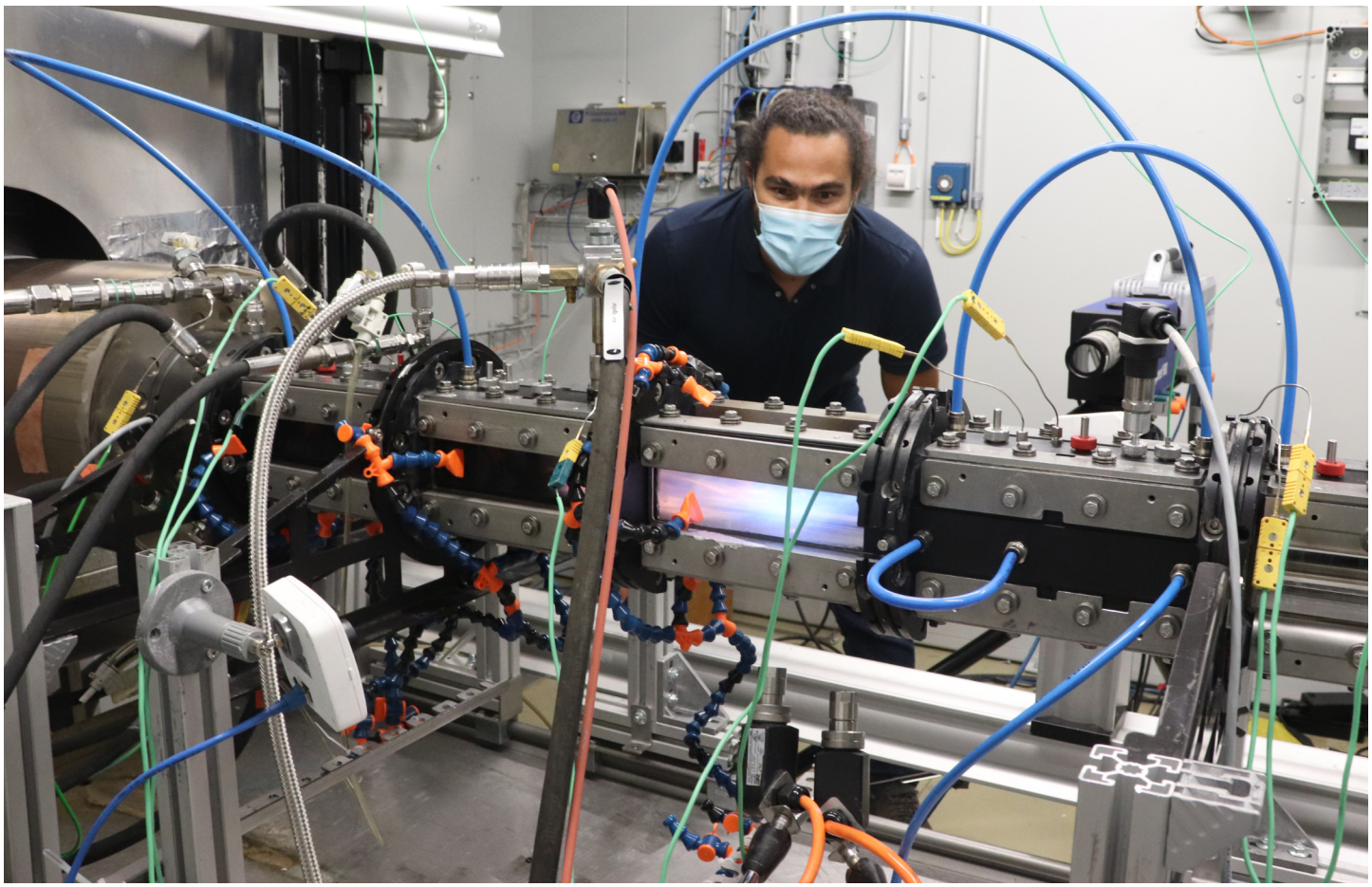
BURNING SYNTHETIC FUELS CLEANLY

Combustion engine automobiles are under pressure. To curb climate change, politicians are discussing replacing diesel and gasoline engines with electrically powered vehicles. But even if gasoline and diesel cars become a thing of the past, energy conversion by combustion will still have a place in ensuring future energy supplies, especially in burning hydrogen and other sustainably-produced synthetic fuels. At a conference held at Eidgenössischen Technischen Hochschule in Zurich (ETHZ), experts from science and industry discussed how to design combustion processes to be low-emission, efficient, and the most suitable applications.



