HYDROGEN FACT SHEET

Hydrogen Production – Nuclear

Introduction

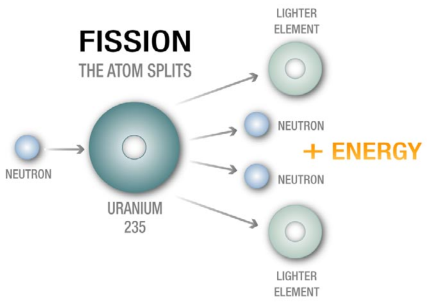
In today's energy supply system, electricity, gasoline, diesel fuel, and natural gas serve as energy carriers. These energy carriers are made by the conversion of primary energy sources, such as coal, petroleum, underground methane sources, and nuclear energy, into an energy form that is easily transported and delivered in a usable form to industrial, commercial, residential, and transportation end-users. The sustainable energy supply system of the future features electricity and hydrogen as the dominant energy carriers. Hydrogen would be produced from a very diverse base of primary energy feedstocks using the resources and processes that are most economical or consciously preferred. Hydrogen produced from off-peak nuclear generated electricity could play an important role early in the transition to a hydrogen-based energy economy. During off-peak hours, nuclear plants generate more electricity than is needed to supply to the grid, and hence electricity is at its cheapest; this excess electricity can be used to produce hydrogen. In the longer term, advanced nuclear hydrogen production concepts still under development may offer additional opportunities to meet large-scale hydrogen demands.

Table 1. Production Technology Scorecard

	Electrolysis	Thermochemical Water Splitting Cycles
Description	Electrolysis uses electrical current to split water into hydrogen at the cathode (+) and oxygen at the anode (-). Steam electrolysis (a variation on conventional electrolysis) uses heat, instead of electricity, to provide some of the energy needed to split water, making the process more energy efficient.	Thermochemical water splitting uses a very high temperature (approximately 1,000°C) to split water into its component parts.
Feedstock	Water	Water
Energy	Electricity produced from nuclear reactors or nuclear waste heat	High temperature heat from advanced gas-cooled nuclear reactors
Other	Relatively minor emissions in the nuclear fuel cycle	Relatively minor emissions in the nuclear fuel cycle
Challenge	Improve hydrogen production efficiencies of current water-cooled light water reactors (LWRs) or advanced light water reactors (ALWRs). Develop advanced high temperature reactors for high-temperature steam electrolysis.	Utilize the high-temperature heat from advanced gas-cooled nuclear reactor technology to split water into hydrogen and oxygen.
Status	Near- to mid-term	Long-term

Processes for Producing Hydrogen

There are three key methods for using nuclear energy to produce hydrogen: electrolysis, high-temperature steam electrolysis, and thermochemical water splitting cycles (see "Production Technology Scorecard" chart for details). Because a fission reaction does not burn anything, nuclear power plants do not release greenhouse gases (GHG) such as carbon dioxide (CO_2), sulfur dioxide (SO_2), nitrogen oxides (NO_X), and other harmful emissions. However, the entire nuclear fuel cycle (uranium mining, transportation, fuel enrichment, fuel processing, power plant construction, and waste management) does produce some GHG. Nuclear power is a proven contributor to energy diversity and security.



Nuclear Fission – The splitting of atoms is called fission. In a nuclear plant, atoms of uranium are split creating the heat that turns water into steam.

The core of a 1,000 megawatt (MW) nuclear reactor contains about 75 tons of enriched uranium. A coolant, usually water, is pumped through the reactor and carries away the heat produced from the nuclear fission. The resulting super-heated steam is used to drive a steam turbine electric generator, producing about 7 billion kilowatt-hours (kWh) of electricity per year. To maintain efficient nuclear reactor performance, one-third of the spent fuel is removed every year and replaced with fresh fuel.

The current approach for producing hydrogen from nuclear energy employs off-peak nuclear-generated electricity and existing water electrolysis production technologies.[1] More efficient techniques, such as thermochemical water splitting cycles and high temperature electrolysis using nuclear electricity and waste heat, can be achieved with temperatures in the range of 700-1000°C. These temperatures are too high for current light water nuclear reactors (LWRs) or the advanced light water nuclear reactors (ALWRs).[2] Generation IV nuclear reactors, currently under development, will attain sufficiently high temperatures to produce hydrogen from high temperature steam electrolysis or thermochemical water splitting.[3]

Current Status

The only approach for producing hydrogen from nuclear energy using currently operational LWRs employs off-peak nuclear-generated electricity and existing water electrolysis production technologies. In the long-term, high- and ultra-high temperature nuclear reactors offer two additional hydrogen production pathways from nuclear energy: more efficient electrolysis using high temperature steam and thermochemical water splitting to produce hydrogen using nuclear waste heat. Viable thermochemical technologies for producing hydrogen will require a dedicated research and development effort to develop appropriate water-splitting chemical process cycles and high-temperature materials.

