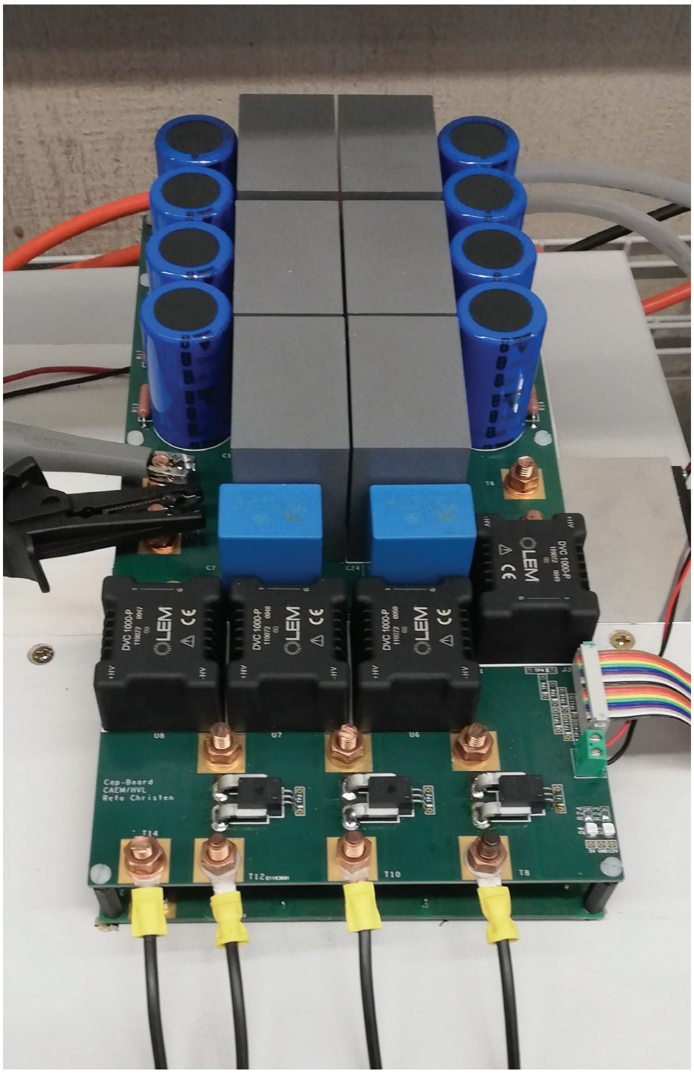
SWITCHING ELEMENTS OF THE THRIFTY VARIETY

From cell phones to cars to data centers: The diverse electrical applications that visibly and invisibly shape our everyday life all contain switching elements made of semiconductor materials. These powerful electronic components have huge energy-savings potential that can be realized by using so-called wide-bandgap semiconductors. This is the conclusion of an expert report of the International Energy Agency's Technology Program 4E, in which Swiss experts are significantly participating.



Researchers in the group of Prof. Dr. Michael Schueller and Dr. Jasmin Smajic at the University of Applied Sciences of Eastern Switzerland (formerly: University of Applied Sciences Rapperswil/HSR) have investigated SiC-MOSFETs for electrical drive trains of industrial motors in a project. MOSFET stands for Metal Oxide Semiconductor Field Effect Transistor. Photo: University of Applied Sciences East

Modern, energy-efficient power electronics are a technology of the future - and individual applications are already in use. A prominent example is the US electric car manufacturer Tesla. It uses modern MOSFET transistors for the drive system of the Tesla Model 3. The electronic components help the inverter to achieve high efficiency, thereby increasing the range of the world›s best-selling electric car. The railroad nation Japan also relies on modern electronic components: There, the latest generation of Shinkansen high-speed trains is being equipped with new types of transistors. These are not only efficient but also compact: The drive system can now be installed in the floor of the passenger cars instead of in separate railcars. This increases the capacity of the trains.

A technical report about the results of several research projects in the field of electricity technologies, which were financially supported by the Swiss Federal Office of Energy. The report has been published in the technical magazine ET Elektrotechnik (issue November 2020).

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In both cases, the efficiency gain is due to the latest generation of transistors. The electronic switching elements are no longer made of the semiconductor material silicon, as was previously the case, but of silicon carbide (SiC). Together with gallium nitride (GaN), this semiconductor belongs to the class of so-called wide-bandgap semiconductors (WBG semiconductors; see text box p. 4). These allow the construction of components that work with very low power losses in electronic switching and control circuits - a central advantage.

