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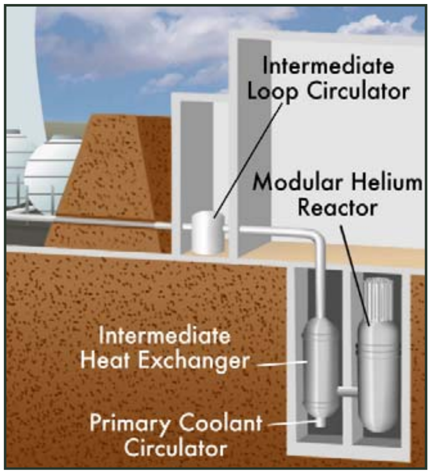
FACT SHEET SERIES

hydrogen PRODUCTION FROM NUCLEAR ENERGY

Hydrogen offers great promise for future domestic energy use. It can be produced using a variety of resources and technologies. One group of production technologies uses nuclear energy. Nuclear energy can produce high quality hydrogen in large quantities at a relatively low cost without any air emissions.

Currently, the most viable hydrogen production technology utilizing nuclear energy is conventional electrolysis, which uses electric energy to split water into hydrogen and oxygen.[1] Light Water Reactors (LWRs), the most common type of reactor used today, can produce hydrogen, electricity or both. As the cost of electrolysis comes down and the cost of fossil fuels rise, nuclear production of hydrogen by electrolysis of water using nuclear-produced electricity is increasingly attractive. However, in the longer term (after about 2020), the most promising nuclear hydrogen production technologies will likely use the high temperatures generated in advanced, high-temperature gas reactors (HGTRs - See "How does a Nuclear Reactor work?") These advanced reactors are more efficient and will be able to provide more economical, large-scale hydrogen production with less nuclear waste and energy use overall.



The High Temperature Gas-cooled Reactor can be used for hydrogen production. *Image courtesy General Atomics*

First, the Basics

Today, there are approximately 437 nuclear power reactors operating in over 25 countries around the world with a total output of some 350,000 megawatts. An additional 28 reactors (27,000 MWe) are currently under construction in 10 countries. Today, the U.S. has 103 LWRs on 64 sites in 31 states. U.S. nuclear reactors supply approximately 20 percent of the country's electricity needs, or 780.2 billion kWh a year.

Uranium is the main fuel for nuclear reactors, and is readily available. Today, 16 countries account for over 99 percent of global uranium production, about 90 million pounds per year. Major suppliers exist in the U.S., Canada and Australia, with Canadian and Australian uranium mines today supplying over 50 percent of the world's uranium. Compared to natural gas or coal, uranium is low in cost, and the cost of nuclear electricity is less sensitive to its price fluctuations. One uranium fuel pellet, about the size of the tip of your little finger, has the equivalent energy potential of 17,000 cubic feet of natural gas, 1,780 pounds of coal, or 149 gallons of oil. Nuclear reactors emit no air emissions; however, spent fuel must be disposed of properly. Today's coal-fired power plants producing the same amount of electricity as the current U.S. nuclear plants would produce 630 million tons of carbon dioxide (CO_2), 2.6 million tons of nitrogen oxide (NOx) and 5.6 million tons of (sulfur dioxide) SO_2 annually.

Nuclear reactors use a controlled nuclear fission reaction to release large amounts of heat to make steam that drives a turbine to create electricity. The core of a 1,000 megawatt LWR contains about 75 tons of enriched uranium. A coolant, water in today's reactors, is pumped through the reactor to carry away the heat produced from the nuclear fission reaction. The resulting steam drives a steam turbine electric generator, which produces about 7 billion kilowatt-hours (kWh) of electricity per year—enough to power about 500,000 to 700,000 homes. Every 18 to 24 months, about one-third of the spent fuel is removed and replaced with fresh fuel.

How does a Nuclear Reactor work?

In a nuclear reactor, the splitting of uranium atoms produces heat. This heat can be used to heat a coolant which then can transport the heat out of the reactor to do useful work. In a Light Water Reactor (LWRs, the most widely used today), the coolant is water which is then used to make steam, turn a turbine and make electricity. High Temperature Gas-cooled Reactors (HTGRs) offer an alternative to conventional Light Water Reactors. HTGRs use helium gas to transfer heat from the nuclear fission reaction in the reactor to other equipment that use the heat. The heat can perform functions like producing steam or driving a gas turbine for electricity generation, or it could be used for hydrogen production. As a coolant, helium can operate at higher temperatures than liquid coolants (usually water). This allows the reactor to operate at much higher efficiencies, and provide the heat necessary for advanced hydrogen production technologies such as high temperature electrolysis and thermo-chemical water splitting[2.] (See the *Relative Temperatures* sidebar on the next page for a comparison of operating temperatures.)

Hydrogen Production Technologies

Current LWR technology can make electricity to produce hydrogen through electrolysis at an overall efficiency of about 25%. However, proposed advanced HTGRs operate at higher temperatures, producing electricity and hydrogen much more efficiently (up to 50%). These advanced reactors potentially have many advantages over the current LWRs used in the U.S. today.

