Fire and ICE: Revving Up for H₂

The first hydrogen-powered cars will likely burn the stuff in good old internal combustion engines. But can they drive the construction of hydrogen infrastructure?

In the day we sweat it out in the streets of a runaway American dream. At night we ride through mansions of glory in suicide machines. Sprung from cages out on highway 9, Chrome wheeled, fuel injected and steppin' out over the line …

Fear not, sports car aficionados and Bruce Springsteen fans: Even if the hydrogen economy takes off, it may be decades before zero-emission fuel cells replace your beloved piston-pumping, fuel-burning, song-inspiring internal combustion engine. In the meantime, however, instead of filling your tank with gasoline, you may be pumping hydrogen.

A handful of automakers are developing internal combustion engines that run on hydrogen, which burns more readily than gasoline and produces almost no pollutants. If manufacturers can get enough of them on the road in the next few years, hydrogen internal combustion engine (or H₂ ICE) vehicles might spur the construction of a larger infrastructure for producing and distributing hydrogen—the very same infrastructure that fuel cell vehicles will require.

If all goes as hoped, H₂ ICE vehicles could solve the chicken-or-the-egg problem of which comes first, the fuel cell cars or the hydrogen stations to fuel them, says Robert Natkin, a mechanical engineer at Ford Motor Co. in Dearborn, Michigan. “The prime reason for doing this is to get the hydrogen economy under way as quickly as possible,” Natkin says. In fact, some experts say that in the race to economic and technological viability, the more cumbersome, less powerful fuel cell may never catch up to the lighter, peppier, and cheaper H₂ ICE. “If the hydrogen ICEs work the way we think they can, you may never see fuel cells’ powering cars, says Stephen Ciatti, a mechanical engineer at Argonne National Laboratory in Illinois.

BMW, Ford, and Mazda expect to start producing H₂ ICE vehicles for government and commercial fleets within a few years. But to create demand for hydrogen, those cars and trucks will have to secure a niche in the broader consumer market, and that won’t be a drive in the countryside. The carmakers have taken different tacks to keeping hydrogen engines running smoothly and storing enough hydrogen onboard a vehicle to allow it to wander far from a fueling station, and it remains to be seen which approach will win out. And, of course, H₂ ICE vehicles will require fueling stations, and most experts agree that the public will have to help pay for the first ones.

Most important, automakers will have to answer a question that doesn’t lend itself to simple, rational analysis: At a time when gasoline engines run far cleaner than they once did and sales of gas-guzzling sport utility vehicles continue to grow in spite of rising oil prices, what will it take to put the average driver behind the wheel of an exotic hydrogen-burning car?

Running lean and green

An internal combustion engine draws its power from a symphony of tiny explosions in four beats. Within an engine, pistons slide up and down within snug-fitting cylinders. First, a piston pushes up into its cylinder to compress a mixture of air and fuel. When the piston nears the top of its trajectory, the sparkplug ignites the vapors. Next, the explosion pushes the piston back down, turning the engine’s crankshaft and, ultimately, the wheels of the car. Then, propelled by inertia and the other pistons, the piston pushes up again and forces the exhaust from the explosion out valves in the top of the cylinder. Finally, the piston descends again, drawing a fresh breath of the air-fuel mixture into the cylinder through a different set of valves and beginning the four-stroke cycle anew.

A well-tuned gasoline engine mixes fuel and air in just the right proportions to ensure that the explosion consumes essentially every molecule of fuel and every molecule of oxygen—a condition known as “running at stoichiometry.” Of course, burning gasoline produces carbon monoxide, carbon dioxide, and hydrocarbons. And when running at stoichiometry, the combustion is hot enough to burn some of the nitrogen in the air, creating oxides of nitrogen (NOₓ), which seed the brown clouds of smog that hang over Los Angeles and other urban areas.

In contrast, hydrogen coughs up almost no pollutants. Burning hydrogen produces no carbon dioxide, the most prevalent heat-trapping greenhouse gas, or other carbon compounds. And unlike gasoline, hydrogen burns even when the air-fuel mixture contains far less hydrogen than is needed to consume all the oxygen—a condition known as “running lean.” Reduce the hydrogen-air mixture to roughly half the stoichiometric ratio, and the temperature of combustion falls low enough to extinguish more than 90% of NOₓ production. Try that with a gasoline engine and it will run poorly, if at all.

But before they can take a victory lap, engineers working on H₂ ICEs must solve some problems with engine performance. Hydrogen packs more energy per kilogram than gasoline, but it’s also the least dense gas in nature, which means it takes up a lot of room in an engine’s cylinders, says Christopher White, a mechanical engineer at Sandia National Laboratories in Livermore, California. “That costs you power because there’s less oxygen to consume,” he says. At the same time, it takes so little energy to ig-
nite hydrogen that the hydrogen-air mixture tends to go off as soon as it gets close to something hot, like a sparkplug. Such “preignition” can make an engine “knock” or even backfire like an old Model T.

