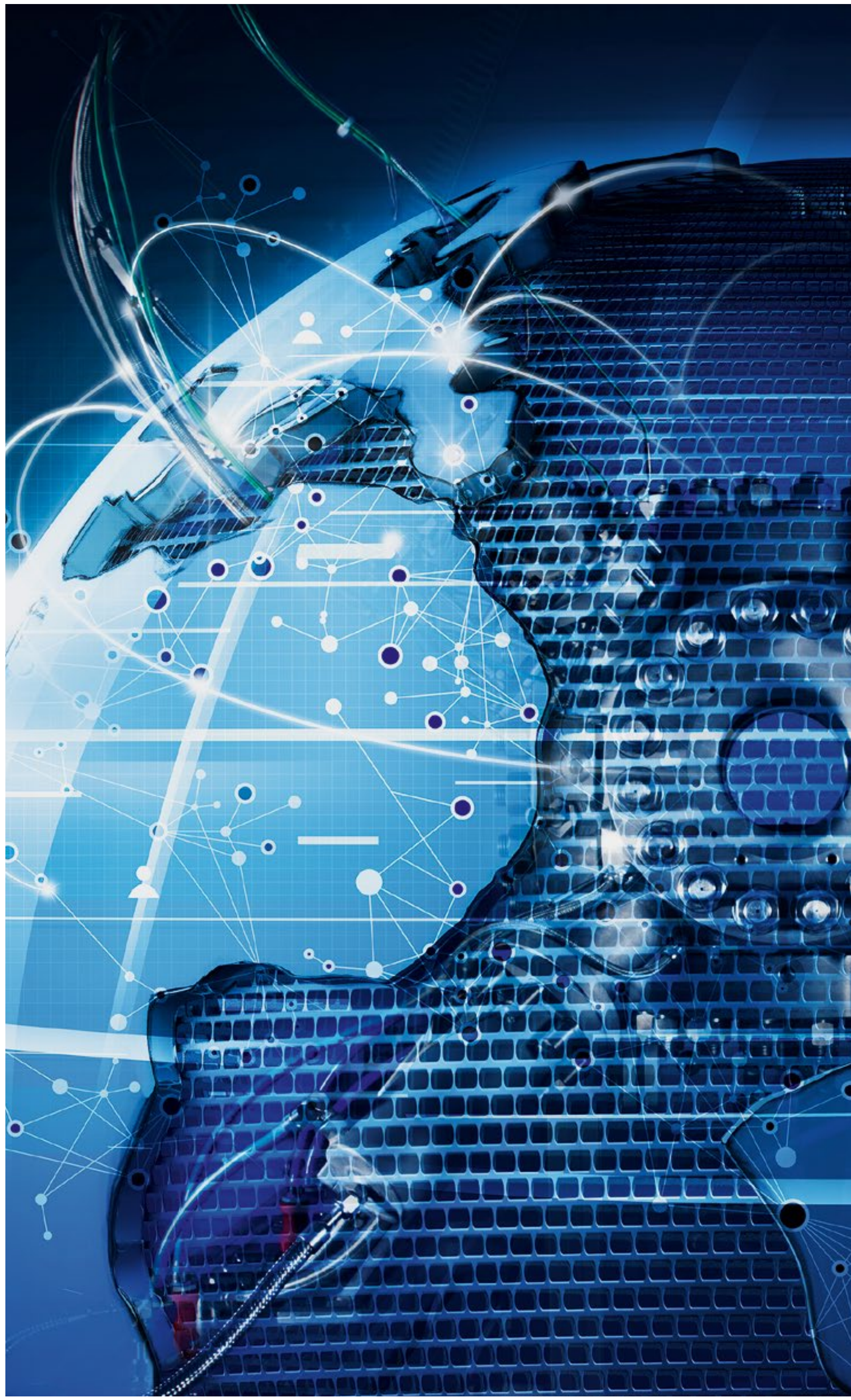
Engine Research in International Cooperations

The German Research Association for Combustion Engines (FVV) has become significantly more international in recent years. Since 2015, it has been using the Collective Research Networking (CORNET) program of the German Federal Ministry for Economic Affairs and Energy (BMWi) to promote international collaboration in pre-competitive industrial collective research on combustion engines. The potential is not only harbored by resource-efficient knowledge acquisition and transfer, but also in the training of the next generation of highly qualified scientists.



