Science & Technology

Hydrogen from a fusion reactor

Hydrogen and hydrides are the fuel of the future, replacing the increasingly scarce fossil fuels. And finding a cheap and efficient method for hydrogen production is the task that will now be taken on by the Lawrence Livermore Laboratory and Brookhaven National Laboratory under a $1 million contract for conceptual design studies involving fusion reactors.

Awarded by the Development and Technology division of the Department of Energy's Office of Fusion Energy, under the direction of Dr. Franklin Coffman, the contracts will fund two projects to study potential designs to couple the heat produced in a fusion reactor to thermochemical hydrogen production cycles and high-temperature electrolysis, using water as its raw material and not natural gas.

Fusion, the reaction that powers the sun, uses as its fuel ordinary seawater. Under specified temperatures and pressures, the heavy isotopes of hydrogen (deuterium and tritium) found in seawater fuse, releasing tremendous amounts of energy that can be harnessed, for example, as heat energy or electricity.

The fusion reaction therefore has several advantages over current hydrogen production methods. First is the very fact that the fusion process utilizes water as its major raw material input. Second is that higher temperatures can be attained in a fusion reaction than in any advanced fission design. The higher the temperature input, the lower the cost of splitting water to liberate the hydrogen.

At approximately 2,500 degrees Celsius, it is possible to split water with only thermal energy (heat), but there are no existing materials that can withstand that temperature. So temperatures up to approximately 1,800 degrees Celsius are under consideration, coupled with electricity. At that temperature, the amount of electricity needed for electrolysis is considerably less than the electricity needed for today's low-temperature electrolysis processes. And only the fusion reaction is capable of reaching such temperatures.

The Brookhaven approach

Two approaches for producing hydrogen are being pursued by the two laboratories.

Brookhaven is using the tokamak (magnetic confinement) fusion reactor design in its high-temperature electrolysis studies.

Dr. Jim Powell at Brookhaven and a team of researchers have been doing conceptual design work to couple fusion reactor heat to high-temperature electrolysis cells for the production of hydrogen. They estimate that a demonstration series of such cells could be ready for testing at the same time that the Engineering Test Facility fusion reactor is ready to demonstrate the commercial feasibility of fusion—in the 1990s.

High-temperature electrolysis consists of conducting the heat from a lithium blanket surrounding the fusion vessel through a series of ceramic ducts. The most efficient design would transfer heat at about 1,800 degrees to a set of between 9 and 12 electrolyzers where an electric current splits water with the help of the heat.

As hydrogen is liberated from the first cell, the temperature drops as the excess heat is transferred to the next cell, so a cascading series is created. The Brookhaven group estimates that 50 to 70 percent efficiencies could be reached depending upon the temperature transferred from the fusion blanket.

Very preliminary estimates by Brookhaven indicate that the cost of hydrogen produced by high-temperature electrolysis would be competitive with today's prices of petroleum, largely because of the need for less electricity. But furthermore, the cost of the electric power used per unit should be lower than today's cost from fossil-fueled units, since fusion uses water as fuel and generates energy at considerably higher energy density than any other process, either combustive or fission.

The only physical problem that needs to be solved in the high-temperature electrolysis process is that of materials able to withstand the 1,500 to 1,800 degree heat required by the system.

The LLL approach

At Lawrence Livermore, under the direction of Dr. Dick Werner, the magnetic fusion program is investigating the coupling of fusion-generated heat to cycles that produce hydrogen from water through the mediation of various intermediate chemical reactions. All of the thermochemical processes under consideration use highly corrosive sulfuric acid at significantly high temperatures to help split the water.

The Livermore team is looking initially at the tandem mirror magnetic fusion design for thermochemical hydrogen production.

Dr. Werner developed the idea of surrounding the confined plasma in the cylindrical center of the tandem mirror device with a liquid lithium-sodium liquid blanket, the lithium is transformed into tritium, which is needed for the fusion reaction.

The liquid sodium is heated and turns into a vapor, at about 900 degrees Celsius. This vapor rises in the container and the heat is transferred into heat exchangers at the top of the vessel. As the heat is drawn off, the gaseous sodium condenses and returns to the liquid bath in droplets.

