce emissions, improve fuel economy and enable advances in engine design, from small 25 mm bore to engines with over 1,000 mm bore and more than 100,000 hp. A leader in the OE light vehicle, commercial truck and off-highway markets, Tenneco Powertrain also supplies related technologies to the power generation, marine, rail and industrial sectors.



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Large Bore Engine Valves & Valvetrain Components

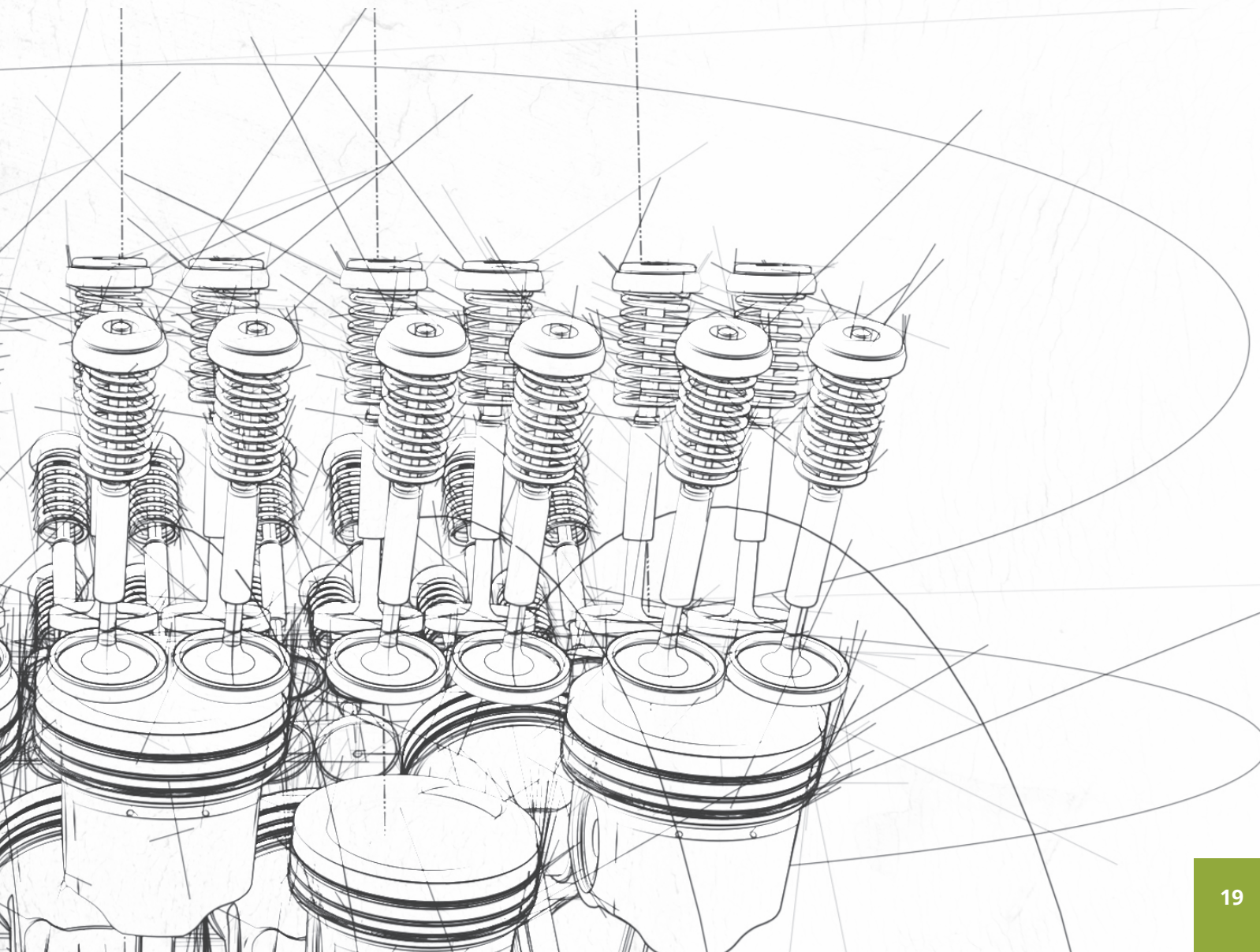
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Large Bore Engine Market Website

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