Affordable Nuclear-Powered Hydrogen Production Within Reach, Studies Suggest

Paving the Way for a Sustainable Energy Future




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Competition from fossil fuels and renewable energy presents a challenge for nuclear power plants as they try to remain profitable. Nuclear-powered hydrogen production could provide plant operators with a good way to diversify their products while increasing profits.

The LWRS Program is helping evaluate the technical feasibility and economics of electrolysis systems that harness electricity and heat from nuclear power plants to split water into oxygen and hydrogen.

These systems not only provide utilities with additional revenue from the sale of hydrogen, but also a means to ramp electricity generation up or down to match variable demand on the grid. Hydrogen serves as a storage medium for a nuclear power plant's excess power. Hydrogen can then be sold to a number of industries or can even be turned back into electricity during times of high grid demand.

Recently, utilities worked with LWRS Program researchers at Idaho National Laboratory (INL) to locate small-scale electrolysis systems at operating light water reactor plants. The nation's first nuclear-powered clean hydrogen production facility, a 1.25-MWe, low-temperature electrolysis system, is producing hydrogen at Constellation's Nine Mile Point plant in New York state. Another low-temperature system is planned for Vistra's Davis-Besse plant in Ohio, and a 200-kWe high-temperature electrolysis system will be installed at Xcel Energy's Prairie Island plant in Minnesota.

Researchers have developed conceptual designs and a cost analysis for combining nuclear plants with larger-scale high-temperature electrolysis systems—100MW and 500MW, respectively.

The analysis showed that, by 2026, combined nuclear-hydrogen systems could produce hydrogen with no significant carbon emissions for under $2/kg. Market studies show that at that price, clean hydrogen could compete in some markets with steam methane, reforming a process that consumes fossil fuels and emits greenhouse gases.

The clean hydrogen produced by these electrolysis systems could help support decarbonizing industries from chemicals production to steel manufacturing, while bolstering clean technologies such as fuel-cell vehicles and sustainable fuels that could replace petroleum fuels.

Researchers developed the hydrogen system designs for a 4-Loop Westinghouse pressurized water reactor, which is the most common design used currently operating U.S. nuclear power plants. A similar effort for boiling water reactors is expected in late 2024. The design could also be adapted for low-temperature electrolysis systems (Electrolysis systems split water into hydrogen and oxygen using electricity in the presence of a catalyst. Low-temperature systems split liquid water, whereas high-temperature systems split steam, which is more efficient).

To develop the conceptual design, researchers collaborated with Sargent & Lundy, an architectural engineering company, and Strategic Analysis, Inc., a consulting firm, with support from Westinghouse Electric Company. The addition of the electrolysis system requires changes to the power plant design, but those changes are minor (see Figure 5).

The studies explored technical questions such as how to size the steam extraction components and pipes to ensure no adverse consequences to the operation of the power plant, where and how to establish control capabilities and how to tap electricity from the nuclear plant's power transmission station. Direct current electricity would be tapped from the high-voltage side of the generator step-up transformer, then transported via a 345-kV transmission line to the hydrogen production facility.

The studies also looked at how and where to extract high-temperature steam from the nuclear power plant. High-temperature steam electrolysis systems require heat at approximately 150°C.

In a pressured light water reactor, heated water is carried to the steam generator in a closed pipe. Inside the steam generator, the heated water in the pipe vaporizes the water outside of the pipe, creating high-pressure, high-temperature steam (300°C) that is routed to the first turbine, which makes most the plant's electricity because this is where the water has the most energy. After the first turbine, the steam has cooled to about 190°C and is routed to a second turbine before it returns to the steam generator as water.

Researchers found that extracting cooler steam before it enters the second turbine was the most cost-effective way to transfer thermal energy to a high-temperature steam electrolysis system to produce hydrogen. Researchers estimated that using this cooler steam for hydrogen production would cost approximately $9/MWhth (megawatt-hours of thermal energy) for a 500 MW hydrogen plant, compared with $13/MWh for steam extracted from the main steam line and $30/MWh for steam from an electric boiler.

For a 500 MW hydrogen plant, cooler steam contributes approximately $0.066/kg-$H_2$, compared with $0.10/kg-$H_2$ for steam from the main steam line and $0.22/kg-$H_2$ for steam from an electric boiler. The cost savings of using steam from the cold reheat of a nuclear power plant could be as much as $0.16/kg H_2. During times of low electricity prices, the cooler steam could prove more valuable for making hydrogen than making electricity.

These demonstration projects help to reduce risks for utilities as they consider adopting these hybrid nuclear-hydrogen technologies. While projected cost of hydrogen at $2/kg depends on the establishment of a robust electrolysis manufacturing industry, advancements in hydrogen technology could reduce that price even further to $1/kg by 2031. The $1/kg price meets the Department of Energy's (DOE) Hydrogen Earthshot objective.

The lessons learned apply not only to the nation's current reactor fleet, but also to the next generation of advanced reactors that have the potential to supply industries with heat at even higher temperatures.

Figure 5. Nuclear power plants can provide heat and electricity for high-temperature water electrolysis.