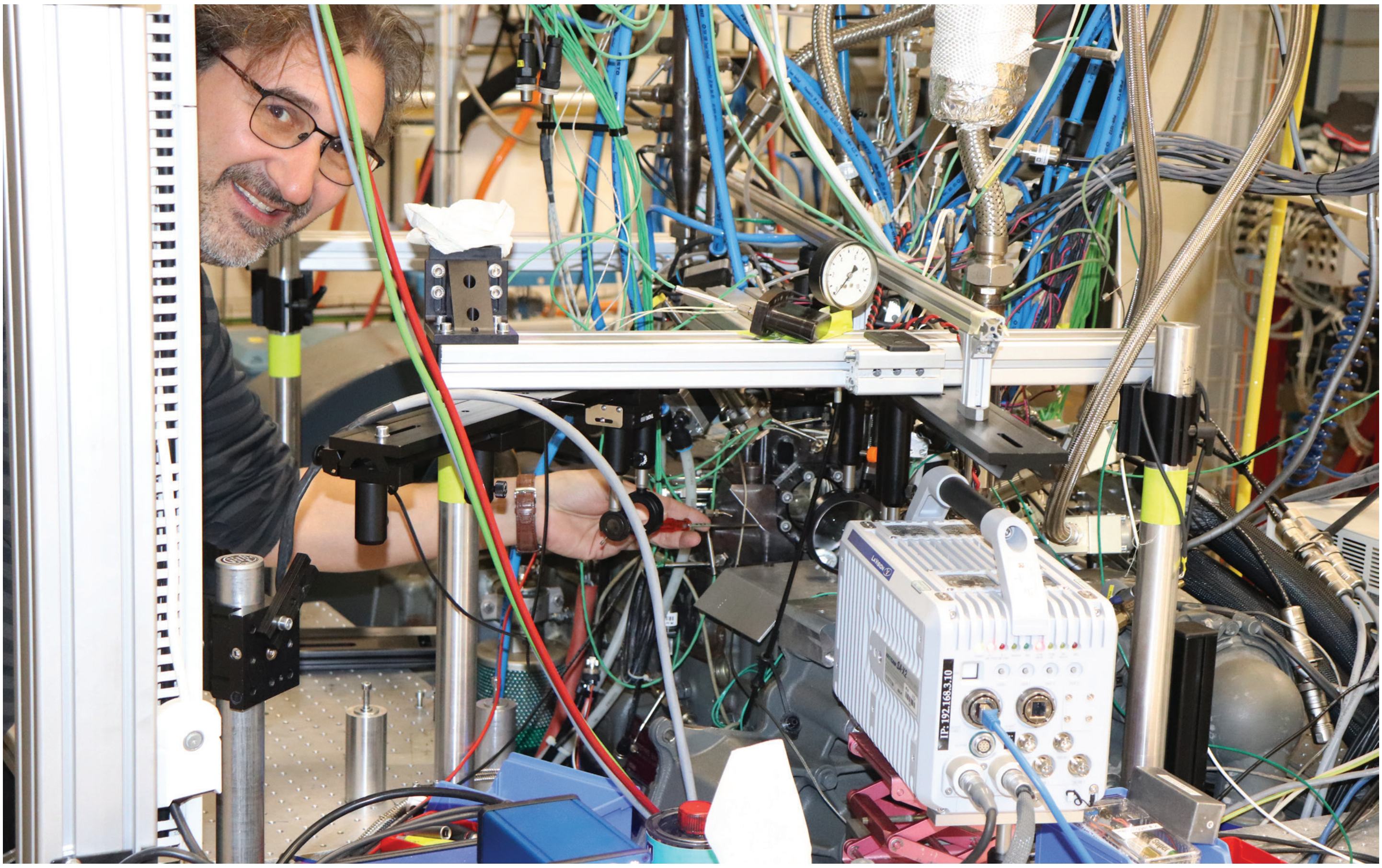
MAKING COMBUSTION CLIMATE-FRIENDLY

With the electrification of passenger cars and commercial vehicles, the classic gasoline and diesel engine is losing importance. However, internal combustion engines will not be obsolete in the foreseeable future, because in certain applications they are difficult to substitute. A new research center set up in recent years at the University of Applied Sciences and Arts Northwestern Switzerland (FHNW) in Windisch is developing the basis for making large engines more sustainable. The focus is on combustion processes with climate-neutral fuels.



