ADDING AN ELECTRIC FUEL TANK TO A HYBRID

by Felix Kramer

VOICES

This year, batteries and electric motors are back in the news, spurred by the popularity of gas-electric hybrids and the recognition that fuel cell cars are electric vehicles. The plug-in hybrid (PHEV), long consigned to a footnote as an interesting but unrealistic idea, may soon enter the mainstream as an automotive option.

Our organization, CalCars, took years to come up with a metaphor that drove home the PHEV concept to drivers: "It's like having a second small fuel tank that you always use first. You fill it at home with electricity, at an equivalent cost of under $1 per gallon. Your energy is cleaner, cheaper, and not imported."

Now, support for PHEVs is coming from unexpected places: Neo-conservatives seeking rapid reductions in oil dependency. Engineers immersed in online communities. Futurists concerned about a vulnerable, centralized power grid. Ethanol advocates discovering feedstock alternatives to corn. They've joined forces with long-time supporters like renewable energy advocates, utilities with cheap off-peak power, fleet owners eager for green cars, and component suppliers seeking new markets.

One by one, objections have fallen away. One points to the complexity of using two systems, but today's hybrids use advanced technology to remove components and engineer some of our highest quality and customer-value cars. Another is that the national power grid is too dirty. But Argonne National Laboratory studies show that electric vehicles beat out gasoline vehicles on well-to-wheel greenhouse gases. It's argued that nobody is interested. Yet, journalists have jumped on CalCars' and EDrive's high-mpg conversion stories. They understand how flexible-fuel PHEVs would use almost no gasoline, although admittedly, some reporters have not factored in electricity and biofuel costs. But when the bipartisan National Commission on Energy Policy dug into the emissions numbers and looked for achievable strategies, they gave PHEVs the highest grades. Then Orrin Hatch, Barack Obama, and other Senators, along with George Schultz, James Woolsey, and other former Cabinet members, hailed the 2 to 4 cents-per-mile cost for local travel as a breakthrough this country needs.

"You fill it at home with electricity, at an equivalent cost of under $1 per gallon."

It's been said that car companies won't build plug-in hybrids. However, DaimlerChrysler is now completing the first original equipment manufacturer PHEVs. Recent statements from Toyota and Ford indicate they are weighing the concept as well. Battery costs are claimed to be too high with their useful life too short. This remains a subject of debate. Even discounting promising materials science advances, batteries are competitive through incremental but substantial technology, production, and cost improvements, and rising gasoline prices. Plus, a new Electric Power Research Institute (EPRI) study finds no technology impediments and sees affordable batteries when produced in volume.

An overly long payback has been claimed, but this topic is fading as many auto buyers demonstrate their willingness to pay more up front for green cars. They recognize that energy security and global warming are not simply issues of "dollars and cents at the pump." Meanwhile, EPRI studies project lower lifetime costs for PHEVs than for any other type of car. PHEVs are an extendable platform that welcomes other solutions like engine efficiencies. They can be designed for any fuel type, starting with gasoline and evolving to biodiesel, cellulosic ethanol, and even hydrogen. This way, PHEVs solve both the "chicken and the egg" infrastructure dilemma and the uncertainty of predicting future technologies.

CalCars.org and our allies plan to partner with OEMs on demonstration programs. We know the auto industry can deliver. After Pearl Harbor, Detroit switched from cars and trucks to planes and tanks in a year. With PHEVs, we have the opportunity to find out how clean and efficient cars can be right now.

— Felix Kramer is founder of the California Cars Initiative (calcars.org), a non-profit group of engineers, environmentalists, and entrepreneurs that combines technology development and advocacy for plug-in hybrid vehicles.

THE HYBRID CO

THE PLUG-IN HYBRID

BY KELLEN SCHEFTER

It's hard to imagine a more gripping state of affairs at the start of the 21st century. A cloud of smog hangs over our cities while the threat of global warming looms ever larger. Oil prices are rising to record highs and while there's no imminent danger of running out of petroleum, no one knows how long supplies will last. For a final dramatic touch, most of that oil sits beneath the powder-keg that is the Middle East.

A hydrogen hero is on the way, but many worry that we don't have time to wait, unsure of what happens if oil supplies drop off and we're caught without a safety net. A growing chorus is clamoring for a near-term solution, something that can be implemented now to significantly reduce oil consumption. The stage has been set for plug-in hybrids.

