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Finding New Ways to Fill the Tank

By MATTHEW L. WALD

CAMBRIDGE, Mass. — Most research on renewable energy has focused on replacing the electricity that now comes from burning coal and natural gas. But the spill in the Gulf of Mexico, the reliance on Middle East imports and the threat of global warming are reminders that oil is also a pressing worry. A lot of problems could be solved with a renewable replacement for oil-based gasoline and diesel in the fuel tank — either a new liquid fuel or a much better battery.

Yet, success in this field is so hard to reliably predict that research has been limited, and even venture capitalists tread lightly. Now the federal government is plunging in, in what the energy secretary, Steven Chu, calls the hunt for miracles.

The work is part of the mission of the new Advanced Research Projects Agency - Energy, which is intended to finance high-risk, high-reward projects. It can be compared to the Defense Advanced Research Projects Agency, part of the Pentagon, which spread seed money for projects and incubated a variety of useful technologies, including the Internet.

The goal of this agency, whose budget is $400 million for two years, is to realize profound results — such as tens of millions of motor vehicles that would run 300 miles a day on electricity from clean sources or on liquid fuels from trees and garbage.

One miracle would be a better battery. A pound of gasoline holds about 35 times more energy than a pound of lead-acid batteries and about six times more than lithium-ion batteries. Cars must carry their energy and expend energy to carry it, so the less weight per unit of energy, the better.

David Danielson, an Energy Department official, oversees a program to invest in start-up companies with new approaches to batteries, which is a new strategy; in the early 1990s, the department decided to concentrate all its efforts in lithium-ion research and gave up on other chemistries.

One new technology would allow every car, at modest extra cost, to shut down automatically at each stop sign or red light; when the driver tapped the accelerator, the battery would instantly get it going again. (Hybrids like the Prius do that, but at a substantial cost premium.)

A team at an infant company is using tiny carbon structures called nanotubes to store electricity. The goal is to create something the size of a flashlight battery, holding only about 30 percent as much energy, but able to charge or discharge in two seconds, almost forever.

The technology could form part of the battery pack for a car, cheaply delivering the energy for a jackrabbit start, without damaging conventional chemical batteries, which can store vastly more energy but can only accept or deliver it slowly.

It could also provide a cellphone battery that would charge in five minutes. That kind of battery is called a capacitor.

Joel E. Schindall, a professor at the Massachusetts Institute of Technology and a scientist on the project, pointed out that a capacitor was the original battery. Benjamin Franklin built a set of glass bottles that stored electricity and released it all at once; he called it a battery because, like guns, the bottles fired simultaneously.

But the nanotubes are modern. The walls of the tubes are about 12 atoms thick, and they grow, like leaves of grass, with just enough space between them to provide docking stations for charged particles. So a lot of charged particles can fit into a small space, with very light structures. He compares the device to a book shelf with very thin shelves placed exactly far enough apart to accommodate the books. Because the connection is physical, not chemical, the charged particles can attach and detach almost instantly. The result is a small, light, powerful package.

The project started out with a Ph.D candidate, Riccardo Signorelli, using tweezers to put tiny squares of aluminum into a vacuum chamber and then pumping in a hydrocarbon gas. When heated, the hydrogen burns away and the carbon atoms arrange themselves into tubes. The breakthrough was doing that on a surface that would conduct electricity.

Dr. Signorelli, now with his Ph.D, is chief executive of FastCap Systems, which, with government help, is converting an industrial loft into a factory.

In another M.I.T. lab, Gerbrand Ceder is developing a “materials genome,” using computers to predict the qualities of materials that could be used in batteries, and then fabricating the ones that the computer finds promising. A materials genome would speed the distribution of knowledge about materials and make development of new materials faster, he said, an idea that impresses officials at the Energy Department.

ARPA-E invested $3.2 million in a battery developed with a materials genome in a start-up company, run by Professor Ceder, that is exploring magnesium. In batteries today, whether they are lithium-ion or old-fashioned lead-acid, an atom shuttles between the positive and negative terminal, carrying a single electron, as the battery charges and discharges. But a magnesium atom would carry two electrons, so a battery storing a given amount of energy could be nearly halved in size and weight.

Another approach being financed by ARPA-E is to convert the tremendous amount of energy stored by plants and trees to a car fuel.

Scientists are tantalized by plants and trees because they store far more energy than is consumed by cars, trucks, trains and planes, and they do it by taking carbon out of the atmosphere. But they do not give that energy back in an easy-to-use form, at least not without taking millions of years to turn into oil. Instead, they make energy-bearing sugars in a form called cellulose, which forms the sinew or skeleton of the plant.

Cellulose is hard to break down. “Cotton is pure cellulose,” said Eric Toone, who is Mr. Danielson’s counterpart for biofuels at the Energy Department. “When you take your cotton shirt and put it in a washing machine, it still comes out as a cotton shirt.”

Engineers have tried using steam, acids and enzymes to break cellulose into useful sugars. The enzymes are usually made by gene-modified bacteria or fungi and resemble the saliva of termites, which is notoriously good at dissolving cellulose. So far, none are commercial, but with Energy Department help, some researchers are trying new methods.

Take Michael Raab, whose start-up, Agrivida, in Medford, Mass., is tinkering with the genes of grass and sorghum to develop plants that make the enzymes internally and digest their own cellulose on cue, leaving behind a murky brown concoction of sugars that can be converted into gasoline, diesel or jet fuel.

Deep inside their cells, his plants produce a smooth, nonreactive molecule, but when the plant is exposed to heat and a change in acidity, the molecule breaks open, like a beer bottle smashed against the bar. The jagged edges are enzymes. They rip apart cell walls and leave fragments that are useful sugars.

Sugars — both the common kind that comes in paper packets for coffee and some more exotic types — can be converted by yeast into ethanol, a technology known since ancient times. Or they can be fed to gene-altered bacteria that will excrete diesel or gasoline components. Or they can be converted chemically, with catalysts.

All these steps, including the tricky one of recovering sugar from cellulose, can be done already, but not cheaply enough to produce tens of billions of gallons a year.

The Energy Department is putting $4.6 million into Agrivida, and similar sums into other start-up firms, many of them intent on finding gasoline substitutes. It is, said one department official, “real science fiction stuff,” ideas promising enough to attract a few million dollars for research but not quite promising enough to draw the private capital required for small-scale production.