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Iron-based hydrogen storage feasibility

1.4-cubic-meter stainless steel reactor at the Hönggerberg campus holds 2–3 metric tons of untreated iron ore. (Credit: ETH Zurich)

Now researchers at ETH Zurich led by Prof. Wendelin Stark, Functional Materials at the Department of Chemistry and Applied Biosciences, have developed a new technology for the seasonal storage of hydrogen that is much safer and cheaper than existing solutions, based on the steam-iron process, known since the 19th century. If there is a surplus of solar power available in the summer months, it can be used to split water to produce hydrogen. This hydrogen is then fed into a stainless steel reactor filled with natural iron ore at 400^{o}C. There, the hydrogen extracts the oxygen from the iron ore—which in chemical terms is simply iron oxide—resulting in elemental iron and water. This chemical process is similar to charging a battery. It means that the energy in the hydrogen can be stored as iron and water for long periods with almost no losses.

When the energy is needed again in winter, the researchers reverse the process: they feed hot steam into the reactor to turn the iron and water back into iron oxide and hydrogen. The hydrogen can then be converted into electricity or heat in a gas turbine or fuel cell. To keep the energy required for the discharging process to a minimum, the steam is generated using waste heat from the discharging reaction. The big advantage of this technology is that the raw material, iron ore, is easily available which does not even need processing before it is put the reactor. Moreover, the researchers assume that large iron ore storage facilities could be built worldwide without substantially influencing the global market price of iron.

The reactor in which the reaction takes place doesn't have to fulfil any special safety requirements either. It consists of stainless steel walls just 6 millimetres thick. The reaction takes place at normal pressure and the storage capacity increases with each cycle. Once filled with iron oxide, the reactor can be reused for any number of storage cycles without having to replace its contents. Another advantage of the technology is that the researchers can easily expand the storage capacity. It's simply a case of building bigger reactors and filling them with more iron ore. All these advantages make this storage technology an estimated ten times cheaper than existing methods.

However, there's also a downside to using hydrogen: its production and conversion are inefficient compared to other sources of energy, as up to 60% of its energy is lost in the process. This means that as a storage medium, hydrogen is most attractive when sufficient wind or solar power is available and other options are off the table. That is especially the case with industrial processes that can't be electrified. The researchers have demonstrated the technical feasibility of their storage technology using a pilot plant on the Hönggerberg campus. This consists of three stainless steel reactors with a capacity of 1.4 cubic meters, each of which the researchers have filled with 2–3 metric tons of untreated iron ore available on the market.

The pilot plant can store around 10 megawatt hours of hydrogen over long periods. Depending on how you convert the hydrogen into electricity, that'll give you somewhere between 4 and 6 megawatt hours of power. This corresponds to the electricity demand from three to five Swiss single-family homes in the winter months. At present, the system is still running on electricity from the grid and not on the solar power generated on the Hönggerberg campus. This is soon set to change: the researchers want to expand the system such that by 2026, the ETH Hönggerberg campus can meet one-fifth of its winter electricity requirements using its own solar power from the summer. This would require reactors with a volume of 2,000 cubic meters, which could store around 4 gigawatt hours (GWh) of green hydrogen.

Once converted into electricity, the stored hydrogen would supply around 2 GWh of power. This plant could replace a small reservoir in the Alps as a seasonal energy storage facility. In addition, the discharging process would generate 2 GWh of heat, which the researchers want to integrate into the campus's heating system. The researchers have made some initial calculations: providing Switzerland with around 10 terawatt hours (TWh) of electricity from seasonal hydrogen storage systems every year in the future—which would admittedly be a lot—would require some 15–20 TWh of green hydrogen and roughly 10,000,000 cubic meters of iron ore.

If reactors were built that could store around 1 GWh of electricity each, they would have a volume of roughly 1,000 cubic meters. This calls for around 100 square meters of building land. Switzerland would have to build some 10,000 of these storage systems to obtain 10 TWh of electricity in winter, which corresponds to an area of around 1 square meter per inhabitant. (Source: *Samuel P. Heiniger et al, Sustainable Energy & Fuels (2023).*