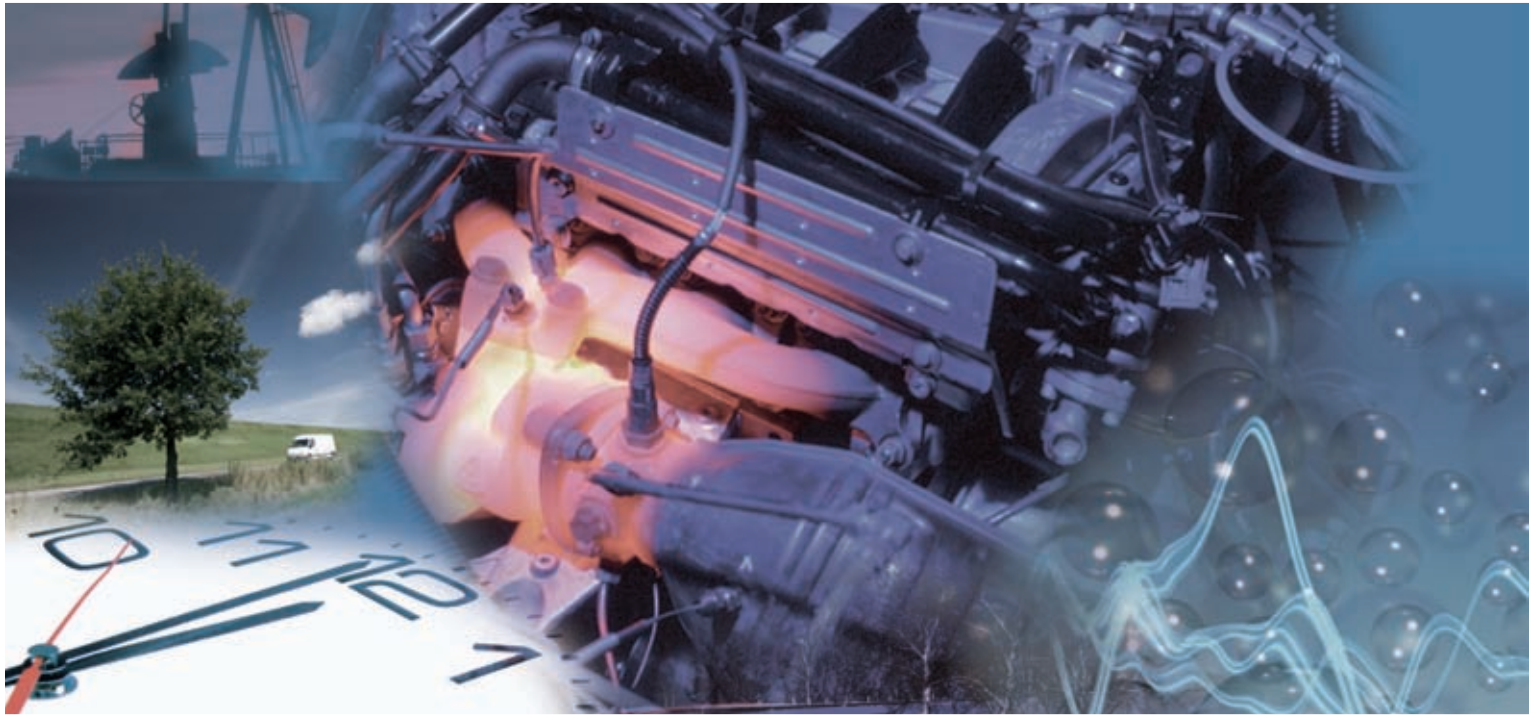
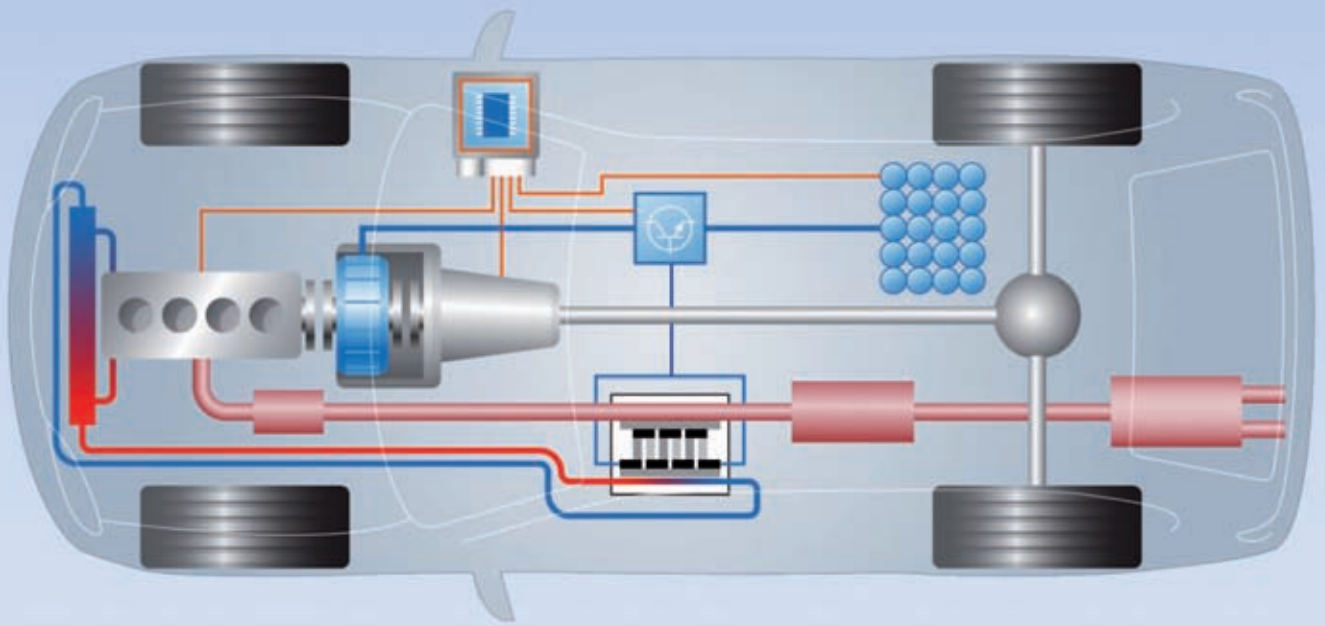


