

At Last, a Magnetic Refrigerator?

New proof-of-principle devices in Japan and North America seem promising

Column 1

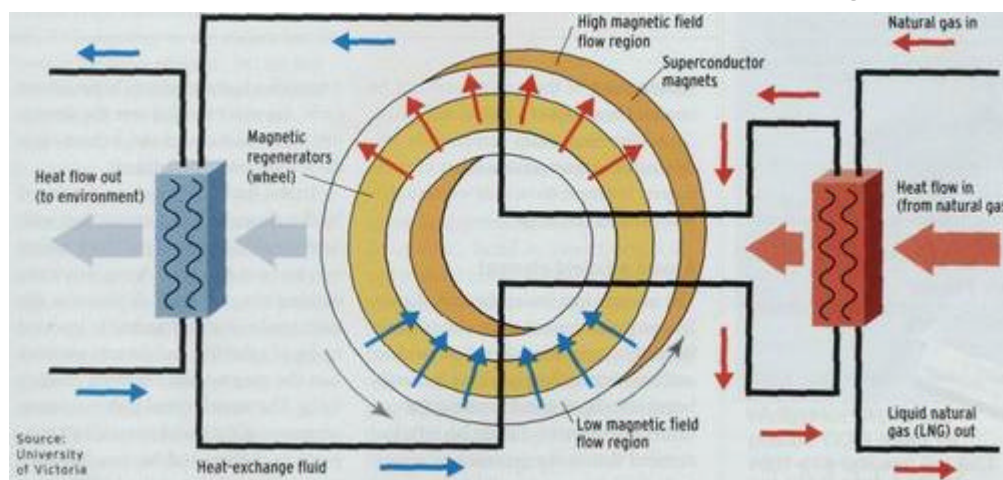
INNOVATIONS : The long search for a practical magnetic refrigeration device may be nearly over. Last month, what is said to be the world's first such device, powered by permanent magnets, was tested successfully by researchers from Milwaukee-based Astronautics Corp. and the U.S. Department of Energy's Ames Laboratory at Iowa State University. The U.S. team's announcement eclipsed a year-ago demonstration by two Japanese firms, Toshiba Corp. and Chubu Electric Power Co. Admittedly,

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their prototype achieved 80 W of cooling power at -2°C , and at an efficiency that compares favorably with home refrigeration appliances. Moreover, it marked the first time a magnetic refrigerator (MR) device was married to an actual cooling chamber. But it relied on a superconducting magnet, which is hardly on the cards for consumer use. Meanwhile, a third team, at the University of Victoria in British Columbia, plans to build a large-scale device that could be used to liquefy natural gas [see diagram].

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In other words, the technology can be easily scaled up for industrial applications. Proponents say MR may one day oust conventional vapor-cycle cooling devices from everything from home air-conditioners and refrigerators to supermarket freezers. In principle, they claim, the technology is more energy efficient and more reliable, because it uses fewer moving parts. In practice, an obvious difficulty is how to configure a refrigeration device around the use of a solid coolant, rather than the liquid-gas cool-



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ants piped around in standard refrigeration systems. The basic cooling cycle is the same for both magnetic and standard compressor-driven

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In the following years Gschneidner and Pecharsky managed to double the magnetocaloric effect by combining the metal with a silicon and germanium alloy.

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magnet, it sustained up to 600 W of cooling load at an efficiency of about 50 percent. {A conventional home refrigerator provides about 200 W of cooling at

units. Recall that in the usual refrigerator, a liquid coolant with a low boiling point vaporizes while at low pressure, absorbing heat from the refrigerator's contents. This heat energy is concentrated by a compressor and the result dissipated in a condenser, with the gas converting to liquid at high pressure. As the liquid passes through an expansion nozzle back into the refrigerator chamber, the cooling cycle begins anew. In a magnetic refrigerator, gadolinium, a rare-earth ferromagnetic metal, plays the role of coolant, staying solid throughout the cycle, while a strong magnet replaces the compressor. The gadolinium concentrates heat when a magnetic field is present, then quickly cools down when the field is removed. Normally, as the gadolinium absorbs heat, it stores some of the energy in the form of increasingly random electron spins. But when a magnetic field is applied, the atoms' magnetic moments align themselves in parallel with the magnetic field, regularizing electron spin. Energy is squeezed out of the system, and can be removed by means of a heat transfer fluid. All ferromagnetic compounds evidence this magnetocaloric effect to some degree, but most do so only within a narrow temperature range. A most efficient element The research into this application of gadolinium got under way at the Ames Lab in the early

They found that the alloy's magnetic ordering temperatures—that is, the temperatures at which the magnetocaloric effect manifests itself—vary over a wide range, from 30 K to 290 K (-243 ° to 17 °C). "There are very few systems that will give you that temperature span," Gschneidner said. "It's unheard of." Even so, the alteration in temperature that gadolinium alloys undergo when magnetized and manifesting the magnetocaloric effect is only about 14 °C, varying only a little with the strength of the magnet being used. That's why magnetic freezing has long been considered impractical for consumer appliances, said a spokesperson for the Japanese effort, "because a change in a magnetic field yields only minimal change in the temperature of a magnetic material." To improve efficiency, MR designers use water as an intermediate cooling medium. The water, which may be combined with antifreeze, absorbs heat from the magnetized rare earth, and then vents it through a heat exchanger. On the reverse cycle, the water flowing over the demagnetized metal is cooled and, in turn, cools the refrigerator compartment. In the first MR prototype developed by the Ames Lab in conjunction with Astronautics, a piston-like device moved into and out of a very strong superconducting magnet every 6 seconds. On each stroke it simultaneously inserted 1.5 kg

about 30 percent efficiency.) The Japanese model—also piston-driven—achieved comparable efficiencies, according to Gschneidner. Some newer MR designs, like the one currently being tested at Astronautics, use a rotary device, not a piston, to place the gadolinium in a magnetic field and remove it periodically, at whatever rate is optimal for the application in view. Although Astronautics did not release performance data on its breakthrough device at press time, it said the MR unit is being tailored to the needs of "specific markets such as home refrigerators, air conditioning, and fluid chilling." The company is considering uses on naval vessels to cool electronic systems. Hydrogen fuel from natural gas Extracting and liquefying hydrogen from natural gas is another possibility, under study by John Barclay at the University of Victoria. Liquefying hydrogen requires huge amounts of energy. Barclay believes the energy savings won by MR could make it economically viable to produce the fuel, even if small-scale liquefying units are used. Some foresee a day when natural gas is pumped directly to filling stations, where it could be liquefied by an MR unit, and the hydrogen separated out and pumped into cars.

19905, when Karl Gschneidner and Iowa State colleague Vitalij Pecharsky began investigating and tweaking the rare earth's performance. Earlier lab tests had revealed that in the presence of a magnetic field the metal could heat up and cool down more efficiently than any other element. Even more importantly, it exhibited a marked magnetocaloric effect at near room temperatures.

of spherical gadolinium particles into the magnet and removed another 1.5 kg. The piston's speed took maximum advantage of the gadolinium alloy's temperature changes and the time it needed to cycle through hot and cold states. The prototype improved 100-fold on the performance of an earlier near-room-temperature device, said its designers. In a 5-tesla field from a superconducting

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