Zero-impact Emissions – Research for a New Generation of ICEs

Until now, analyses of the exhaust gas levels of vehicles with combustion engines have focused solely on their pollutant emissions. With the "Zero-impact Emissions" approach, the concentration of pollutants in the ambient air forms the basis of assessing the exhaust gas level. Through several projects, the FVV is expanding pre-competitive research and laying the groundwork for the development of "Zero-impact Vehicles" whose emissions have no impact on air quality.

1 ZERO-IMPACT VEHICLES

The pollutants emitted by vehicles with Internal Combustion Engines (ICEs) have already been reduced significantly over the last decades. When defining new emissions limits, the legislature first sets new values for the maximum permissible pollutant concentration around vehicles. This was done by measuring the concentration of pollutants in a certain place at a certain time, from which stricter emission limits and more extensive test procedures for vehicles and other polluters such as heaters and

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Prof. Dr.-Ing. Kurt Kirsten is Head of Advanced Engineering and Innovation at the APL Group, and holds various functions at FVV.
"A zero-impact powertrain can enhance and secure the solution space for sustainable, low-emission mobility of people and goods."

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Philipp Weinmann, M. Sc. is Emission Expert at Purem GmbH. He is heading FVV's research project on particle formation through injection of UWS into SCR systems.
"An improved understanding of the processes in exhaust gas after-treatment allows emissions to be reduced even further, thus significantly decreasing their influence on people and the environment."

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Dr.-Ing. Frank Bunar is Senior Technical Consultant Powertrain Calibration & Technology at IAV GmbH. He is heading the FVV research project on powertrains for zero-impact tailpipe emissions.
"Hybrid drives are competitive, user-friendly and, when used with e-fuels, climate-friendly. In a ZIV, the strengths of combustion engines and electric motors complement one another perfectly in this respect."

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Ao. Univ.-Prof. Dr.-Ing. Stefan Hausberger is Head of the Emissions Research Department at the Institute of Thermodynamics and Sustainable Propulsion Systems (ITNA) at Graz University of Technology. Together with his team, he was in charge of the study on zero-impact vehicle emissions commissioned by the FVV.
"Cars and commercial vehicles with zero-impact pollutant emissions are feasible; it is likely that Euro 7 will already be in this range."

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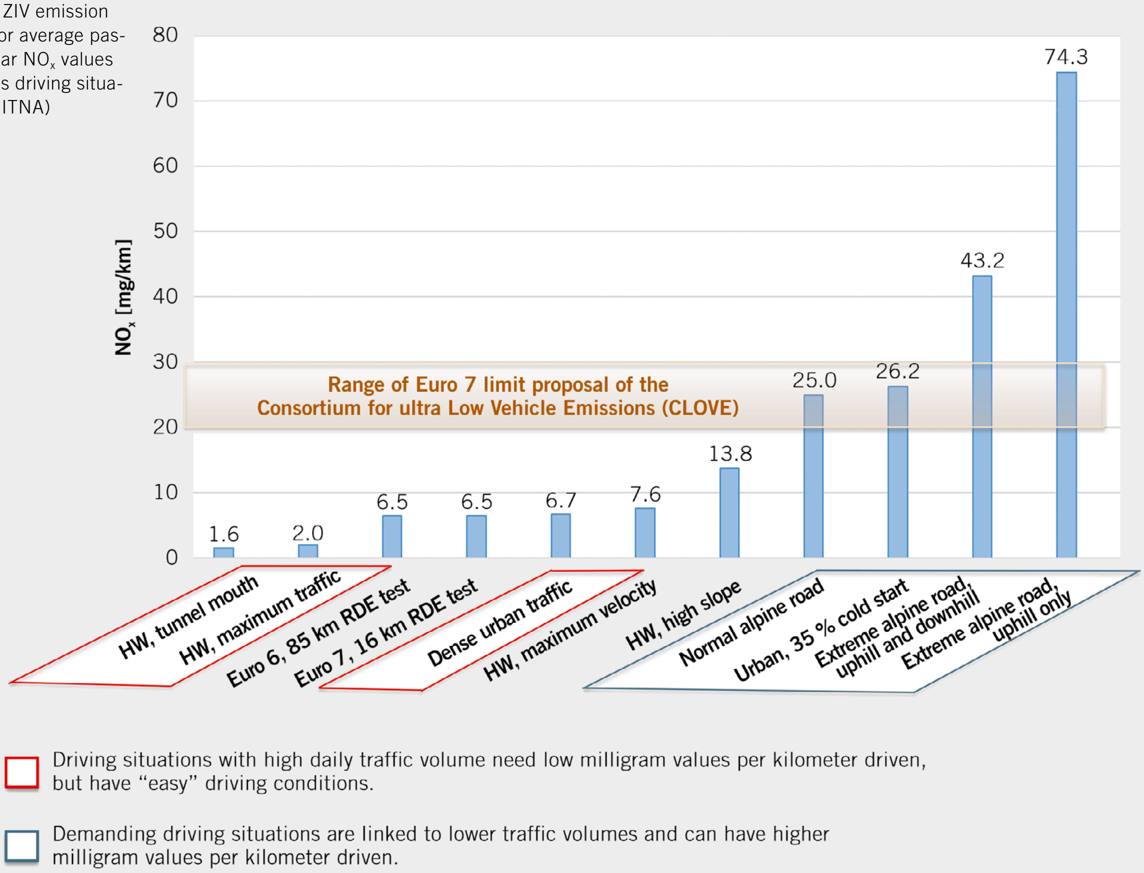
Science for a moving society