Thermoelectrics in Motion

Electric Power from Waste Heat - A Chance for the Automotive Industry





Thermoelectric generators also make hybrid vehicles more efficient

Developing More Efficient Vehicle Drives

Even shortly after it was founded, IAV caused a sensation through its involvement in developing the "Eco Polo" and a three-liter car. Since then the company has been working on vehicles that have continued to reach new levels of efficiency - for example by developing and improving thermoelectric generators.

The engineers from Berlin-based engineering provider IAV can look back on over 25 years of developing innovations for the automotive industry. More than 3,000 members of staff are hard at work on activities geared toward sustaining tomorrow's mobility: Hybrid powertrains, electric vehicles, new combustion processes and intelligent assistance systems belong to the principal work domains of IAV's four development centers in Germany (Berlin, Gifhorn, Chemnitz) and the USA (Northville). All the world's premier automakers and suppliers are clients of the company which, on the basis of its own development work and research projects, has secured a formidable head-start in areas at the fore of future automotive development.

IAV has competencies in the entire vehicle: Experts in powertrains, electrics and electronics as well as vehicle development, the company's staff can provide automobile manufacturers with support in developing new technologies - from the idea to mass production. IAV is in full command of intermeshing all disciplines and knows the effect they have in the entire vehicle. This knowledge is crucially important for developing innovative approaches - particularly when it comes to getting all-new components fit for the vehicle.

