MICRO-CHP: LOTS OF ELECTRICITY, FEW EMISSIONS

Combined Heat and Power (CHP) plants in the low power range, Micro-CHP, are designed to supply single and multi-family houses with electricity and heat in a decentralized way. At present, ETH Zurich is developing such a Micro-CHP with the heating company Hoval Aktiengesellschaft (Vaduz) and lubrication oil producer Bucher AG Langenthal. For this performance class, the CHP has very high electrical efficiency and promises low pollutant emissions. The novel device is still only experimental and a functional model exists in a laboratory. It uses natural gas, but can function on biogas, which paves the way for a renewable energy supply.

ETH researcher Christian Schürch with the laboratory model of the Micro-CHP. His finger points to the Lambda probe, to the right of it a temperature sensor for measuring exhaust gas temperature. Photo: B. Vogel

A technical report about the results of a pilot and demonstration project in the field of combustion/CHP, which is financially supported by the Swiss Federal Office of Energy. The report has been published in the technical magazine Swiss Engineering STZ (issue May 2017).

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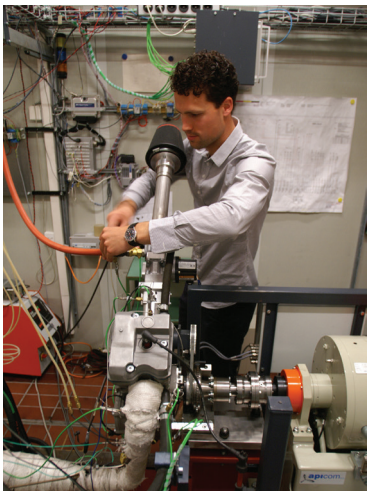
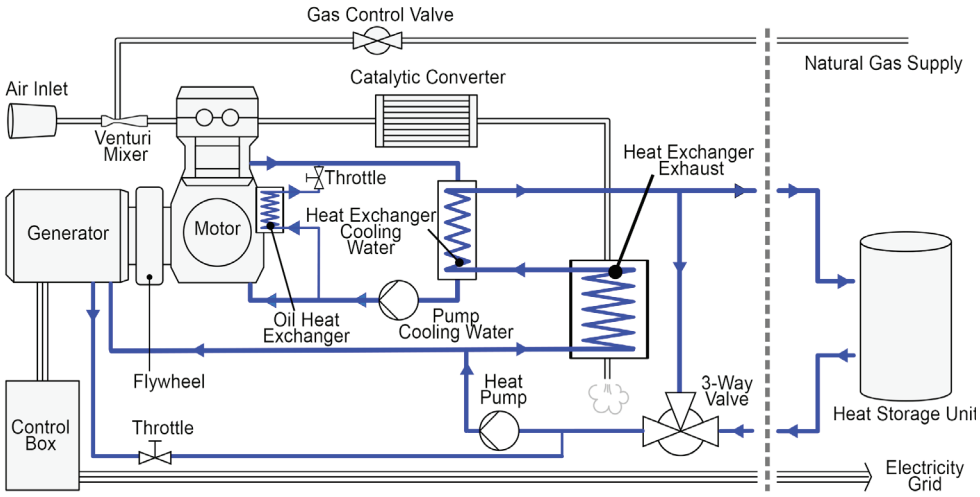


Step by step towards a Micro-CHP: In the project ALADIN I (2011 to 2014), researchers from the ETH Zurich studied the technical foundations of a Micro-CHP (picture left with the former ETH doctoral student Philipp Vögelin). During the project ALADIN II (2015 to 2017), they developed a Micro-CHP on the basis of the acquired laboratory knowledge (middle picture). This resulted in a functional model (picture on the right), which is now being tested and optimized by Hoval Aktiengesellschaft (Vaduz), Bucher AG Langenthal and sa-charging solutions AG (Mellingen / AG). The metal frame shows the size of the functional model, the control box is attached on the right. Photos: B. Vogel (2), Hoval Aktiengesellschaft.

