HYBRIDS' RISING SUN

This year Toyota will sell 150,000 gas-electric hybrid cars around the world. It's one of the most radical transformations in automotive technology in a century. And with U.S. automakers trailing far behind, Toyota's gamble might just shake up the industry. BY PETER FAIRLEY

PHOTOGRAPHS BY JEREMY SUTTON-HIBBERT

Green power: No longer cramped eco-cars, new hybrids at Toyota's factory in Tsutsumi, Japan, will compete for horsepower-loving U.S. drivers.

BANNERS TWO METERS TALL outside Toyota Motor's sprawling factory in Tsutsumi, Japan, scream "Hybrid," the word emblazoned over an image of the earth. Inside, beneath signs reading "Yoi shina, yoi kangae" ("Good thinking, good products"), assemblers in blue jackets and white gloves turn out about 400 of Toyota's newly designed Prius hybrid sedans every day.

Apart from the signage, it looks much like any other automotive factory floor—and that's what's remarkable. The Prius, which uses both a gasoline engine and an electric motor for propulsion, gets an average of 55 miles to the gallon—about double the mileage of a comparable gasoline car. What's more, the latest model rolling off the factory floor at Tsutsumi doesn't sacrifice power or comfort and sells for only about $1,000 more than a base model of Toyota's mid-size sedan, the Camry.

And the Prius is only a preview of Toyota's ambitious plans for the new hybrid technology. By the end of this year, the automaker plans to sell a luxury sport utility vehicle using the technology—a hybrid Lexus—in the United States. Within a decade, say Toyota executives, the gas-electric combination could be offered in every category of vehicle the automaker sells, from subcompacts to heavy-duty pickup trucks. "When Toyota's SUVs hit the market, and people see what a really powerful hybrid electric vehicle can do, I think it's going to rattle a few cages," says former General Motors chairman Robert Stempel, who chairs Rochester Hills, MI-based technology developer Energy Conversion Devices.

You can be forgiven for thinking that fuel cells, which use hydrogen to produce electricity, were the auto industry's next new thing. GM and other automakers have for years shown off various versions of fuel cell prototypes that do away entirely with the internal-combustion engine *(see "Electricity-Producing Vehicles," TR December/January 2003)*. But it will be at least five years—and more like a decade, according to many experts—before a fuel cell car is cheap enough for the mass market. Then there's the challenge of storing sufficient hydrogen, the lack of hydrogen filling stations, and the problem of producing hydrogen in the first place. In contrast, hybrids are available now, and they fuel up at the local pump. Toyota alone expects to sell 130,000 Prius hybrids in 2004. Throw in the hybrid Lexus slated for export and a handful of Japan-only hybrid models, and the company's sales of gas-electric vehicles should easily top 150,000—a figure that Toyota says could double by 2006. While that is a small fraction of Toyota's total sales—which hit nearly 6.8 million in 2003—it is still a big number for an unconventional automotive technology.

Indeed, gas-electric hybrids are the first significant break with carmakers' total reliance on the internal-combustion engine in nearly a century. And the implications of a widespread switchover to gas-electric hybrids are immense for both consumers and the auto industry. Even bumping up the average gas mileage of U.S. vehicles to a modest 40 miles per gallon by 2012 would mean the United States could trim its oil consumption by three million barrels per day—more than it imports from all the Persian Gulf countries. And though buyers would have to pay more initially for gas-electric hybrids, they could save, on average, $5,000 at the gas pump over the 15-year life of a vehicle.

