Underwater battery in a quarry lake

Innovative intermediate storage for solar and wind energy

By Anne Hardy

Without short-term storage for renewable energy there will be no energy transition – of this, physcist Horst Schmidt-Böcking is convinced. He wants to realise his idea of building underwater pumped-storage power plants at the open-pit coal mine Hambacher Loch.

Horst Schmidt-Böcking points to a graph that shows how many current spikes from solar and wind energy we are unable to use: »In Germany in 2018, we had to deliver 50 billion kilowatt hours of excess ecological electricty to other countries, or discard it, and shut down wind turbines as well,« he regrets. That is far more energy than what the power plants in the Rhenish lignite mining region produce in a year, i. e. 31 billion kilowatt hours (kWh). This unused energy is in turn missing on days that are windless or cloudy. This makes electricity expensive and increases CO_2 emissions.

The retired physics professor estimates that we need ten times as much renewable energy storage capacity for short-term storage as is currently available in Germany through water pumped storage plants. »One bright spot for storage is the huge advances in lithium-ion batteries that have been made recently,« he explains. However, he says, due to the chemicals used, among other things, battery production is not environmentally friendly. In addition, the lifespan is limited to about 3000 charging cycles. »In the short and medium term, you will not be able to cover the demand for short-term storage with such batteries,« Schmidt-Böcking estimates.

Pumped-storage power plants as a model

The Frankfurt atomic physicist from and his retired colleague Gerhard Luther from the University of Saarbrücken have been thinking about an environmentally friendly alternative to batteries since 2009. They based their work on the principle of pumped-storage power plants. Traditionally, a lake or river is dammed and connected to a lower or higher reservoir. To generate electricity, the water from the upper reservoir is allowed to drive turbines down on a lower altitude. Conversely, excess energy can be stored by pumping the water back up against gravity.

Unfortunately, the geographical conditions for this type of pumped-storage power plant in Germany are not favourable. The recently realised Goldisthal power plant in Thuringia was heavily criticised by environmentalists because of the severe disruption to the landscape and ecosystems and was temporarily stopped by a lawsuit filed by the environmental organisation BUND Thüringen. The top of the mountain Großer Farmdenkopf had to be removed for the reservoir. With its storage capacity of 8.5 gigawatt hours, the power plant, which went into operation in 2003, is one of the largest in Europe.

That is about one third less than the city of Frankfurt consumes in electricity per day. Accordingly, the estimated short-term storage requirement of 400 gigawatt hours is many times that amount. More pumped-storage power plants would have to be built. But

In November 2016, the prototype of the »underwater battery« was lowered to the bottoms of Lake Constance and tested for four weeks. The hollow sphere can temporarily store electricity at the bottom of bodies of water.

IN A NUTSHELL

- The »sea egg« for storing surplus green electricity is based on the principle of the pumped storage power plant.
- A feasibility study at Lake Constance showed that 90 per cent of the stored electricity can be recovered.
- A gigantic »water battery« in the Hambacher Loch could play a key role in the energy transition and secure the future of the Rhenish mining area as an energy region.

that is unrealistic, as the most recent project planned in Atdorf in the Black Forest has shown. The energy provider finally abandoned the project in 2017 because the legally required reviews of the ecological mapping and the land compensation concept seemed too time-consuming and cost-intensive.