1 MOTIVATION

International research cooperations are a proven method of resource allocation in many disciplines. They are especially common where complex fundamental research is to be financed. In the European Union, an instrument was created in 2005 that allows application-oriented collaborative research to be organized and financed across national borders in the form of European Research Area Networks (ERA-Net). Following this, in 2011 the German Federation of Industrial Research Associations (AiF) founded CORNET on behalf of the German Federal Ministry for Economic Affairs and Energy (BMWi), which gives small and medium-sized enterprises in particular access to cutting-edge international research through pre-competitive collective research. At present, ministries and funding organizations from 13 countries and regions are involved in CORNET; the projects are funded on the basis of national and regional funding mechanisms with domestic taxation being a key principle.

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"International research cooperations bring up-and-coming scientists together."

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"The international collaboration between AICE and FVV promotes the exchange of knowledge and best practices in the research of conventional, modern and future powertrain solutions."

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"CORNET networks national and regional collective research programs of various countries in order to allow even small and medium-sized enterprises to benefit from international research projects and to further internationalize FVV."

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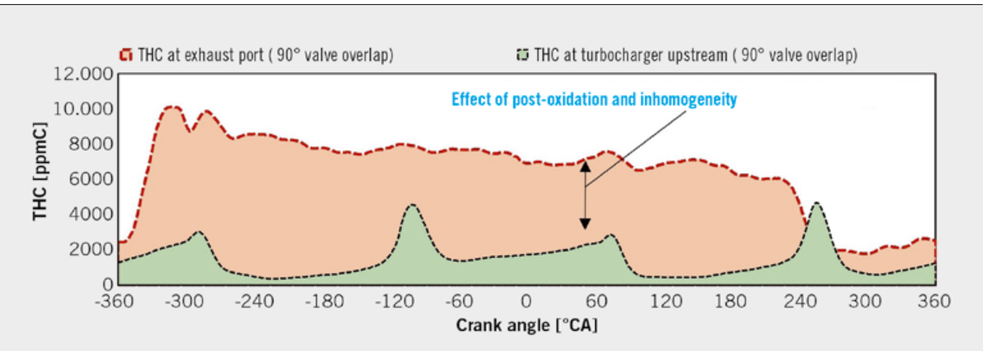

FIGURE 1 Measured concentration of unburned hydrocarbons (Total Hydrocarbons, THC) in the outlet duct and downstream of the turbocharger for an operating point at 1600 rpm, at medium load and 90° valve overlap (© FVV)

A joint execution of research projects with German and foreign Research, Technology and Development (RTD) research facilities is thus linked to the German research association finding a partner organization in the country whose facilities are to be involved.

Due to the strong standing of the internal combustion engine and turbo engine sector within Germany, the FVV has long worked with highly effective domestic RTD performers with only very few exceptions. The test facilities required for pre-competitive work were available in Germany, or – like the plain bearing test rig at the Clausthal University of Technology – were financed by the FVV in collaboration with other research associations. One exception to this is the traditionally close partnership with the Swiss Institute of Energy Technology at ETH Zurich, which has test facilities that are unique worldwide. For instance, the rapid compression and expansion machine run in Zurich enables the detailed optical investigation of individual combustion processes at pressures of more than 100 bar and temperatures of over 950 K.

Over the last decade, the FVV research network has become increasingly international, with new members joining from inside and outside Europe. By opening up in this manner, the research association took the gradual globalization of its own member companies into account. In particular, the cooperation with Japan has been greatly expanded and deepened through bilateral projects. Consequently, the Japanese Research Association of Automotive Internal Combustion Engines (AICE) was founded in 2014, based on the FVV model. Following comprehensive preliminary work and coordination, in 2017 the FVV submitted the first German-Japanese pilot project "Post-Oxidation" to CORNET [1], which is now close to completion. On the Japanese side, this project is sponsored by the New Energy and Industrial Technology Development Organization (NEDO). Further projects have been initiated with international sponsors and RTD performers since this time.