Intensive Research in Switzerland

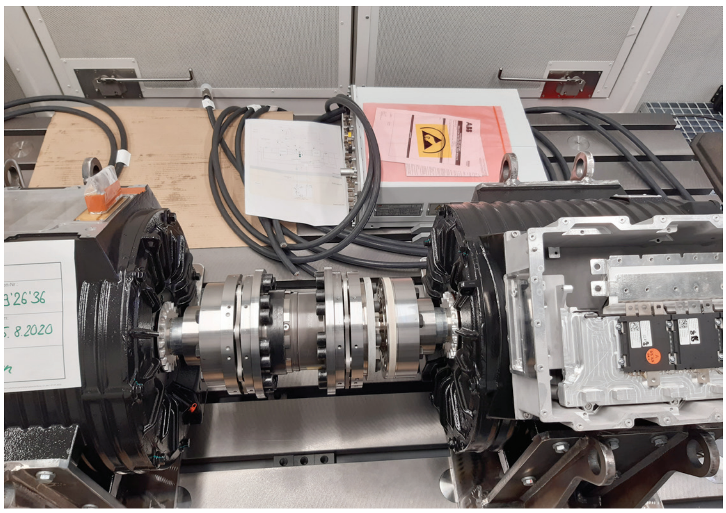
Swiss industry is also already exploring applications for this energy efficient technology. Bus manufacturer Hess and the industrial company ABB are cooperating in a pilot and demonstration project supported by the SFOE: For the project, which was launched in 2019, they are developing a SiC-based converter for electric buses. Two other research projects supported by the SFOE are also exploring wide-bandgap technologies: Scientists from the University of Applied Sciences Northwestern Switzerland in Windisch are studying an inverter based on hybrid Si/SiC for applications in electric cars. Meanwhile, researchers at the University of Applied Sciences of Eastern Switzerland in Rapperswil are studying the use of SiC transistors in the electrical drive trains of industrial motors, including their durability.

Other Swiss projects focus on SiC components for AC/DC converters for the conversion of alternating current into direct current, such as those used in charging stations for electric vehicles. Experts from the Swiss Federal Institute of Technology in Lausanne (EPFL), on the other hand, have already completed several studies on GaN-based components for efficient high-voltage direct current sources (such as battery chargers) and micro-converters for photovoltaic systems.

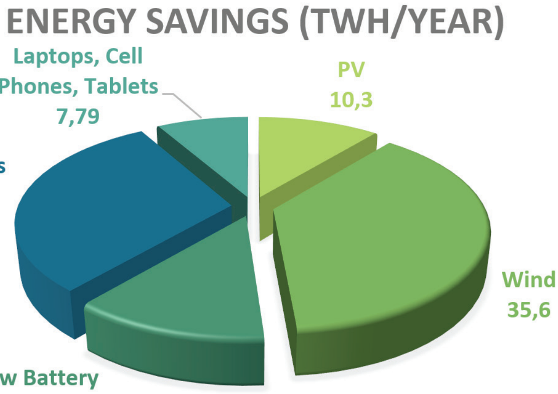
Save More Electricity Worldwide than Switzerland Consumes

Transistors made of SiC and GaN semiconductors can be used to build low power-loss inverters for converting current, voltage and frequency. The savings potential is considerable, as the PECTA experts working under the umbrella of the International Energy Agency (IEA) show in a report published in spring. PECTA stands for ‹Power Electronic Conversion Technology Annex›. The Annex was initiated by Switzerland in 2019 and has since been working under the leadership of Switzerland, Austria, Denmark and Sweden. PECTA brings together specialists from academic research and experts from industry. The expert panel is part of the IEA technology program 4E (for: Energy Efficient End-Use Equipment), which is dedicated to the energy efficiency of end devices.