FIGURE 1 ZIV emission targets for average passenger car NO_x values in various driving situations (© ITNA)



industrial facilities were derived, in order to prevent the air quality targets from being missed. However, the prescribed emissions and the hoped-for effect on the quality of ambient air often did not correlate under all conditions, resulting in the emissions limits having to be reduced further and further over the years.

In order to determine an effective target to prevent environmental damage caused by pollutant emissions, the FVV has expanded the consideration of vehicle exhaust emissions to include their situation-dependent immission potential. In the "Zero-impact Emissions" (ZIE) approach, unlike the old practise, the measured concentrations in the air form the basis for assessing the level of pollutants. In this context, a "Zero-impact Vehicle" (ZIV) is a vehicle whose exhaust emissions are so low that it causes no measurable negative impact on the environment and air quality.

2 CONCEPTIONAL STUDY

In order to create a basis for ZIE/ZIV research activities and to define their goal, the conceptual study "Zero-impact Vehicle Emissions" first described the requirements that a ZIV would have to fulfill [1]. The project, self-funded by the FVV, was conducted at the research association Forschungsgesellschaft für Verbrennungskraftmaschinen und Thermodynamik (FVT) in Graz (Austria), the Institute of Thermodynamics and Sustainable Propulsion Systems (ITNA) at Graz University of Technology, and Aviso in Aachen (Germany).

Literature research at the start of the study showed that it is impossible to define with certainty a precise limit for

TABLE 1 Traffic or driving situations for the investigation within the scope of the project "Zero-impact Tailpipe Emission Powertrains" (© TME)

	Basic situation	Specifics for the emissions analysis
1	Neckartor Stuttgart	Yearly average
2	Neckartor Stuttgart	Rush-hour traffic in winter with maximum possible traffic volume
3	Cross-country highway	Heavy traffic on eight-lane section in winter as orientation for maximum highway traffic in Germany
4	City highway	High traffic volume
5	Brenner highway	Highway in mountains as orientation for maximum traffic volume, measured on one day in 2020
6	Parking lot traffic	High proportion of cold starts, maneuvering, low speed
7	High mountain pass	Driving on a pass

the pollutant concentration below which no negative effects occur. After benchmarking the definition of emission limits for a ZIV, the research team selected the most demanding scale, the so-called 3-%-irrelevance criterion for the study. According to this criterion, the share of road traffic in immissions must be classified as irrelevant, that means, it may contribute a maximum of 3 % to the locally permissible total immission load. In the study, this corresponds to the contribution of the sum of all passenger cars and commercial vehicles with combustion engines traveling in the relevant vicinity of an immission measuring point. The research team also picked the measurement point at Neckartor in Stuttgart (Germany) as their typical reference location with a high pollution load. Particularly high values for pollutants have regularly been measured there in the past. Using this data, the researchers calculated the maximum emissions per vehicle kilometer that may be emitted in the Neckartor area if the pollutant concentration is to remain below the 3 % limit. These investigations were then repeated with the data from other measuring points distributed representatively throughout Germany.