The plug-in hybrid is an evolution of the "conventional" hybrid vehicle. Plug-in hybrids function the same way, assisting the engine with battery power or electric energy captured during deceleration, but take the idea a step further. Increased battery capacity allows plug-ins to rely more on electricity and less on gasoline, extending electric-only driving range and delivering even better fuel economy. The extra electric power is drawn from the electrical grid by plugging into power outlets while a vehicle isn't being driven.

The virtue of the plug-in hybrid comes to light with some statistics. A majority of Americans live within 20 miles of their jobs and most trips are less than 20 miles long. With an electric-only range of up to 60 miles, daily drives to work in a plug-in hybrid might not require any gasoline at all as long as the battery is recharged each night. For longer trips, the vehicle reverts back to conventional hybrid operation. If plug-in hybrids are ever designed and built from the ground up, rather than being converted from existing models like we're seeing today, an even smaller engine could improve fuel economy at every stage.

Though the Toyota Prius is not a plug-in hybrid, it serves as a good platform for a conversion. The California Cars Initiative, a non-profit organization, first built one to show it could be done. The conversion turned out to be so promising

CONNECTION

that some companies are looking to make a for-profit business out of it.

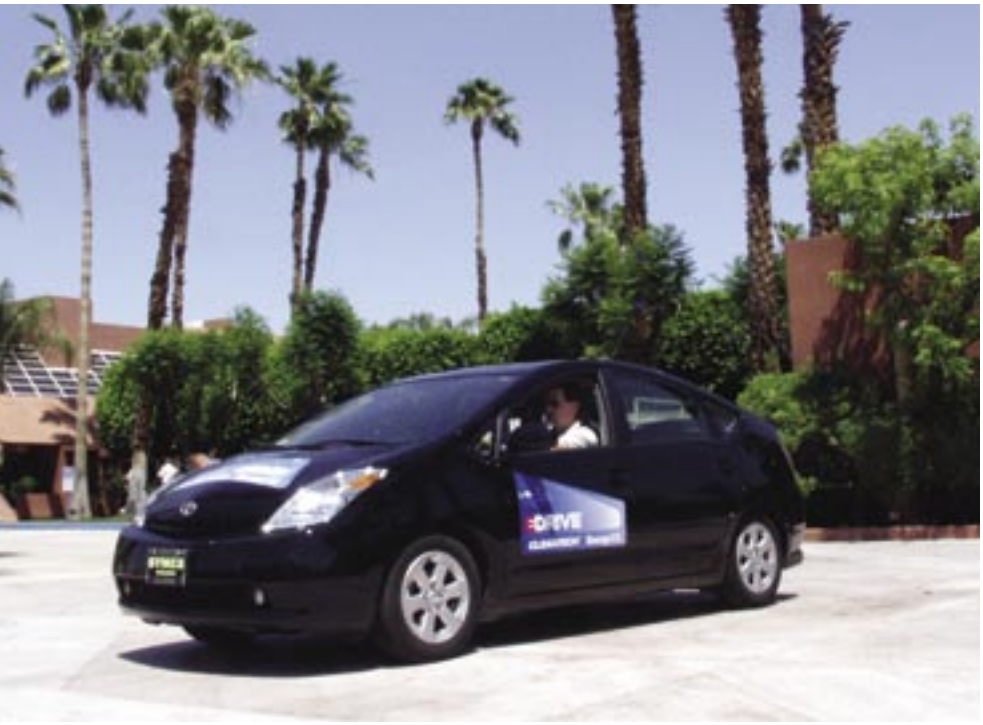
Engineering firms EnergyCS and Clean-Tech have joined forces to form EDrive Systems, which is developing a conversion kit for the second-generation Toyota Prius. The kit removes the stock Panasonic nickel-metal-hydride (NiMH) battery and replaces it with a Saphion lithium-ion battery from Valence. The new battery adds 170 pounds to the Prius, but also makes about 9 kWh instead of the original's 1.3 kWh. That means there's much more electrical power available to drive the car.

Some careful software tweaks are made to handle the extra power of the hardware. The EDrive system takes advantage of a built-in "EV mode" that forces the Prius to run purely on electric power until speeds reach 33 mph. This ensures that no precious fuel is sapped until the computer deems it absolutely necessary. According to EDrive, in a stock Prius, the batteries would only provide about one mile in this mode; the company's converted plug-in Prius extends that range to as much as 35 miles.