In their report, the PECTA experts estimate the savings potential that could be achieved by using and integrating WBG semiconductors in power electronics components for specific applications. The experts quantify the worldwide annual savings potential for five application areas: Wind turbines (36 TWh/year), data centers (28 TWh/year), electric cars (12 TWh/year), photovoltaic systems (10 TWh/year) and laptops, tab-



The Roadrunner project, in which bus manufacturer Hess and the ABB Group are developing a converter based on WBG semiconductors, was launched in 2019. The photo on the left shows a prototype of the converter. The picture on the right shows the test bench on which, among other things, journeys can be simulated. Photos: ABB Schweiz AG lets and cell phones (8 TWh/year). For these five areas alone, the total annual savings potential is 94 TWh, more than one and a half times Switzerland's annual electricity consumption. "This first rough calculation, which does not even include important areas such as industrial motors, shows the enormous potential of WBG semiconductors. We should make every effort to realize this potential," says Roland Brüniger, head of the SFOE's Electricity Technologies research program and PECTA chairman.

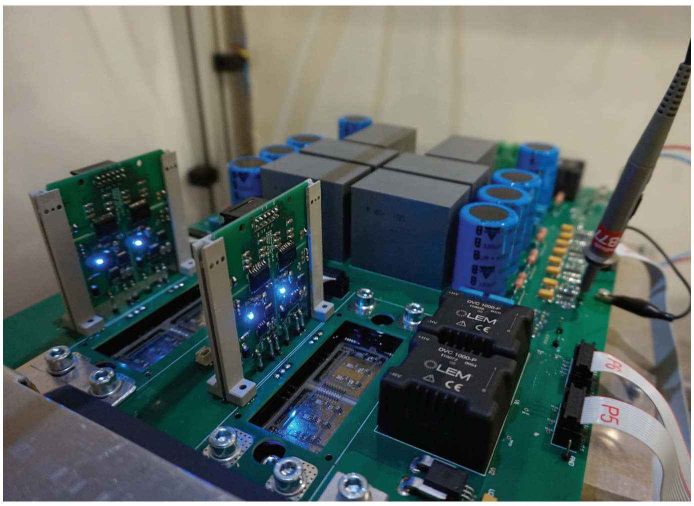


Potential global savings in selected application areas when switching to WBG semiconductors. Graphic: PECTA report

On the Threshold of Marketlaunch

In certain industrial sectors, components with WBG semiconductors are already in use today, while development in other sectors is less advanced. The PECTA experts have summarized the available data in an Application Readiness Map (ARM) document. They drew on work carried out by the European Center for Power Electronics (ECPE), the trade association of the European power electronics industry. According to the ARM, the first systems with WBG technology are on the market in the automotive and railroad sectors, as well as in data centers, power grid infrastructure and photovoltaic inverters. More products will reach market maturity in the next two to six years. This step is expected to be in the industrial and industrial automation sector, for large electrical drives and for inverters of wind power plants, among others.

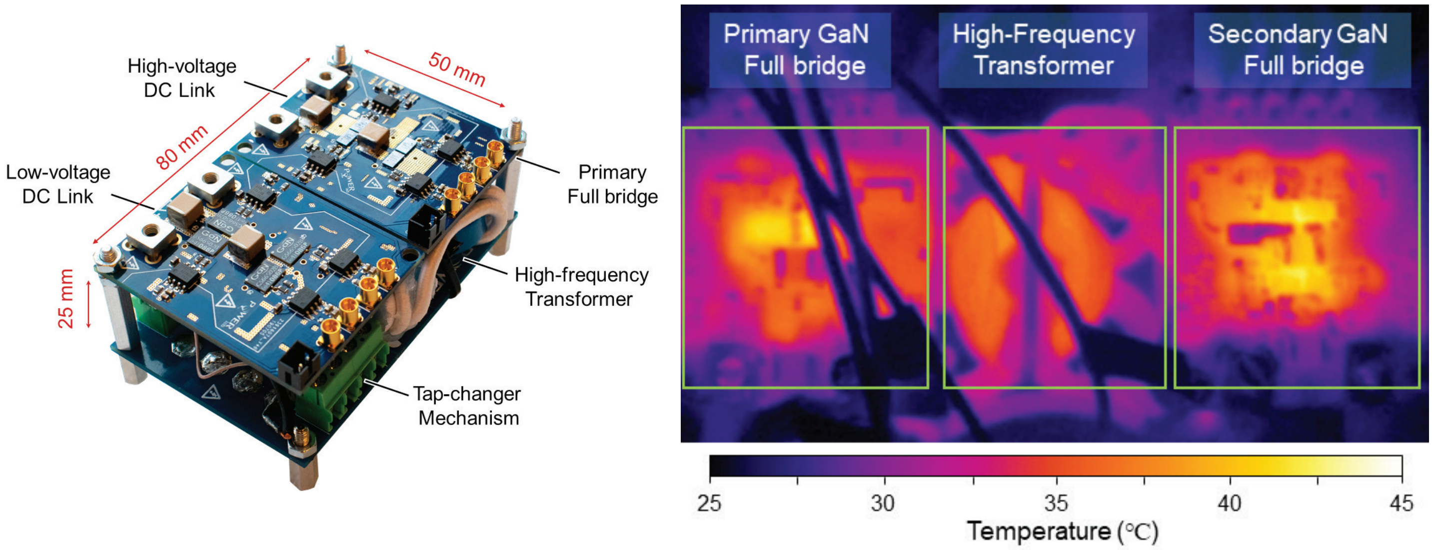
The market for WBG semiconductors appears to be very dynamic. However, a look at ARM with its expected development also makes it clear that, according to current estimates, many WBG applications are unlikely to come onto the market before 2030 at the earliest, or will only then reach a significant market share. Against this background, political measures might be advisable to push ahead with the market launch of WBG technology where it is not yet technically mature, does not yet work reliably, or is simply too expensive. To help policymakers make the right decisions, the PECTA experts list in their report a range of policy instruments that could accelerate market introduction. In a next step, they now want to solidify measures that identify the areas where promotion would be particularly effective and where major savings could be achieved. One such area might be wind energy, which, according to forecasts, is expected to grow strongly worldwide in the coming years.


