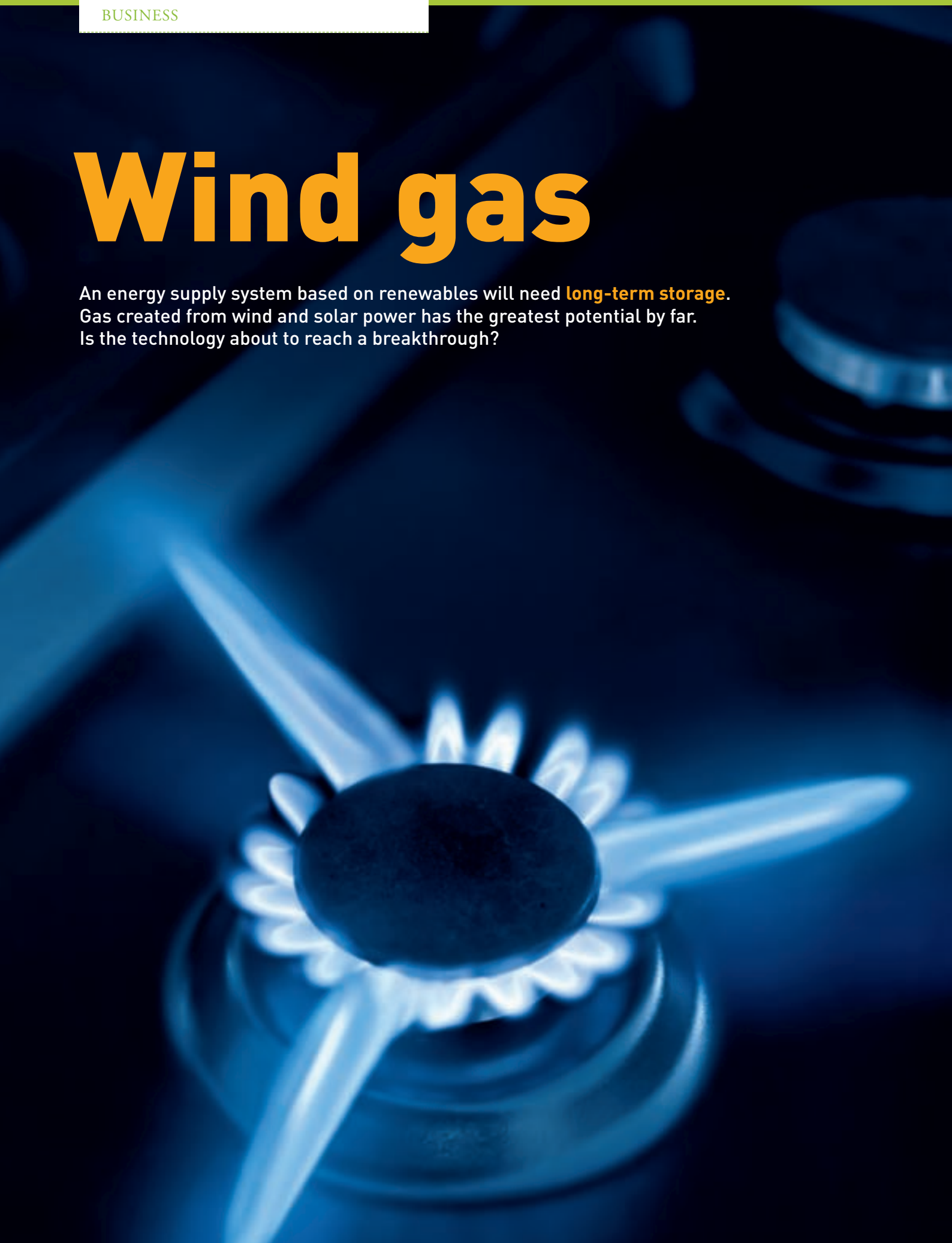
Wind gas

An energy supply system based on renewables will need **long-term storage**. Gas created from wind and solar power has the greatest potential by far. Is the technology about to reach a breakthrough?