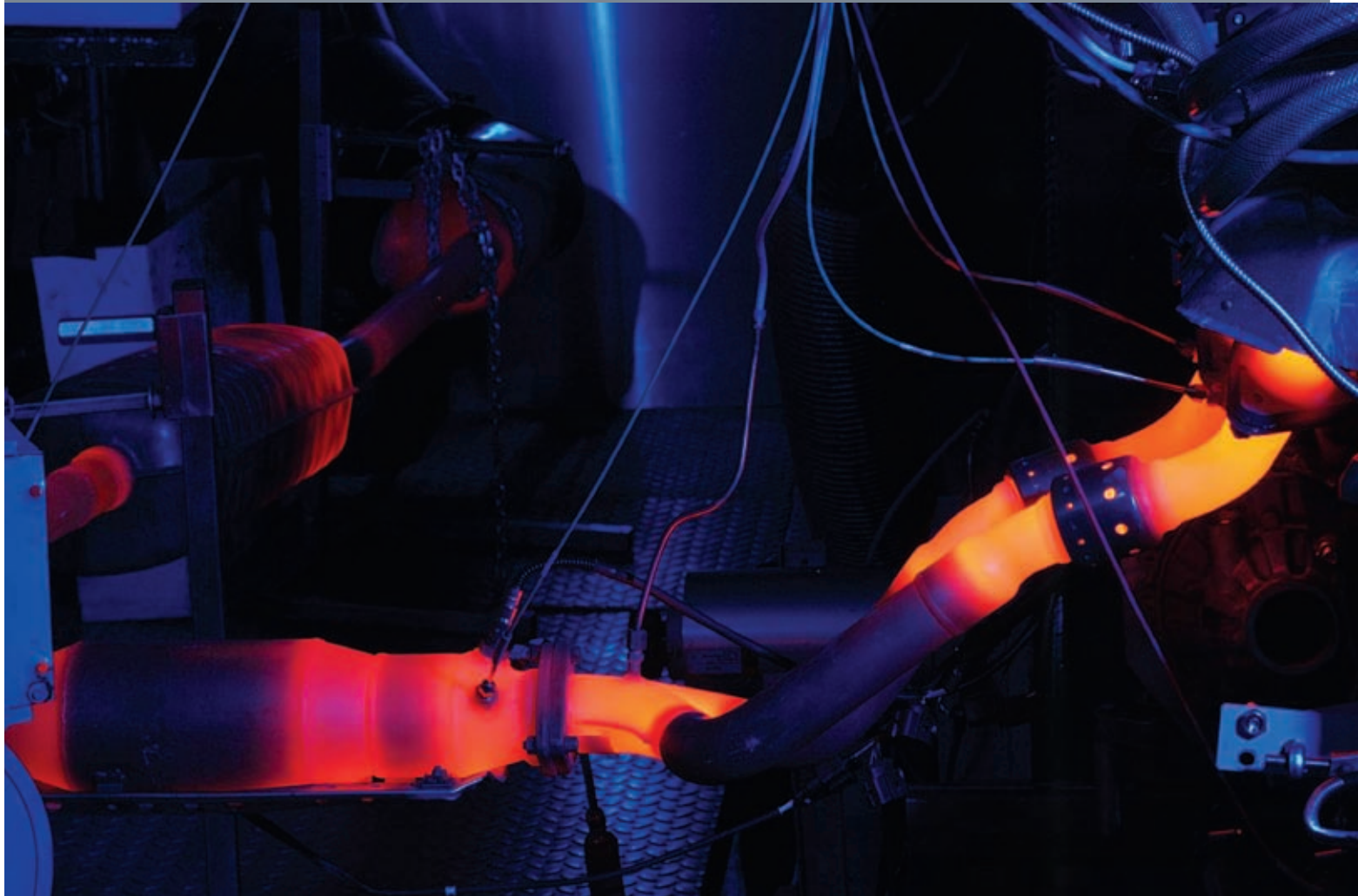
Reducing CO₂ emissions to combat climate change is the subject currently dominating automotive development. Yet innovations to protect the environment have always been at the focus of attention at IAV: Back in 1986, the company was involved in developing the "Eco Polo" (consumption: 1.7 liters per 100 kilometers, or 138.36 US mpg) and the Lupo 3 I-TDI. Thermoelectrics fit perfectly into this tradition: IAV has been working for many years on recovering unused thermal energy from the flow of exhaust gas to cut fuel consumption and CO₂ emissions.

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The Eco-Polo - only 1.7 l per 100 km



The motor vehicle produces thermal energy in abundance - such as here in the exhaust system



Tapping Huge Quantities of Unused Energy

Fossil energy sources are growing scarce while in some regions of the world the demand for mobility is rising fast. Sustainable management is only possible if we utilize energy more efficiently. Thermoelectrics can help us to do this - in the automobile and beyond.

Climate change and long-term price rises for fossil energy sources are posing a huge challenge for the automotive industry: It must satisfy the need for personal mobility while at the same time meeting the demand on the part of consumers for environmental compatibility, fuel efficiency, safety, comfort, performance and driving fun. On top of this, most countries are tightening their limits on the emission of carbon dioxide and pollutants.

Added to this is the probability of a significant increase in the vehicle population over the coming decades in the emerging countries - such as India and China. This could make oil scarce: The International Energy Agency (IEA) has calculated that demand by 2030 will rise by 45 percent to 106 million barrels a day (compared with 2006). Many experts doubt it will be possible to produce so much oil.