2 PROJECT POST-OXIDATION

For the first CORNET project, which was to establish the cooperation between German and Japanese RTD performers, a number of considerations had to be made regarding both organizational matters and the subject matter of the work. The most relevant was the selection of the topic: the competencies of the RTD performers as well as the industrial feasibility in both countries had to be taken into account, whereby the research topic itself was to focus on the sustainability of combustion engines per se. A suitable topic was found in the modeling of post-oxidation in the exhaust gas of spark-ignition engines. Post-oxidation is the term used to describe the oxidation of rich combustion products (H_2, CO, HC) in the exhaust gas using scavenged air. The oxygen excess can be achieved with suitable valve timings, where intake air is guided directly to the exhaust tract through the open outlet valve during the valve overlap phase. This process is called scavenging; it leads to a lower residual gas content in the combustion chamber and thus to a reduced knocking tendency. In addition, the exothermic reactions associated with post-oxidation and the increased volumetric flow result in a higher enthalpy flow, which the exhaust gas turbocharger converts intoa higher boost pressure and improved response behavior. In order to keep the three-way catalytic converter in the conversion window, an optimal regulation of post-oxidation is required. This challenge becomes even greater in transient operating ranges and can lead to unwanted peaks in measurements of Real Driving Emissions (RDE).

Therefore, the starting point of the project executed jointly by the Department of Mechanical Engineering at Chiba University, the Aizawa Lab at Meiji University and the Institute of Automotive Engineering at the University of Stuttgart [1] is to develop a manageable zero- respectively one-dimensional model for post-oxidation that enables the virtual parameterization of engine control units. The first step for creating such a model was varying the control times in order to identify characteristic map ranges in which post-oxidation is also possible when stationary, in order to ensure good reproducibility of the measurement results. To this end, tests were carried out on a complete engine, which had previously been equipped with special measuring technology in the outlet manifold and upstream and downstream of the turbocharger. In doing so, a characteristic map range with post-oxidation sufficiently large for the development of the model was identified, **FIGURE 1**. Even in this project phase, a pronounced dependency on oxygen content, exhaust gas temperature and mixing was evident. This was followed by modeling the reaction kinetics, the understanding of which is indispensable for building a valid three-dimensional Computational Fluid Dynamics (CFD) model. Among other findings, it was revealed that hydrogen combustion from fuel-rich combustion is a good indication of post-oxidation. The direct measurement of the hydrogen concentration resulting from this project represents a new approach.

The subsequent CFD simulations were performed with both a complete engine model and a significantly more finely meshed outlet duct model. The data records collected with the finer mesh were necessary to validate the complete engine model. The collaborative project will be completed in February 2021. It is already foreseeable that at the end of the work a one-dimensional model will have been created, which enables accurate predictions of post-oxidation to be made in transient operating conditions with a computing time of just a few seconds. Further research is needed with regard to validations of other engines, testing transferability to other post-oxidation processes, for example secondary air injection when warming up the engine, and the dependency on other synthetic so-called e-fuels.

3 PROJECT MEASUREMENT OF FUEL AND OIL TRANSPORT

In a second German-Japanese CORNET project, innovative measuring procedures are to be used to analyze the oil film thickness and fuel and oil transport in the piston assembly [2]. Although similar topics have already been examined in a range of FVV projects, the researchers hope to gain new findings on optimizing both the friction and emission behavior of combustion engines. To this end, measurements are to be carried out on both diesel and spark ignition engines using laser-induced fluorescence and a photochromatic method. Photochromism is the reversible change of the absorption spectrum when excited by UV light, **FIGURE 2**. As the excitation remains for a relatively long period of time even after the UV source has been switched off, this method can also be used to visualize for example mass transfer of oil or of fuel residue on the cylinder wall. These methods have never been combined before and are to enable a significantly deeper understanding of the processes during engine operation. In addition to improving the measuring technology used, the results are also intended to assist in creating new simulation tools. Implementation of the project began in early 2020, and four RTD performers are involved: Tokai University and Tokyo City University from Japan, the Institute for Analytical Measurement Technology Hamburg and the Institute of Internal Combustion Engines at the Technical University of Munich.