By Karsten Wiedemann

The energy policy marathon in Berlin is over, and the nuclear phase-out has been adopted, but our work has only just begun. Our energy supply system has to be ready to absorb a greater share of renewable energy, and intermittent wind and solar power has to be brought in line with consumption, which also fluctuates. How will that work? "We have to expand the grid, we need flexible power plants that ramp up and down quickly, and we need demand management," says Michael Sterner of the Fraunhofer Institute for Wind Energy and Energy Systems (Fraunhofer-Iwes) in Kassel, Germany. He says that energy storage is the last option in terms of efficiency, but there is no way around it if renewables grow as expected. "Storage demand will grow exponentially," Sterner says, adding that the growth rate will depend upon grid expansion and the flexibility of power plants. Fraunhofer-Iwes estimates that power production will require storage by the time we have 30 percent renewable electricity. By the time renewables make up 80 percent – the German government's target for 2050 – 30 terawatt-hours (TWh) of storage capacity will be needed.

It is already apparent that German capacity – a mere 0.04 TWh – is insufficient, and current storage is only short and midterm (see box and table). "What we need is long-term storage," Sterner says. Norwegian pumped-storage plants are often mentioned as an option. While Norway does not have any storage basins, it does have lakes with impressive capacity. It is unclear, however, when they could be used, if at all. More subsea cables would be needed, and Germany is also not the only country interested in storing power there.

The Norway connection will thus only be part of the solution. As a researcher, Sterner discovered another part. It was practically under our feet: natural gas lines. There is a whole lot of space in them. Germany's more than 400,000 kilometers of natural gas lines transport twice as much energy as the country's power grid does each year. In addition, Germany has 47 subterranean gas storage sites with a capacity of 217 TWh, equivalent to a third of the country's annual power consumption. An additional 80 TWh – as much as Norway's pumped storage – is to be added to this natural gas network by 2030. It would also be enough to meet Germany's complete energy needs for two months.

Gas storage facilities like this one in the German town of Oberhausen are now considered historic sites.

Photos: Uli Staiger, Berthold Steinhilber/Laif

Storage capacities in Germany

Technology	Capacity	Use	Discharge time	Efficiency
Pumped storage	0.04 TWh	(Non-)spinning reserve for peak loads	Short to mid-term	75-80%
Compressed-air storage	0.0006 TWh	(Non-)spinning reserve for peak loads	Short to mid-term	Max. 70 %
Batteries	0.45 TWh*	Balancing energy, own consumption	Short term	More than 90 %**
Gas network	130 TWh	Power, heat, mobility	Long term	60-80%***

* Assumption: 42 million electric vehicles, ** lithium-ion technology,
*** for power conversion into methane or hydrogen without subsequent power production

Sources: Iwes, DLR

If all of Germany's power plants failed at once, the lights would go off in just a few hours. The storage capacity – such as at the country's nearly two dozen pumped-storage plants, which would soon empty in such a situation – is merely designed to absorb power from central plants (coal and nuclear) when power demand is low. Public resistance makes it unlikely that further **pumped-storage** capacity will be added. For economic reasons, pumped-storage plants are currently designed to run during the day, but in the future they could be used to absorb peak solar power production instead of nuclear power. Compressed-air storage can also provide power for a few hours. Here, compressed air is stored underground. When energy is needed again, the compressed air enters a combustion chamber, where it is mixed with natural gas and used to drive a turbine that generates electricity. Only two such systems currently exist, one of which is run by the German power provider Eon in the town of Huntdorf, Lower Saxony. It was built to store power from the Unterweser nuclear plant and can generate electricity for two hours. The potential for compressed-air storage is also limited as the technology is expensive and locations are few.

Electrochemical storage could play a greater role. Like a sponge, batteries in millions of electric vehicles would soon store energy – at least in theory. At present, there are only a few thousand such cars, and even if electric vehicles completely replaced internal combustion engines, they would have ten times the energy storage capacity of all of Germany's pumped-storage plants – but also only for a few hours.

The man behind the reaction

Chemist Paul Sabatier was born in the southern French town of Carcassonne in 1854. He studied in Toulouse, where he also became professor of chemistry in 1884, a position he held for an impressive 46 years. He even continued to hold lectures until he passed away in 1941. Today, the School of Medicine and Natural Sciences at the University of Toulouse is named after Sabatier. In his research, he mainly dealt with catalysis; he published "Catalysis in Organic Chemistry" in 1913. In 1902, he developed what became known as the Sabatier reaction, in which carbon dioxide and hydrogen are turned into methane and water. Ten years later, he received the Nobel Prize in chemistry for this finding.