The »sea-egg« in Lake Constance

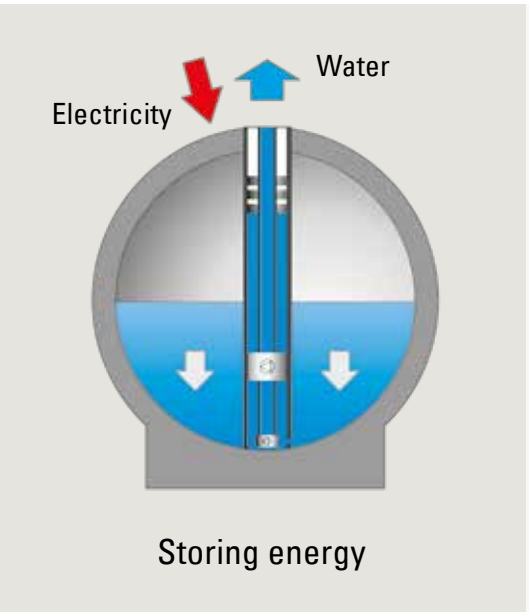
After the successful feasibility study, Schmidt-Böcking and Luther have further developed their idea on a larger scale: »We propose a huge water battery in the former Hambacher Loch opencast lignite mine explains the physicist. When no more lignite is mined here in 2038, there are plans to flood the area. At present, the groundwater level is being lowered so much that the dryness of the upper soil layers is making itself felt as far away as Luxembourg, 100 kilometres away. Large quantities of groundwater are being pumped into the nearby Erft river. This is less than ideal from an ecological standpoint, as the chemical composition of the water is different from that in the river.

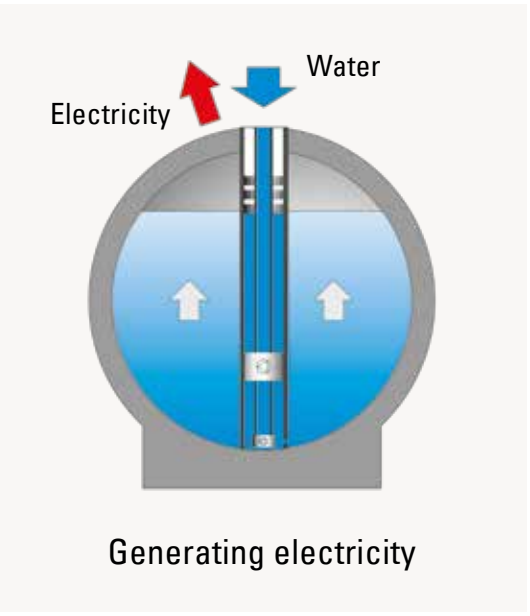
ence in Berlin, which was about the technical realisation of the energy transition. In the bottom of the pit, which is on average about 450 metres deep, a cavity about 100 metres high could be built from concrete over an area of four square kilometres. To make it stable and inexpensive, the interior would be divided into many segments. These would have a much larger volume than the »sea egg« and could be equipped with commercially available turbines.

An invisible underwater pumped-storage power plant such as this could store more than 300 gigawatt hours (GWh) in one cycle. By comparison, that is more than seven times as much as all the existing water pumped-storage plants in Germany combined. At 100 filling cycles per year, the plant would store about 30 billion kilowatt hours (30 terawatt hours, TWh), which corresponds to the amount of energy currently produced in the Rhenish lignite mining area. If one thinks in even larger dimensions and doubles the height of the cavity to 200 metres, the storage capacity of the »water battery« increases to about 400 GWh. At 200 cycles per year, it could cover Germany's entire short-term storage needs for renewable energies.

If all of Germany's surplus wind and solar energy were stored in the Hambach pumped hydro power plant, carbon dioxide emissions could be reduced by more than 30 to 50 million tonnes per year. That corresponds to about five percent of Germany's total CO_2 emissions. You would have to subtract the CO_2 footprint of the concrete structure from that. »You could also save concrete by weighting the cavity against

At the bottom of the lake, an electric pump turbine pumps the sphere empty against the high external pressure of the water. This is how energy is stored. If water is allowed to flow in, the pump turbine generates electricity again (graphic on the right). Entire rows of such spheres could thus temporarily store large amounts of solar or wind power (graphic on the left).





After the end of open-cast mining, the »Hambacher Loch« will fill with groundwater. Before that, the idea is that an underwater pumped storage power plant could be installed at the deepest point.

buoyancy with overburden, which is produced anyway during earthworks,« Schmidt-Böcking says. He estimates that the carbon dioxide balance would then be compensated after about two years.

