nifty," says Bruce Margon of the Space Telescope Science Institute in Baltimore, Maryland, although he adds that the result will probably be controversial, because the measurements are extremely difficult.

If Lanzetta is right, the new findings have far-reaching implications for ideas about the formation of galaxies, among other things. Many galaxies may have formed early and rapidly instead of gradually, as most cosmologists have assumed. Such a fast-start scenario also would make it easier to explain why the early universe appears to have already been "polluted" with relatively heavy elements, which are produced in stars and then dispersed through space by supernova explosions.

Some astronomers are skeptical. Barry Madore of NASA's Infrared Processing and Analysis Center in Pasadena, California, who hasn't read Lanzetta's paper yet, says the results might be easier to swallow if there were independent confirmation. In fact, one unrelated study comes up with a somewhat different conclusion. Rodger Thompson of the University of Arizona's Steward Observatory in Tucson carried out a similar analysis using data from the Hubble Space Telescope's infrared NICMOS camera. His results point to a less violent beginning for the universe, with a star formation rate that stayed relatively constant for a couple of billion years before gradually tapering off. Thompson says the discrepancy might be due to subtle differences in the way the two teams corrected for the missing light.

Although Lanzetta says studies of distant quasars support his conclusions, he concedes that his analysis doesn't constitute definitive proof. But he hopes that future instruments such as the Next Generation Space Telescope and the Atacama Large Millimeter Array might see part of the missing light. –GOVERT SCHILLING

Govert Schilling is an astronomy writer in Utrecht, the Netherlands.

THERMODYNAMICS

Quantum Engine Blasts Past High Gear

All engines, whether the colossal thrusters on the space shuttle or the gasoline-fired power plant under the hood of your car, have to obey the laws of thermodynamics. Among other things, the laws set clear limits on the engines' efficiency: how much work they can squeeze from a given energy input. But take those classical axioms and add quantum mechanics, and unusual things can happen. Recently, Marlan Scully, a physicist at Texas A&M University, College Station, has discovered that in the quantum world, you can sometimes reap more horsepower than you'd expect.

Scully found that in theory he could take the hot exhaust from one kind of heat engine and drive a laser with it. Lasers work by storing energy in the internal quantum energy states of atoms or molecules and then releasing the energy in the form of photons. But heat engines generally ignore the internal states and instead harness the thermal motions of atoms and molecules in the "working fluid" (for example, the hot gas made by burning gasoline) as it expands and moves pistons to turn a crankshaft. The twist in Scully's scheme is to trade energy between the external and internal states of the atoms in a carefully choreographed way so as to squeeze a few more drops of work out of the engine.

Image not available for online use.

Overdrive. In theory, a quantum afterburner could supercharge a heat engine by turning exhaust energy into laser light.

CREDIT: ALAN "HOT-RODDIN' DADDY" STONEBRAKER

In a paper accepted for publication in *Physical Review Letters*, Scully applies the concept to a type of heat engine called the Otto cycle, a cousin to the common car engine. Scully considers an idealized version of this engine without the exploding gasoline, instead just considering what happens as gas is compressed, is heated, does work, and is cooled again.

In his scheme, Scully takes the still-hot gas in the expanded piston chamber and routes it into a laser cavity, where the internal quantum states of the gas molecules come into play. The hot exhaust that would normally just be shoved out the door gets used to create more useful work by means of the laser emission. As a result, the total energy out is more than you'd expect from classical thermodynamic analysis of an "ideal" Otto cycle engine.

"I think it's a nice paper, very fun, and it's potentially useful," says Seth Lloyd, a physicist at the Massachusetts Institute of Technology. After hearing Scully give a talk about the concept, Lloyd dubbed the theoretical gadget a "quantum afterburner" by analogy to the devices that squeeze extra thrust out of the exhaust from a jet engine. "It takes advantage of a source of energy that hasn't been taken advantage of before," Lloyd says. After all, "the steam engine wasn't very useful until James Watt came along and made it more efficient. He didn't invent the steam engine, but he figured out how to control it."

