REINVENTING THE WHEELS
The Automotive Efficiency Revolution

Amory B. Lovins

Ned Ahrens/King County Metro Transit

A new diesel hybrid-electric bus is tested in Seattle, Washington.

A "car-efficiency revolution" that could move the world beyond oil is in the making, as automakers start shifting to lighter-weight materials, sleeker aerodynamics, hybrid-electric propulsion, and non-petroleum fuels.

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Transportation drives global oil trade and is a key environmental challenge, especially in cities.

Most cities are designed around cars, not people—changing cars "from a convenient accessory of life into its central organizing principle," according to environmental author Alan Thein Durning. It need not be so. Moreover, new car technologies already exist, and others are under development, with potential to transform the paradigms of global development and energy security. These technologies, if pursued, will be good for business throughout the world, provide safe and affordable mobility, be environmentally friendly, and create competitive advantage. They are not the stuff of science fiction, but realities we can expect to see emerge even within this decade.

The world cannot go on turning nearly five trillion liters of oil per year, half of it for transport, into the roughly 42 percent of global carbon dioxide emissions reported by the International Energy Agency in its 2005 *World Energy Outlook*. Oil's direct and hidden costs—climate change, insecurity, geopolitical rivalry, price volatility, and degradation of economic and social development—make it unsupportable.

The most fundamental solutions are the simplest. More sensible land use strengthens neighborhoods and lets people be already where they want to be. Smart policies let all means of getting around—from walking and biking to ultralight trains and advanced buses—compete fairly at honest prices. From Singapore to Curitiba (Brazil), cities that treat cars without favoritism have no car problem, yet they achieve excellent mobility for all. In time, so could even the car-centric United States and other industrialized countries if they stopped incentivizing sprawl and cars through their tax systems and zoning laws.

Less driving is good. But with seven-eighths of the world's people without cars so far—China and Africa have only about the car ownership that America enjoyed around 1915—we will also need better cars. Fasten your seatbelt: Automaking's greatest revolution in a century is now gathering speed.

If the best conventional technologies now in some cars were in all cars, we would save at least a fourth of their fuel, repaying the investment in less than a year at current U.S. gasoline prices. But we can do better still by exploiting cars' physics.

New Automotive Materials

A modern car's engine, idling, driveline, and accessories dissipate seven-eighths of its fuel energy. Only one-eighth reaches the wheels. Of that, half heats the tires and road or heats the air that the car pushes aside. Only the last 6 percent accelerates the car (then heats the brakes when you stop). And since about 95 percent of the mass being accelerated is the car, not the driver, less than 1 percent of the fuel energy ultimately moves the driver—unimpressive, considering it is the fruit of 120 years of engineering effort.

Happily, three-fourths of a car's propulsive energy need is caused by its weight, and every unit of energy saved at the wheels saves another seven units we don't need to waste on the way to the wheels. Thus, making cars that are radically lighter weight has huge fuel-saving leverage.

Lighter weight formerly meant costly metals such as aluminum and magnesium. Now, ultralight steels can double a car's efficiency without extra cost or decreased safety. With clever design, even conventional steels can yield surprising results. A German startup firm's 2+2-seat 450- to 470-kilogram diesel roadster (www.loremo.com) combines 160- to 220-kilometer-per-hour (100- to 137-mile-per-hour) top speeds with a fuel economy from 1.5 to 2.7 liters per 100 kilometers (87 to 157 miles per U.S. gallon), and will sell in 2009 for 11,000 euros to 15,000 euros.

Advanced polymer composites are even stronger and lighter. They can halve a car's weight and fuel use, yet increase safety, because carbon-fiber composites can absorb up to 12 times as much crash energy per kilogram as steel. Such materials can make cars big (comfortable and protective) but not heavy (hostile and inefficient), saving both oil and lives. A new manufacturing process (see sidebar) can even make a carbon-fiber car cost the same to produce as its steel version. That's because its costlier materials are offset by simpler automaking and a smaller propulsion system.