So how do we get green electricity into natural gas lines? By converting it into hydrogen or methane and injecting this gas into the network. Excess wind and solar power could drive electrolyzers, which split water into oxygen and hydrogen. Hydrogen reacts with carbon dioxide (CO_2) to produce water and methane, the latter being the main component in natural gas. The process is known as "power to gas." Greater flexibility is one advantage. The renewable gas – or e-gas, as Michael Sterner calls it – can be used to produce heat or power or as a motor fuel. Power production and consumption would then no longer have to happen at the same time or place. "Ideally, we would subsequently use the e-gas to power gas turbines without emissions," he emphasizes. There would then be a closed cycle.

Hydrogen or methane?

The principle is well known. Electrolysis has been used in the chemicals industry for more than 150 years. Methanation goes back to a reaction developed at the beginning of the twentieth century by French chemist Paul Sabatier (see box). And the U.S. has been making synthetic gas from brown coal on a large scale for decades in order to become less dependent on natural gas imports. "The new thing is that we are now making the gas from electricity in a process combining electrolysis and methanation," says Ulrich Zuberbühler of Baden-Württemberg's Center for Solar Energy and Hydrogen Research (ZSW). The product is synthetic natural gas (SNG). The ZSW is working with Fraunhofer's Sterner and Solarfuel on a power-to-gas process. For a year now, a pilot unit has been in operation in Stuttgart, and a newer, bigger unit is planned. Automobile maker Audi is interested in the concept and in making its own fuel from electricity. "We are not talking about magic here," Zuberbühler says. Indeed, a lot of research still needs to be done. "Up to now, electrolyzers were designed to run all the time. Now, the pilot systems have to show us how the machines work when they run intermittently," he explains.

> "We are not talking about magic here."
> Ulrich Zuberbühler, ZSW

The ZSW is focusing on a two-stage process consisting of electrolysis and methanation, but hydrogen can also be directly injected into natural gas lines. The good thing about this option is its greater efficiency. In electrolysis, some 20 percent of the energy is lost, followed by an additional 20 percent if methane is produced. Experts recommend selling pure hydrogen to the network wherever possible to keep energy losses down. Greenpeace Energy does so, as do the wind power firm Enertrag and oil firm Total at their combined power plant in Prenzlau. "The goal is to connect renewable power production intelligently with the production, storage, and consumption of hydrogen," says Total spokesperson Manuel Fuchs. Technical specifications stipulate that hydrogen cannot make up more than ten percent of the natural gas network, however, because hydrogen has a lower calorific value and can change the properties of natural gas.

Yet, hydrogen is hardly a newcomer to natural gas lines. Into the 1980s, Germany used "syngas," essentially gasified coal which is around 50 percent hydrogen along with shares of methane and carbon monoxide. Because the process is complicated and inexpensive natural gas could be imported from Russia, syngas was phased out. Now, the technical specifications that restrict the share of hydrogen are being revisited. An EU research project has already proven that appliances from heaters to gas stoves can handle a greater share of hydrogen, but the jury is still out on gas turbines.

Photos: Paul-Langrock.de, Mary Evans Picture Library/Picture Alliance

Energy losses are decisive

Whether hydrogen or methane is made, clean gas from wind and solar power will not be free. Only 50 percent of the wind power converted into methane and used to power a cogeneration unit is available as final energy. The figure drops to a third if the waste heat from power production is not used. Sterner believes the energy losses are tolerable. "These systems will only run as need be, so they will probably only make up around five percent of power production." He also points out that excess power would otherwise be lost. That is already a problem. A study conducted on behalf of the German Wind Energy Association found that 89 gigawatt-hours of wind power are lost each year in Germany because wind farms have to be taken off the grid at times of surplus production. As renewables grow, the volume of intermittent power will only increase.