The team of Prof. Dr. Nicola Schulz has built and tested a DC-DC converter (22 kW; DC voltage 700 V to DC voltage 400 V) based on SiC at the University of Applied Sciences Northwestern Switzerland (Windisch site) in a project supported by the SFOE. Photo: FHNW

Energy Consumption Over the Entire Life Cycle

The PECTA experts have compiled extensive documentation - and yet they are only just beginning their work. In their report, they outline a range of further research approaches that would support adoption of WBG technology. These include life cycle analyses, in order to be able to assess the sometimes relatively high energy consumption of semiconductor production in the overall context of a technical solution. Another important point is standardization, as is already available today in sub-areas of converters for motors with IEC (International Electrotechnical Commission) standards. Standardization, the PECTA experts emphasize in their report, should be implemented in close cooperation with industry.

↗ The **PECTA report** ‹Wide Band Gap Technology: Efficiency Potential and Application Readiness Map› is



A research team led by Prof. Elison Matioli at the Swiss Federal Institute of Technology in Lausanne (EPFL) has investigated how the efficiency of electronic components can be improved using GaN semiconductors. On the left: Image of a DC-DC converter based on GaN, operating at a frequency of 300 kHz. On the right: Thermal camera images from different parts of the converter show that the GaN components have relatively low losses in the form of heat. Source: A. Jafari, M. Samizadeh Nikoo, F. Karakaya, and E. Matioli, «Enhanced DAB for Efficiency Preservation Using Adjustable-Tap High-Frequency Transformer,» IEEE Trans. Power Electron., vol. 35, no. 7, pp. 6673-6677, July 2020

available at:
https://www.iea-4e.org/news/pecta-first-report

- Further information about **PECTA** can be found at https://pecta.iea-4e.org/ or https://nachhaltigwirtschaften.at/de/iea/technologieprogramme/4e/iea-4e-tcp-pecta.php

- An **interview** with Prof. Ulrike Grossner (ETH Zurich) on the perspectives of WBG technologies: https://pubdb.bfe.admin.ch/de/publication/download/10023

- **Information** on this topic is available from Roland Brüniger (roland.brueniger[at]brueniger.swiss), head of the SFOE's Electricity Technologies research program.

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

FAST, SMALL, EFFICIENT

Semiconductors with a wide bandgap allow the construction of electronic components with various advantages: They switch faster, process higher voltages and frequencies, can be built smaller and operate at higher ambient temperatures. Another decisive advantage is that components based on WBG semiconductors have lower power losses and therefore operate with higher efficiency. This means that a higher proportion of energy is available for the respective technical application instead of being lost in the form of heat. Lower heat losses reduce the amount of energy needed to cool the electronic circuits. BV

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