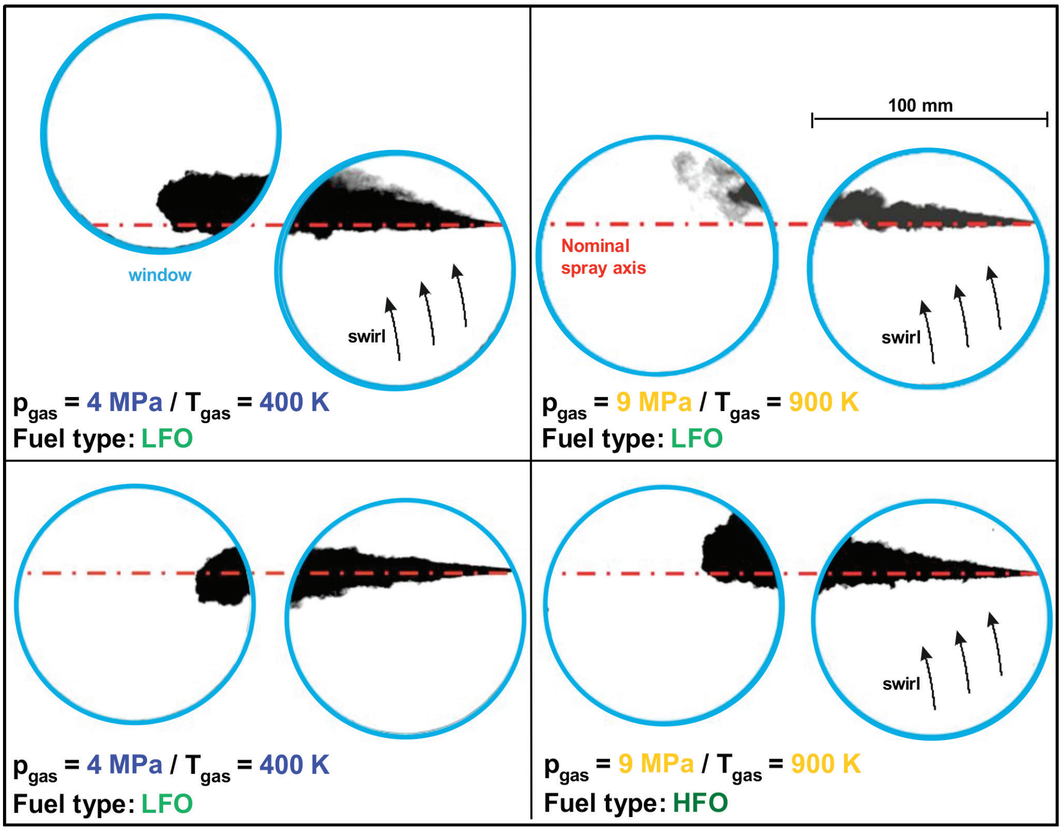
All fuel is not the same fuel

Energy conversion during the combustion process is exceptionally well researched - but continues to lead to new, fascinating questions. Researchers who study engines are currently focusing on fuel diversity. The reason is the growing importance of gas from renewable sources. There are also issues of fuel quality, which tends to strongly fluctuate.



Comparison of spray morphology approximately 1.6 ms after commencement of injection in terms evaporation, angular momentum and fuel quality (at constant gas density of 33 kg / m³). LFO stands for Light Fuel Oil, HFO for heavy fuel oil. Illustration: WinG & D

Dr. Benedikt Vogel, commissioned by the Swiss Federal Office of Energy (SFOE)

Natural gas is not a renewable energy source, but natural gas burns with less harmful residues than coal or heavy oil. Thanks to these properties, natural gas is the preferred fuel for internal combustion engines. But natural gas is not all the same; there is much variability in quality. In additon to the main component methane, natural gas contains other constituents. In Swiss natural gas of Russian origin, ethane, propane and butane comprise around around 6% —in natural gas produced at other sites, this proportion may rise to 20% or more. In addition to the origin of the gas, the manufacturing process plays a major role in determining the composition of a gas.