Decentralized power plants that produce electricity and heat at the same time are in trend. This is achieved, for example, by connecting photovoltaic modules to a heat pump. Also popular are natural gas, biogas, wood or oil-fueled combined heat and power plants. These are typically used in Switzerland to supply industrial enterprises and entire neighborhoods. They achieve a total efficiency of 88 to 95%; up to 40% as electrical energy, the rest as heat. A recent development is Micro-CHP in the low power range (5 to 15 kW_{el}) for application in single and multi-family houses as well as in commercial enterprises. Several of these systems are already on the market.

High Efficiency, Low Emissions

"Available plants with an electrical efficiency of 22 to 28% still lay far behind the efficiency of large plants, and they have not yet exhausted the potential to avoid pollutants," says Christian Schürch, research assistant at the Swiss Federal Institute of Technology in Zurich. For several years now, Schürch and his ETH research team have been working on the development of a Micro-CHP with high electrical efficiency and low pollutant emissions. As in gas heating systems, gas is burned in the Micro-CHP. It is burned in an engine, however, not in a boiler: the mechanical energy is converted into electricity by a generator, the heat contained in the exhaust



The diagram shows the construction of a Micro-CHP. Illustration: ETHZ.

gases and in the engine coolant is used via a heat exchanger to provide heating and hot water.

The Micro-CHP is now set to leave the test environment of academic research. A pilot and demonstration facility at Bucher AG Langenthal will demonstrate the potential of the new development from spring 2017 onwards. The producer of lubricating oils, better known under the product name Motorex, is involved as an industrial partner in the development of the Micro-CHP. The heart of the Micro-CHP is a small one-cylinder four-stroke engine retrofitted for gas operation by Swissauto Wenko AG in Burgdorf (BE). In its basic form, the engine is used in quad bikes or motorcycles. The Micro-CHP is based on a further development of the engine, which is primarily used in hybrid drive trains such as range extender modules - with low consumption and high mechanical and electrical efficiency.

The Secret of the Right Oil

In order to operate this engine with maximum efficiency, an optimized lubricating oil is required. The single-cylinder engine retrofitted for gas operation imposes specific requirements on the lubricating oil, which seals the gap between the piston ring and the cylinder wall and reduces wear. A stable base oil must be supplemented with the appropriate additives (chemical additives), so that the engine, in comparision to when it is used in an automotive application, is stable, safe and functions with minimal service requirements over a long period of time. In order to mix the right oil, the development department of Bucher AG Langenthal has more than 60 base oils and over 600 additives as well as more than 2500 oil formulations at hand.

It is known from earlier projects that the use of a suitable lubricating oil alone can improve the energy conversion in an engine by up to 2%. In order to achieve the best possible results, tests are carried out in Langenthal and in parallel at the Swiss Federal Laboratories for Materials Testing and Research (Empa) in Dübendorf with various mixtures. "At the moment the scientific aspect is still at the forefront of the tests, but we hope that with the additional knowledge we can later produce a commercial lubricating oil for Micro-CHPs. In addition, our development expenditure will result in licensing revenues," says Markus Staubli, Head of Key Account Management and member of the management team at Bucher AG Langenthal.

FIGHTING COLD START EMISSIONS

Depending on the application, Micro-CHPs would frequently be switched on and off, rather than run in continous mode. In the first minutes after operation, cold start emissions are produced, since the three-way catalyst does not operate to full effect until after seven to ten minutes, when it is heated to 650 ° C. "We want to ensure that Micro-CHPs have low emissions during their entire operating time, including during the start-up phase," says Christian Schürch from ETH Zurich, who heads the ALADIN II project.

One way to achieve this is to shorten the warm-up time of the catalyst by insulating or electrically heating it during the start-up phase. Another approach is control engineering to reduce the number of operating pauses and keep "off" time to a minimum. Modified operating modes are also conceivable: By delaying the ignition point, for example, hotter exhaust gases are produced, which heats the catalytic converter more quickly, but reduces the mechanical efficiency of the engine since the center of combustion no longer occurs at the optimal time; or the engine is run rich during in the starting phase, that is, with excess fuel, and by adding secondary air after the engine exit the residual fuel would be combusted before and in the catalytic converter, in order to heat it. "All measures with the exception of the insulation reduce the efficiency of the system. It is the focus of the research work to find out which measure is the best choice under which conditions, "says ETH researcher Schürch.