For example, an uncompromised mid-size sport utility vehicle (SUV) designed in 2000 (figure 1), equipped with the most popular efficiency-doubling hybrid-electric drive system, could carry five adults in comfort and up to two cubic meters of cargo, haul a half-ton up a 44 percent grade, accelerate from 0 to 100 kilometers per hour in 7.2 seconds, be safer than a steel SUV even if it hits one, yet use less than a third the normal amount of gasoline, getting about 3.56 liters per hundred kilometers, or 67 miles per U.S. gallon.

Courtesy Hypercar Inc.

Figure 1: The Revolution concept car, an ultralight (857-kilogram) carbon-fiber mid-size sport utility vehicle, designed in 2000.

If produced at a rate of 50,000 cars per year, its retail price would be $2,510 (in year 2000 U.S. dollars) higher than today's equivalent steel SUV, but only because it is hybrid-electric, not because it is ultralight. Saved gasoline would repay this investment in two years at U.S. fuel prices or one year at European Union or Japanese fuel prices. Manufacturing such cars would use far less space and two-fifths less capital than today's leanest plant, thanks to up to 80-fold less tooling and to elimination of the body shop and paint shop—the two hardest and costliest steps in automobile manufacturing.

Alternative Automotive Fuels

Many cars already on the road can burn advanced biofuels—say, 15 percent gasoline and 85 percent ethanol, ideally cellulosic ethanol made with new processes from woody plants such as switchgrass or crop wastes. An ultralight hybrid car burning such "E85" fuel could cut its oil use by another three-fourths, to just 7 percent of the current level. Brazil has already eliminated its oil imports, two-fifths via sugar-cane ethanol that now competes without subsidy. Three-fourths of Brazil's new cars can burn anything from pure ethanol to pure gasoline, although all of its gasoline is at least 20 percent ethanol. Sweden plans to be oil-independent by 2020, chiefly via ethanol made from forest wastes and the requirement that its top-selling 60 percent of filling stations offer renewable fuel by 2009.

In the longer run, one can make a robust business case for tripled-efficiency, ultralight-hybrid cars to use compressed hydrogen gas as fuel and turn it into electricity in a fuel cell. A heavy, inefficient car would need an excessively bulky tank and a big, costly fuel cell. But an ultralight, aerodynamic car would need two-thirds less propulsive energy and smaller tanks. And just 3 percent as much cumulative production volume would be needed to make the three-fold smaller fuel cell cost effective—thus it could become cost effective many, many years earlier. Such cars when parked (which is 96 percent of the time) could even become profitable power plants on wheels, selling electricity back to the grid when and where it's most valuable. In a parking structure, there would be a pipe to get hydrogen into the car and wires to get electricity out. At times of peak power demand, you could turn the fuel cell on and the car could run as a power plant, crediting the owner's account.

Meanwhile, adding more batteries to conventional hybrid cars, if cost effective, could displace fuel now used for short and, perhaps, medium trips.

Cost-Effective Technologies

The modern car needs to be functional, aesthetic, safe, fuel-frugal, and affordable. Makers of cars and public policy often assume that efficient cars must be small, sluggish, unsafe, ugly, or costly. But integrative design and new technologies can achieve all desired car attributes, today and tomorrow, simultaneously and without compromise. We therefore will not need high fuel taxes or efficiency standards to induce people to buy unattractive cars; rather, they'll want to buy the super-efficient cars because they're *better*, just as most people prefer digital media to vinyl records.

AP/Wide World Photo

An electric car is recharged at an alternative fuel station in San Diego, California.

For conventionally improved cars that do cost more up front, car buyers' short view—looking at just the first two to three years' worth of fuel savings—is a big obstacle. High fuel prices discourage driving but have little effect on car choices because they're diluted by nonfuel costs, then heavily discounted. The most powerful way to influence car choice is "feebates." Within each size class, new-car owners pay a fee or get a rebate—which and how big depend on a car's efficiency—and the fees pay for the rebates. The increased price spread encourages a buyer to buy an efficient model of the size he or she prefers. The buyer saves money; automakers make more profit; national security improves. Such feebates, now starting to emerge around the world (in Canada, France, and some states in the United States), are more effective and politically attractive than fuel taxes or standards.

The car-efficiency revolution faces many challenges, but each can be overcome. Hybrids, invented by Dr. Ferdinand Porsche in 1900, were reengineered nearly a century later by Japanese automakers with strong leadership and balance sheets. These popular hybrids now offer up to doubled efficiency, many with boosted performance as a free bonus.