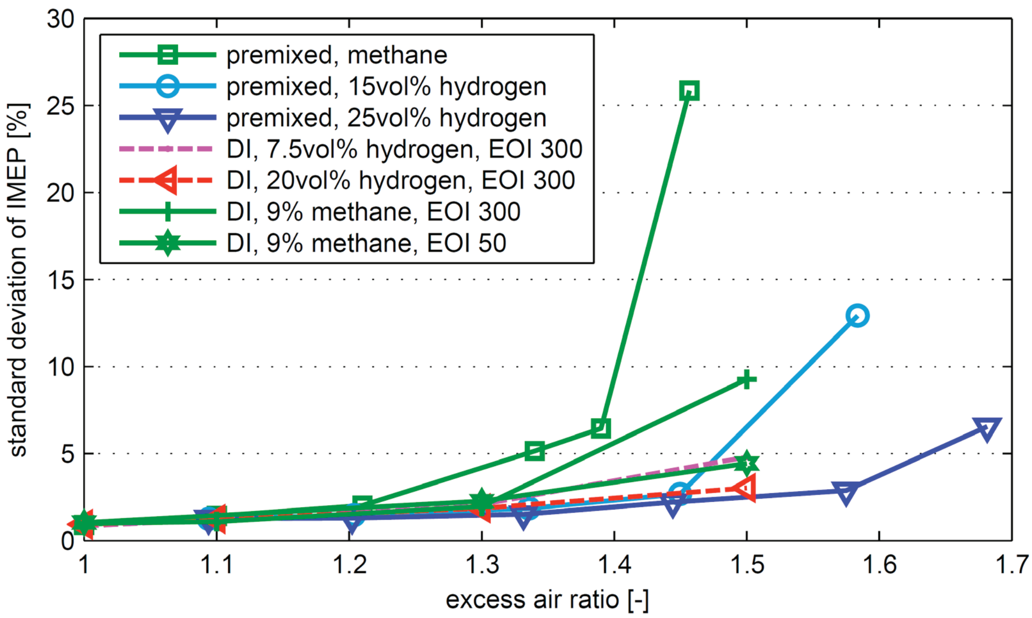
A technical report about the conference 'Verbrennungsforschung in der Schweiz' of September 9th 2015 at ETH Zurich, which was organized by the Swiss Federal Office of Energy.

This is shown by biogenic gases, which are obtained by fermenting biomass (biogas) or wood (wood gas), as well as gases in which hydrogen or methane is mixed, that have been recovered using renewable electricity.

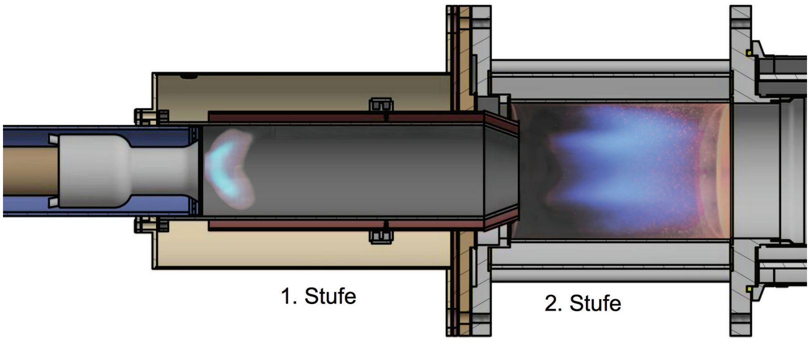
A Bridge to Industry

The different qualities of gas offered on the global market concern not only direct consumers but also science, as displayed during the symposium about Swiss combustion research, organized by the Swiss Federal Office of Energy, the ETH Zurich and the Paul Scherrer Institute, which took place in September 2015 in Zurich. The Combustion Symposium aimed to bridge the gap between academic research and industrial applications. This was shown at the Zurich meeting by the example of gas turbines. Chemical Engineer Dieter Winkler reported on a project about staged combustion in gas turbines, which the University of Applied Sciences and Arts Northwestern Switzerland (FHNW) has carried out in cooperation with the industrial group Alstom. A test plant was designed to operate with natural gas to which propane, unreactive CO_2 or highly reactive hydrogen are added (each with a share of up to 20%).