Prof. Nicolas Noiray heads the Combustion and Acoustics for Power and Propulsion Systems Lab (CAPS Lab) at ETH Zurich. Before the French-born researcher came to ETH in 2014, he worked in gas turbine research at Alstom's Baden (AG) site. Photo: B. Vogel

A technical report about the results of the 'Conference on Combustion Research in Switzerland' of September 2021, which was organized by the Swiss Federal Office of Energy and partners. The report has been published in the technical magazine Swiss Engineering STZ (issue November 2021).

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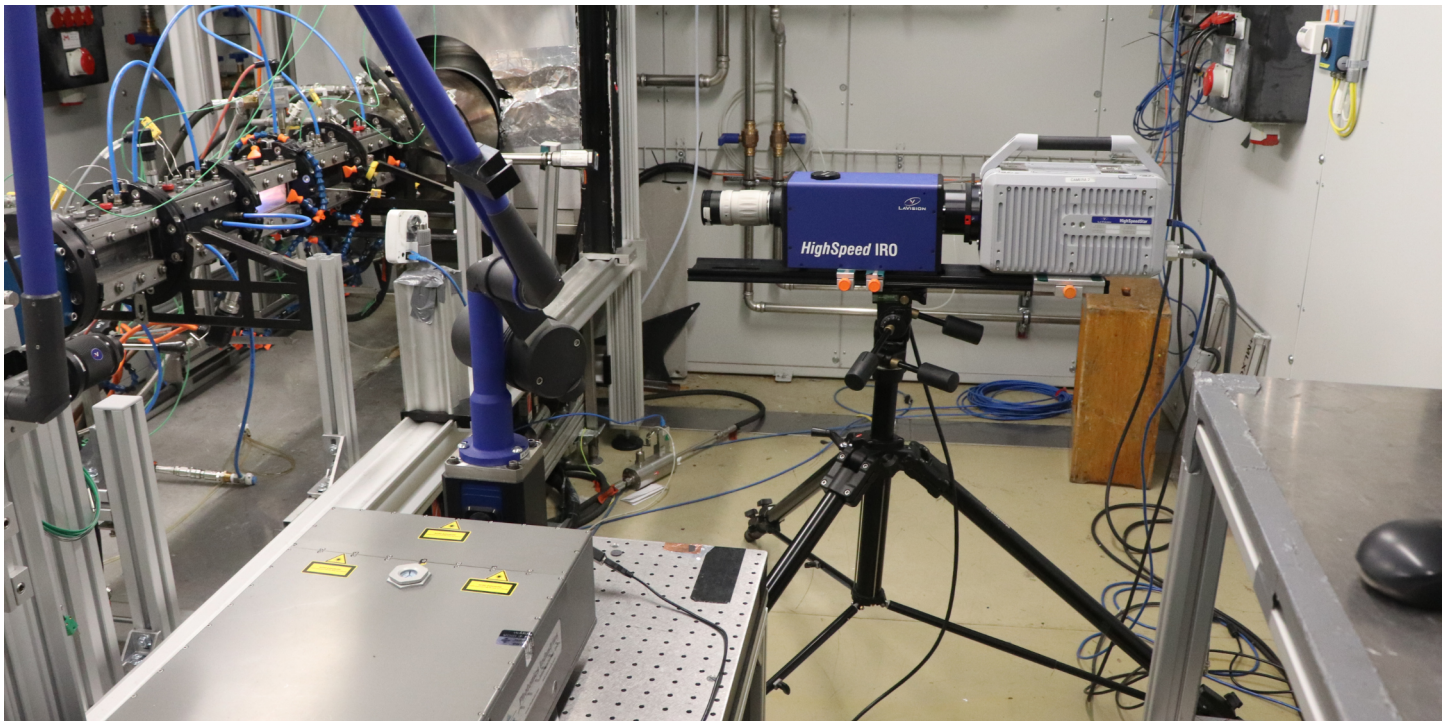
Discussions about electrification pervade conversations about the future of transport. Such discussions are so widespread, one may wonder why ETHZ researchers are studying combustion technologies at all. Prof. Nicolas Noiray, who heads the Laboratory for Combustion and Acoustics for Energy Systems' at ETHZ, is not at a loss for an answer: "Combustion is not the problem in the transformation of energy supply, but part of the solution," says Noiray. Today, he says, 70% of the world's electricity still comes from fossil fuels, and sustainable solutions must be found. "One key towards that goal is to convert renewable electricity into storable synthetic fuels. These can be used on demand in fuel cells or gas turbines to generate renewable electricity and to stabilize the power grid. Safe combustion of synthetic fuels such as hydrogen without emitting pollutants is a challenge. We need intensive scientific research into combustion technologies for these sustainable fuels, which will be used in future electric power generation, but also in long-haul aviation and shipping, transport modes that cannot be electrified in the foreseeable future."