4 PROJECT INJECTION OF SYNTHETIC FUELS

The most international CORNET project to date is currently in the starting phase: RTD performers from Germany, Austria, the United States and China are working together to investigate the injection behavior of future synthetic fuels for compression ignition engines [3]. **FIGURE 3**, **FIGURE 4** and **FIGURE 5** show laboratory equipment used by participating facilities. To study these fuels, the spray and ignition behavior of individual fuel components such as n-alkanes, alcohols or oxymethylene ethers and the dependency of this behavior on external parameters will be tested. The laboratory equipment of the five involved institutes allows much of the measuring technology available today to be covered, and thereby creates the basis for a fast and reliable characterization of the individual fuel components. Accordingly, the project can make a significant contribution to a fast market introduction of fuels that release less or almost no CO_2, even from a well-to-wheel perspective.

5 SUMMARY AND PERSPECTIVES

The initial summary of the new international cooperations is a very positive one. The experiences made so far indicate that the CORNET projects strengthen all three pillars of the FVV – technology, network and young academic talents. Through the collaborative nature of the work, which brings together the competencies and laboratories of various RTD performers, the pre-competitive industrial collective research achieves its goal more quickly and with far less expenditure. This method enables international technology expertise on future topics, such as the further reduction of exhaust gas emissions or the use of synthetic fuels, to also be made available to Small and Medium-sized Enterprises (SME). Especially for these enterprises that have to prevail in the heavily globalized engine industry, building and maintaining their own network of research and development partners is a significant challenge. Therefore, the CORNET program and the continuous support of the projects by FVV working groups represent a great opportunity for SMEs in particular. For the FVV itself, the cooperations strengthen its networking with foreign members and foster mutual understanding. The work in international research projects poses multiple challenges for young academic talents. Alongside complex technical matters, project management tasks and, not least, intercultural encounters have to be mastered. As a result, the CORNET projects are especially well-suited to preparing young specialists for future professional tasks in a global industry.

As funding for pre-competitive industrial collective research has to be distributed across an increasing variety of powertrains and energy sources, it is recommended to ensure that research projects are as resource-efficient as possible and the potential that lies in international cooperations is exploited.

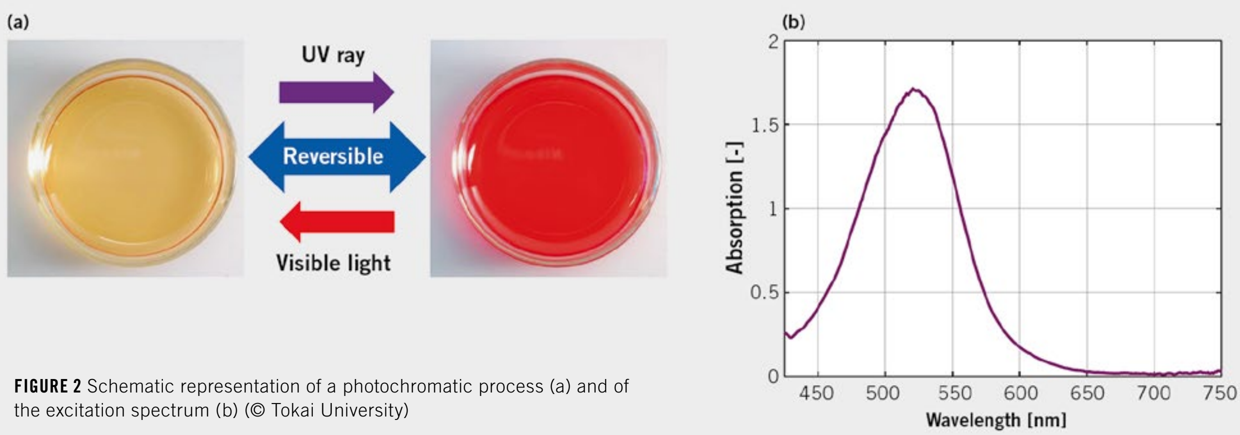

FIGURE 2 Schematic representation of a photochromatic process (a) and of the excitation spectrum (b) (© Tokai University)