The test series with staged combustion confirmed the assumption that the new burner technology can work relatively "cleanly" with such unusual fuels and also during partial load operation. "We have shown experimentally that at partial load, fewer emissions result than at full load operation of conventional gas turbines without new burner technology," Winkler summarizes.



Empa research on the combustion process in gas engines: This image shows the cyclic variations in combustion for the different cases examined in relation to the excess air. Large cyclical variations lead to irregular engine operation and high emissions. It is evident that in the 'premixed' cases (i.e. without direct injection, abbreviated DI) hydrogen-enriched methane leads to significantly more stable and lean burn results (measured by the standard deviation of the indicated mean effective pressure / IMEP). The direct injection of hydrogen brings no real benefits in the examined test vehicle. One interesting feature is the direct injection of a small amount of methane in the direction of the ignition plug, this leads to a very strong expansion of the lean running limit. It could thus be demonstrated experimentally that the direct injection of a small amount of methane in the direction of the spark plug creates good conditions for robust combustion. Benefits will be only be able to be quantified after goal-oriented development of the engine for a carburation process. Graphics: Empa



Schematic representation of staged combustion. Illustration: FHNW

These research results are of considerable practical importance. The presentation made by Dr. Syed Khawar, a development engineer at Alstom Switzerland, showed this clearly. "Staged combustion is the current trend in the industry," Syed said, and illustrated the conclusion with the Alstom GT24 and GT26 gas turbines. These turbines each have two combustion chambers arranged in series. Unlike the experimental plant of the FHNW, aeration does not take place separately in each of the two combustion chambers. Instead, the still oxygen-containing exhaust gas of the first combustion chamber – after having driven a high pressure turbine – goes into the second combustion chamber. There fuel is again mixed in, whereby the mixture in turn ignites and expands through a low pressure turbine.

Alstom wants to build modern gas turbines so that they can cope with a wide range of fuels / reactivities ('fuel flex'), but that can also be operated so that gas power plants can compensate for fluctuations in production of wind and solar power ('load flex'). The developers are working towards very low nitrogen oxide (NO_x) emissions and at the same time towards further increases in the efficiency of combined gas and steam turbines above the 61% acheiveable today, as Syed says: "We and our competitors are working on an efficiency of 65% or more."

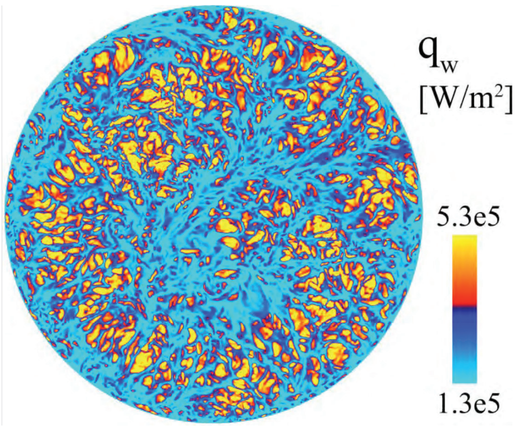
One Engine, Two Fuels

While industry works on the "multi fuel-ability" of gas turbines, developers of marine engines are working to optimize and bring to market so-called "dual fuel" operating and combustion processes. Today's 2-stroke marine engines are generally operated with heavy fuel oil or marine diesel (MDO). "Dual fuel" engines that are increasingly in use in the shipping industry are fueled by gas, which is ignited by a small amount of diesel fuel. "Two-stroke dual-fuel engines from Winterthur Gas & Diesel stand out because of the otto-cycle process control during gas operation. They require no engine modifications or exhaust aftertreatment to meet future emission limits, both in terms of nitrogen oxide emissions, as well as with regard to sulfur dioxide and particulate emissions," says Dr. Sebastian Hensel of the Winterthur Gas & Diesel Ltd. Hensel's company is a research and development center for marine engines, which together with the shipbuilding company CSSC (China) and the engine manufacturer Wärtsilä (Finland), operate in Winterthur.