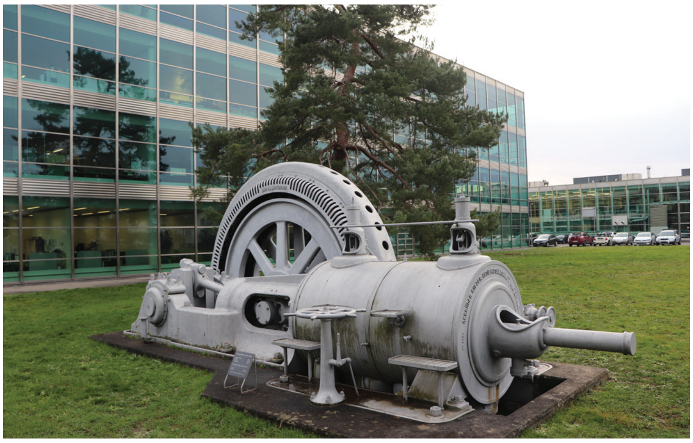
The Flex-OeCoS test bench in the newly built 'Combustion Research Laboratory' at the University of Applied Sciences and Arts Northwestern Switzerland in Windisch: Prof. Kai Herrmann points with a screwdriver to the location of the optical combustion chamber, which can be used to realistically investigate novel combustion processes for alternative fuels. Photo: B. Vogel

A technical report about the results of several research projects in the field of combustion, which were financially supported by the Swiss Federal Office of Energy. The report has been published in the technical magazine Swiss Engineering STZ (issue April 2023).

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Federal Office of Energy SFOE

The electrification of public transport is a megatrend. The number of electric cars sold is rising, and there is forward drive to expand charging infrastructure. The public discussion around electrification mainly revolves around road traffic because of its immediate importance. But this view falls short, as Kai Herrmann, professor at the University of Applied Sciences and Arts Northwestern Switzerland (FHNW) at Windisch, points out: "Electrification makes sense in many areas. Nevertheless, large internal combustion engines powered by climate-neutral fuels are likely to continue to play a role during a transitional phase. It›s about applications where renewable energies are not permanently available or storage is not feasible, for example, in large engines that power cargo ships or ensuring decentralized power generation on demand when the wind doesn't blow or the sun doesn't shine."

