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CHARGING: Makers of the hybrid-electric cars that are on the road today call them “grid independent,” but making them chargeable from the grid could enormously boost their gasoline fuel efficiency.



Take This Car And PLUG IT

**Eager hybrid owners can't wait
to connect their cars to the power grid**

A funny thing has happened on what U.S. policy makers thought was going to be the high road to a hydrogen economy. Initiatives aimed at putting hydrogen fuel cell-powered cars on the road by 2020—visualized by President George W. Bush in his 2003 State of the Union address as the centerpiece of his plans to wean the country from fossil fuels—are taking longer than promised. At the time of the speech, hybrid-electric cars, which offer higher fuel efficiency than regular cars because of electric motors that help drive the wheels, were seen in the United States as but a minor detour or way station en route to a world of hydrogen fuel cells.

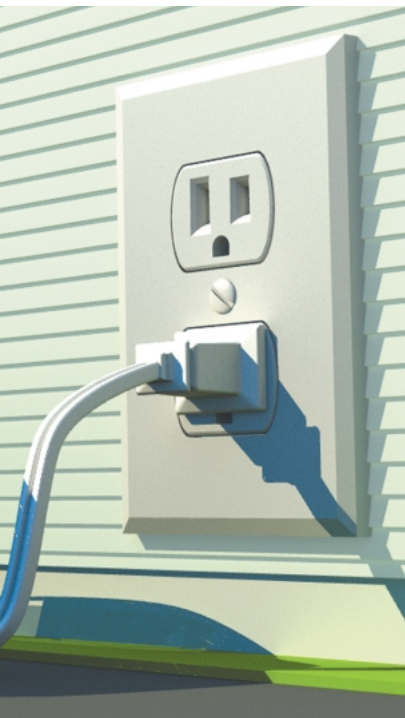
But they suddenly are looking like the main way to go, or even maybe the ultimate destination. Models produced by companies such as Toyota Motor Corp., in Toyota City, Japan, and Honda Motor Co., in Tokyo, are flying out of dealer showrooms. Among those who have been able to purchase hybrids (usually after a two- to six-month wait) are some early adopters—like a group of physics professors at Harvard

University, in Cambridge, Mass.—who have made tinkering with hybrids their primary extracurricular activity.

Now, a derivative of hybrids that will improve fuel economy even more by maximizing the use of the electric motor is poised to make what is already an undeniably attractive concept downright irresistible. Some of the most eager owners of the Prius, the world's most popular hybrid, have been hacking the cars, swapping their 1.3-kilowatt-hour battery packs for bigger ones with capacities as large as 9 kWh.

The modifications also include the addition of plugs so the new, bigger battery packs can be recharged from wall outlets. The resulting machines, referred to as plug-in hybrids, can be propelled exclusively by their electric motors for, in some cases, more than 30 kilometers without their gasoline engines ever turning on. The factory-built Prius can run on electricity only, but for just a kilometer or two.

This group of hackers and other technologists say that in a few years, we could have a car that, after its batteries



are topped up overnight via a wall socket, could handle a daily commute using only electrons for fuel—unlike the hybrids on the market now, which still derive all their power from gasoline [see box, “Stretching the Hybrid’s Electric Capabilities,” and illustration, “Charging”].

Dramatizing the potential of the plug-in during the Tour de Sol race from 13 to 16 May in Schenectady and Albany, N.Y., a modified Prius equipped with a fully charged 9-kWh lithium-ion battery pack achieved 2.31 liters per 100 km (102 miles per gallon) on a 240-km course. It is representative of the modified hybrids that clean-car promoters and hobbyists have been building, partly for fun, partly to show how wide adoption of

Researchers have shown that battery packs offering an effective electric range of 32 km will yield up to a 50 PERCENT REDUCTION IN PETROLEUM CONSUMPTION

plug-ins could lead to dramatically lower gasoline consumption and oil imports.

Because of that promise, a strange-bedfellow alliance of environmentalists and security hawks has emerged. They are united by a conviction that the hybrid—not the futuristic fuel cell-driven hydrogen vehicle favored by the Bush administration in its FreedomCar program and other initiatives—is the way to cut both noxious emissions and oil dependence right now.