From a business perspective, if hybrids take off in the marketplace, Toyota will almost certainly emerge as the player to beat, thanks to its hefty investment in the technology over the last decade. "They have seized the high ground," says Rich Schaum, a former chief engineer at Chrysler. "It's a long-term strategy which may force the hands of their competitors." Indeed, as recently as three or four years ago, GM, the world's largest automaker, was characterizing hybrid cars as a pit stop on the road to fuel cells. But last year GM announced it would have the manufacturing capability to build as many as one million hybrids by 2007, if buyers want them, and that by 2008, it would build three basic hybrid architectures—the platforms for as many as a dozen hybrid car and truck models. Most major automakers plan to bring hybrids to market in the next five years *(see "Hybrids Head for Showrooms," p. 38)*; still, these other manufacturers are badly trailing Toyota, and some competitors are even turning to Toyota's technology: GM and Ford Motor are buying key hybrid parts, such as nickel-metal-hydride batteries and sophisticated transmissions, that were developed by Japanese suppliers in partnership with Toyota.

A little exploring beyond the Tsutsumi factory floor shows how Toyota set all this in motion.

COMING CLEAN

Drive beyond the cluster of auto plants around Tsutsumi and nearby Toyota City and into the hills north of Nagoya, and you find another Toyota plant—this one bereft of banners. At this factory, called Hirose, Toyota did something extraordinary for a carmaker: it built dedicated facilities to fabricate state-of-the-art semiconductor chips. Most carmakers are satisfied to buy off-the-shelf electronics or farm out electronics manufacture to suppliers. Toyota is doing everything in-house. Its high-tech chip plants churn out the power controllers that constitute the

FOSSIL FUEL FRUGALITY: Cars, SUVs, and other "light" trucks emit 16 percent of all carbon dioxide and other greenhouse gases released in the United States. **If every American switched to a hybrid vehicle that got 40 miles to the gallon—up from today's average of 24 miles per gallon—it would cut these emissions by nearly half.** Though unlikely to slow potential climate change, experts say, that might at least offset the extra emissions from the 71 million more passenger vehicles expected on U.S. roads by 2020.

Check my amps: Under a Toyota hybrid's hood, high-power electronics inside a laptop-sized housing govern power flows between motors, batteries, and brakes.

Electrical attraction: A visitor focuses on a hybrid displayed in a showroom in Japan.

HYBRIDS HEAD FOR SHOWROOMS

IN THE NEXT FEW YEARS, the six top sellers of cars in the United States plan to roll out a range of hybrid cars and light trucks. New models include "full hybrids," which add all-electric propulsion to the traditional engine, and so-called mild hybrids, in which a less extensive electric system supplements the engine or does things like stop and restart the engine at traffic lights.

■ **DAIMLERCHRYSLER** (Stuttgart, Germany)
Canceled Durango SUV hybrid project in 2002; began fleet sales of mild-hybrid diesel-electric Ram pickup in 2004; experimenting with full-hybrid diesel-electrics

■ **FORD MOTOR** (Dearborn, MI)
Canceled Explorer SUV hybrid introduction in 2001; full-hybrid Escape SUV now due out this summer; full-hybrid option promised for Futura sedan, which debuts in 2005

■ **GENERAL MOTORS** (Detroit, MI)
Canceled full-hybrid VUE SUV promised for 2005; mild-hybrid Silverado and Sierra pickups to debut this year, the VUE in 2006; promising full hybrids, including a Malibu sedan and Tahoe and Yukon SUVs in 2007, and Silverado and Sierra pickups in 2008

■ **HONDA MOTOR** (Tokyo, Japan)
Insight two-seater, a mild hybrid, was first hybrid to reach the U.S. market in 1999; now sells Insight and mild-hybrid Civic worldwide; adding mild-hybrid Accord sedan this fall

■ **NISSAN MOTOR** (Tokyo, Japan)
Test-marketed hybrid Tino compact car with proprietary lithium battery in Japan in 2000; licensing Toyota technology for a possible 2006 full-hybrid Altima mid-size sedan

■ **TOYOTA MOTOR** (Toyota City, Japan)
Launched first hybrid car in 1997; sells full-hybrid Prius worldwide and six other hybrids in Japan; full-hybrid Lexus and Highlander SUVs promised for export by fall 2004 and early 2005; considering full-size hybrid pickup trucks and Camry

hybrid vehicle's heart, making Hirose the centerpiece of a hybrid investment that some analysts peg at $1 billion.