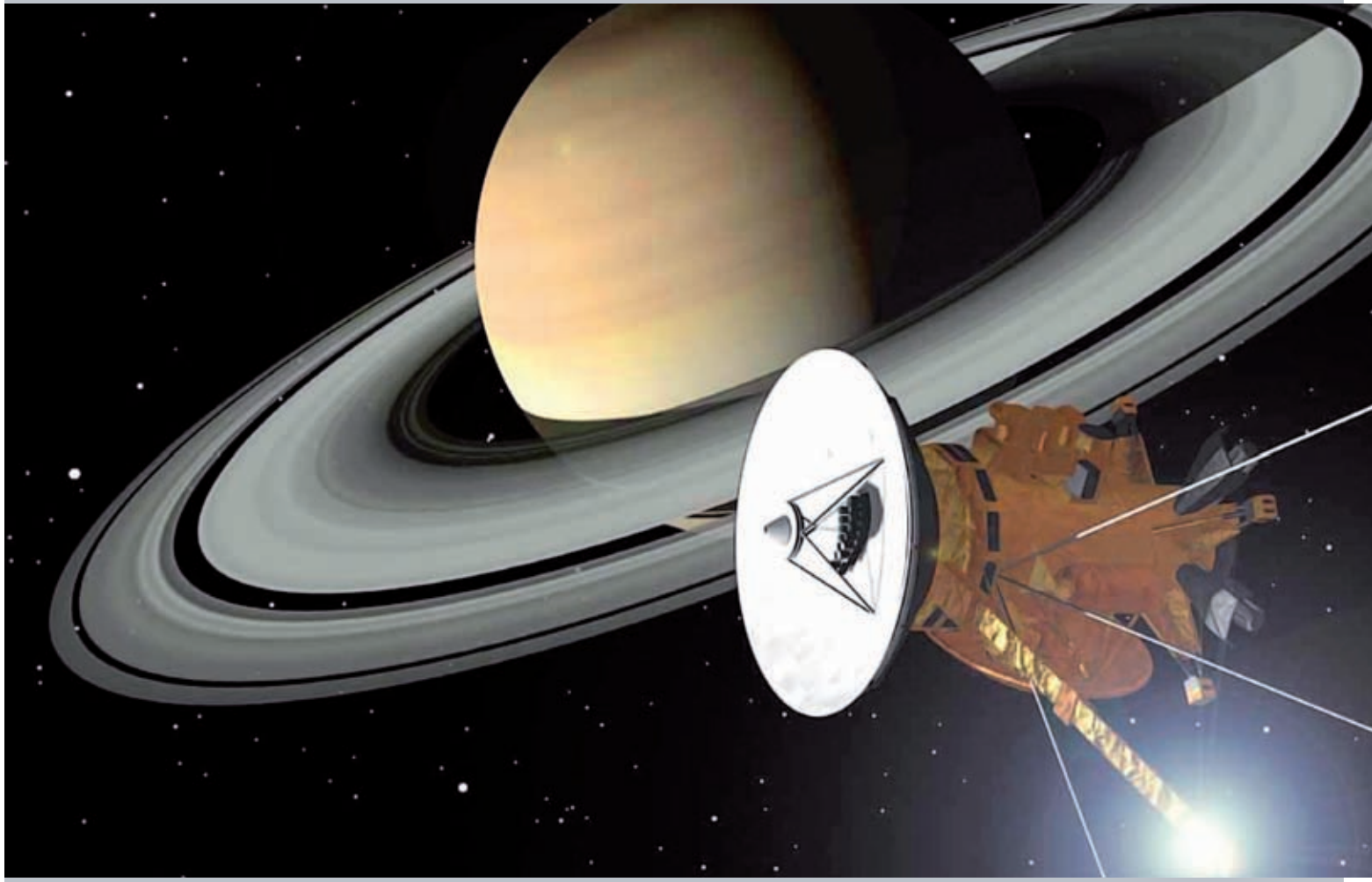
The automotive industry must find an answer in response to these trends. In addition to developing new technologies, such as electric and hybrid drives, greater efficiency is also needed for conventional vehicles powered by combustion engines. But this will only be possible by scrutinizing and further optimizing all components.