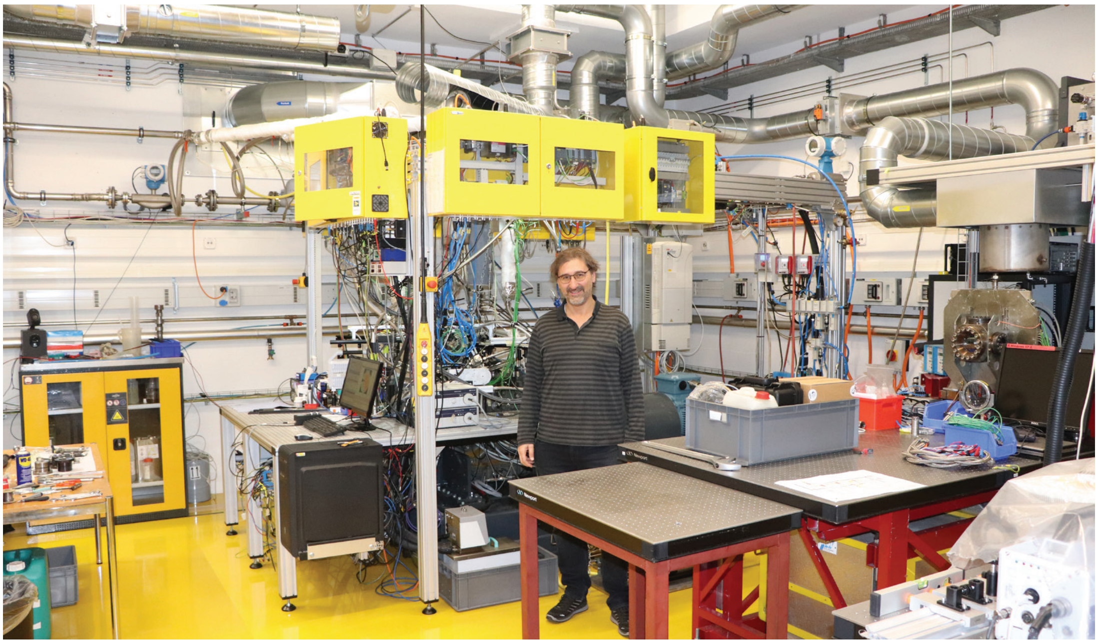


Campus of the University of Applied Sciences and Arts Northwestern Switzerland in Windisch, School of Engineering. In the building at the back right is Prof. Kai Herrmann's combustion laboratory. In the foreground, a Sulzer steam engine with a generator from Brown Boveri from 1915 reminds the public of Swiss industrial achievements. Photo: B. Vogel

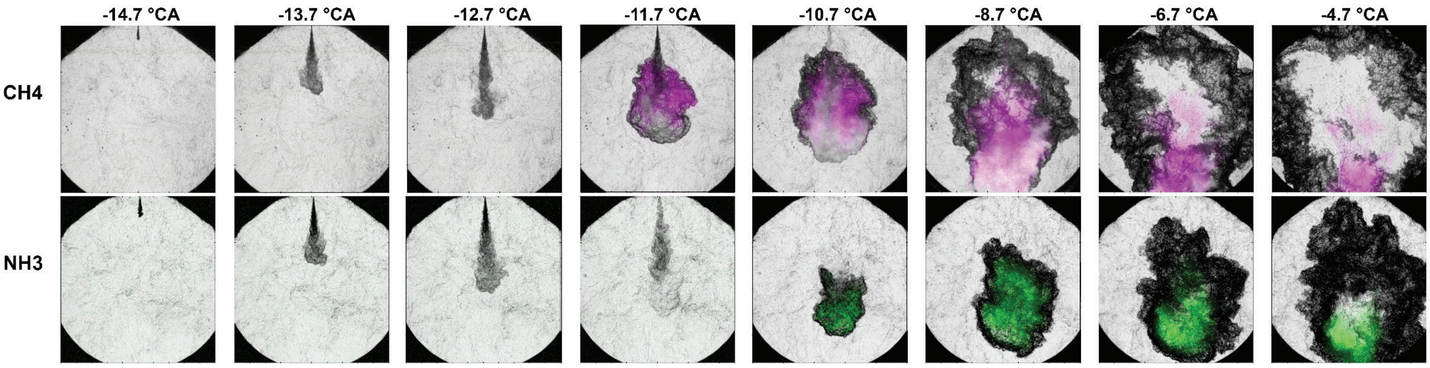
Combustion research at Windisch

Kai Herrmann comes from the world of large engines. Before becoming a professor in Windisch in 2016, the mechanical engineer, who was educated at ETH Zurich, worked for the Swiss subsidiary of the Finnish ship engine manufacturer Wärtsilä, among others. Over the years, he maintained contacts with the Winterthur company Gas & Diesel (WinGD), which emerged from Wärtsilä, the measurement technology company Kistler (Winterthur), Liebherr Machines Bulle SA, and FPT Motorenforschung AG, the long-established research and development center for commercial vehicle engines in Arbon. With this backdrop of experience, Herrmann established a center for combustion research at the FHNW Institute of Thermal and Fluid Engineering (ITFE) at the School of Engineering in Windisch in 2018.