ETH researchers have developed realistic operating profiles and will now examine these at their laboratory and the four external functional models using a mobile exhaust gas analyzer. BV

Over 32% Electrical Efficiency

The pilot and demonstration facility in Langenthal is the result of many years of research and development. In the ALADIN I project (2011 to 2014), researchers from the ETH Laboratory for Aerothermochemistry and Combustion Systems (LAV) had converted a single cylinder gasoline engine from Swissauto Wenko AG with 325 ccm of gas operation into a small

power plant to generate electricity (around 7 kW) and heat (around 14 kW). Instead of plain bearings, as is customary in industrial engines, the engine has rolling bearings; this results in less friction loss and thus promises a higher efficiency in energy conversion. In order to achieve the ambitious efficiency targets, a high-quality generator is also used.

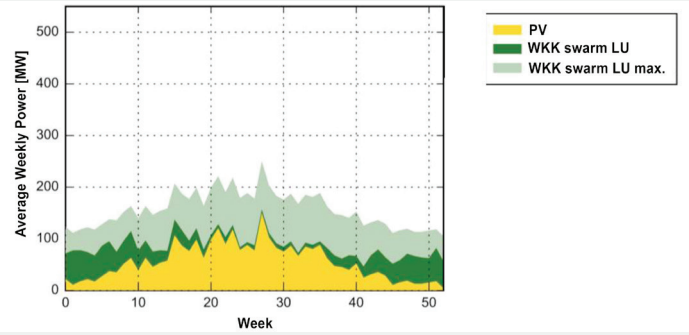
The heat exchanger not only uses the heat of the wet exhaust gases, but also the latent heat, which is released by condensation of water vapor generated during combustion (Hoval's value-added technology). In addition, the waste heat from the engine is also used— in contrast to typical industrial applications of water-cooled generators and lubricating oils. The Micro-CHP is equipped with a three way catalytic converter, unlike its big brothers. This minimizes pollutant emissions. With respect to the catalytic converter, the engine must be operated stoichiometrically. This means that the fuel-air mixture is combusted completely, without excess air.

In the current ALADIN II project (2015 to 2017), the engine, which has been retrofitted for natural gas and equipped with a catalytic converter, will be combined with a generator, heat exchanger and other components into a compact housing unit and developed into a complete, near market, functional model. In this model, the plant at ETH Zurich achieves an electrical efficiency of 32.7%, which means that the target ("over 30%") is reached.

The desired thermal efficiency of 60% is also realized - with a return temperature of of 30 °C in the heating circuit, this efficiency measure increases to 76% (based on the lower calorific value of natural gas). The emission reductions achieved for NO_x (<5.0 mg / Nm^3), CO (<3.0 mg / Nm^3) and HC (<3.0 mg / Nm^3; respectively measured in hot exhaust gas directly after the catalyst) should be considered a success: "The achieved values are far below regulations as well as below those of competitors," says Christian Schürch, a research associate

A SWARM OF MICRO CHP'S

During continuous operation, a Micro-CHP achieves the maximum electricity yield—this is the operating concept that Hoval is pursuing (see main text). However, other operating concepts are also under discussion: Micro-CHPs could be used to compensate for production gaps from solar and wind power. In order to effectively achieve this, a large number of Micro-CHPs would need to be combined into a network providing high power. A contractor could flexibly put such a network into operation primarily when electricity prices are high due to a surplus of demand. In order to make this possible, the participating households must have sufficient heat storage (hot water storage), so that the micro-CHPs can be operated flexibly over time.



A research team from the ETH Zurich and the Paul Scherrer Institute recently completed a project co-financed by the SFOE that investigated the possibilities and limitations of such 'swarms' of Micro-CHPs. "Since the connected buildings require more heat in winter, the bulk of the electricity produced by such a swarm occurs during the winter half of the year; thus it complements the photovoltaic production, which is lower in winter," says Dr. Gil Georges, summarizing one of the main results. The ETH researchers have also prepared case studies from the Cantons of Lucerne, Basel and Thurgau. According to these studies, such swarms could be operated without requiring biomass from other Cantons. However, swarms of CHPs could compete with other uses of biomass and waste, the scientists note.