Around one third of the energy in fuel is given off unused as waste heat through exhaust emissions, a further third heats the cooling system - of every three liters of gasoline or diesel, the engine "uses" two to heat the atmosphere. Thermoelectric generators are capable of converting part of this into electric energy, thereby significantly enhancing the energy efficiency of future automobile generations.

And not only that: Every year, the manufacturing industry in the USA alone produces 600 terawatt hours of waste heat that could be used. There is no doubt: Thermoelectric generators will make a major contribution to sustaining the supply of energy for humankind.



Costly cooling in case of too much waste heat



Cassini-Huygens probe - Thermoelectrics have proven their worth in aerospace for decades



Generating Free Electricity from Waste Heat

Space probes far away from the sun have been obtaining their energy from thermoelectric generators for decades. The principle also makes sense on Earth - provided the efficiency of energy converters can be further improved.

The physicist Thomas Johann Seebeck discovered the thermoelectric effect ("Seebeck effect") back in 1821: Electric voltage is produced between two points of an electric conductor if they are at different temperatures - the charge carriers migrate from the hot to the cold side ("thermodiffusion"). The voltage is proportional to the temperature difference and depends on the material, its "Seebeck coefficient".

And it also works the other way round: Physicist Jean Peltier discovered in 1834 that an electric current is capable of transporting heat. "Peltier elements" can generate heat differences, thus making it possible, for example, to use them for cooling electronic components or for constructing refrigerators without a compressor.

In most cases, thermoelectric generators (TEG) these days work on the basis of two p and n-doped semiconductors with different Seebeck coefficients. To achieve the required voltage, they are connected alternately in series. They come in different sizes for power outputs ranging from a few milliwatts to several dozen watts. Thermoelectric films are a new development.

Good thermoelectric materials must have a high Seebeck coefficient, good electric and low thermal conductivity. They can be characterized by the ZT figure of merit - the higher the ZT, the more effective they are.

Today, commercial thermoelectric applications tend to employ compound semiconductors (Bi_2Te_3) that work well at room temperature. For example, PbTe is used for mean temperatures from 200 to 600 degrees Celsius, with alloys of silicon and germanium being particularly suitable for high temperatures. Researchers are currently examining eleven groups of materials with a vast range of characteristic properties.

To date, TEGs have only been used in niche applications where price (aerospace) or quality (e.g. camping products) is immaterial. Commercial products have a ZT value of 0.9 at best. Values of 4 to 8 can be achieved in theory - the best materials that exist manage 1.5 and, using nano-structures, ZT values of more than 2.5 would be within reach. For automotive use, a ZT value of 1.5 to 2 will suffice.



Thermoelectric generators save large quantities of fuel, particularly during quasi-steady-state operation, e.g. in motor coaches

Cutting Fuel Consumption by Five to Ten Percent

Thermoelectrics are predestined for applications in motor vehicles: On the one hand vehicles unavoidably create large quantities of heat, on the other they need more and more electric power – power that can be produced at zero cost with thermoelectric generators. This ingenious principle of nature has the potential to cut fuel consumption by five to ten percent.

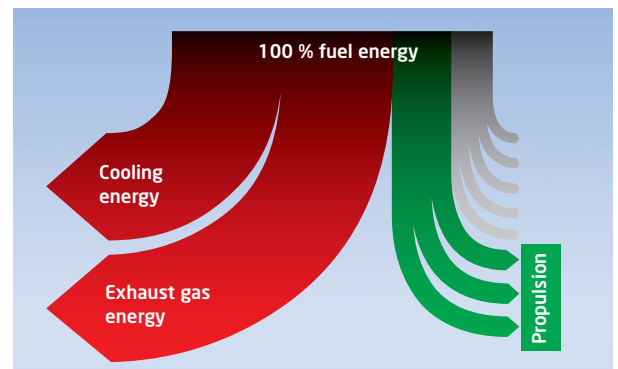
Despite all the advances being made, the principle underlying combustion engines means they only utilize part of the energy in fuel for propulsion. Well over half is lost in the form of heat – the majority through exhaust emissions, much of the rest through the cooling water. So far, this heat has hardly been used: Part of it is transferred to the powertrain components and exhaust-gas aftertreatment system during the warm-up phase. Some of it is also used for supplying the heating system and any turbo-charging components on board.

With vehicles containing more and more electric systems, there is also a greater demand for electric energy, e.g. for comfort and safety systems. This power currently costs the motorist dearly: It is generated at a low level of efficiency from fuel and is many times more expensive than electricity used at home – depending on the vehicle, generating electric power accounts for over ten percent of the fuel it uses.