The vessel is lined with a spongy, controlled heat transfer material that will transfer the heat, at about 400 to 500 degrees Celsius, from the liquid bath to heat exchanger tubes. The lower temperature of the heated sodium can be precisely controlled by producing a large temperature gradient across the spongy liner material. This then houses the hot liquid in a relatively cool container.

Both the higher and lower temperatures would be used as the thermal input for various thermochemical cycles. Most cycles need the heat to break down sulfuric acid into oxygen and sulfur dioxide which are used with water in chemical reactions to liberate hydrogen.

The Livermore and Brookhaven projects, with supporting research ongoing at the University of Washington and Exxon Corporation, are both in the preliminary stage and will consider various technologies for the transfer of fusion-generated heat. Each laboratory will receive $400,000 in Fiscal Year 1980 and both hope to have designs that can be engineered into bench-scale models, using small-scale heat sources before fusion is ready, to test the initial design concepts.

The design of the tandem mirror machine

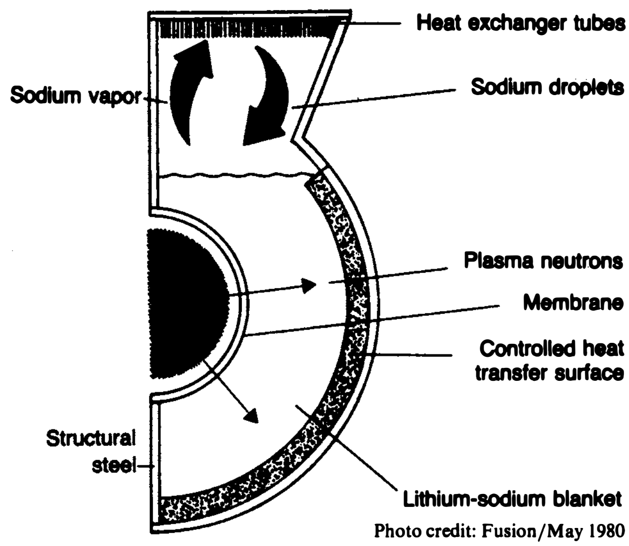

Photo credit: Fusion/May 1980

There are two fusion reactor designs being looked at by the scientists involved in the program to produce hydrogen as a byproduct of the fusion reaction.

The tokomak design being used in the Brookhaven study is a donut-shaped device that uses a magnetic field to confine the fusion plasma (very hot, ionized matter) until the very high temperatures and pressures are reached for ignition.

At Lawrence Livermore, the design being considered is the tandem mirror. The mirror design is open ended (unlike the tokamak) and uses a strong magnetic field at both ends to prevent the plasma from escaping, acting like a mirror to reflect the plasma back into the center.

The basic idea of the tandem mirror is to use the complex mirror with its large assemblies of neutral beams (to heat the plasma) as an end plug for a long cylinder. The cylinder, which consists of a very simple solenoidal magnetic field, contains the fusion plasma while the endplug mirrors contain the nonreacting plasma. Since electrons tend to escape out the ends of a mirror before the ions do, a positive electric charge builds up in the mirror and can then be used to stably repel plasma from entering the mirror, turning the mirror into an efficient end-plug.

In the preliminary design for using the tandem mirror to produce hydrogen shown above, the confined plasma in the cylindrical center is surrounded with a liquid lithium-sodium bath. Both the high and low temperature heat produced is used for a thermochemical hydrogen process.

The heat at 900 degrees Celsius is removed from the top of the container. It is captured from the deposition of fusion neutrons in the liquid lithium-sodium blanket. The sodium is heated and vaporizes. The heat is transferred through heat-exchanger pipes that are also filled with liquid sodium. The vapor then condenses and falls in droplets back into the liquid bath. It should be noted that the neutron bombardment of the blanket produces another useful byproduct: tritium from lithium. Tritium is a heavy isotope of hydrogen and can be used to fuel the fusion reaction.

Lower temperature heat, about 400 to 500 degrees Celsius, is carried off from the vessel through a controlled heat transfer surface lining the steel container. Both qualities of heat are transferred to the thermochemical hydrogen production process to break down sulfuric acid into oxygen and sulfur dioxide which are used with water in chemical reaction to liberate hydrogen.