In demand, ETHZ expertise on combustion

Given this backdrop, research into combustion processes remains a necessity. ETHZ has keen expertise in this area. Professor Nicolas Noiray is supported by a group of about 20 people, including doctoral students and postdocs, but also engineers and administrative staff. It is no coincidence that ETHZ holds a conference every two years during which combustion researchers present their latest results and discuss them with experts from industry. At the most recent conference, 150 people came together in mid-September to exchange and discuss current research results.

Renowned combustion researcher Konstantinos Boulouchos, who retired as ETHZ professor emeritus in January 2021, gave the introductory keynote address. Boulouchos outlined the Herculean task involved in moving away from fossil fuels. One challenge is to master decarbonization in the next 30 years. That is a very short time, considering that road vehicles, airplanes and ships sometimes have lifespans of 30 to 40 or more years. It is essential, Boulouchos said, to build decarbonized powertrains into existing means of transportation. A second challenge lies in the high prices for synthetic, CO_2-free or CO_2-neutral fuels: Although these can be produced using renewable electricity, they still cost three to five times more than fossil fuels. The goal must be to produce synthetic fuels at a lower cost – and to make fossil fuels more expensive through CO_2 emissions pricing. To make synthetic fuels



The camera enables high-speed images of the flame, up to 20,000 frames per second, which can be seen in blue-red on the left in the experimental setup. Photo: B. Vogel

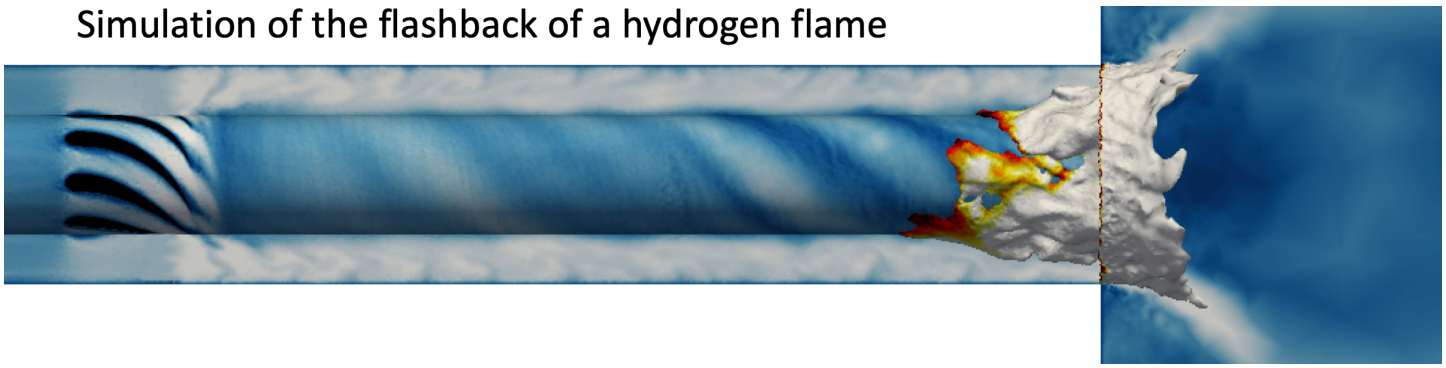


Illustration of flame flashback in the combustion chamber of a gas turbine powered by a methane-hydrogen mixture or pure hydrogen, as simulated by Dr. Alex Novoselov in a SFOE-supported project. Illustration: CAPS/ETHZ

competitive at current production costs, the price per ton of emitted CO_2 would have to be raised from the present €50 to €600, Boulouchos calculated, pointing out that this price should fall significantly in the future thanks to cheaper processes and economies of scale.