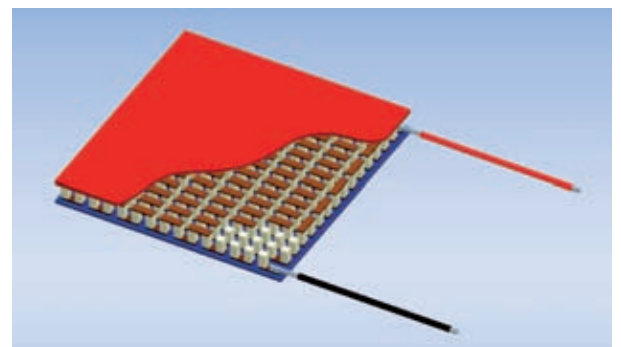
Using thermoelectric generators (TEG), at least part of this energy can be generated for the vehicle electric system from waste heat at no cost. TEGs can also supply power to autonomous sensors, actuators and vehicle systems.

As yet, however, TEGs have not found their way into production vehicles. Inadequate efficiency and relatively high costs have hitherto prohibited their use. Automobile manufacturers need modules that are not only effective in the way they work but are also low in price, non-toxic, simple to produce as well as easy to recycle.

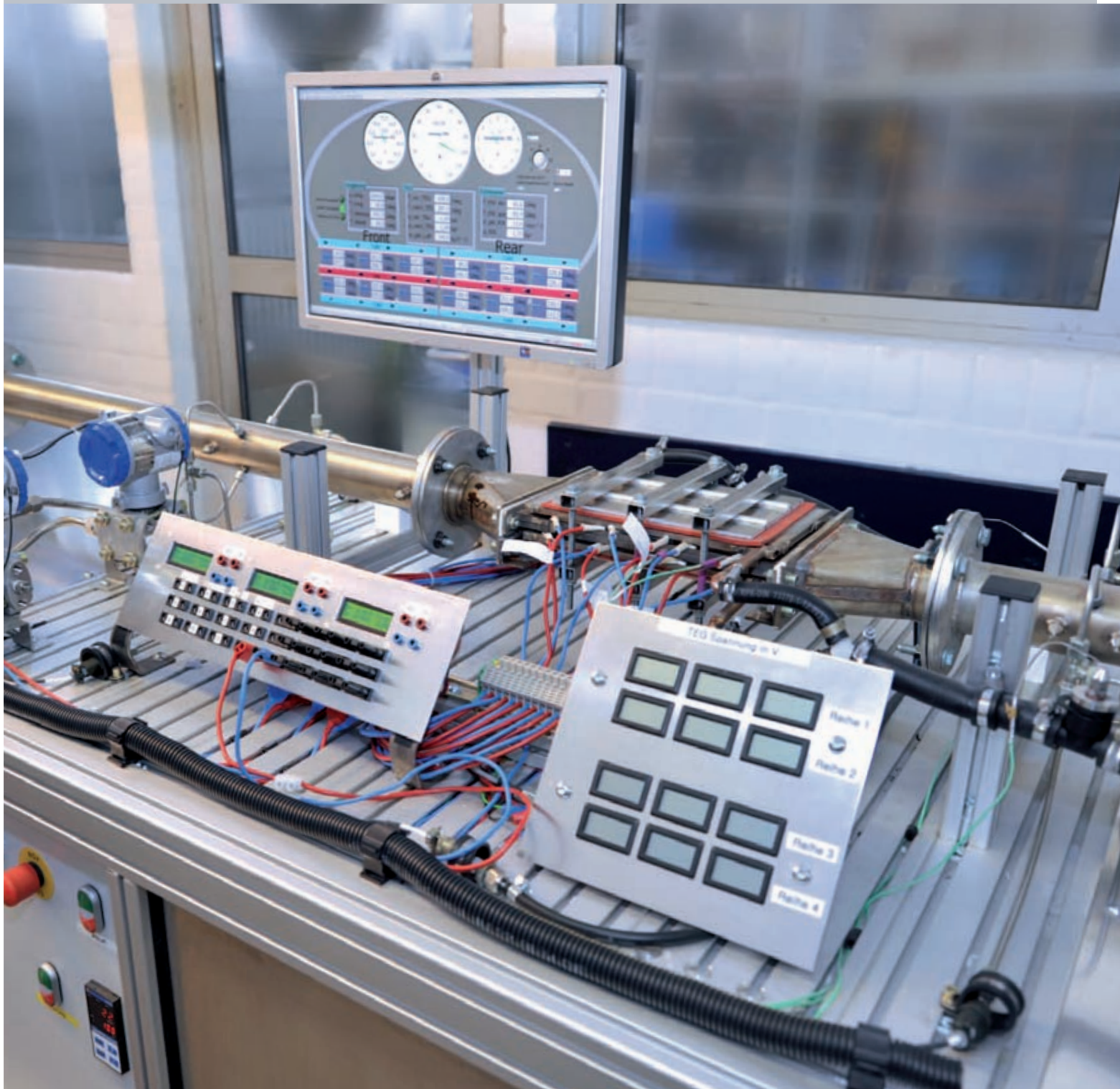
In recent years, interest in TEGs has grown – also because they can help cut CO₂ emissions. Thermoelectric materials with greater levels of efficiency are also being developed. Experts estimate that TEGs are capable of reducing fuel consumption by five to ten percent. Using TEGs, the 50 million motor vehicles in Germany alone could save ten terawatt hours of energy every year.