The special feature of the laboratory is a test bench for investigating combustion processes as they occur in real IC engines. The ITFE had developed the "Flex-OeCoS" - the name of the test bench - together with the Laboratory of Aerothermochemistry and Combustion Systems (Professor Konstantinos Boulouchos) at ETH Zurich (see text box p.4). The research facility was initially commissioned at the ETH Zurich. After Prof. Boulouchos retirement in 2019, it was transferred to



The combustion research group of Kai Herrmann is comprised of only a few permanent employees. Many tasks are carried out by students as part of their bachelor's or master's theses or, in some cases, dissertations. The laboratory cooperates with various universities (e.g. KIT Karlsruhe, Uni Stuttgart). Guest exchanges of doctoral students (e.g. Polytechnica Valencia, TU Graz) have also become established practice. Photo: B. Vogel



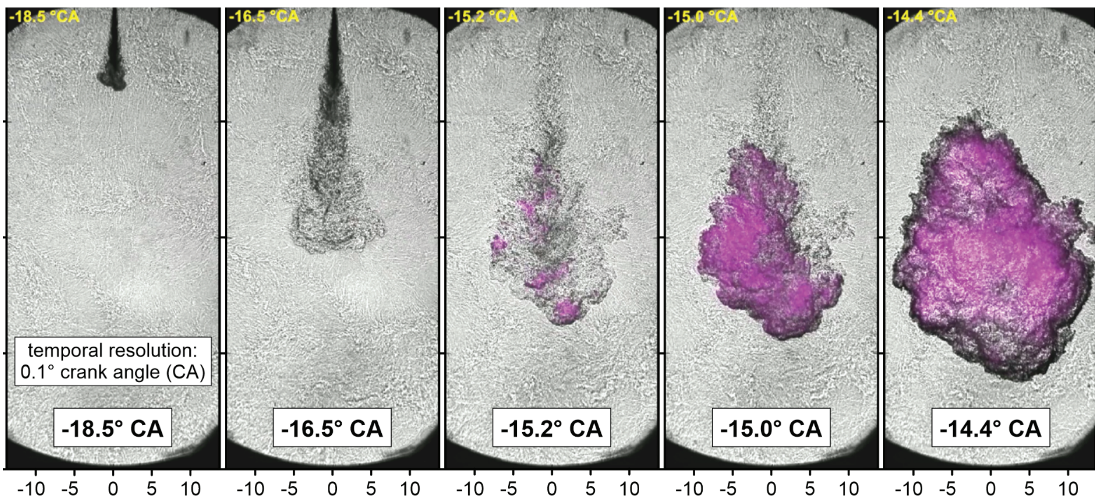
The two image sequences show from left to right the development over time of the ignition of a methane/air (top) or ammonia/air mixture (bottom) in the optical combustion chamber of the Flex-OeCoS test bench. In the case of ammonia, the delayed inflammation (ignition) or the slower flame propagation can be clearly seen. Photos: ITFE

Windisch, where it was substantially further developed. Since then, it has been used to study combustion processes that allow renewable fuels to be used efficiently and largely without emissions. These fuels are produced synthetically with renewable energies and do not contain any energy source of fossil origin. When using ‘green’ hydrogen, but also ‘green’ ammonia or methanol, the CO_2 emissions from the operation of an internal combustion engine can be classified as climate-compatible.