Scully acknowledges that his analysis is controversial. But he says that doubters who once attacked him for flirting with perpetual motion have come around. "In thermodynamics, the devil is in the details, but so are the angels," he says. "You have to look at a specific physical system [such as the engine] and not just abstract thermodynamic calculations." Ronnie Kosloff, a theoretical chemist at Hebrew University in Jerusalem, agrees that Scully's concept is on solid ground: "It is consistent with all the laws of thermodynamics."

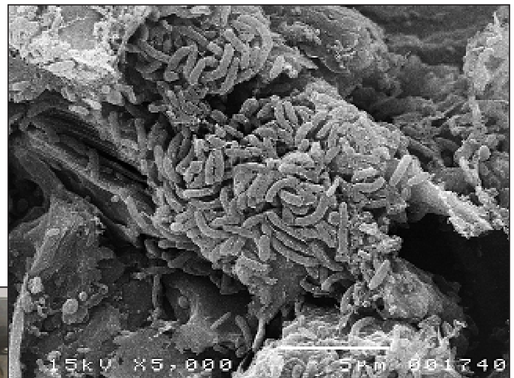
To check that his equations were on the up-and-up, Scully recently put his quantum afterburner to the ultimate theoretical test: hooking it up to an engine running at maximal efficiency. Until then, he had applied it only to the Otto cycle engine, which runs less efficiently than thermodynamics allows. But when Scully probed how well such a device would work with the ideal Carnot cycle, the gold standard of thermodynamic machines, the quantum afterburner couldn't squeeze out any extra energy—proof, Scully says, that his theoretical device is playing by the rules. –DAVID VOSS

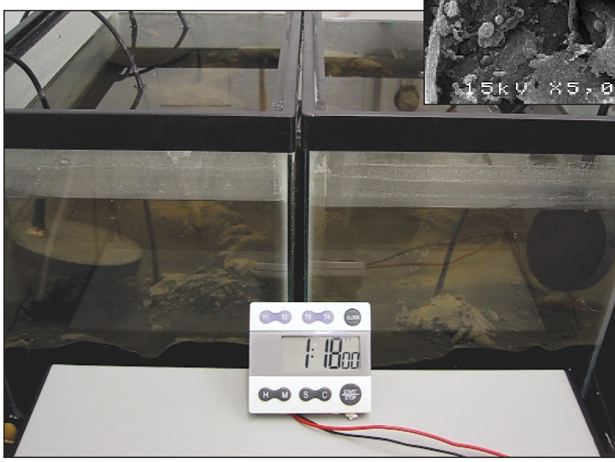
GEOBACTERIA

Microbes Use Mud to Make Electricity

Self-recharging bacterial batteries that clean up organic pollution as they generate electricity? Sounds more like science fiction than science. But on page 483, microbiologists report coming one step closer to making microbial fuel cells a reality: They harnessed bacteria to generate electricity from underwater sediments. The microbes make excess electrons that they stick directly to graphite wires, which in turn send current to a second wire much like a car battery does. For fuel, the bacteria use organic material in the sea floor. These bacterial batteries will probably never power a car, but they should be adequate to run underwater sensors, says Derek Lovley, a microbiologist at the University of Massachusetts, Amherst, who with Daniel Bond led the work on these unusual energy sources.

Because organic sediments are so abundant, "theoretically there could be an inexhaustible source" of fuel, Lovley notes. And because many pollutants are organic, these portable generators might also help get rid of hazardous materials. "The whole field is very exciting," says Greg Zeikus, a microbiologist at Michigan State University in East Lansing, because the work has broad potential for both helping pollution cleanup and providing a cheap power supply. "This work has come closer to developing accessible marine batteries as a way to meet our electricity needs."





Zap! In experiments in fish tanks, this bacterium (*top*) can make electricity from organic sediments.

Lovley's team was not the first to notice that microbes could steal electrons from oxygen-deficient mud and somehow transfer them to electron-accepting rods placed into the oxygen-containing sediments overhead. But now, Lovley and his colleagues "take a concept that has been known for a while and make good on it," says Diane Newman, a microbiologist at the California Institute of Technology in Pasadena.