The results show that the requirements for a ZIV differ widely depending on the driving situation and environmental conditions. At locations with high traffic volume, many vehicles emit pollutants; therefore, a low emissions level per vehicle kilometer is needed in order to meet the specifications for the 3-% target. However, driving conditions in locations like these are not usually very challenging, so emissions limits are easier to meet there. Extreme driving conditions, such as accelerating fast and driving at high speed, are only possible where there is little traffic. As a result, fewer vehicles are present and emitting pollutants at any given time in these locations.

The zero-impact target is most difficult to achieve in the case of heavy urban or highway (HW) traffic, **FIGURE 1**. From this, the researchers deduce that future Real Driving Emissions (RDE) testing procedures should concentrate on adhering to the emissions specifications in heavy urban and HW traffic and that these situations should be checked with appropriate limit values. It would also be useful to apply different limit values to extreme situations such as driving up mountains, that tend to be less dense, as the emissions margin per vehicle kilometer is much greater for these situations than in heavy urban traffic [2].

3 ZIE POWERTRAINS

Building on the conceptional study, an investigation was conducted at the Chair of Thermodynamics of Mobile Energy Conversion Systems (TME) at RWTH Aachen University to determine which exhaust gas treatment concepts could enable future vehicles to meet the ZIE limit [3] as part of the research project "Zero-impact Tailpipe Emission Powertrains". Using the defined scenarios from the Zero-impact Vehicle Emissions study as their starting point, the teams from both research projects identified seven specific traffic or driving situations that combine challenging driving conditions with unfavorable pollutant concentration aspects, for example high traffic volumes and densely built-up areas as at Neckartor in Stuttgart, **TABLE 1**. For these situations, the maximum tailpipe emissions allowed per vehicle were taken as the new limit. If a vehicle meets the respective emissions limit in all of these critical cycles, then zero impact is also achieved in less critical situations.

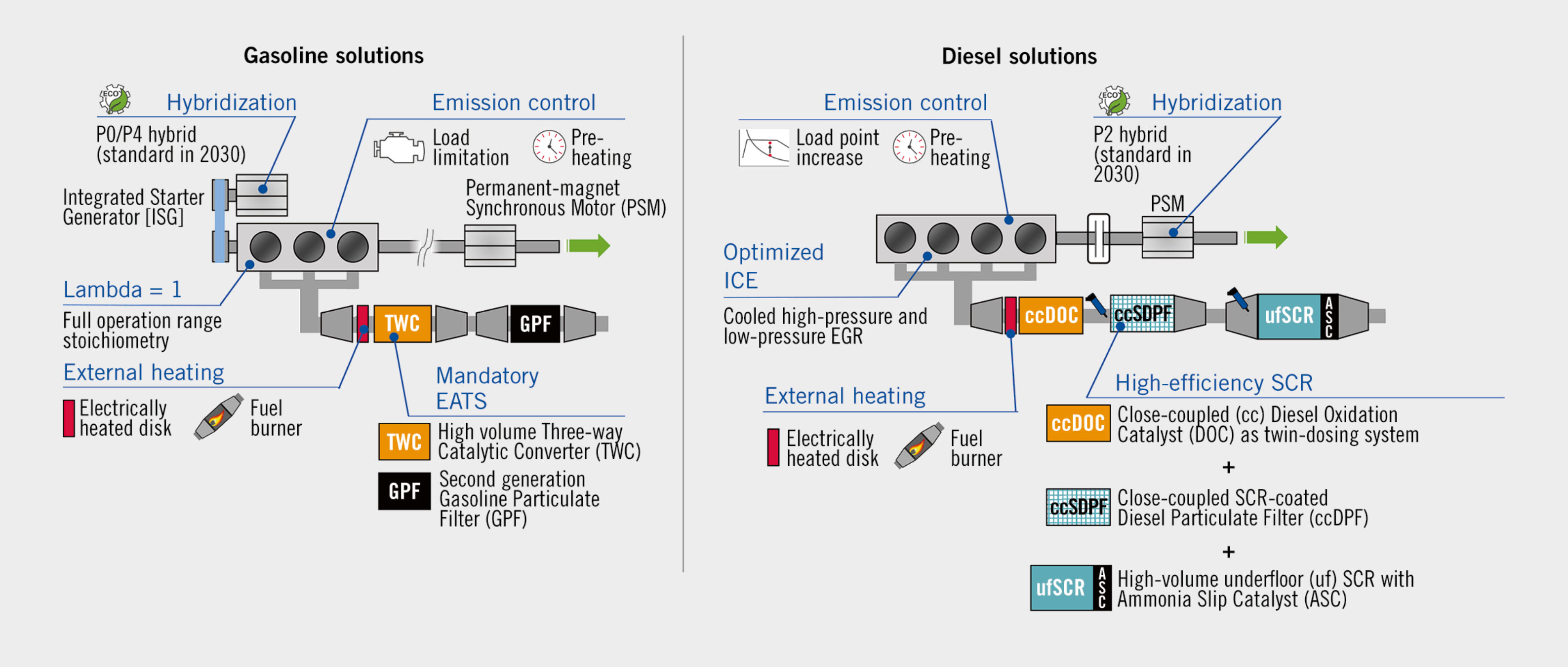
Having developed the various limit consideration scenarios, the researchers conducted a simulation analysis for each test case with two reference vehicles: a mid-range car with gasoline engine, and a light commercial vehicle (van) with diesel engine. Both vehicles meet the current Euro 6d emissions standard.