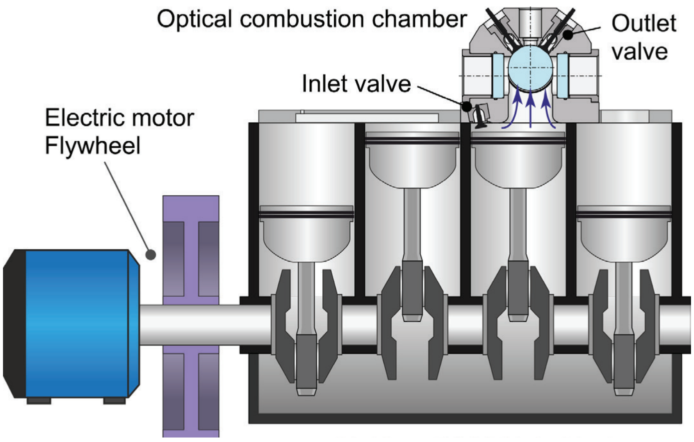
Conversion to dual-fuel operation

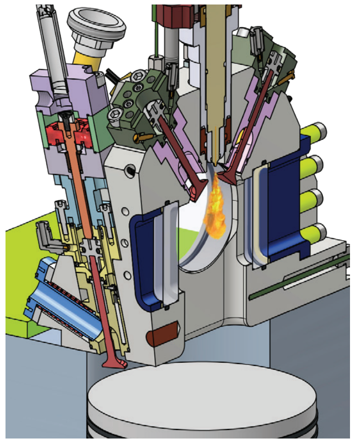
Herrmann and his team focus on studying large engines, such as those used in ocean-going cargo ships. In this case, large means engines with up to 110,000 hp (80 megawatts) of power and a consumption of 30 tons of fuel per 100 kilometers. The latest generation of these engines uses the dual-fuel combustion process: The fuel is no longer heavy fuel oil or marine diesel oil as in the past, but a natural gas-air mixture ignited by a separate mechanism. Ignition takes place directly in the combustion chamber by means of a liquid fuel jet (‹pilot›) of diesel, for example. In larger (2-stroke) engines, ignition occurs according to the same principle in a pre-chamber. Switching from heavy fuel oil/marine diesel oil to natural gas reduces pollutant emissions by 40 to 80% (soot) or by up to 90% (NO_x, SO_x) and more, depending on the engine type, while emissions of the greenhouse gas CO_2 are reduced by as much as 15 to 20%.

This is remarkable progress, but it is only an interim step toward decarbonizing shipping on the world›s oceans. “With our research, we want to make contribution to further reducing greenhouse gas emissions from large engines,” says Herrmann. “We can do this if we make improvements to engines that run on natural gas, or if we further develop engines so that they can run on renewable, climate-neutral fuels.” With this goal in mind, researchers led by Herrmann



The FHNW scientists can distinguish between vaporizing fuel and the ignited part of the fuel mixture (highlighted by coloring) by simultaneous application of optical measurement techniques (Schlieren/ chemiluminescence) and thus make the ignition processes and flame propagation vividly visisble. Photo: ITFE





Schematic representation of the Flex-OeCoS test bench (left). The optical combustion chamber can be seen enlarged in the figure (right): The center pilot fuel injector ignites a gas-air mixture during dual-fuel combustion. Illustration: ITFE

are conducting several research projects. They are financed by international programs and direct grants from industry (e.g. WinGD), but also by contributions from the SFOE. There are also collaborations with German universities such as RWTH Aachen, KIT Karlsruhe and the University of Stuttgart, and the projects support training of several doctoral students.

Alternative fuels ammonia and methanol

Two projects (PROGrESs, PREFER) are dedicated to the problem of pre-ignition. This refers to a misfire of the natural gas-air mixture in dual-fuel engines, caused by an unintentional spontaneous ignition of lubricating oil in the combustion chamber. The researchers want to find why this misfire sometimes happens and thus create the prerequisite for engine manufacturers to take suitable measures to prevent the "malfunction" with a view to optimum operation (efficiency, emissions).

In research into alternative fuels, the scientists in Windisch are focusing on ammonia and methanol. Both substances serve as energy carriers for hydrogen, can be produced synthetically with renewable energies (e.g. wind or solar power) and can be stored well in liquid form. Synthetic methanol (CH_3OH) emits only as much CO_2 during combustion as was removed from the atmosphere during production and is therefore considered climate-friendly. Ammonia (NH_3) is carbon-free, but

A TEST RIG UNIQUE IN THE WORLD

The test bench at the Institute of Thermal and Fluid Engineering (ITFE) at the University of Applied Sciences and Arts Northwestern Switzerland (FHNW) in Windisch (AG) is named Flex-OeCoS. The acronym stands for: "Flexibility regarding Optical engine Combustion diagnostics and/or the development of corresponding Sensing devices and applications." Loosely translated, this means: The test bench is used to investigate engine combustion processes and to develop corresponding sensors.

The heart of the research facility, which is unique in this form worldwide, is an optically accessible combustion chamber (cylinder head) on a Liebherr engine block. However, the test bench must not be taken as a 1-to-1 image of an engine. Indeed, the combustion chamber is only diameter 60 x 20 mm in size. However, the test bench is designed in such a way that it can be used to reproduce the conditions that prevail in the combustion chamber of engines. The processes that take place on the test bench are thus transferable to real engines.