Energy transition in the Rhenish mining area

Schmidt-Böcking has sought talks with politicians for the realisation of the project. The timing is favourable, because a total of 14.8 billion euros is to flow into the structural transformation of the Rhenish mining area after the phase-out of lignite by 2038. With the support of the state, the region has already selected 100 projects with which it wants to become a pioneer of the energy transition.

In spring 2020, the city of Kerpen, whose jurisdiction includes the adjacent Hambach open-cast mine, submitted a funding application for the »Speicher Stadt Kerpen« (Storage City Kerpen) to the state of North Rhine-Westphalia together with partners from business and science. Among the 83 future projects, an »energy arena« consisting of wind turbines and photovoltaic systems is planned at the Hambach Loch. It would make sense to combine these with a water battery. Schmidt-Böcking and Luther were able to inspire the technical councillor of the city of Kerpen with the idea.

The physicist proposes to start building the first segments of the pumped hydro power plant

About Horst Schmidt-Böcking

Prof. Dr. Horst Schmidt-Böcking, born in 1939, was a professor at the Institute for Nuclear Physics at Goethe University from 1982 to 2004. With his research group, he developed the COLTRIMS reaction microscope, which is now used by laboratories worldwide to measure reactions in atomic and molecular beams with the highest temporal resolution. He received numerous awards for his work, including the prestigious Stern-Gerlach Medal of the German Physical Society and the Davisson-Germer Prize of the American Physical Society, the first German to do so. Since his retirement, he has been committed to making the historical achievements of Frankfurt physicists known to a broad public. Together with Karin Reich, he wrote a biography of Nobel Prize winner Otto Stern.

The future lake in the Hambacher Loch would have ebb and flow like the North Sea with a large underwater pumped storage power plant. A dam (black line) with sluices (red) could limit the tides in the shore zone to make it usable for recreational activities.

parallel to the phasing out of lignite mining. In this way, there could be a continuous transition from fossil to renewable energy. In addition, many existing jobs would be preserved, because earthworks would still be necessary. Initially, a small auxiliary lake could be created in the shallow area of the Hambacher Loch, connected to the first hollow segments via a pipe system. When lignite mining ends in 2038 and all the hollow-body segments are completed, the pipe connections to the auxiliary lake would be removed and the entire Hambacher Loch flooded. This proposal was included in the final report on the energy reuse of residual opencast mining holes in North Rhine-Westphalia published at the end of 2019, which was commissioned by the North Rhine-Westphalian Ministry of Economics.

A lake with tides

To use the lake landscape as a local recreation area, the tides at the lake need to be factored in. The tidal range depends on the volume of the water battery. »If you want to limit the tidal range to a maximum of one metre, then the maximum storage capacity would be limited to 40 gigawatt hours per cycle,« Schmidt-Böcking calculates. If, on the other hand, the »big solution« with a storage capacity of 250 gigawatt hours is the goal, the tidal range would be about seven metres. Since the flooded lake will ultimately have a water surface of about 42 square kilometres, Schmidt-Böcking proposes separating the shore zone by a ring-shaped dam in which the ebb-tide movement is limited to less than one metre. This stabilises the living conditions for animal and plant life.

In the meantime, Schmidt-Böcking and Luther have contacted the engineering firm schlaich bergermann und partner. The Stuttgart-based company specialises in the planning and construction of visionary facilities in the field of renewable energy. The company will analyse the feasibility and make reliable calculations that can serve as a basis for political decisions. The two physicists hope that politicians will then demonstrate the necessary pioneering spirit. Because that will also be important if the energy transition is to succeed. »I'm 81 now,« says Schmidt-Böcking, »and I'd like to live to see it.« ●

The author

Dr. Anne Hardy, born in 1965, studied physics and holds a doctoral degree in history of science. As a freelance journalist, she specialises in natural science and medical topics.

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