The Hirose plant is off-limits to journalists, but the story of Toyota's program is one that its architect—Takehisa Yaegashi, the unassuming engineer revered within Toyota as "the father of the hybrid"—is eager to tell. Drinking black coffee in a nondescript meeting room in Toyota's offices in Tokyo, Yaegashi traces the origins of Toyota's hybrid strategy back to the early 1970s, when the U.S. Congress set the first national limits on tailpipe emissions.

In 1971, Yaegashi was a 28-year-old mechanical engineer, two years out of Hokkaido University, when Toyota assigned him to its new clean-engine project. Over the next 20 years, he designed everything from exhaust-scrubbing catalytic converters to emission-reducing engine control systems. All this helped make Toyota's fleet of cars one of the cleanest sold in the United States. (The cars in Toyota's 2003 U.S. fleet get an average of 32.3 miles per gallon of gasoline, 3.6 miles more than GM's cars. Toyota's SUVs and light trucks, however, get an average of 21.9 miles to the gallon, only eight-tenths of a mile better than GM's.)

But Toyota didn't stop at innovative catalytic converters. By the early 1990s—even as Toyota followed the lead of U.S. automakers by making popular but fuel-guzzling SUVs—Toyota's leaders prepared to redouble their efforts to clean up the automobile and make it more fuel efficient. "We saw two things happening at the same time: demand for cleaner air and demand for greater fuel savings," recalls Yaegashi.

At the time, the solution seemed to be battery-powered electric vehicles. Toyota built electric versions of its small SUV, while GM test-marketed a sporty two-seater. But neither of these early electric vehicles ever made it to mass production; the batteries limited their range to barely 100 kilometers. Still, these experiments taught engineers an important lesson: you could make electric cars powerful, quiet, and peppy by using high-power electronics to manage the flow of electricity between the battery and the electric motors. As Stempel puts it, "The electronic revolution gave the engineers the tools they needed to make electric cars quite drivable. That broke open the logjam."

CHANGING LANES

Still, the batteries were a problem. Few consumers would buy cars that needed to be plugged in after less than an hour on the highway. So Toyota's management switched gears and decided to exploit what it had learned to build a vehicle that would outperform traditional all-electric cars: the gasoline-electric hybrid.

The idea was to capture the best of gasoline and electric cars. At low speeds, where combustion engines are at their least efficient and most polluting, Toyota's hybrid uses an electric motor instead. At higher speeds, where an electric motor lacks sufficient muscle, a small gas engine kicks in. The engine can directly spin the wheels or spin a generator to provide electricity. Hybrids also capture energy from another source: the brakes. Touch the brake pedal, and the electric motor switches roles and serves as a generator, transforming the car's kinetic energy into electricity to recharge the batteries. All these tricks are possible because hybrids—unlike conventional cars—have high-power electronics and large batteries.

By 1995 Toyota had unveiled its Prius concept car. Just two years later Toyota's distributors in Japan were selling the

Hybrid ramp-up: A conventional production line in Tsutsumi, Japan, produces about 400 unconventional hybrid Prius sedans every day.

Prius, as well as a hybrid bus. By 2001 they were selling a hybrid minivan and a luxury sedan in Japan *(see "Car Culture," p. 40)*. And in 2000, Toyota began selling an improved Prius in the United States, competing with a hybrid model from Honda Motor, the Insight compact sedan.

Still, Toyota executives felt the hybrids were too sluggish. But whereas Honda boosted the Insight's performance by making it as light as possible, Yaegashi's team revamped the Prius with brawnier electric motors and batteries that can make even heavier cars peppy. They added a smaller, smarter power controller that better regulates the flow of electricity between the batteries, the brakes, and the electric motor and generator. The result is the most powerful hybrid yet, the 2004 Prius—the version rolling off the Tsutsumi assembly lines—which accelerates better than a four-cylinder Camry but gets roughly twice the gas mileage.