Herrmann calls the test bench a "work of art." The scientist is enthusiastic about his research facility for good reasons: The Flex-OeCoS's optically accessible combustion chamber enables detailed investigation of combustion processes under engine-relevant operating conditions such as pressure, temperature, and flow. Its flexibility (e.g. variable valve timing, injection, turbocharging, etc.) and sophisticated metrological instrumentation allow a wide variety of combustion processes to be investigated and measurement data to be acquired with high precision. With the aid of optical measurement technology, special cameras can also be used to observe the processes in the combustion chamber with high temporal resolution at up to 50,000 images per second.

Modern cargo ships are powered by dual-fuel engines that burn natural gas (with diesel ignition). Researchers at the FHNW in Windisch want to know, among other things, how such engines might also be powered by alternative, climate-neutral fuels in the future. Photo: Shutterstock

combustion can produce the extremely climate-damaging greenhouse gas N_2O (nitrous oxide).

Increasing ignitability

With two projects (CREDO, N2Ooff), FHNW researchers will further study ammonia. Within the framework of these projects, the Flex-OeCoS test bench is used to investigate, among other things, how mixture formation, ignition delay, flame propagation and heat release behave. They are also interested in the combustion conditions under which the formation of nitrous oxide could be prevented as much as possible. The researchers also want to clarify how the ignitability of ammonia, which is difficult to ignite, can be increased by adding hydrogen. Research into the corresponding combustion processes on the test bench will provide important information to answer these questions.

Within the framework of this research focus, whether natural gas and the pilot (diesel) required for ignition could be replaced in dual-fuel engines by CO_2-reduced fuels, such as OME (oxymethylene dimethyl ether), is also being investigated. The oxygenated synthetic diesel substitute OME could eliminate fossil fuel altogether and prevent soot formation. However, due to the lower calorific value of OME, the injection quantity would have to be adjusted so that the engine still "runs smoothly," as the FHNW researchers demonstrated.

Great interest from engine manufacturers

Diesel engine combustion processes are also being studied at the Flex-OeCoS test bench in Windisch. In one project (Adapted Fuels), the researchers wanted to know how the unwillingness of methanol (as a possible diesel substitute) to ignite could be overcome. In the experiments, this was achieved with an admixture of 10 % diethyl ether (also known as the narcotic ether). In the longer term, these results could pave the way to less climate-damaging fuels for internal combustion engine applications (e.g. combined heat and power plants). Another project (GIHPCO) is investigating whether, or with which "ignition aids," a high-pressure gas injection (analogous to liquid diesel) can be ignited directly in the combustion chamber. Finally, another research project (TurbFlow-PIVPOD) is investigating mixture formation, which is essential for ignition processes.

It is not yet possible to estimate which results from combustion research will have the greatest significance for the drive and energy systems of the future. In any case, competition for the best ideas has been launched. The company WinGD is developing large engines for marine propulsion systems that run on ammonia or methanol. The company Silent-Power AG (Cham) uses CO_2-neutral methanol, among other substances, in a combined heat and power plant to generate heat and electricity. The company Casale (Lugano) wants to distinguish itself with plants for the production of 'green' ammonia, among other things. Herrmann is convinced that his research will contribute to a fossil-free energy supply. "There is a lot of interest in our research at the moment," says the combustion expert.

- Further information on the individual **research projects** can be found on the Aramis platform under the link www.aramis.admin.ch/Projektsuche by entering the acronym of the project in the search field.

- For **information** on the SFOE-funded research projects, please contact Stephan Renz (info@renzconsulting.ch), external head of the SFOE research program Combustion-based Energy Systems.

- Further **technical** articles on research, pilot, demonstration, and flagship projects in the field of combustion can be found at www.bfe.admin.ch/ec-verbrennung.

Author: Benedikt Vogel, on behalf of the Swiss Federal Office of Energy (SFOE)
Version: June 2023