How can this trend be kept productive? "The technology is expensive, and it won't happen on its own," Sterner says. Gas produced with wind power will require some startup subsidies and proper policy support, for instance by being treated legally and financially like refined biogas. The German government says it plans to do so. Its resolution on the Energy Management Act adds hydrogen and synthetic methane to the definition of biogas, provided that 80 percent of the power for electrolysis and the carbon dioxide needed for the process comes from renewable sources. At present, EUR 0.07 to 0.08 is paid in Germany per kilowatt-hour (kWh) of biomethane. "At that rate, the equipment could pay for itself one day," Sterner says, provided that the power for electrolysis does not cost more than EUR 0.02 per kWh – a price only currently offered by nuclear plants. The capacity utilization of such units is another hurdle. Electrolyzers are expensive and need to be kept in operation. Simply using them to store excess power will not suffice. One option would be to have power-to-gas systems take part in the balancing-power market.

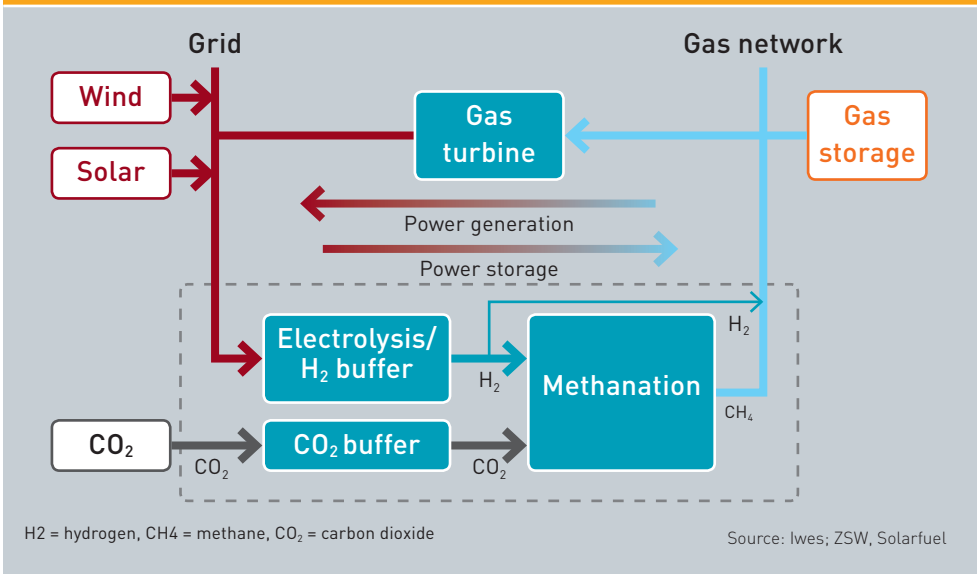
> "The need for storage will grow exponentially."
> Michael Sterner, Iwes

The natural gas sector has already warmed up to the idea of using its infrastructure to store energy. Germany's Technical and Scientific Association for Gas and Water (DVGW) is looking into the role that gas can play in the country's energy supply on behalf of firms in the sector. DVGW's Frank Gröschel says the power-to-gas process is promising. The firms are interested for good reason. Demand for heat – the main application for natural gas – is dropping and will continue to do so as efficiency increases further. "Gas is going to fulfill new responsibilities as a source of energy," Gröschel explains.

As well as cost, sites are another challenge. Experts expect many power-to-gas systems to be installed in northern Germany, where a lot of wind power is produced. Proximity to power and gas lines is decisive for sites, as is access to sources of carbon dioxide if methane is to be produced. As transport over long distances is expensive, CO_2 has to be available locally – for instance, from facilities that separate CO_2 in the process of refining biogas into biomethane. One aspect of this is that this biogenic CO_2 was absorbed by the plants during their growth phase.

Experts agree that the grid will have to be expanded even if renewable power is stored in gas lines. But in spots, a load could be taken off the grid. For instance, a few municipal utilities in Germany are looking into working with electrolyzers because the growth of solar power is overloading their medium-voltage grids. Instead of expanding the grid, hydrogen could be used to store the power. ◀

The ABC of power to gas



H2 = hydrogen, CH4 = methane, CO_2 = carbon dioxide

Source: Iwes; ZSW, Solarfuel