Toyota has already announced that in 2004 it will sell a hybrid Lexus SUV, dubbed the RX400h, whose V6 engine will deliver power rivaling that of a V8 but with the fuel efficiency of a compact car, and a hybrid Highlander—Toyota's mid-size SUV—that is more powerful than the gas-only model. And the company hints that hybrid versions of the Camry and even a brawny pickup truck like the Tundra are not far behind.

Toyota's SUVs and minivans exploit hybrid technology to offer yet another payoff: advanced four-wheel drive. Conventional four-wheel-drive vehicles employ a bulky and costly drive axle that delivers mechanical power to the rear axle through the familiar hump on the cabin floor. On optional four-

CAR CULTURE

TOYOTA SELLS SEVEN gasoline- and diesel-electric hybrid vehicles in Japan, from subcompact cars to delivery trucks. When I asked to drive them all, Toyota officials brought me to the company's very own automotive theme park, called **Megaweb**, on the Tokyo waterfront.

At Megaweb, which is a hot dating spot for Tokyo teens and twentysomethings, you can test your skills in sophisticated hydraulic driving simulators, explore the History Garage jammed with vintage cars, and tour various eateries via electric cars that communicate wirelessly to avoid collisions. And then there's Megaweb's cavernous glass and steel showroom sporting all 80 Toyota models of car, van, and SUV.

But the centerpiece is a 1.4-kilometer test track. My test drives began with a dark red Prius, delivered to the starting lane by a Megaweb pit crew in jumpsuits. A green "ready" light on the dash reminded me that starting a Toyota hybrid is like turning on a DVD player: the electromechanical vehicle tests its circuits, powers up its display, and awaits command. I punched the Prius's electronic shift control up to *D*, stepped on the pedal, and, pit flags waving, entered the track.

A touch-screen display on the dashboard explained what was happening under the hood, showing how electrical pulses were flowing from the battery to the electric motor to the wheels. As we cruised past Megaweb's 40-kilometer-per-hour speed limit, the gas engine kicked in seamlessly. When I hit the brakes at a red light, the dashboard display showed that the wheels had become a power source, spinning a generator to recharge the batteries.

Next up was a light-green metallic Estima minivan, a hybrid with a twist: electric motors on both axles and an electronic traction system enable the vehicle to monitor and adjust the power to each wheel in real time. It certainly felt good to zip up and down the track at Megaweb in a van that gets 44 miles per gallon. (Toyota has sold more than 22,000 hybrid Estimas in Japan since their debut in 2001. But the Estima is considered underpowered for the U.S. market.)

By the time I was done at Megaweb, I had driven another minivan and a hybrid luxury sedan. But by the 10th lap, I had had my fill of maneuvering my way around the piazza and trying to beat the traffic signal. So I blew through the red light. Toyota's hybrid technology was happy to oblige.

Voltage view: An in-dash display shows a hybrid's electricity flows.

wheel-drive models, Toyota's hybrids feed power through a high-voltage cable that drives an electric motor on the rear axle, freeing up cabin space and making the vehicle more stable by deftly adjusting the torque on each wheel by the millisecond.

So is the $1 billion bet paying off? Yaegashi laughs and demurs. "I hesitate to say we are very much ahead of the others, but I do want to emphasize the difference between Toyota and the other companies," he says. "We have a six-year advantage in mass-producing hybrids."

TAILGATING

Catching up looks like a bumpy road for other automakers. Even Honda, probably Toyota's most advanced hybrid competitor, has its work cut out, according to industry experts. "When it comes to engineering the system as a whole, I think Toyota has three, four years' advantage over the others, even compared to Honda," says Koji Endo, a Tokyo-based auto analyst for Credit Suisse First Boston. Honda's models—which include a hybrid Insight and Civic, and an Accord due this year—have less electrical power and are more expensive to produce than Toyota's, Endo says.