In a manifesto issued last fall in the form of a letter to the U.S. public and then again last March as an open letter to President Bush, a group representing foreign policy intellectuals and advocates of clean energy called for the “technological transformation of the transportation sector through what might be called ‘fuel choice.’” The group supports increased reliance on alternative fuels that are domestically produced, such as gasohol and biomass, and on cars such as plug-in hybrids that can draw energy from the grid.

“The United States should implement technologies that exist today and are ready for widespread use,” the group said in its core statement, “Set America Free.” In effect, the report pits a group that includes influential Republicans against a Republican president on the question of whether the country should continue to spend several hundred million dollars a year to promote far-off hydrogen vehicles when it could do more today to accelerate adoption of hybrid-electric and alternative-fuel vehicles.

BOLD IN ITS VISION, the “Set America Free” report asserted that a plug-in hybrid with a 100-km-range battery could cut fuel consumption by 85 percent and that conventional cars could be converted to run on alternative fuels with the addition of control chips and fuel-line modifications costing less than US \$100. Combining advanced plug-in and flexible-fuel features could ultimately yield a vehicle capable of going 100 km



High-Tech Fabergé

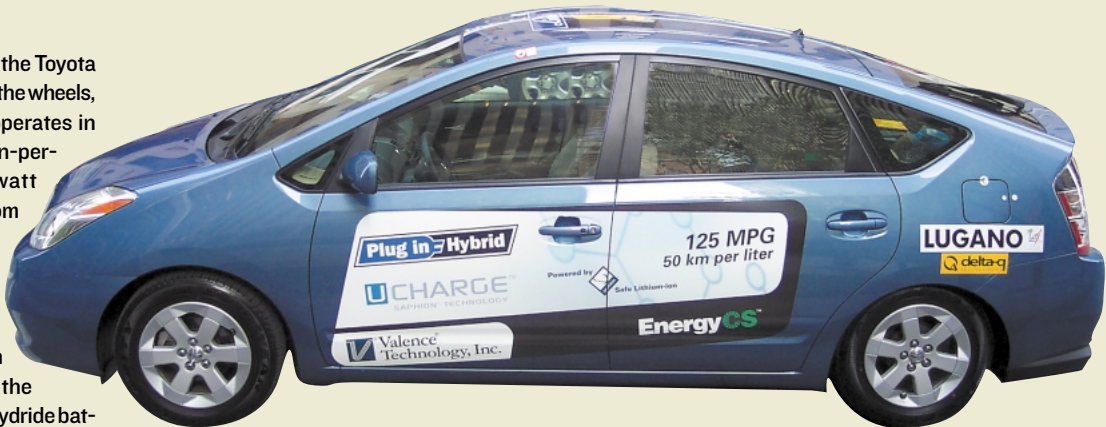
PALO ALTO, CALIF., is recognized as the birthplace of Silicon Valley, but until now it lacked a public landmark commemorating its fame. An effort to change that began in 2000 when the town’s art commission asked multimedia artist Adriana Varella to propose a project. She designed a giant egg, a Styrofoam sculpture covered in discarded circuit boards, only to see the final product—obviously symbolizing birth—go up in flames in a warehouse fire. Undeterred, Varella selected about 600 more circuit boards and distributed them to engineers, academics, and even a few homeless people, asking that each write a phrase about circuits on a board, which she then collected and used to rebuild the sculpture. On 6 May, the 2.13-meter-tall sculpture was installed in Lytton Plaza, a brick-paved public space abutting Palo Alto’s main commercial street, University Avenue. It was to be formally unveiled a month later, but after just two days a group of teens began to tear off the wrappings, bringing its gestation to a premature end. Varella didn’t mind. “It was just curiosity,” she says, which of course is what she wants.

— TEKLA S. PERRY

STRETCHING THE HYBRID'S ELECTRIC CAPABILITIES

Conventional U.S.-market Prius

The motor and battery pack in the Toyota Prius deliver bursts of power to the wheels, so that the gasoline engine operates in its most efficient revolution-per-minute range. The 30-kilowatt motor can accelerate the car from a dead stop to about 65 kilometers per hour. At that point the engine kicks in (if it hasn't done so already) to keep the motor from running faster than 6000 r/min and to prevent the 1.3 kilowatt-hour nickel-metal hydride battery pack from going below a state of 40 percent charged. Even if a driver putters along at 40 km/h or slower, the car's computerized control system will activate the engine before this threshold is reached. When running, the engine shunts 30 percent of its torque back to the vehicle's 15-kW generator, which keeps the battery pack topped up. Regenerative braking captures additional energy that otherwise would be lost as heat.