In the scenarios number 5 und 7 in **TABLE 1**, the ZIE conformity could be verified for both gasoline and diesel engines with current technology for Euro 6 due to the moderate traffic volume and low proportion of cold starts. Extreme urban driving scenarios with high proportions of cold starts, extended start-stop phases and short driving distances, as well as highway journeys with increased engine loads, were challenging for both engine scenarios. The research team chose revised gasoline and diesel powertrains, optimized for the emissions and CO_2 requirements for the period after 2030, as the starting point for further work. In the case of the gasoline engine, this was lambda = 1 combustion throughout the characteristic map range, engine downsizing while maintaining the current catalytic converter volume, a particle filter, and P0/P4 mild hybridization (48 V). P2 mild hybridization (48 V) was implemented in the diesel powertrain. Hybrid technology with the primary goal of increasing system efficiency was also used here synergistically to reduce pollutants.

In order to optimize emission behavior during a cold start, an electrically heated catalytic converter can be integrated into both gasoline and diesel engines. This allows the Exhaust Aftertreatment System (EATS) to be heated to operating temperature quickly. However, it requires preheating to enable the full reduction potential, either before the journey or while starting solely electrically [4]. Alternatively, it may be useful to deploy a fuel burner that utilizes the entire thermal energy to heat the exhaust gas system. In the case of the diesel engine, there is also the option of engine-related measures such as increased EGR rates, optimized injection patterns and timings, power limitation and shifting the load point using an electric motor. In some cases, this would also allow the heating time of the exhaust gas aftertreatment components to be reduced in a targeted way. For both engine concepts, choosing a suitable operating strategy, that means, limiting the maximum engine load at the start of the journey, is a cost-efficient method of reducing emissions. However, it is important to consider that the driver would notice this in the form of a power limitation.

To reduce emissions during high load cycles, such as highway driving, increasing the volume of the catalytic converter in a gasoline engine boosts the cleaning effect. A variable valve train that holds the outlet valves closed at such operating points can be used to prevent oxygen flooding and saturation of the catalytic converter. In a diesel engine, the use of an SCR system with an underfloor catalytic converter close to the engine and a twin dosing system offers a great deal of potential for reducing emissions in a warm operating state. The possible measures for fulfilling the ZIV requirements with gasoline and diesel engines are summarized in **FIGURE 2**.

