been estimated to be equivalent to that afforded by an increase of 19 percent in the amount of hydrogen generated.

The generated hydrogen would be sent through a cooler to reduce its temperature to 80 °C as required for the fuel cell(s). During operation of a hydrogen-burning fuel cell, water is generated in liquid and vapor forms. The liquid water could easily be recycled to the storage tank. Depending on detailed calculations yet to be performed, it may be advantageous to also recycle the water vapor by condensing it and pumping the resulting liquid water to the storage tank, provided that the weight of the condenser did not exceed the weight of the water saved. At 80 °C, the waste heat from the fuel cell would be of too low a grade to be useful for most purposes; however, if the fuel-cell power system were part of a motor vehicle, the waste heat could be used to heat the passenger compartment in winter.

In the advanced hydrogen generator, the reactor vessel (or one of two or more vessels, depending on the design) would be initially charged with magnesium hydride. The advanced hydrogen generator would exploit two reactions: the aforementioned exothermic reaction at a temperature ≥330 °C plus the endothermic reaction $MgH_2 \rightarrow Mg + H_2$ at a temperature ≥300 °C. Once the initial heating was complete and both reactions under way, the Mg produced in the endothermic reaction would be consumed in the exothermic reaction, which, in turn, would generate sufficient heat to maintain the endothermic reaction. The main advantages of the advanced hydrogen generator over the basic one would be that (1) it would produce twice the amount of hydrogen for a given amount of magnesium, but (2) the cost of operation is likely to be less than that of the basic hydrogen generator because it is likely that MgH_2 could be produced at less than twice the cost of the corresponding amount of Mg.

The main waste product of both the basic and advanced systems would be MgO, which has extremely low toxicity. MgO could be safely and easily recycled in a magnesium-refining plant for less than the cost of Mg because MgO is an intermediate product of the refining process.

This work was done by Andrew Kindler and Sri R.. Narayan of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to:

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Refer to NPO-43554, volume and number of this NASA Tech Briefs *issue, and the page number.*

Alternative OTEC Scheme for a Submarine Robot

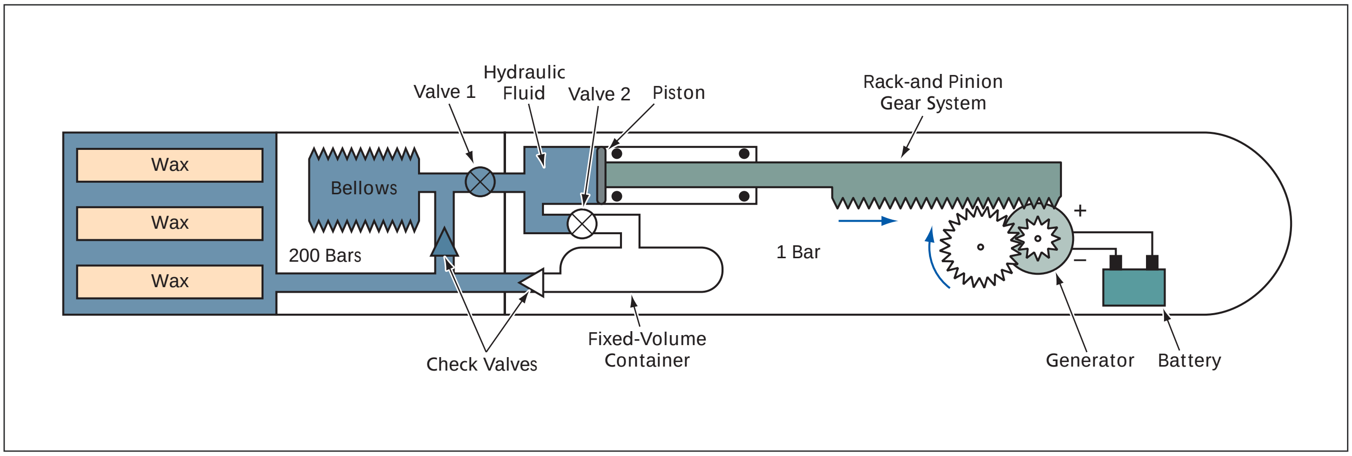
Expansion/contraction of a wax upon freezing/thawing would be exploited.

NASA's Jet Propulsion Laboratory, Pasadena, California

A proposed system for exploiting the ocean thermal gradient to generate power would be based on the thawing-expansion/freezing-contraction behavior of a wax or perhaps another suitable phase-change material. The power generated by this system would be used to recharge the batteries in a battery-powered unmanned underwater vehicle [UUV (essentially, a small exploratory submarine robot)] of a type that has been deployed in large numbers in research pertaining to global warming. A UUV of this type travels between the ocean surface and various depths, measuring temperature and salinity.

This proposed system would be an alternative to another proposed ocean thermal energy conversion (OTEC) system that would serve the same purpose but would utilize a thermodynamic cycle in which CO_2 would be the working fluid. That system is described in "Utilizing Ocean Thermal Energy in a Submarine Robot" (NPO-43304), imediately following this brief. The main advantage of this proposed system over the one using CO_2 is that it could derive a useful amount of energy from a significantly smaller temperature difference.

At one phase of its operational cycle, the system now proposed would utilize the surface ocean temperature (which



The **Wax Would Expand and Contract** upon melting near the ocean surface and freezing at depth, respectively. The expansion and contraction would cause the hydraulic fluid to flow cyclically against the piston to periodically drive the generator to charge the battery.

lies between 15 and 20 °C over most of the Earth) to melt a wax (e.g., pentadecane) that has a melting/freezing temperature of about 10 °C. At the opposite phase of its operational cycle, the system would utilize the lower ocean temperature at depth (e.g., between 4 and 7 °C at a depth of 300 m) to freeze the wax. The melting or freezing causes the wax to expand or contract, respectively, by about 8 volume percent.

The operational cycle is best described by reference to the figure. The wax would be contained in tubes that would be capable of expanding and contracting with the wax. The wax-containing tubes would be immersed in a hydraulic fluid. Near the ocean surface, the expansion of the wax upon heating to >10 °C would push hydraulic fluid into a bellows in a chamber pressurized to about 200 bars (about 20 MPa). Valve 1 would then be opened, allowing the pressurized hydraulic fluid to push against a piston that, in turn, would push a rack-and-pinion gear system to spin a generator to charge a battery. Next, valve 2 would be opened, allowing the hydraulic fluid to drain into a fixed-volume container. Later, upon cooling to <10 °C at depth, the contraction of the wax upon freezing would cause hydraulic fluid to flow from the fixed-volume chamber into the chamber containing the wax tubes, thus completing the cycle.

This work was done by Jack Jones and Yi Chao of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).

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