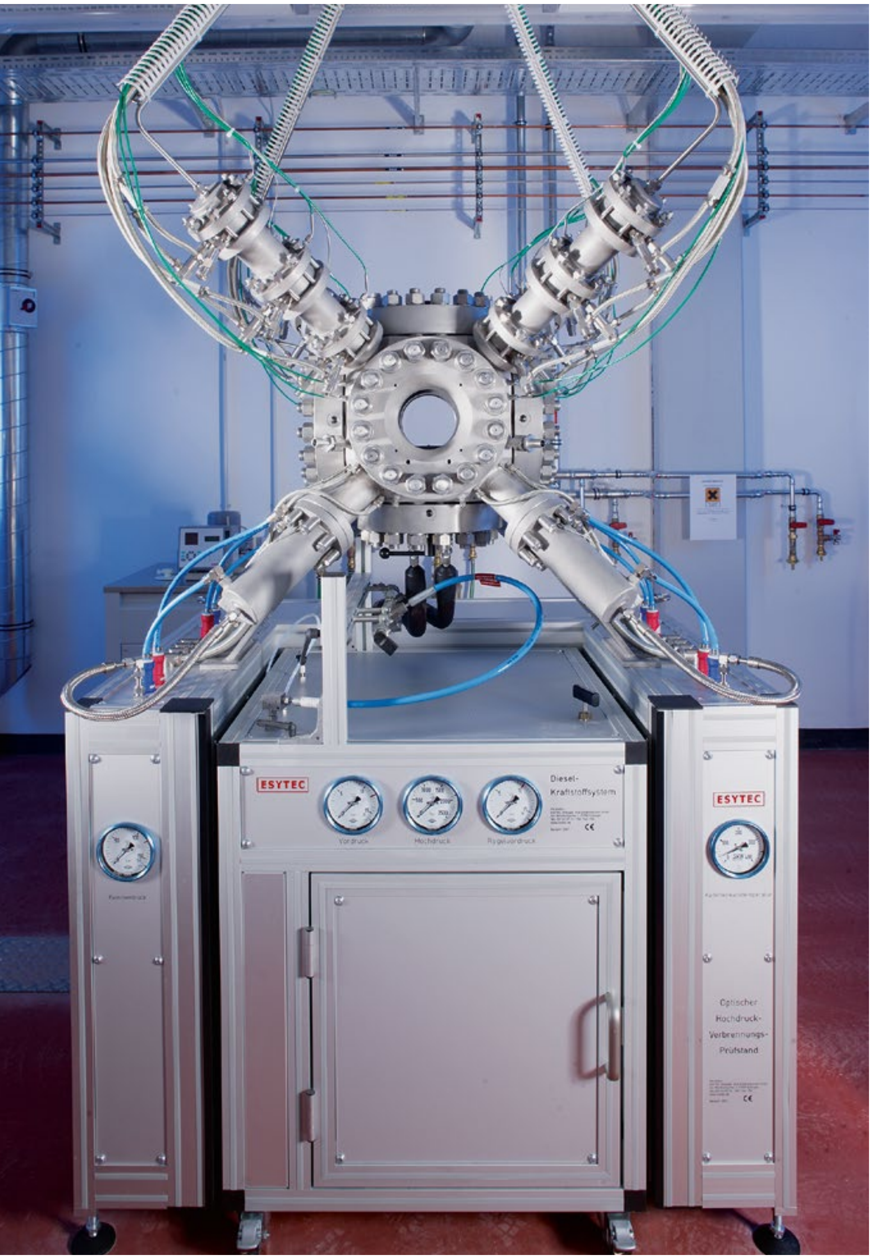

FIGURE 3 Constant-flow container of the Friedrich-Alexander-Universität Erlangen-Nürnberg in Germany (FAU) (© FAU)