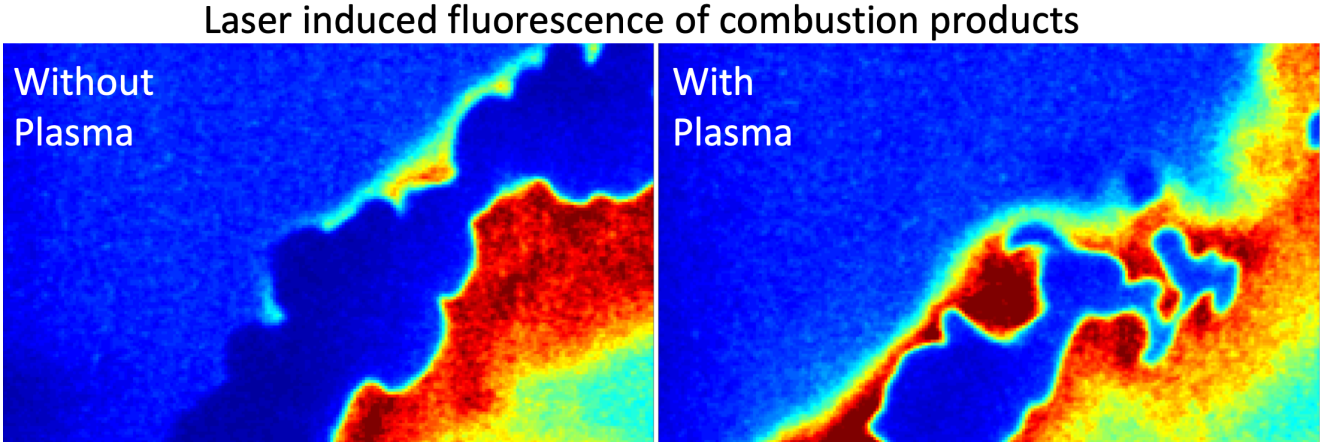
Research for a Herculean task

In his introductory presentation, the energy expert made a calculation that he himself described as 'provocative': The electrification of all road vehicles, ships and aircraft in the 27 states of the European Union (EU27) would require around 4500 TWh of electricity annually - that is about 1.36 times more than the entire EU27 consumed in renewable and non-renewable electricity in 2017 (3300 TWh). Boulouchos pointed to another problem: European wind power production in the first half of 2021 was 21% lower than in the first half of 2020 because of unsuitable weather conditions. As a result, coal-fired power generation rose sharply (+38%) because gas-fired power plants could not compensate for the shortfall.

The conference participants presented several research approaches that could help countries transform to a sustainable energy system in the future. Scientists from ETHZ, FPT Motorenforschung AG, Vir2sense GmbH, University of Applied Sciences Northwestern Switzerland and Paul Scherrer Institute presented the results of their theoretical, experimental and numerical investigations. One focus was on gas turbines, such as those used today in gas or combined fuel power plants to generate electricity and heat in some cases, and also power jet-engines. Because gas-fired power plants allow flexible operation, they can be used to bridge periods of low solar and wind power.

