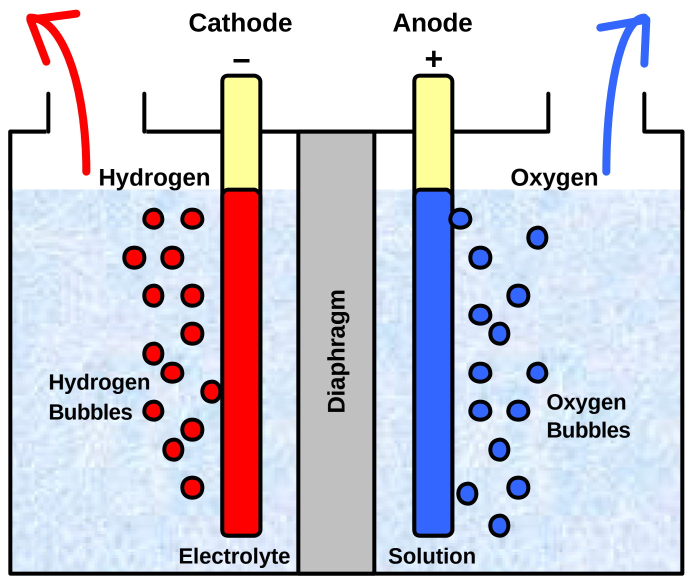
High-Temperature Electrolysis

High-temperature water electrolysis involves the separation of water into hydrogen and oxygen through electrolysis at high temperatures. Ideally, water can be separated directly (thermolysis), however this process requires temperatures in excess of 2500°C. Water can also be separated at room temperature using electrical energy (conventional electrolysis) to break the chemical bonds between hydrogen and oxygen. Because temperatures of 2500°C are impractical, electrolysis can be used to lower the process temperature, while minimizing the energy input necessary.

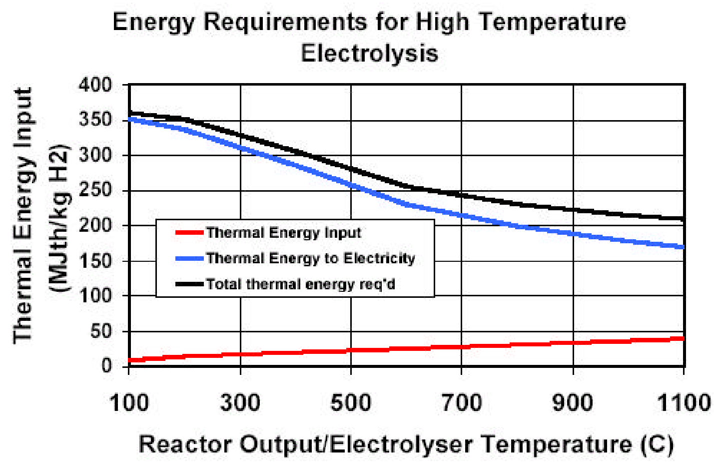
Hydrogen production through conventional water electrolysis is an established technology. Electrolysis currently comprises 4% of the world's hydrogen production and is used mainly in areas with very cheap electricity, such as those rich in hydro or geothermal resources, or in applications requiring high purity hydrogen, such as semiconductor manufacturing. Conventional electrolysis separates water into its constituent elements - hydrogen and oxygen - by charging water with an electrical current. It takes about 142 MJ to produce 1 kilogram of hydrogen, in practical terms that is about 40-50 kilowatt hours per kilogram of hydrogen. The charge breaks the chemical bond between the hydrogen and oxygen and splits apart the atomic components, creating charged particles called ions. The ions form at two poles: the anode, which is positively charged, and the cathode, which is negatively charged. Hydrogen ions gather at the cathode and react with it to form hydrogen gas, which is then collected. Oxygen goes through a similar process at the anode.

