REINVENTING THE WHEELS

by Amory B. Lovins and L. Hunter Lovins

New ways to design, manufacture, and sell cars can make them ten times more fuel-efficient, and at the same time safer, sportier, more beautiful and comfortable, far more durable, and probably cheaper. Here comes the biggest change in industrial structure since the microchip.

On September 29, 1993, the unthinkable happened. After decades of adversarial posturing, and months of intensive negotiations with Vice President Al Gore, the heads of the Big Three auto makers accepted President Bill Clinton's challenge to collaborate. They committed their best efforts, with the help of government technologies and funding, to developing a tripled-efficiency "clean car" within a decade, and a year later they reported encouraging progress. Like President John F. Kennedy's goal of putting people on the moon, the Partnership for a New Generation of Vehicles (PNGV) aims to create a leapfrog mentality -- this time in Detroit. However, the PNGV's goal is both easier to attain and more important than that of the Apollo program. It could even become the core of a green industrial renaissance -- instigating a profound change not only in what and how much we drive but in how our whole economy works.

The fuel efficiency of cars has been stagnant for the past decade. Yet the seemingly ambitious goal of tripling it in the next decade can be far surpassed. Well before 2003 competition, not government mandates, may bring to market cars efficient enough to carry a family coast to coast on one tank of fuel, more safely and comfortably than they can travel now, and more cleanly than they would with a battery-electric car plus the power plants needed to recharge it.

To understand what a profound shift in thinking this represents, imagine that one seventh of America's gross national product is derived from the Big Three typewriter makers (and their suppliers, distributors, dealers, and other attendant businesses). Over decades they've progressed from manual to electric to type-ball designs. Now they're developing tiny refinements for the forthcoming Selectric XVII. They profitably sell around 10 million excellent typewriters a year. But a problem emerges: the competition is developing wireless subnotebook computers.

That's the Big Three auto makers today. With more skill than vision, they've been painstakingly pursuing incremental refinements on the way to an America where foreign cars fueled with foreign oil cross crumbling bridges. Modern cars are an extraordinarily sophisticated engineering achievement -- the highest expression of the Iron Age. But they are obsolete, and the time for incrementalism is over. Striking innovations have occurred in advanced materials, software, motors, power electronics, microelectronics, electricity-storage devices, small engines, fuel cells, and computer-aided design and manufacturing.

Artfully integrated, they can yield safe, affordable, and otherwise superior family cars getting hundreds of miles per gallon -- roughly ten times the 30 mpg of new cars today and several times the 80-odd mpg sought by the PNGV.

Achieving this will require a completely new car design -- the ultralight hybrid, or "Hypercar" (a term we now prefer to our earlier term "supercar," because that also refers to ultrapowerful cars that get a couple of hundred miles per hour rather than per gallon). The Hypercar's key technologies already exist. Many firms around the world are starting to build prototypes. The United States is best positioned to bring the concept to market -- and had better do so, before others do. Hypercars, not imported luxury sedans, are the biggest threat to Detroit. But they are also its hope of salvation.

The Ultralight Strategy

Decades of dedicated effort to improve engines and power trains have reduced to only about 80-85 percent the portion of cars' fuel energy that is lost before it gets to the wheels. (About 95 percent of the resulting wheelpower hauls the car itself, so that less than one percent of the fuel energy actually ends up hauling the driver.)

This appalling waste has a simple main cause: cars are made of steel, and steel is heavy, so powerful engines are required to accelerate them. Only about one sixth of the average engine's power is typically needed for highway driving, and only about one twentieth for city driving. Such gross oversizing halves the engine's average efficiency and complicates efforts to cut pollution. And the problem is getting worse: half the efficiency gains since 1985 have been squandered on making engines even more powerful.

Every year auto makers add more gadgets to compensate a bit more for the huge driveline losses inherent in propelling steel behemoths. But a really efficient car can't be made of steel, for the same reason that a successful airplane can't be made of cast iron. We need to design cars less like tanks and more like airplanes. When we do, magical things start to happen, thanks to the basic physics of cars.