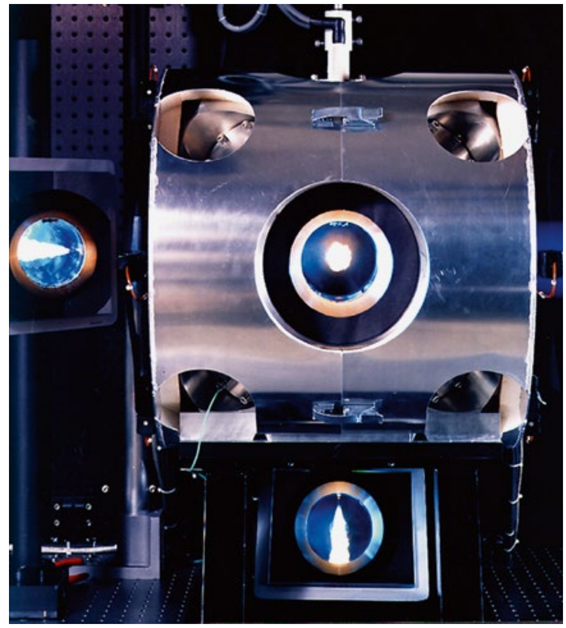

FIGURE 4 Constant-volume container of the Sandia National Laboratories (SNL) in the USA (© SNL)

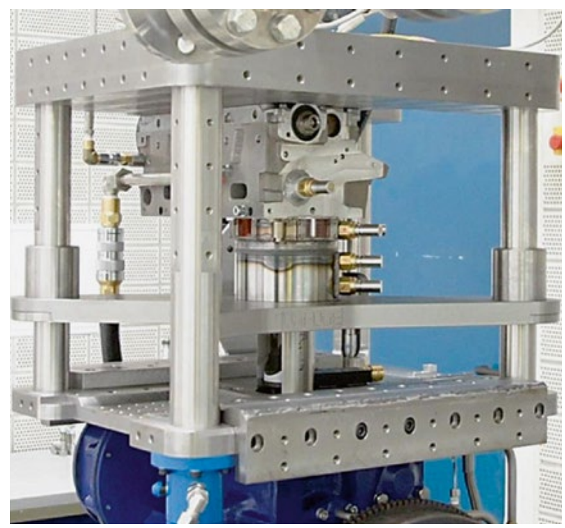

FIGURE 5 Optically accessible diesel engine of the University of Duisburg-Essen in Germany (© University of Duisburg-Essen)

REFERENCES

[1] IGF research project "Post-oxidation (HC, CO and PM) in the exhaust manifold of SI engines." Funding: CORNET (234 EN/1) and FVV (1336). Coordinators: Christine Burkhardt (EnginOS), Yoshihiro Imaoka (Nissan Motor). RTD performers: Prof. Dr.-Ing. Michael Bargende (Institute of Automotive Engineering, University of Stuttgart), Prof. Dr.-Ing. Yasuo Moriyoshi (Chiba University), Prof. Dr.-Ing. Tetsuya Aizawa (Aizawa Lab, Meiji University). In: FVV (ed.): Proceedings R590, Frankfurt am Main, 2019, pp. 171-200

[2] IGF research project "Clarification of fuel and oil flow behaviour around the piston rings of internal combustion engines." Funding: CORNET (260 EN) and FVV (1396). Coordinators: Dr.-Ing. Markus Gohl (APL), Motoichi Murakami (Toyota Motor Corp). RTD performers: Prof. Dr.-Ing. Gerhard Matz (Institute for Analytical Measurement Technologies, Hamburg), Prof. Dr.-Ing. Georg Wachtmeister (Chair of Internal Combustion Engines, Technical University of Munich), Prof. Dr. Akihiko Azetsu (Tokai University), Dr. Yuji Mihara (Tokyo City University) (unpublished)

[3] IGF research project "Injection, mixing and autoignition of e-fuels for CI engines." Funding: CORNET (274 EN) and FVV (M2118). Coordinators: Dr. Uwe Leuteritz (Liebherr). RTD performers: Prof. Dr.-Ing. Michael Wensing (Institute of Engineering Thermodynamics, Friedrich-Alexander-Universität Erlangen-Nürnberg), Prof. Dr. techn. Bernhard Geringer (Institute for Powertrains and Automotive Technology, Vienna University of Technology), Prof. Dr.-Ing. Sebastian Kaiser (Institute for Combustion and Gas Dynamics, Universität Duisburg-Essen), Lyle Pickett (Sandia National Laboratories), Prof. Dong Han (Shanghai Jiao Tong University) (unpublished)

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