To further hold off engine intervention, the computer is told the battery is full until the actual state of charge dips below 20 percent. This bit of misinformation forces Toyota's Hybrid Synergy Drive to inject as much electric power as possible into the drive system. After the battery is about 80 percent depleted, the EDrive Prius carries on like a normal hybrid and maintains the charge of the battery as needed. Once the EDrive Prius is parked, it's plugged into an external 110-volt charger that can replenish a fully depleted battery in about seven to nine hours.

An additional dash-mounted readout precisely meters fuel consumption and displays how far the throttle pedal can be depressed before prompting the engine to start up. It's a useful tool because driving style matters. Aggressive driving and 75 mph cruising will yield 70-80 mpg, say the EDrive folks, while relatively mellow driving earns well over 100 mpg. Low speed city driving and cruising at 55 mph can reportedly push fuel economy closer to 200 mpg. And when the battery is depleted after 50-60 miles of driving, fuel economy reverts back to the roughly 45-50 mpg of the stock Prius.

EDrive Systems hopes to sell its conversion kit for $10,000 to $12,000 in early 2006. At this cost, EDrive's market



Greg Hanssen behind the wheel of his EDrive plug-in hybrid. *Green Car Journal* got over 100 mpg in this car.

is limited to those with the bucks to support making such a statement, but it's a start.

The Prius is not the only vehicle lending itself to plug-in conversion. DaimlerChrysler is working with the Electric Power Research Institute (EPRI) to build 40 plug-in hybrid versions of its Sprinter commercial van for use in demonstration fleets. Electric boost comes from a 70 kW motor positioned between the transmission and clutch, which is fed by a 14 kWh NiMH battery stowed beneath the cargo floor.

Drivers of the plug-in Sprinter hybrid can push a button to put the vehicle in electric-only mode, which is good for a range of about 19 miles. When not selected, the hybrid's electronic controller alternates power between the vehicle's diesel engine and electric motor to optimize fuel economy, or combines the two when power demands are high. This plug-in variant is designed for recharging on Europe's 230 volt network, a task that takes about six hours for a fully depleted battery.

The stock Sprinter, with its small, 4-cylinder diesel engine, is already quite the efficient hauler with fuel economy as high as 30 mpg. Converted to a plug-in hybrid, DaimlerChrysler says fuel economy improves anywhere from 10 to 50 percent, depending on use. That means up to 45 mpg from a commercial delivery vehicle – simply unheard of in its class. So far, DaimlerChrysler is the only automobile manufacturer producing its own plug-in hybrids.

One of the most notable forces behind the rising profile of the plug-in is Felix Kramer and his Palo Alto-based California Cars Initiative. The group is mobilizing support from fleets, government agencies, and private buyers in an attempt to break the vicious cycle that plagues many new technologies: Motorists won't buy plug-ins on a large scale unless the price is right, and the price won't come down until automakers are convinced there will be buyers.

Not content to wait around for the manufacturers, Kramer is looking at other ways to put plug-in hybrids on the road. The plan is to utilize venture capital, set up a Qualified Vehicle Modifier company that could work with automakers in a fully certified capacity, and convert existing hybrid models without voiding original vehicle warranties. In Kramer's mind, conversion possibilities include Ford's Escape Hybrid and models using Toyota's Hybrid Synergy Drive such as the Prius, Highlander Hybrid, Lexus RX400h, and other upcoming models.

The potential of the plug-in hybrid in reducing emissions and oil dependency has put environmentalists and conservative think-tanks in an unusual position: They're on the same side. Set America Free, the Center for Security Policy, and others have joined electric vehicle die-hards in calling for mass production of plug-in hybrids. Support from former Secretary of State George Shultz and former CIA director James Woolsey lends considerable credibility to the cause.

Despite this clamoring, the U.S. government has yet to respond in a big way. An amendment to the massive energy bill recently approved by President Bush allocates a relatively tiny $40 million for hybrid vehicle development, some of which could go toward plug-in hybrids...but there's no guarantee.

This leaves local government to take charge. The City of Austin, Texas, with help from its municipal utility Austin Energy, has become the first city to develop an incentive plan for plug-in hybrids. "Plug-In Austin" is looking to raise $50-$100 million to provide

rebates on plug-in hybrid purchases for public and private use, as well as for running an educational campaign to generate consumer interest. Austin is one of 10 cities that will begin testing DaimlerChrysler's Sprinter plug-in hybrid next year.