Hacked U.S. Prius with Plug-in Capability

Instead of having the motor mainly deliver peak power to complement the gasoline engine, the aim is to get as much distance as possible from the electric drive train without the engine's kicking in. To keep the motor going for more than 30 km rather than just the 1 or 2 km of the conventional Prius, the hacked versions [like the Tour de Sol model, above] boast battery packs with storage capacities on the order of 9 kWh.

The battery pack can be charged directly from an ordinary wall socket, with inverters rectifying the ac current. The vehicle's control system is modified to prevent the transfer of propulsion from motor to engine at the usual speed. But with this tinkering come compromises: in its all-electric mode, when the motor and battery pack are doing the heavy lifting, the control system will not let the vehicle reach highway speeds.

on a mere 0.47 liter of gasoline (500 mi/gal), the report claimed.

The environmentalists and security-minded luminaries behind the report, such as Frank Gaffney, a senior defense official in Ronald Reagan's administration, and R. James Woolsey, the hawkish director of the U.S. Central Intelligence Agency during President Bill Clinton's first administration, urged Bush to commit \$1 billion over the next five years to the establishment of a domestic alternative fuels industry. In addition, they said, the federal government should implement tax credits and other incentives "to encourage rapid production and consumer purchase of advanced vehicles like hybrids, plug-in hybrids, and flexible-fuel vehicles" and to produce "more efficient vehicles across all models."

Eyeballing the draft comprehensive energy bill, which once again is wending its way through the U.S. Congress after being stalled for two years,

signers of the report are hoping that its points about hybrids and alternative fuels will make it into the final version.

"There's very little doubt in my mind that these sorts of steps will be taken at some point," says Gaffney, founder and president of the Center for Security Policy in Washington, D.C. "The question is [do we take them] after we have realized the very unpleasant national security crisis that we're forecasting, or do we do it in advance of that."

Gaffney referred to what the report called a "perfect storm" of circumstances requiring that "we effect over the next four years a dramatic reduction in the quantities of oil imported from unstable and hostile regions of the world." Other report signers include a Reagan national security adviser and a Clinton chief of staff.

THE "SET AMERICA FREE" REPORT

is based on two well-founded assumptions. One is that the

hydrogen economy cannot be realized for at least a couple of decades, a supposition that emerges clearly from recent reports by organizations such as the National Academy of Sciences, in Washington, D.C., and the American Physical Society, based in College Park, Md. Until basic scientific breakthroughs occur, the reports concluded, the hydrogen vision will do nothing to liberate the United States from energy dependence or improve prospects for bringing down greenhouse gas emissions.

The other assumption is that U.S. consumers will be willing, even eager, to pay a premium of a few thousand dollars to get cars that are more fuel efficient and environmentally friendly. Sales of conventional hybrid-electric cars jumped 81 percent in the United States last year and are expected to double this year. These grid-independent (non-plug-in) hybrids cut carbon emissions up to 25 percent

and smog precursors by 15 percent. Their gains in fuel efficiency are even more impressive: the Prius gets 4.7 L/100 km (50 mi/gal) on highways, compared with the top-selling Toyota Camry's 7.1 L/100 km (33 mi/gal), and does better yet in stop-and-go traffic, when the battery powers the car more of the time.

But make that car a plug-in, with a battery big enough to keep the vehicle in its electric mode for all daily errands and commuting, and the potential fuel savings become truly prodigious. Researchers have shown that battery packs offering an effective all-electric range of 32 km will yield up to a 50 percent reduction in gasoline consumption. And the hope is that in a few years, when advanced batteries like lithium-ion become cheap enough, there will be plug-ins with an effective electric range approaching 100 km.

At that point, says Mark S. Duvall, manager of technology

European/Asian Prius

With air pollution a strong factor in Asia and Europe, the Prius version sold in those markets allows the driver to shut off the engine and run just on electricity, though the car is not a plug-in. The electric-only capability is desirable when creeping along in the central districts of cities where internal combustion engines have been banned or strictly limited at certain times. (Milan, Italy, recently ordered cars, motorcycles, and trucks off the roads on alternate days, and other cities, including London, have also taken steps to curtail automobile traffic in their business districts.)