The company, with its 350 plus employees, uses a visually accessible combustion chamber, in which the physicochemical processes of diesel combustion in two-stroke engines can be reproduced exactly. At this unique test bench, Beat von Rotz has been studying the injection and the ignition characteristics of various fuels as part of his doctoral thesis, especially the numerous parameters of spray morphology of the injection jet (e.g. pressure and temperature in the combustion chamber, injection pressure, angular momentum, fuel-injector-orifice diameter, fuel quality). He is also exploring microscopic spray parameters (droplet size and velocity) as well as characteristics of the ignition process. This provides a comprehensive set of reference data, which includes basic knowledge of the special characteristics of the injection and ignition processes and helps the engineers to create reliable models for the development of new engines.

Simulations with Unprecedented Accuracy

The “dual fuel” theme interests not only consumers but also the scientists at the Aerothermochemistry and Combustion Systems Laboratory (LAV) at ETH Zurich. This brings the research of LAV graduate student Daniele Farrace to the fore, who is pursuing the new concept of "dual fuel" engines. Although research on internal combustion engines has a long tradition, new research still provides more precise results. Thus thanks to simulation tools like DNS (Direct Numerical Simulation), the processes in a combustion chamber can be described with a never before seen accuracy. ETH researcher Dr. Martin Schmitt applies DNS for the first time on engine-like geometries. He thereby was able to divide the volume of a combustion cylinder into 135 million tiny partial volumes. For each one of these elements, its simulation data contains information on speed, pressure, temperature and chemical composition.



Thanks to a DNS simulation tool, ETH Zurich researchers can represent the distribution of heat in the cylinder of an internal combustion engine with an accuracy previously unacheiveable. Photo: ETHZ

It is no wonder that such simulations can only be tackled with a mainframe computer. Schmitt would need the computing power of 2,500 personal computers for his work. "With my research I could contribute to controlling pioneering engine technologies like HCCI," says Schmitt. HCCI, the homogeneous charge compression ignition, is aimed at the simultaneous combustion of as homogeneous a fuel mixture as possible in order to minimize the pollutant emissions. This research project also shows how sophisticated combustion research is today. “In the results our researchers can demonstrate today are included more than 20 years of work from our institute,” says Prof. Dr. Konstantinos Boulouchos, head of LAV at ETH Zürich.

Industry Can Only Innovate with Research

The results from basic research are an important input for Swiss industrial companies. This is made clear, for example, in the gas quality sensors that MEMS AG (Birmenstorf) develops together with Empa. This is also made clear by Guoqing Xu, who is conducting research as a doctoral student at the ETH for the construction machinery manufacturer Liebherr Machines Bulle SA. His scientific work is used to develop predictive models for a line of gas engines produced by Liebherr. The idea to build a bridge towards industrial application also struck Dr. German Weisser from ABB Turbo Systems Ltd. (Baden) at the combustion conference in Zurich. Weisser emphasized research is essential for his company. Only in this way could ABB Turbo Systems develop products, such as the Turbocharger, and solutions that make it possible for customers (manufacturers of diesel and gas engines, retail) to gain added value from their engines and equipment in the form of increased performance and efficiency, lower emissions, and increased operational flexibility. The 200 scientists and engineers in the R & D department must therefore have appropriate simulation tools to describe motor core processes (combustion, pollutant formation), but also to evaluate the reliability of relevant parameters.

The R & D activities must always be aligned to provide the right answers to current trends in the motor industry, says Weisser. The ABB-combustion expert summarizes these trends this way: as quality of liquid fuels declines, the popularity of gaseous fuels rises, further increasing efficiency and further growing the regulatory and operational requirements. To achieve these objectives, engine research should always look at the whole system, emphasizes Weisser, because: "What counts in the end is the performance of the entire system."

» Information concerning Swiss combustion research provided by Stephan Renz, head of the BFE-combustion research program: renz.btr[at]swissonline.ch
» For additional technical papers on research, pilot, demonstration and flagship projects in the field of combustion, see www.bfe.admin.ch/CT/verbrennung

Dual fuel 2-stroke test engine from Winterthur Gas & Diesel in Winterthur. Photo: WinG&D

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