The "Plug-In Austin" campaign is designed to expand to other communities around the country. Representatives from Austin Energy are approaching the nation's 50 largest cities in an effort to encourage them to replicate Austin's program. Already, Seattle City Light in Washington state has shown interest in offering customers incentives to buy plug-in hybrid vehicles in the Puget Sound region. Across the country and across the political spectrum, the plug-in hybrid is winning fans.

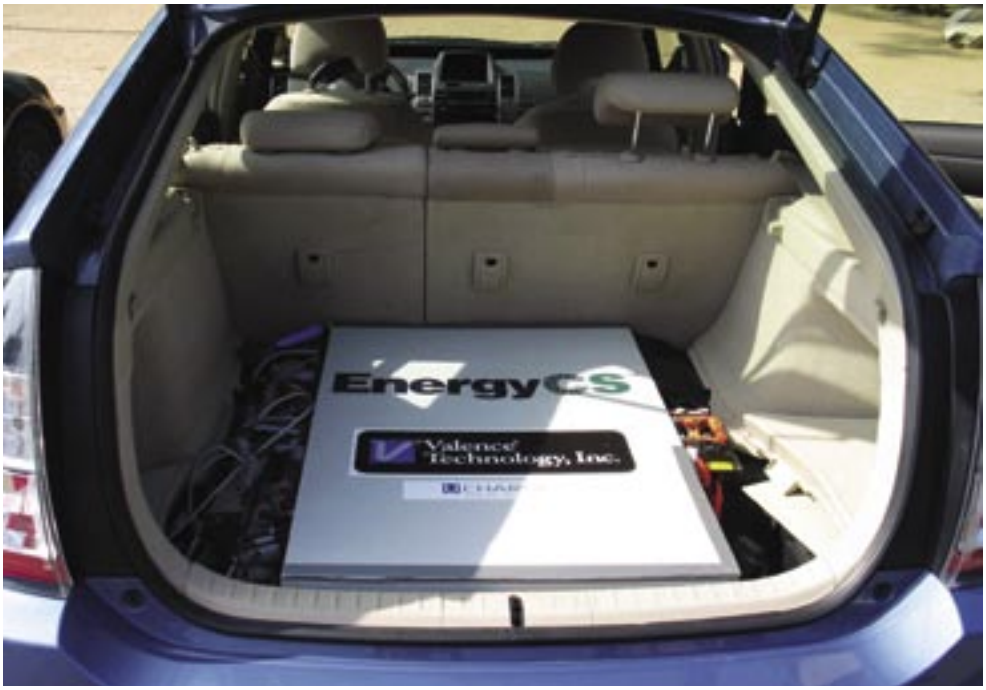
Professor Andy Frank at the University of California, Davis is an ardent proponent of plug-in hybrids and, having built plug-in prototypes since 1972, is also one of the most experienced. Rather than an intermediary step to hydrogen, Professor Frank believes the plug-in could be an end in itself. A plug-in hybrid with a 60 mile electric range, like the ones Frank and his students build, reportedly uses only 10% gasoline and 90% electricity on an annual basis. "That 10% of gasoline could be replaced by biofuels," says Frank, taking an interesting direction that could find gasoline use eliminated altogether.

Like other hybrids, the Highlander shuts down its gasoline engine during coast-down and idling to conserve fuel and reduce emissions.

The possibilities don't end there. "We have the capability, for the first time, of integrating the electric grid with transportation," explains Frank. The electrical grid right now has enough excess capacity to support half the nation's vehicle fleet if they were converted to plug-in hybrids, says Frank. The energy is domestically produced, the infrastructure already exists, and, though much of our electricity today comes from coal-burning powerplants, renewable and non-polluting sources such as wind and solar power could play a larger role. "People don't think of plug-ins as alternative fuel cars, but they are," says Frank. "You could be running your car on solar or wind power."

At less than a dollar per gallon during off-peak hours, when most plug-ins would be recharged, plug-in hybrid drivers would be paying a lot less in fuel costs. As for the extra up-front cost, Frank points to a UC Davis study that shows how automakers could build plug-in hybrids by adding only $7,000 to the price of a $20,000 car. So why isn't this already happening? Some in the auto industry maintain that battery technology isn't ready yet, a claim that Frank and others dismiss. More significantly, Frank asserts there's a general reluctance to invest, with struggling giants in the industry unwilling to take risks unless convinced there's a good chance that a sizeable return will result.