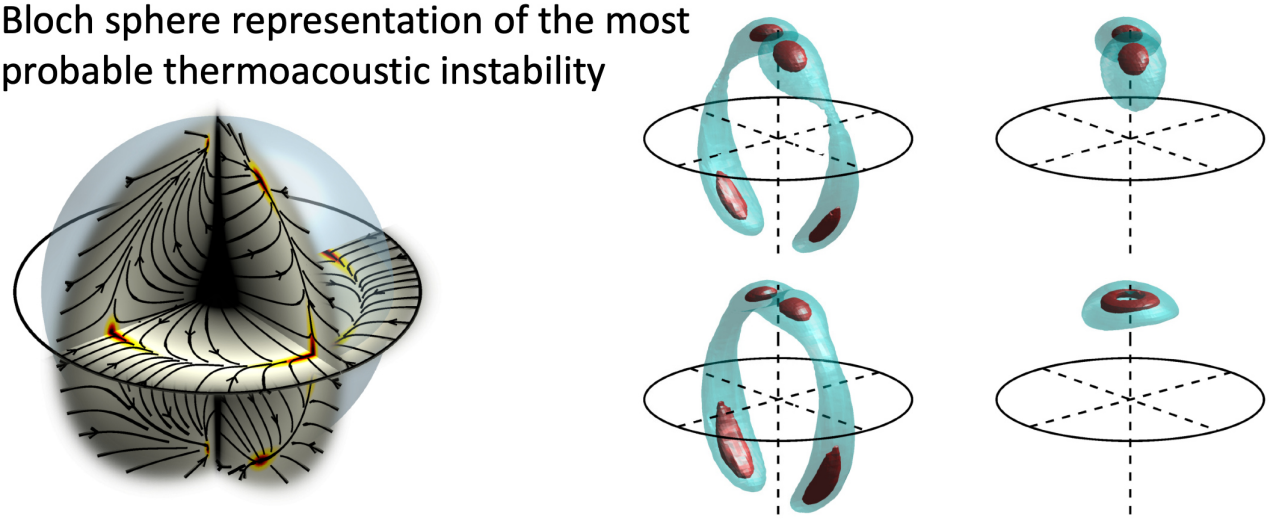
Gas turbines with hydrogen

Traditionally, gas turbines use natural gas (methane). Thanks to technical innovations, in the future they will be able to run on a mixture of natural gas and hydrogen, or on pure (and ideally sustainably produced) hydrogen. Research is needed to make this happen. This is because hydrogen is more reactive than methane; it is challenging to burn hydrogen wi-



ETH scientist Dr. Sergey Shcherbanev is researching whether a plasma can strengthen the anchoring of the flame. In the picture: Snapshot of the combustion flame without and with plasma. Illustration: CAPS/ETHZ

Bloch sphere representation of the most probable thermoacoustic instability



CAPS researcher Abel Faure Beaulieu studies thermoacoustic instabilities in combustion processes. In the picture: Models of sound propagation in a ring burner. Illustration: CAPS/ETHZ

thout nitrogen oxide emissions. In a SFOE-supported project, ETH researcher Dr. Alex Novoselov is investigating how flashbacks, i.e. dangerous flames propagation from the combustion chamber into the fuel supply, can be prevented in gas turbines operated with hydrogen-methane mixtures or pure hydrogen. Another research approach aims to push combustion processes in the desired direction (e.g., less nitrogen oxide emissions when hydrogen is burned) via the admixture of a plasma (mixture of free charge carriers such as ions and electrons). ETH scientist Dr. Sergey Shcherbanev is conducting research on the topic. His colleague Abel Faure Beaulieu, in turn, is working on thermoacoustic instabilities that can damage combustion systems by means of vibrations, which particularly affect low-emission systems.

Two industry representatives provided insight into their companies' research and development activities at the conference. One of these presentations related to gas turbines of the latest design with two combustion chambers. The stepwise combustion with two flames enables a higher energy-yield and lower emissions of pollutants. Dr. Andrea Ciani, project manager at Ansaldo Energia, which took over parts of Alstom's research in Baden in 2016, presented the latest generation of the company's burner design. The 'Center Body Burner' (CBB) consists of an insert for the second burner stage and can be used in the combustion of methane-hydrogen mixtures or pure hydrogen. In a 1:1-high-pressure test series at the German Aerospace Center in Cologne, the company recently demonstrated that the CBB can significantly reduce nitrogen oxide emissions when hydrogen is burned.

Digital twins support sustainability

Dr. Markus Wenig from the Winterthur-based marine engine developer WinGD presented a completely different research approach. Together with the Fachhochschule Nordwestschweiz, WinGD designs digital twins of marine engines. Combustion models are incorporated into digital representations of the real engines. With digital twins, engines can be tested before making expensive investments to build the real engine ('testing-before-investing'). Another application concerns virtual system integration, e.g. of hybrid systems. "In the future, digital twins will also help us to show the profitability of replacement measures in the direction of sustainability," emphasized Wenig.

For Stephan Renz, head of the SFOE's Combustion-Based Energy Systems research program and co-organizer of the conference, the event clearly highlighted the importance of synthetic fuels for energy supply: "Swiss combustion researchers from academia and from development centers of internationally active companies are working almost exclusively on CO_2-reducing chemical energy sources."

↗ For **information** on the 'Conference on Combustion Research in Switzerland' - organized by ETHZ, Paul Scherrer Institute and the Swiss Bundesamts für Energie- please

contact Stephan Renz (info[at]renzconsulting.ch), external Head of the SFOE Research Program Combustion-based Energy Systems.

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

Representatives from industry and research informally discuss their work at the Conference on Combustion Research in Switzerland. Photo: S. Renz

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