Combustion engines generate more heat than mechanical energy



Structure of a modern thermoelectric generator



IAV's hot-air test bench for TEG systems in the exhaust system

Integrating Thermoelectric Generators into Tomorrow's Vehicles

IAV works in all fields of automotive development. This also benefits activities in the thermoelectrics domain. Because only by understanding the entire vehicle is it possible to exploit its potential to the full and avoid conflicts with other components.

Developing thermoelectric generators (TEG) and taking them to mass production is a huge challenge. But the effort is worth it because vehicles of tomorrow must become more efficient and have less of an impact on the environment. Even if the technology is ingeniously simple and less complex than other methods of converting waste heat - three challenges must be overcome before TEGs can be used in future vehicle generations.

The first one concerns the thermoelectric material itself: Researchers need to develop and produce materials that are optimally tuned to the requirements and operating conditions in the vehicle - the focus here being on cost-effectiveness and efficiency. A high ZT value - ideally much greater than 1 in the relative temperature range - and long-term stability at maximum exhaust gas temperatures are the basic prerequisites. On top of this, the materials must also be readily available, non-toxic and harmless to the environment. And ultimately, they must be easy to manufacture, process and recycle.

Almost equally as demanding, the other two challenges are a focus of attention at IAV: Integrating thermoelectric materials in thermoelectric generators and integrating thermoelectric generators in vehicles.

IAV experts are looking for solutions and concepts that gather up waste heat effectively, avoid disturbances and channel the flow of heat in the most efficient way possible through the thermoelectric material. The legs and connection contacts must be optimized to ensure operating safety and minimize electric losses.

Added to this are the high thermal, thermomechanical and mechanical loads in exhaust systems. Modern approaches are now moving away from the conventional design of TEG technology and embracing simple, robust and cost-effective concepts.

The third challenge lies in integrating the thermoelectric generator in the vehicle. This calls for solutions that not only optimize geometrical, mechanical, electrical and functional integration but also keep costs down and take into account the particular nature of the vehicle and the purpose it serves. This is where, for example, questions are currently

being addressed in relation to the place of installation and integration in existing exhaust system components, emission management (bypass), recooling as well as conditioning and using the electric energy.

Doing so, particular attention must be paid to the way in which the thermoelectric generator interacts with the exhaust-gas aftertreatment systems, to optimizing integration in the cooling system and to other aspects, such as manufacturability, installation options and system costs. IAV is in a position to cover all stages in production-ready development - from the concept to module development, and from integration to the start of production.

IAV has been concentrating on the subject of thermoelectrics for three years. Here, our developers benefit from over 25 years of experience in the many and varied fields of automotive development - because thermoelectric generators can only be integrated appropriately by considering the effects they have on the entire vehicle.

IAV has built up a wealth of expertise to overcome the complex challenges posed by integrating TEGs in vehicles.

Development tools, such as simulation systems and comprehensive test equipment, are available for testing components, the powertrain and overall vehicle in the operating state. The "Thermoelectrics Laboratory" allows IAV's experts to measure key component parameters and test TEGs under conditions that match those in the exhaust system. And finally, IAV has fitted out an experimental vehicle that provides the capability of installing different TEGs and measuring them on the road.



IAV's experimental vehicle for testing TEG systems under real-life conditions in road traffic