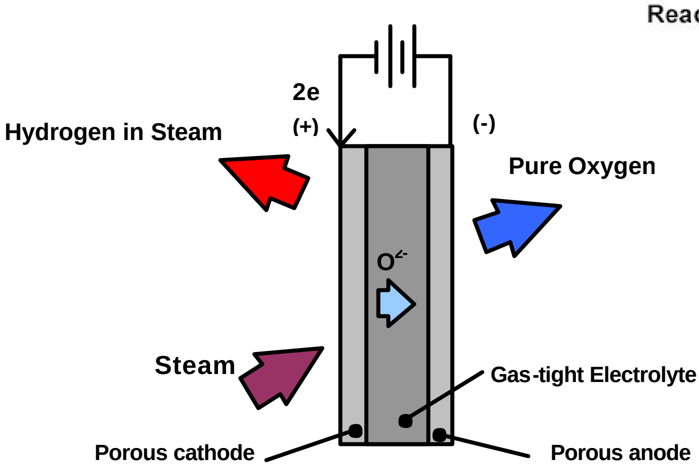


Standard Electrolysis

Current hydrogen production using conventional electrolysis is limited to electrolyzers of up to a few kilowatts. The capacity of the elecrolyzers is not limited by the membrane surface area. Individual electrolyzer modules are stacked to increase production capacity. Because electrolysis systems are modular, electrolysis can be done at a large central plant, at a refueling station, or even at home. Electrolysis is able to take advantage of a variety of primary energy sources to create hydrogen because the process itself requires only electricity. The main drawbacks of conventional electrolysis for large-scale hydrogen production are the amount of electricity required for the process and the high cost of membrane production.

High-temperature electrolysis (HTE), or steam electrolysis as it is sometimes called, is a variation of the conventional electrolysis process. Some of the energy needed to split the water is added as heat instead of electricity, thus reducing the overall energy required and improving process efficiency. Because the conversion efficiency of heat to electricity is low compared to using the heat directly, and energy efficiency can be achieved by providing the energy to the system in the form of heat rather than electricity. The figure on the right demonstrates the effect of increased temperature of feed steam on system energy requirements. About 350 mega-joules (thermal) are needed to produce 1 kilogram of hydrogen at 100°C, whereas it takes only about 225 megajoules at 850°C. The HTE process, while conceptually the same as conventional electrolysis, differs in its hydrogen production mechanism.





High Temperature Electrolysis

In HTE, high-temperature steam is separated at the anode as ions of oxygen pass through an ion conducting membrane (such as zirconium oxide) away from the steam. The input stream to the electrolyzer is about 50:50 steam and Hydrogen. The output from the electrolyzer is typically 75% hydrogen and 25% steam by volume. The hydrogen can then be separated from the steam in a condensing unit. Additional steam is added after removal of about 1/3 of the hydrogen to produce a 50:50 gas stream for reintroduction to the electrolyzer.

Primary issues that need to be addressed are durability and reliability of the thin electrolytes and sealing around the periphery of the planer electrolyte sheet. Electrodes, corrosion resistance, tolerance to impurities in feed water, and scalability are also important issues. Research is being conducted jointly between the Offices of Nuclear Energy and Energy Efficiency and Renewable Energy. Initial results of single-module tests are very promising in terms of demonstrating high efficiency high-temperature steam electrolysis using solid-oxide membranes, which are currently being developed for fuel cells. Subsequent research will be focused on testing cells fabricated from alternate membrane and other electrolyzer materials that have been optimized for HTE. Long-duration performance tests will also be performed, and various electrolyzer-stacking configurations will be developed and tested.

HTE is ideally suited for use with an advanced nuclear reactor system because a portion of the heat from the reactor can be used to create steam, while high efficiency electrical conversion cycles make maximum advantage of the high-temperature reactor heat source. It is expected that with this combination of a high-temperature reactor and high-temperature electrolysis, the process will achieve a thermal conversion efficiency of 40 to 50% while avoiding the challenging chemistry and corrosion issues associated with other hydrogen production processes.