By using the available sustainable biomass (wood, waste, manure), 6 TWh of electricity can be generated with the Micro-CHP, 5.4 TWh of which in winter. This corresponds to 16% of the current winter power demand in Switzerland. "The concept of the swarm works technically, but the decisive question is whether a viable business model can be developed," says Gil Georges. BV

at ETH Zurich and head of the project ALADIN II. "A further reduction is hardly possible with today's catalysts."

Four Functional Examples in Practice

In the next step four functional Micro-CHP models will be produced to supplement the laboratory system at the ETH. With the new models, the industrial partners will test and optimize the plant in the coming months and years in cooperation with the ETH. In addition to the plant in Langenthal, a second functional model exists on the premesis of the heating company Hoval in Vaduz (FL). Here the developers focus on integration into heating systems and improvements in design and sound / heat insulation. Sa-charging solutions AG in Mellingen (AG) is also working with two additional functional models to carry out continuous tests over 1000 to 2000 operating hours. Among other things, various operating patterns such as continuous operation or on / off operation (see text box p. 2) are being examined.

Hoval has already entered the market with a medium-sized CHP (20 to 560 kW_{el}). With the Micro-CHP, the company would expand its product range in the low power class. "Our goal is a Micro-CHP with an electrical output of, for example, 5 kW and a heat output of 10 kW, which would typically carry the basic load of the hot water supply for a multi-family house all year round. This is because only when a Micro-CHP unit runs continuously it generates enough electricity for own consumption, which is central to the efficiency of the plant," says Markus Telian, Head of R & D at Hoval.

Operation without Fossil Fuels is Possible

The four functional models must now prove in upcoming test runs that they master continuous operation with low maintenance costs and high efficiency. On this basis, Hoval's management will decide whether to proceed with serial production / market introduction of the Micro-CHP in two years. Gas prices and the purchase price of electricity will play a role in the cost-effectiveness calculations.

The Micro-CHP can be operated with natural gas or equivalent biogas (high methane content). According to Peter Regenass, Chairman of the Board of Directors of the Bucher-Motorex Group (Langenthal), Micro-CHPs will play an important role in the supply of renewable energies: "I am absolutely convinced that we will use renewable electricity in the future, to produce methane gas from power-to-gas technology, to feed this non-fossil gas into the gas network and to use decentralized energy production in "Micro-CHP plants."

- For **guided tours** of the pilot and demonstration system at Bucher Langenthal AG or further information on the project by **Bucher AG Langenthal**, please contact: Markus Staubli (markus.staubli [at] motorex.com), project manager at Bucher AG Langenthal, or Peter Regenass (peter.regenass [at] motorex.com), Chairman of the Board of Directors of the Bucher-Motorex Group.
- Information on the project for the **SFOE** is given by Stephan Renz (info [at] renzconsulting.ch), head of the SFOE research program Combustion and CHP.
- Information on the project for **Hoval Aktiengesellschaft**: Martin Moisi (martin.moisi [at] hoval.com), project manager at Hoval Aktiengesellschaft.
- Further **technical reports** on research, pilot, demonstration and flagship projects in the area of combustion-based energy systems can be found at www.bfe.admin.ch/CT/verbrennung

PILOT, DEMONSTRATION AND FLAGSHIP PROJEKTS OF SFOE

The Swiss Federal Office of Energy (SFOE) supports the development of a Micro-CHP plant as part of the ALADIN II project. The research and development projects implemented by ETH Zurich with industrial partners are among the pilot, demonstration and flagship projects with which the SFOE promotes the economical and rational use of energy and promotes the use of renewable energies. The SFOE supports pilot, demonstration and flagship projects with 40% of eligible costs. Applications can be submitted at any time.

- **Information**:
  www.bfe.admin.ch/pilotdemonstration
  www.bfe.admin.ch/leuchtturmprogramm

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