Detroit's Big Three are farther behind. Over the last two years, GM, Ford, and DaimlerChrysler have scrapped or delayed half a dozen ambitious hybrid projects. "What they're learning is that making this transition to electric drive technology is not going to be a piece of cake," says Dan Sperling, director of the Institute of Transportation Studies at the University of California, Davis. "You can't just say, 'Okay, I'm going to build a hybrid car,' buy the technology, and put it out there next year."

Last year, Ford delayed the release of its debut hybrid: a version of its Escape SUV. John Kassakian, director of MIT's Laboratory for Electromagnetic and Electronic Systems, which researches automotive electronics, says Ford is paying the price for its early attempts to shoehorn hybrid technology into existing vehicles. Unlike Toyota's hybrid SUVs, for example, Ford's four-wheel-drive Escape hybrids will not have electric motors on each axle, which Ford says would require costly retooling. "Modifying an existing vehicle looks on the surface to be the most efficient way of getting from point A to point B, but you don't end up with a solution that's optimized for cost and performance," says Kassakian. Ford now says it will sell the SUV this year.

Still, the Big Three and other automakers' decision to finally pursue gas-electric hybrids is itself notable. Until recently, GM considered its money better spent on fuel cell technology. It invested hundreds of millions of dollars in fuel cell R&D and rolled out a radical prototype fuel cell car that it has promised to mass-produce by 2010. "More-efficient petroleum-based vehicles alone will not solve our petroleum dependence problem. We believe long term you've got to get to energy sources beyond petroleum, and that's why hydrogen is so attractive," says Larry Burns, GM's R&D vice president. But even Burns acknowledges that automakers need to master hybrids, too, if only for competitive reasons. "We don't know for sure how big the hybrid segment will be—I don't think anyone can predict that right now—but we want to give our customers the choice," he says.

Sales on track: In Toyota's Tokyo showroom and amusement center, called Megaweb, an autonomous car cruises around a track.

High-power vision: Takehisa Yaegashi, Toyota's "father of the hybrid," says the company has a six-year technological head start.

FUEL CELL FUTURE

At Japan's bustling Nagoya Motor Show late last year, Toyota showed off three concept cars. One was a metallic-blue SUV, another an open-topped, bone-white sports car. Both were gas-electric hybrids. But the spotlight finally fell on a metallic-blue hybrid sedan with a twist: it uses a fuel cell, not a gas engine.

Toyota calls it the Fine-N, and it uses many of the tricks that the company has learned from its gas-electric vehicles. "Clearly, the [hybrid] technologies that we're pursuing—the motors, the power electronics, all the logic it takes, even the art of caring for the batteries—are essential elements of the fuel cell vehicle," says Schaum, the former Chrysler chief engineer, now a vice president at electric-motor developer WaveCrest Laboratories of Dulles, VA. "You really have to master this before you are ready for the hydrogen economy."

If he is right, Toyota's early dominance of gas-electric hybrids could give it a strong head start toward the future. Every automaker is spending heavily on developing fuel cell cars, and Toyota is no exception—even as it races to dominate hybrids. If it winds up dominating fuel cells, too, it could rob Detroit of its last, best chance to regain its footing as a leader in automotive technology.

Still, no one at Toyota is forgetting today's marketing realities. At Nagoya, Toyota's presentation of its futuristic hybrids-to-hydrogen vision was accompanied by a standard industry touch. As if to suggest that advanced fuel-cell cars are ready for the mainstream, Toyota trotted out young women known as "show companions" to demonstrate the Fine-N prototype. On a spinning platform, a woman in a short skirt and high boots opened the car's rear door, stepped into its rear seat, punched a button, and reclined out of view. It may be at the vanguard of advanced automotive technology, but Toyota hasn't forgotten what sells cars. TR

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