Press a button [above], and the Prius runs just on its battery at speeds less than 55 km/h for 1 or 2 km. The electric-only setting is not locked in, however. At any speed greater than 55 km/h or with aggressive acceleration, the vehicle's control system will override the driver's selection and start the engine.

The button exists in U.S. models but is not connected to the car's control system.



development for transportation at the utility-sponsored Electric Power Research Institute (EPRI), in Palo Alto, Calif., the car will run on electricity most of the time. Such a vehicle will use only 10 to 15 percent as much liquid fuel as a conventional vehicle.

Duvall points out that there's really not that much difference between the systems in the conventional hybrid cars made by Toyota and Honda, or in Ford's hybrid SUV, and those that would be needed to build a plug-in hybrid. Yet the companies have not made plug-ins available and evidently don't plan to do so anytime soon.

To take Toyota, the leader of the pack: "The corporation is committed to hybrid technology, but so far [only for hybrids that] are grid independent," according to David Hermance, executive engineer at the Toyota Technical Center USA Inc., in Torrance, Calif. Why? Hermance says the answer is simple: the cost of the

larger battery packs is so high Toyota could never make a profit selling them at a price consumers would be willing to pay. And that's just one hurdle, says the Toyota engineer.

HERMANCE POINTS OUT not only that one Prius-hacking tinkerer paid \$15 000 for his lithium-ion battery pack, but that the added batteries make the car heavier—by 68 kilograms in the case of lithium-ion and nearly twice that for lead-acid. Thus, the car's fuel economy is actually worsened when the gasoline engine is running. And there's also the matter of having to replace the battery pack more often during the lifetime of the vehicle because cycling a battery from fully charged to 20 percent charged wears out even advanced batteries.

"So you have a higher up-front cost, a heavier vehicle that gets less fuel economy with less performance, and the prospect of replacing the battery during [the car's] life," he says.

But the individuals and groups like the nonprofit CalCars—the California Cars Initiative, based in Palo Alto—that have installed bigger battery packs and modified the electronics in the Prius have done so to show that turning the car into a plug-in hybrid is realistic.

Ron Gremban, the lead technologist on CalCars' Prius+ project, concedes that the group's modified Prius does not perform as well as it might and costs more than it would if produced by Toyota. But "a company with the resources of a Toyota, Honda, or General Motors could build a more elegant, full-function version for far less money," he believes.

How much less is the subject of debate. Toyota's Hermance insists that, barring a spectacular breakthrough in battery chemistry, the cost of nickel-metal hydride batteries will remain around \$100/kWh for the foreseeable future. He concedes that the Prius's nickel-

metal hydride battery packs have become significantly cheaper since Toyota began producing the car for the Japanese market in late 1997—power densities have gone up, allowing the car to get the same acceleration with a smaller battery pack. But energy density hasn't really improved, so energy storage remains as expensive as ever.

On this point, CalCars' Gremban simply disagrees. He claims that achieving higher power densities is much more expensive than maximizing energy storage, and he observes that with larger battery packs storing much more energy, the higher power densities are not needed. Accordingly, production-volume nickel-metal hydride batteries might cost car companies only on the order of \$500/kWh—much closer to the \$300/kWh price target, cited by EPRI's Duvall, that will make it practical for a car company to offer a vehicle with a 100-km all-electric range.

In any case, plug-in development is already in gear. Duvall reports that his organization and DaimlerChrysler AG, of Stuttgart, Germany, are currently testing four Sprinter vans built at a Daimler facility in Mannheim, Germany. If all goes according to plan, those four vehicles will be the first plug-ins to be tested on U.S. roads.

"The project has really developed nicely," says Duvall—so much so that EPRI is negotiating the final details of an alliance of utility and fleet customers to fund and test another 30 prototype vehicles that will hit U.S. roads beginning next year. Asked when we'll see a Daimler plug-in in dealer showrooms, Duvall said, "If [Daimler] makes a production decision to make this vehicle, it would enter the market sometime in 2008 or 2009."

—WILLIE D. JONES