The team used lab fish tanks to recreate the ocean's saltwater environment. Collaborator Leonard Tender of the Naval Research Laboratory in Washington, D.C., positioned graphite wires (which act as electron-accepting anodes) into oxygen-deficient sediments collected from the sea floor. Then he placed graphite wires (the cathodes) in the overlying oxygen-containing water to receive electrons. In three different experiments, the team measured the number of electrons transferred to the anode and then to the cathode. Even in these crude experiments, the current was enough to power a small calculator, the scientists report.

After several weeks, the researchers identified the microbes that were growing on the mud-implanted electrodes. To their surprise, Lovley and his colleagues found that one type of microbe—*Desulfuromonas acetoxidans*, from a family called Geobacteraceae—had all but taken over the battery electrode, ousting the others. These geomicrobes are famous for their ability to detoxify toluene and other organic solvents, notes microbiologist Caroline Harwood of the University of Iowa in Iowa City.

Previously, microbiologists had shown that different microbes could move electrons from oxygen-deficient to oxygen-rich substances through intermediate substances that they produced. "The microbes were involved, but not directly with the electrode," Lovley explains. But geobacters, as the family is commonly called, need no such go-betweens. They can convert the mud's organic matter directly, and that might prove quite useful in pollution control, he points out.

Before using organic pollutants to fuel electricity production leaves the realm of science fiction, Lovley and his colleagues warn, the work needs to be replicated in field conditions. And Harwood points out that the bacteria might quickly exhaust local organic fuels and have to be moved to a different spot. The efficiency of the transfer also needs improving, something that Lovley and others are fervently working on; otherwise, says Zeikus, it would take fields of electrodes to get enough energy to power many undersea devices.

–ELIZABETH PENNISI

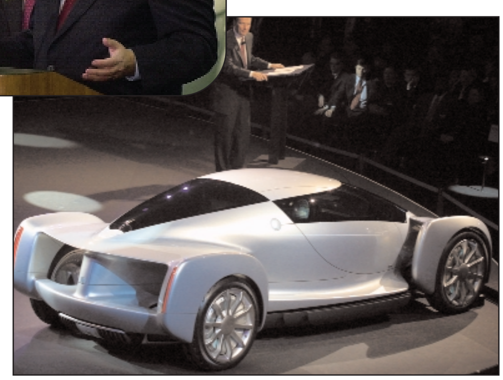
TRANSPORTATION RESEARCH

Bush Trades Hybrid for Hydrogen Model

The federal government's most prominent joint research project with industry moved onto a slower track last week. Secretary of Energy Spencer Abraham announced that he is junking the Clinton Administration's Partnership for a New Generation of Vehicles (PNGV)—an 8-year-old government effort to build superefficient cars—in favor of building vehicles powered by pollution-free hydrogen fuel cells. Abraham released no budget details of the new program, called Freedom CAR (Cooperative Automotive Research), but analysts say most of the old program's research efforts will continue. The deadlines for getting a car on the road, however, have been pushed way back.

In unveiling PNGV in 1993, the Clinton Administration promised to work with major automakers to create family sedans that, by 2004, could go nearly 36 kilometers on a liter of gasoline (80 miles per gallon). But some environmentalists and free-market advocates complained that the program was an industry subsidy that undermined efforts to increase mandated fuel efficiency standards (*Science*, 30 July 1999, p. 680). The government has spent more than $1 billion on the partnership—including more than $125 million this year—and the big three automakers spent even more.

The results to date have been uneven. In a series of annual reviews, the U.S. National Academies found that the project had made progress in developing lightweight materials and longer lasting batteries, improvements that are being incorporated into hybrid electric-gas vehicles due out within the next 5 years. (Toyota and Honda are already producing such cars.) Fuel cell developers also got high marks for their work on devices



Gas man. Energy Secretary Spencer Abraham calls for putting hydrogen fuel cell cars on the highway.

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