DOE Hydrogen Program Record	
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Title: Hydrogen Production Potential from Nuclear Power	
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Item

A nuclear power plant providing 1 GW of power for hydrogen production year-round could produce between approximately 150,000 and 160,000 metric tons (tonnes) of hydrogen per year using polymer electrolyte membrane (PEM) electrolyzers. Ten such plants could provide over 1.5 million tonnes of H_2 or roughly 15% of the hydrogen produced today in the U.S.[1] Between 180,000 and 210,000 metric tons of hydrogen per year could be produced if the 1 GW nuclear plant utilized solid oxide electrolysis cell (SOEC) technology.

Background

This analysis estimates the amount of hydrogen that a nuclear power plant could produce using electrolysis,[2] based on a range of assumptions for electricity generation for the grid. In recent years, several nuclear plants throughout the U.S. have experienced a decline in revenue as a result of low prices of natural gas, regional growth, and subsidies for renewables, and the market structures of regional power grids.[3,4] Hydrogen production is one of several applications nuclear plants are considering to increase their annual revenues.

While the average utilization of the nuclear power plant fleet in the U.S. is over 90%,[5] this record focuses on the amount of hydrogen that nuclear power plants could produce when electricity demand is low, using specific assumptions of plant capacity, electrolyzer efficiency, and the percentage of the year the plant is supplying electricity to the grid. For instance, a 1 GW plant that transitions fully from electricity production for the grid to hydrogen production could produce over

[1] Connelly, E., et al., 2019. "Current Hydrogen Market Size: Domestic and Global." U.S. Department of Energy. https://www.hydrogen.energy.gov/pdfs/19002-hydrogen-market-domestic-global.pdf

[2] The analysis focuses only on electrolysis operation from nuclear power. Additional operation strategies are viable but are out of the scope of this work.

[3] Steckler, N. and Gadomski, C., 2018. Reactors in the Red: Updated Profit Margins for U.S. Nukes. Bloomberg New Energy Finance.

[4] U.S. Department of Energy. Office of Scientific and Technical Information, 2014. Nuclear-renewable hybrid energy systems: Opportunities, interconnections, and needs. https://www.osti.gov/servlets/purl/1357209

[5] U.S. Department of Energy, Office of Nuclear Energy, 2019. The Ultimate Fast Facts Guide to Nuclear Energy. https://www.energy.gov/sites/prod/files/2019/01/f58/Ultimate%20Fast%20Facts%20Guide-PRINT.pdf

183,000 tonnes of hydrogen per year using high-temperature electrolysis, and over 150,000 tonnes of hydrogen per year using low-temperature electrolysis.

Tables 1 and 2 illustrate the ranges of hydrogen a plant could produce when not supplying electricity to the grid at its rated capacity, and not in an outage or scheduled maintenance. This record assumes that plants experience outages for refueling or maintenance for an average of 34 days in an 18–24 month cycle, for an average of ~5% a year, based on an EIA study reporting that average refueling outages have decreased from an average of 46 days in 2012 to 34 days in 2018;[6] during this time, the plant is unavailable to supply power to the grid or produce hydrogen. Values of electrolyzer efficiency are based on input from industry stakeholders and previous DOE records[7,8,9] for PEM electrolyzers and SOECs using steam heated to 700°–800°C.

As shown in Tables 1 and 2, a 1 GW plant using 5% of its rated capacity to generate hydrogen annually can produce over 7,900 tonnes of H_2 in a year using low-temperature PEM electrolyzers and over 9,700 tonnes of H_2 using high-temperature SOECs. Similarly, a 1 GW plant producing hydrogen for 55% of the year can produce over 86,000 tonnes of hydrogen in a year using low-temperature PEM electrolysis and over 106,000 tonnes in a year using high-temperature SOEC electrolyzers.[10] If a nuclear power plant were to be used exclusively for hydrogen production, it could produce over 150,000 tonnes of hydrogen per year using low-temperature PEM electrolysis and over 183,000 tonnes of hydrogen per year using high-temperature SOEC electrolysis.

Example:

1 GW x 1,000,000 kW/1 GW x 0.95 (fraction of year that plant can make hydrogen) x 365 (days/yr) x (24 hr/day)/56 kWh/kg H_2 = 150,000,000 kg/yr or 150,000 tonnes/yr

This translates to approximately 410 tonnes per day (i.e., 150,000,000 kg/365 days ≅ 410,000 kg per day).

