Future Publishing LLC
August 2022| Volume 01 | Issue 02 | Pages 01-02
Journal homepage: https://fupubco.com/fuen
Future Energy
https://doi.org/10.55670/fpll.fuen.1.2.1
Open Access Journal
ISSN 2832-0328

News & Views

Retrieving nuclear power plants by producing hydrogen

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In February 2022, the U.S. Department of Energy (DOE) established a $6 billion program to support America's clean nuclear energy infrastructure. Before that, in the fourth quarter of 2021, the DOE dedicated $20 million in funding to the technologies that produce clean hydrogen from nuclear power. This approach reinforces producing hydrogen from zero-carbon electricity and represents a crucial economic product for nuclear power plants beyond electricity. The DOE plans to decrease the cost of hydrogen to $1 per 1 kilogram in one decade and open up new markets for the nuclear industry.

Nuclear power currently supplies 52% of the U.S. clean electrical power, and the government has identified the current fleet of 93 nuclear reactors as a vital resource to obtain net-zero emissions economy-wide by 2050. Since 2013, twelve nuclear reactors have been closed in the U.S. due to expiring their operating licenses, and another eight reactors are going to shut down by 2025. Continuing this trend, more than 10% of the U.S. nuclear power capacity will be lost within the next decade. That's a massive loss because nuclear generates approximately 20% of the US power and more than half of its clean energy. Several reasons make it difficult for nuclear power to compete in energy markets: its high maintenance cost, low natural gas price, fast development of renewables, and renewable energy price mitigation. One opportunity to retrieve nuclear power generation systems is to employ nuclear's thermal heat and electricity to produce hydrogen. Nuclear power plants can produce so-called pink hydrogen in various methods that would significantly mitigate greenhouse gas emissions while exploiting the constant thermal energy and electricity it reliably provides. Compared to natural gas boilers, a nuclear power plant could produce high-quality steam at lower prices without pollutant emissions that could be used in the steam methane reforming (SMR) process. This high-quality steam could be split into pure hydrogen and oxygen in the solid oxide steam electrolyzer (SOSE) [1]. Compared to the room-temperature electrolyzers, the electrochemical decomposition of steam at extremely high temperatures offers two advantages: 1. the efficiency of a high-temperature electrolyzer is more than a room-temperature electrolyzer because the energy supplied as heat is cheaper than electrical power. 2. at the steam temperature, the utilized energy in the high-temperature electrolyzer is low due to the low theoretical decomposition voltage. The SOSE is a promising hydrogen production technology with high scalability, high application flexibility, pure hydrogen production, and enhanced reaction kinetics at higher temperatures with low capital costs [2]. Some drawbacks come in the form of degradation of ceramic electrolyte and electrodes at the high-temperature operation, which means a lack of stability and low durability should be improved before the SOSE technology is developed commercially [3]. It is claimed that hydrogen production via nuclear electrical power has a comparable carbon footprint to hydrogen produced by renewables. However, the cost of this hydrogen production route is still high because the electrolysis process is not especially efficient, and approximately 20% of the power employed to produce hydrogen from the electrolyzer is used in the process [4]. The DOE dedicated $8 billion earmarked for regional "clean hydrogen hubs" to develop the application of hydrogen in the industrial sector and beyond; $1 billion for a clean hydrogen electrolysis program to decrease the costs of hydrogen produced from clean electricity; and $500 million to preserve hydrogen manufacturing and recycling initiatives [5]. Thermal decomposition of methane or methane pyrolysis is another technique that can be used for nuclear hydrogen production. In the non-catalytic process, CH_4 pyrolysis takes place at high temperatures (1100–1200 °C), which requires steep energy. However, using catalysts in the process can mitigate the required temperature. For instance, nickel catalysts and iron catalysts work effectively in the range of 500–700 °C and 700–900 °C, respectively. One of the main characteristics of hydrogen production via CH_4 pyrolysis that makes it competitive with SMR is that even though carbon is one of the products of this process, it is black carbon (pure solid carbon). Pure carbon can be used in various sorts of applications, such as carbon-fiber production, and the process of capturing and utilizing solid carbon would be simpler than capturing and sequestering CO_2. In nuclear reactors, especially in the advanced reactors such as Generation-IV nuclear, extremely high-temperature steam (500-1000°C) in the form of lower-cost heat is available, which is the key advantage of nuclear hydrogen production via CH_4 pyrolysis. In general, a 1,000 MW nuclear power plant could provide more than 150,000 tonnes of hydrogen annually. It means ten nuclear power plants with the mentioned capacity could produce about 1.5 million tonnes of hydrogen per year, or 15% of current hydrogen produced in the US. This new revenue could be helpful to build an economic stream to keep the nation's at-risk nuclear power plants up and running—possibly preparing higher market value for hydrogen in the US and countries that require hydrogen fuel. Extending the life of the operating reactors, it will allow the industry to unveil new advanced reactors online.

It is expected that the advanced reactors operate at considerably higher temperatures that would allow nuclear plants to efficiently produce hydrogen to drastically scale up the industry [1]. Worldwide, the production of 70 million tonnes of hydrogen from renewable energy would need the commissioning of more than 56 million hectares of photovoltaic panels or one million new wind turbines. The alternative, low-carbon hydrogen from nuclear electricity would represent 400 GW of new nuclear power plants. However, since several countries are decreasing the share of nuclear power in their energy mix, this is a pipe dream.

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