There are two main categories of hydrogen production technologies using HTGRs:

- Thermochemical water-splitting cycles
- High-temperature electrolysis

Like conventional electrolysis, both technologies separate water into hydrogen and oxygen. Both technologies also use high temperature heat for economical, emission-free hydrogen.

Thermochemical (TC) Water-splitting Cycles

Thermochemical production of hydrogen involves the separation of water into hydrogen and oxygen through chemical reactions at high temperatures (450-1000˚C). A TC water-splitting cycle involves a series of chemical reactions, some at higher temperatures than others. Engineers carefully choose chemicals to create a closed loop system that reacts with water to release oxygen and hydrogen gases. All reactants and compounds are regenerated and recycled. Studies conducted through the Nuclear Energy Research Initiative have identified more than 100 different TC water-splitting cycles. A few of the most promising cycles have been selected for further research and development based on the simplicity of the cycle, the efficiency of the process and the ability to separate a pure hydrogen product. The biggest challenge with TC processes today is corrosion of process reactors and system materials.

Of the identified processes, the sulfur family, including the sulfur-iodine (S-I) cycle and the Hybrid Sulfur (HyS) cycle, has shown the most promise for hydrogen production (see *Figure 1*).

The S-I cycle uses iodine (I_2) and sulfur dioxide (SO_2) as chemical reactants to split water. First, water reacts with I_2 and SO_2 to form hydrogen iodide (HI) and sulfuric acid (H_2SO_4). The HI and H_2SO_4 are separated from each other. H_2SO_4 and HI are decomposed in separate thermal decomposition steps into SO_2 and O_2, and I_2 and hydrogen (H_2) respectively. The SO_2 and I_2 are recycled and used again and again. The H_2 and O_2 gases are available as products.

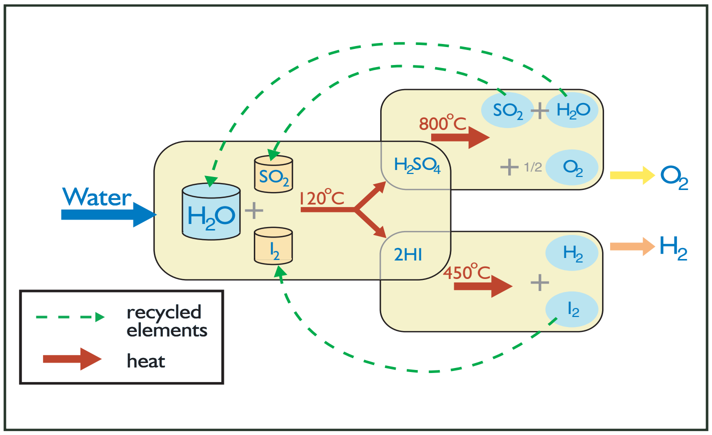


Figure 1 - Hydrogen production using the Sulfur Iodine Thermochemical Process
Image courtesy Entergy

Relative Temperatures

Processes That Need Thermal Energy	**Temperature**
Conventional electrolysis	none
Thermochemical (TC) water splitting	450-1000˚C
High temperature electrolysis (HTE)	100-1100˚C
Thermolysis	> 2500˚C
Processes That Produce Thermal Energy	**Temperature**
Light Water Reactor (LWR)	up to 350˚C
Liquid Metal-cooled Reactor (LMR)	up to 550˚C
High Temperature Gas-cooled Reactor (HTGR)	up to 1100˚C

The reaction that requires the greatest heat input is the thermal decomposition of H_2SO_4, typically at temperatures in the range of 800°C. Higher temperatures tend to favor greater efficiency.

The Hybrid Cycle uses the same high temperature decomposition of H_2SO_4 into SO_2 and O_2, but substitutes electrolysis of SO_2 and H_2O into H_2SO_4 and H_2, for the HI reaction and decomposition step. This avoids the use of iodine and potentially simplifies the process.

High-temperature Electrolysis (HTE)

HTE, or steam electrolysis, involves the separation of water into hydrogen and oxygen through electrolysis at high temperatures (up to 1100˚C). Conceptually, HTE is the same as conventional low-temperature (<100˚C) electrolysis. However, HTE uses heat from the reactor to replace some of the premium electricity required in conventional low-temperature electrolysis. How much extra heat is needed? To produce 1 kilogram of hydrogen at 100°C, the system needs about 350 megajoules of heat energy. At 850°C, only about 225 megajoules are needed—a potential savings of more than 35% at the higher temperature.

Summary

Nuclear energy can help provide the hydrogen needed for a Hydrogen Economy. Today's LWRs produce hydrogen by conventional low temperature electrolysis, while advanced reactors can potentially improve electricity production, economically producing emissions-free hydrogen. Together with fossil and renewable resources, nuclear energy and its companion technologies can produce hydrogen for our portable, stationary and transportation needs.

[1] For more information on conventional electrolysis, visit www.HydrogenAssociation.org and view the fact sheet "Hydrogen Production from Renewables" in the *General* section.

[2] For more information about nuclear energy, see the Nuclear Energy Institute website at www.nei.org.