[6] U.S. Energy Information Administration, 2018. "U.S. nuclear plant outages increased in September after remaining low during summer." https://www.eia.gov/todayinenergy/detail.php?id=37252#

[7] Peterson et al., 2020. Hydrogen Production Cost From PEM Electrolysis – 2019. DOE Hydrogen and Fuel Cells Program Record. https://www.hydrogen.energy.gov/pdfs/19009_h2_production_cost_pem_electrolysis_2019.pdf

[8] Peterson et al., 2020. Hydrogen Production Cost From High-Temperature Electrolysis – 2020. DOE Hydrogen and Fuel Cells Program Record. https://www.hydrogen.energy.gov/pdfs/20006-production-cost-high-temperature-electrolysis.pdf

[9] Peterson and Miller, 2016. Hydrogen Production Cost from Solid Oxide Electrolysis – 2016. DOE Hydrogen and Fuel Cells Program Record. https://www.hydrogen.energy.gov/pdfs/16014_h2_production_cost_solid_oxide_electrolysis.pdf

[10] It is important to note that most nuclear reactors do not operate at such low utilization. From 2014–2019, the utilization in the 25th percentile of all nuclear power plants in the U.S. was 80%. Utilization data was accessed from the Bloomberg New Energy Finance U.S. Coal and Nuclear Retirement Monitor on November 4, 2020. https://www.bnef.com/interactive-datasets/2d5d59acd9000033

Table 1: Amount (tonnes) of Hydrogen Nuclear Plants Can Produce Using Low-Temperature PEM Electrolysis

Nuclear Power Plant Power (GW)	Fraction of Year Supplying Electricity To Grid (%)	Fraction of Year Spent in Outages[11]	Fraction of Year that Plant Can Make Hydrogen (hours producing hydrogen/total hours in a year)	Energy Required to Produce Hydrogen (kWh/kg)[12]	Hydrogen Produced in a Year (Tonnes/year)
1.0	0.9	0.05	0.05	51–56	7,900–8,500
1.0	0.8	0.05	0.15	51–56	24,000–26,000
1.0	0.7	0.05	0.25	51–56	39,000–43,000
1.0	0.4	0.05	0.55	51–56	86,000–94,000
1.0	0	0.05	0.95	51–56	150,000–162,000

Table 2: Amount (tonnes) of Hydrogen Nuclear Plants Can Produce Using High-Temperature SOEC Electrolysis

Nuclear Plant Power (GW)	Fraction of Year Supplying Electricity to Grid (%)	Fraction of Year Spent in Outages	Fraction of Year that Plant Can Make Hydrogen (hours producing hydrogen/total hours in a year)	Electrical Energy Required to Produce Hydrogen (kWh/kg)[13]	Electrical Equivalent of Thermal Energy Used to Produce Hydrogen (kWh/kg)[14]	Hydrogen Produced in a Year (Tonnes/year)
1.0	0.9	0.05	0.05	37–43	2.4	9,700–11,000
1.0	0.8	0.05	0.15	37–43	2.4	29,000–33,000
1.0	0.7	0.05	0.25	37–43	2.4	48,000–56,000
1.0	0.4	0.05	0.55	37–43	2.4	106,000–122,000
1.0	0	0.05	0.95	37–43	2.4	183,000–211,000

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[11] As explained in Footnote 6, plants typically experience outages once every 18–24 months, and each outage lasts an average of 34 days. As such, in the calculations shown in Tables 1 and 2, it was assumed that plants spend 5% of each year in outages.

[12] The electrolysis system is assumed to operate at approximately 20 bar and includes compression. Hydrogen drying was accounted for in the total electrical usage. Additional energy may be required for compressing hydrogen if intended for transportation.

[13] The electrolysis system is assumed to operate at approximately 20 bar and includes compression. Hydrogen drying was accounted for in the total electrical usage. Additional energy may be required for compressing hydrogen if intended for transportation.

[14] The high-temperature electrolysis case assumes 35% thermal-to-electrical conversion efficiency within lightwater nuclear reactors. The total electrical energy usage is then the summation of the electrical energy and the electrical equivalent of thermal energy. Diversion of steam for high-temperature electrolysis will reduce this efficiency slightly by reducing turbine efficiency; this effect was not accounted for. Losses of heat in piping were also not accounted for. Advanced reactors could have higher thermal-to-electrical efficiency. Source: Energy Education, 2020. Nuclear Power Plant, available at: https://energyeducation.ca/encyclopedia/Nuclear_power_plant#:~:text=Typical%20nuclear%20power%20plants%20achieve,potentially%20reach%20above%2045%25%20efficiency