**Power play**

To surmount such problems, BMW, Ford, and Mazda are taking different tacks. Ford engineers use a mechanically driven pump called a supercharger to force more air and fuel into the combustion chamber, increasing the energy of each detonation. “We basically stuff another one-and-a-half times more air, plus an appropriate amount of fuel, into the cylinders,” says Ford’s Natkin. Keeping the hydrogen-air ratio very lean—less than 40% of the stoichiometric ratio—prevents preignition and backfire, he says. A hydrogen-powered Focus compact car can travel about 240 kilometers before refueling its hydrogen tanks, which are pressurized to 350 times atmospheric pressure. And with an electric hybrid system and tanks pressurized to 700 atmospheres, or 70 MPa, Ford’s Model U concept car can range twice as far.

Mazda’s H2 ICE prototype also carries gaseous hydrogen, but it burns it in a rotary engine driven by two triangular rotors. To overcome hydrogen’s propensity to displace air, Mazda engineers force the hydrogen into the combustion chamber only after the chamber has filled with air and the intake valves have closed. As well as boosting power, such “direct injection” eliminates backfiring by separating the hydrogen and oxygen until just before they’re supposed to detonate, explains Masanori Misumi, an engineer at Mazda Motor Corp. in Hiroshima, Japan. Mazda’s hydrogen engine will also run on gasoline.

When BMW’s H2 ICE needs maximum power, it pours on the hydrogen to run at stoichiometry. Otherwise, it runs lean. A hydrogen-powered Beemer also carries denser liquid hydrogen, boiling away at −253°C inside a heavily insulated tank, which greatly increases the distance a car can travel between refueling stops. In future engines, the chilly gas might cool the airflow mixture, making it denser and more potent than a warm mixture. The cold hydrogen gas might also cool engine parts, preventing backfire and preignition. BMW’s H2 ICE can run on gasoline as well.

Unlike Ford and Mazda, BMW has no immediate plans to pursue fuel cell technology alongside its H2 ICEs. A fuel cell can wring more useful energy from a kilogram of hydrogen, but it cannot provide the wheel-spinning power that an internal combustion engine can, says Andreas Klugescheid, a spokesperson for the BMW Group in Munich. “Our customers don’t buy a car just to get from A to B, but to have fun in between,” he says. “At BMW we’re pretty sure that the hydrogen internal combustion engine is the way to satisfy them.”

The first production H2 ICE vehicles will likely roll off the assembly line within 5 years, although the automakers won’t say precisely when. “We would anticipate a lot more hydrogen internal combustion engine vehicles on the road sooner rather than later as we continue to develop fuel cell vehicles,” says Michael Vaughn, a spokesperson for Ford in Dearborn. Focusing on the market for luxury performance cars, BMW plans to produce some hydrogen-powered vehicles in the current several-year model cycle of its flagship 7 Series cars. Automakers will introduce the cars into commercial and government fleets, taking advantage of the centralized fueling facilities to carefully monitor their performance.

**Supplying demand**

In the long run, most experts agree, the hydrogen fuel cell holds the most promise for powering clean, ultraefficient cars. If they improve as hoped, fuel cells might usefully extract two-thirds of the chemical energy contained in a kilogram of hydrogen. In contrast, even with help from an electric hybrid system, an H2 ICE probably can extract less than half. (A gasoline engine makes use of about 25% of the energy in its fuel, the rest going primarily to heat.) And whereas an internal combustion engine will always produce some tiny amount of pollution, a fuel cell promises true zero emissions. But H2 ICE vehicles enjoy one advantage that could bring them to market quickly and help increase the demand for hydrogen filling stations, says James Francfort, who manages the Department of Energy’s Advanced Vehicle Testing Activity at the Idaho National Engineering and Environmental Laboratory in Idaho Falls. “The

They’re already getting it in California, which gives manufacturers environmental credits for bringing H2 ICE vehicles to market. And in April, California Governor Arnold Schwarzenegger announced a plan to line California’s interstate highways with up to 200 hydrogen stations by 2010, just in time to kick-start the market for H2 ICEs.

Ultimately, the fate of H2 ICE vehicles lies with consumers, who have previously turned a cold shoulder to alternative technologies such as cars powered by electricity, methanol, and compressed natural gas. With near-zero emissions and an edge in power over fuel cells, the H2 ICE might catch on with car enthusiasts yearning to go green, a demographic that has few choices in today’s market, says BMW’s Klugescheid. If the H2 ICE can help enough gearheads discover their inner tree-hugger, the technology might just take off. “There are enough people who are deeply in love with performance cars but also have an environmental conscience,” Klugescheid says.

Developers hope that the H2 ICE vehicles possess just the right mixture of environmental friendliness, futuristic technology, and good-ol-fashioned horsepower to capture the imagination of the car-buying public. A few short years should tell if they do. In the meantime, it wouldn’t hurt if Bruce Springsteen wrote a song about them, too.

—ADRIAN CHO