1 Electrolysis dissociates water into its separate oxygen and hydrogen parts.

2 Current LWRs and ALWRs have operational temperatures under 350°C.

3 Generation IV designs are still on the drawing board and will not be operational before 2020 at the earliest. They will tend to have closed fuel cycles and burn the long-lived actinides now forming part of spent fuel, so that fission products are the only high-level waste. Many will be fast neutron reactors. Reactor types suitable for thermochemical hydrogen production include helium gas-cooled reactors, heavy metal-cooled reactors such as lead-bismuth, and molten salt-cooled reactors. Helium gas-cooled reactors have, unlike other reactor designs that need further development, demonstrated high temperature capabilities. The Japan Atomic Energy Research Institute is preparing to demonstrate the production of hydrogen by using the heat from its High-Temperature Engineering Test Reactor (HTTR) initially in steam reforming of natural gas, and later with this iodine-sulfur thermochemical process. The Oak Ridge National Laboratory in the U.S. is also developing the iodine-sulfur process with a view to using high-temperature reactors for it.

The Advantages

In the U.S. today, there are 103 LWRs situated on 64 sites in 31 different states. Since these nuclear reactors account for approximately 20 percent of U.S. electricity needs, or 780.2 billion kWh, there exists opportunities for domestic hydrogen production from nuclear energy as well as better utilization of off-peak electricity generation. Production of hydrogen from nuclear energy emits no GHG or other emissions. Nuclear generated electricity avoids, on average, 155 million metric tons of carbon equivalent, 2.4 million tons of NO_X, and 5.1 million tons of SO_2 annually in the U.S. per year that would be produced from coal-powered power plants. However, there are carbon emissions from the fuel cycle: mining, transportation, and uranium enrichment. There are also emissions from power plant construction and waste management.

Uranium, the main fuel for nuclear reactors, is readily available from stable, U.S.-friendly countries. In 2002, 16 countries produced over 99 percent of the world's uranium. Major suppliers exist in the U.S., Canada, and Australia, with Canadian and Australian uranium mines today making up over 50 percent of the world's uranium supply. Compared to natural gas, uranium is low in cost and less sensitive to price increases. One uranium fuel pellet, about the size of the tip of your little finger, has the equivalent energy generation potential of 17,000 cubic feet of natural gas, 1,780 pounds of coal, or 149 gallons of oil.

Finally, the hydrogen produced by nuclear reactors through electrolysis or thermochemical water splitting processes is very pure, especially compared to hydrogen produced via coal or steam methane reforming. Fuel cells require very pure hydrogen, and the high purity of hydrogen produced from nuclear reactors meets this requirement.

Challenges

The safety of nuclear reactors in the U.S. has been a very high priority in their design and engineering. About one third of the cost of a typical reactor is attributed to safety systems and structures. The Chernobyl accident in 1986 was a stark reminder of the importance of safety. At Chernobyl in Ukraine 30 people were killed (28 by high levels of radiation) and thousands more injured or adversely affected. This reactor lacked the basic engineering provisions necessary for licensing in most parts of the world.

The long-term storage of nuclear wastes is a major challenge facing nuclear energy. The Nuclear Waste Policy Act of 1982 specifies that radioactive waste will be disposed of underground in a deep geologic national repository or stored in giant steel-and-concrete casks. Significant scientific research and development (R&D) needs to be done to satisfy long-term storage and safety requirements.

Electricity Generation Facts

Electricity generated and consumed is measured in terms of **kilowatts-hours (kWh)**, and the rates that customers typically pay are dependent on when the electricity is used. Usage and power generation costs are typically highest during the Peak generation periods, and least during the Off-Peak. For reference, at the point of use, there are 3,412 Btu's per kWh.

PEAK periods occur when demand for electricity is high. *(Example: during the day; often between 8AM and 6PM)*

OFF-PEAK periods occur when demand for electricity is low. *(Example: at night; often between 12AM and 6AM.)*

MIXED-PEAK periods occur in-between Peak and Off-Peak hours. In some locales there are additional divisions in these categories and demand for electricity is low. *(Example: at night; often between 12AM and 6AM).*

The siting of new nuclear reactors will present a serious challenge to developers and would include a lengthy approval process. Most U.S. nuclear plant sites were designed to host four to six reactors and most of these sites have never been fully utilized. Obtaining approvals for the development of new or existing facilities will represent a significant challenge in the development of nuclear hydrogen production capabilities.

Implications for the Transition to a Hydrogen Economy

Nuclear energy is a viable, primary energy source that offers the potential for producing hydrogen through a process that is economical and produces relatively minor emissions in the nuclear fuel cycle. Together, nuclear energy and hydrogen technology offer a potential solution to our energy security needs. A transition to a hydrogen economy featuring nuclear energy may be one of the more economical alternatives. In the future, high-temperature reactors will provide the necessary energies to produce large-scale quantities of hydrogen via high-efficiency, high-temperature electrolysis or thermochemical water splitting cycles. DOE seeks to develop high- and ultra-high temperature thermochemical technology that produces hydrogen in the long-term (2015) that is cost competitive with gasoline at refueling stations or stationary power facilities. Overcoming negative public perception, long-term storage, safety, and siting issues, and further demonstrations of advanced reactors are needed to prove that producing hydrogen from nuclear energy processes is a viable option for the future.

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U.S. Department of Energy
www.eere.energy.gov/hydrogenandfuelcells

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