Because about five to seven units of fuel are needed to deliver one unit of energy to the wheels, saving energy at the wheels offers immensely amplified savings in fuel. Wheelpower is lost in three ways. In city driving on level roads about a third of the wheelpower is used to accelerate the car, and hence ends up heating the brakes when the car stops. Another third (rising to 60-70 percent at highway speeds) heats the air the car pushes aside. The last third heats the tires and the road.

The key to a superefficient car is to cut all three losses by making the car very light and aerodynamically slippery, and then recovering most of its braking energy. Such a design could:

- cut weight (hence the force required for acceleration) by 65-75 percent through the use of advanced materials, chiefly synthetic composites, while improving safety through greater strength and sophisticated design

- cut aerodynamic drag by 60-80 percent through sleeker streamlining and more-compact packaging
- cut tire and road energy loss by 65-80 percent through the combination of better tires and lighter weight.

Once this "ultralight strategy" has largely eliminated the losses of energy that can't be recovered, the only other place the wheelpower can go is into braking. And if the wheels are driven by special electric motors that can also operate as electronic brakes, they can convert unwanted motion back into useful electricity.

However, a Hypercar isn't an ordinary electric car, running on batteries that are recharged by being plugged into utility power. Despite impressive recent progress, such cars still can't carry very much or go very far without needing heavy batteries that suffer from relatively high cost and short life. Since gasoline and other liquid fuels store a hundred times as much useful energy per pound as batteries do, a long driving range is best achieved by carrying energy in the form of fuel, not batteries, and then burning that fuel as needed in a tiny onboard engine to make the electricity to run the wheel motors. A few batteries (or, soon, a carbon-fiber "superflywheel") can temporarily store the braking energy recovered from those wheel motors and reuse at least 70 percent of it for hill climbing and acceleration. With its power so augmented, the engine needs to handle only the average load, not the peak load, so it can shrink to about a tenth the current normal size. It will run at or very near its optimal point, doubling efficiency, and turn off whenever it's not needed.

This arrangement is called a "hybrid-electric drive," because it uses electric wheel motors but makes the electricity onboard from fuel. Such a propulsion system weighs only about a fourth as much as that of a battery-electric car, which must haul a half ton of batteries down to the store to buy a six-pack. Hybrids thus offer the advantages of electric propulsion without the disadvantages of batteries.

One Plus Two Equals Ten

Auto makers and independent designers have already built experimental cars that are ultralight or hybrid-electric but seldom both. Yet combining these approaches yields extraordinary, and until recently little-appreciated, synergies. Adding hybrid-electric drive to an ordinary car increases its efficiency by about a third to a half. Making an ordinary car ultralight but not hybrid approximately doubles its efficiency. Doing both can boost a car's efficiency by about tenfold.

This surprise has two main causes. First, as already explained, the ultralight loses very little energy irrecoverably to air and road friction, and the hybrid-electric drive recovers most of the rest from the braking energy. Second, saved weight compounds. When you make a heavy car one pound lighter, you in effect make it about a pound and a half lighter, because it needs a lighter structure and suspension, a smaller engine, less fuel, and so forth to haul that weight around. But in an ultralight, saving a pound may save more like five pounds, partly because power steering, power brakes, engine cooling, and many other normal systems become unnecessary. The design becomes radically simpler. Indirect weight savings snowball faster in ultralights than in heavy cars, faster in hybrids than in nonhybrids, and fastest of all in optimized combinations of the two.

All the ingredients needed to capture these synergies are known and available. As far back as 1921 German auto makers demonstrated cars that were about one-third more slippery aerodynamically than today's cars are. Most of the drag reduction can come from such simple means as making the car's underside as smooth as its top. Today's best experimental family cars are 35 percent more slippery still. At the same time, ultrastrong new materials make the car's shell lighter. A lighter car needs a smaller engine, and stronger walls can be thin; both changes can make the car bigger inside but smaller outside. The smaller frontal area combines with the sleeker profile to cut through the air with about one third the resistance of today's cars. Advanced aerodynamic techniques may be able to double this saving.

Modern radial tires, too, waste only half as much energy as 1970s bias-ply models, and the best 1990 radials roughly halve the remaining loss. "Rolling resistance" drops further in proportion to weight. The result is a 65-80 percent decrease in losses to rolling resistance, which heats the tires and the road.