"What I'm trying to demonstrate is that if a bunch of students can do it, the car companies should be able to do even better." Andy Frank, the California Cars Initiative, the City of Austin, and many others feel it's up to them to take the lead in getting the word out and generating demand. With the success they've met, and the wide-ranging benefits that plug-ins put within reach, there's every reason to believe that at least some in the auto industry are paying very close attention.



Saphion lithium-ion batteries used in this plug-in hybrid are positioned in the rear cargo area.

A FUTURE OF E-HYBRIDS, NOT FUEL CELLS

by Joseph J. Romm

VOICES

We urgently need action to make our vehicles far less polluting. The scientific consensus is growing increasingly strong that the business-as-usual growth path in global warming pollution will lead to serious if not catastrophic climate change.

Hybrid gasoline-electric vehicles are the best near-term strategy. Absent tough fuel economy regulations, however, hybrid technology will increasingly be used to boost horsepower. So the current energy bill, which provides subsidies for hybrids but no fuel economy or carbon dioxide regulations, represents a major embarrassing failure of political leadership.

Ultimately, we will need to replace gasoline with a zero-carbon fuel. Hydrogen is the least likely such fuel, and hydrogen fuel cell cars increasingly appear to be an environmental dead end.

Bill Reinert, U.S. manager of Toyota's advanced technologies group, was asked in January 2005 when fuel cell cars would replace gasoline-powered cars or hybrids, and he replied, "If I told you 'never,' would you be upset?" The National Academy of Sciences noted this summer that "using hydrogen as a transportation fuel would necessitate several significant breakthroughs." The Director of MIT's Sloan Automotive Lab told Congress in July 2005, "the total time to noticeable impact" for hydrogen fuel-cell cars "is likely to be more than 50 years."

Hydrogen simply offers very little prospect of helping to reduce greenhouse gas emissions for four or more decades. As many analyses have shown, hydrogen won't be close to a cost-effective climate solution until we have almost completely eliminated carbon dioxide emissions from electricity generation. We just can't wait that many decades. Worse, a 2004 report from the European Union found that hydrogen cars deployed anytime soon could well increase greenhouse gas emissions.

"Ideally these advanced hybrids would also be flexible fuel vehicles capable of running on a blend of biofuels and gasoline."

So what will we be driving in the future to reduce greenhouse gas emissions and oil consumption? The most promising pathway is the e-hybrid, a hybrid that can be plugged into the electric grid, and run in an all-electric mode for a limited range before it reverts to being a regular gasoline-powered hybrid (discussed at length in the new paperback edition of *The Hype about Hydrogen*). Since most vehicle use is for relatively short trips such as commuting, followed by an extended period of time during which the vehicle is not being driven and could be charged, even a relatively modest all-electric range of 20 or 40 miles could allow these vehicles to replace a substantial portion of gasoline consumption and tailpipe emissions.

Whereas hydrogen fuel cell vehicles would likely have at least three times the annual fuel bill of regular hybrids, e-hybrids would have one half to one third the fuel bill of regular hybrids.

The potential greenhouse gas benefits of e-hybrids are also huge. They have an enormous advantage over hydrogen fuel cell vehicles in utilizing zero-carbon electricity. That is because of the inherent inefficiency (and cost) of generating hydrogen from electricity, transporting hydrogen, storing it on-board the vehicle, and then running it through the fuel cell. So e-hybrids will likely travel three to four times as far on a kilowatt-hour of renewable electricity as fuel cell vehicles.

Ideally, these advanced hybrids would also be flexible fuel vehicles capable of running on a blend of biofuels and gasoline. Such a car could travel 500 miles on one gallon of gasoline (and five gallons of cellulosic ethanol) and have under one-tenth the greenhouse gas emissions of current hybrids.

Long-term research into hydrogen cars makes sense. But for the sake of the global climate, most of the near-term development and deployment money now being spent on hydrogen should be shifted over to e-hybrids and biofuels.

— Dr. Romm is executive director and founder of the Center for Energy and Climate Solutions (www.cool-companies.org) and a former Acting Assistant Secretary of Energy. Romm is also author of "The Hype About Hydrogen: Fact and Fiction in the Race to Save the Climate."