U.S. automakers are playing catch-up and need help with retooling and retraining (which needn't cost the Treasury). Their choice is stark: whether America will continue to import efficient cars to displace oil, or *make* efficient cars and import neither oil nor cars. A million jobs hang in the balance. But the process Austrian economist Joseph Schumpeter called "creative destruction" is sweeping the overbuilt auto business: The market will change either the managers' minds or the managers, whichever comes first.

China's and India's ambitious automakers will quicken the pace, leapfrogging over Western technology. And countries without an auto industry may choose to start one of a wholly new kind—not based on steel, but more like making computers with wheels than cars with chips.

Altogether, tripled-efficiency cars, trucks, and planes are feasible with today's technology, repaying their extra cost in a year or two. More efficient use of oil in buildings and industry, and substituting saved natural gas and advanced biofuels, could together *eliminate* U.S. oil use by the 2040s, revitalize the economy, and stop 26 percent of carbon dioxide emissions. Getting off oil altogether would cost an average of $15 per barrel (in year 2000 U.S. dollars)—a fifth of the recent world oil price—so the transition will be led by business for profit.

A U.S. version of such a transition was mapped by my team's 2004 Pentagon-cosponsored study *Winning the Oil Endgame*, and implementation is under way—for example, Wal-Mart doubles its heavy trucks' efficiency, Boeing markets the 20 percent-more-efficient (at no extra cost) 787, and the Pentagon explores radically more efficient military platforms whose technology could transform civilian vehicles much as military research and development created the Internet. Other countries can do as well or better if they just aim high, think boldly, and take markets and technological progress seriously. Super-efficient cars, and their analogues in other kinds of vehicles, are among the best ways to make the world richer, fairer, and safer. ■

The opinions expressed in this article do not necessarily reflect the views or policies of the U.S. government.

PROGRESS IN MAKING AFFORDABLE LIGHT AUTO MATERIALS

Amory B. Lovins

Carbon fiber—stiffer and stronger than steel but a third its density—embedded in plastic resin forms very light and strong "advanced composite" material, analogous to wood (cellulose fibers embedded in lignin) or concrete (steel rebar embedded in cement and aggregate). Advanced composites, increasingly familiar in sporting goods, have long been used in military and aerospace structures, but to compete in automaking their production must become about a thousandfold cheaper and faster. The handicraft process for placing the carbon fibers in the proper positions, impregnating them with liquid resin, and slowly baking the combination to "cure" it by a chemical reaction is far too slow and costly for making auto bodies: Specialty cars made in this way, like the Formula One-inspired Mercedes SLR McLaren, cost hundreds of thousands of dollars.

Courtesy DaimlerChrysler

Carbon-fiber composites are used to make doors, hood, and body for the Mercedes-Benz SLR McLaren at a plant in England.

Some automakers are making encouraging progress in bridging this cost gap. BMW has 60 specialists perfecting its proprietary process, which uses the world's biggest resin-transfer-molding press and is already making more than a thousand carbon-fiber roofs and hoods per year for high-end models. Toyota and Honda are widely believed to want to migrate advanced manufacturing technique from their carbon-fiber airplane divisions back to automaking.

Meanwhile, higher-volume production, especially for aerospace (over half the weight of Boeing's new 787 is advanced composites), is making composite materials better and cheaper, and innovators outside the auto industry are developing new manufacturing processes.

For example, a small private Colorado firm, Fiberforge, a firm this writer chairs and owns stock in, is working with automakers, their suppliers, and other industries to commercialize a novel process that appears able at scale to achieve 80 to 100 percent of the performance of hand-layup aerospace composites at 10 to 20 percent of their cost. This process first makes a flat "tailored blank"—super-strong polymer "plywood" with variously oriented layers of carbon fiber and thermoplastic—automatically and precisely formed by a digitally controlled machine akin to an inkjet printer. The tailored blank is then heated until the thermoplastic softens, and stamped on a hot die in a conventional thermoforming press to mold it into the desired complex shape. One minute later, the cooled part is ready to trim and use.

Further information is available at http://www.fiberforge.com/ and in the trade press articles and technical papers linked to that site. ■

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