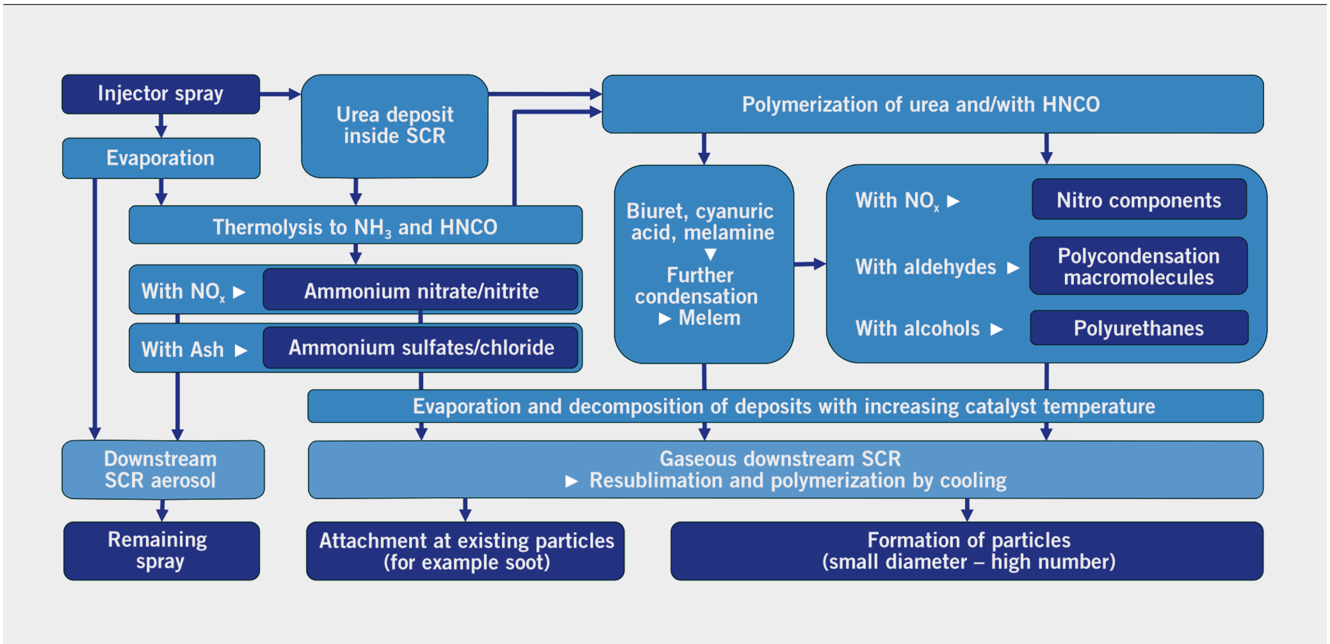
FIGURE 2 Measures for meeting the ZIV requirements (© TME)



4 COMPONENT-RELATED EMISSION RESEARCH

When a Urea-water Solution (UWS), also known as AdBlue, is injected, particles can form in the exhaust tract for the SCR catalyst. Through the research project Formation of Particles with UWS Injection, the findings on specific emission formation mechanisms should provide an additional level of detail [5]. The continuous reduction in pollutants in combustion engines is producing more phenomena that were previously masked and could not be measured separately. However, the precise process of how these sometimes extremely small particles are formed from UWS injection is yet to be clarified. Within the framework of the FVV-funded research project, conducted by the TME and the Institute

FIGURE 3 Theoretical particle formation pathways through injection of UWS (© RWTH Aachen)



for Occupational, Social and Environmental Medicine (IASU) at Uniklinik RWTH Aachen, the formation of particles and, in addition, their emission relevance (number, size distribution and composition) are to be investigated in order to derive indications for future development for ZIVs. **FIGURE 3** shows possible chemical processes for attachments to existing particles or new particle formation under UWS injection.

The project's approach is divided into two major packages of work. The first one concentrates on the online particle measurements at the engine test bench and on particle sampling. A diesel and a hydrogen engine will be used here. In parallel to this, the second package is intended to provide deeper insights through detailed chemical analyses of the samples and by combining all the results in a descriptive model. Both packages aim to create realistic test setups that enable direct transfer. Initial results are expected in 2023, so that they can be incorporated directly into exhaust gas system and components development for the next emissions levels.

5 CONCLUSION AND OUTLOOK

In its research activities, the FVV fundamentally pursues a technology-neutral approach. As the research results show, combustion engines still have significant potential in this context. The member companies should be free to choose whichever powertrain concept they want. The fundamental technologies needed to implement a ZIV already exist. Future activities will need to focus on using these technologies in a way that allows them to develop their full potential. FVV makes a crucial contribution to this by enabling manufacturers, suppliers and development service providers to work together with universities and other research institutions in a collaborative, precompetitive way.

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