Suitable small gasoline engines, of the size found in outboard motors and scooters, can already be more than 30 percent efficient, diesels 40-50 percent (56 percent in lab experiments). Emerging technologies also look promising, including miniature gas turbines and fuel cells -- solid-state, no-moving-parts devices that silently and very efficiently turn fuel into electricity, carbon dioxide, water, and a greatly reduced amount of waste heat.

In today's cars, accessories -- power steering, heating, air conditioning, ventilation, lights, and entertainment systems -- use about a tenth of the engine's power. But a Hypercar would use scarcely more energy than that for all purposes, by saving most of the wheelpower and most of the accessory loads. Ultralights not only handle more nimbly, even without power steering, but also get all-wheel anti-lock braking and anti-slip traction from their special wheel motors. New kinds of headlights and taillights shine brighter on a third the energy, and can save even more weight by using fiber optics to distribute a single pea-sized lamp's light throughout the car. Air conditioning would need perhaps a tenth the energy used by today's car air conditioners, which are big enough for an Atlanta house. Special paints, vented double-skinned roofs, visually clear but heat-reflecting windows, solar-powered vent fans, and so forth can exclude unwanted heat; innovative cooling systems, run not directly by the engine but by its otherwise wasted by-product heat, can handle the rest.

Perhaps the most striking and important savings would come in weight. In the mid-1980s many auto makers demonstrated "concept cars" that would carry four or five passengers but weighed as little as 1,000 pounds (as compared with today's average of about 3,200).

Conventionally powered by internal combustion, they were two to four times as efficient as today's average new car. Those cars, however, used mainly light metals like aluminum and magnesium, and lightweight plastics. The same thing can be done better today with composites made by embedding glass, carbon, polyaramid, and other ultrastrong fibers in special moldable plastics -- much as wood embeds cellulose fibers in lignin.

In Switzerland, where more than 2,000 lightweight battery-electric cars (a third of the world's total) are already on the road, the latest roomy two-seaters weigh as little as 575 pounds without their batteries. Equivalent four-seaters would weigh less than 650 pounds, or less than 850 including a whole hybrid propulsion system. Yet crash tests prove that such an ultralight can be at least as safe as today's heavy steel cars, even if it collides head-on with a steel car at high speed. That's because the composites are extraordinarily strong and bouncy, and can absorb far more energy per pound than metal can. Materials and design are much more important to safety than mere mass, and the special structures needed to protect people don't weigh much. (For example, about ten pounds of hollow, crushable carbon-fiber-and-plastic cones can absorb all the crash energy of a 1,200-pound car hitting a wall at 50 mph.) Millions have watched on TV as Indianapolis 500 race cars crashed into walls at speeds around 230 mph: parts of the cars buckled or broke away in a controlled, energy-absorbing fashion, but despite per-pound crash energies many times those of highway collisions, the cars' structure and the drivers' protective devices prevented serious injury. Those were carbon-fiber cars.

In 1991, fifty General Motors experts built an encouraging example of ultralight composite construction, the sleek and sporty four-seat, four-airbag Ultralite, which packs the interior space of a Chevrolet Corsica into the exterior size of a Mazda Miata. The Ultralite should be both safer and far cleaner than today's cars. Although it has only a 111-horsepower engine, smaller than a Honda Civic's, its light weight (1,400 pounds) and low air drag, both less than half of normal, give it a top speed of 135 mph and a 0-to-60 acceleration of 7.8 seconds -- comparable to a BMW 750iL with a huge V-12 engine. But the Ultralite is more than four times as efficient as the BMW, averaging 62 mpg -- twice today's norm. At 50 mph it cruises at 100 mpg on only 4.3 horsepower, a mere fifth of the wheelpower normally needed.

If equipped with hybrid drive, this 1991 prototype, built in only a hundred days, would be three to six times as efficient as today's cars. Analysts at Rocky Mountain Institute have simulated 300-400-mpg four-seaters with widely available technology, and cars getting more than 600 mpg with the best ideas now in the lab. Last November a four-seater, 1,500-pound Swiss prototype was reported to achieve 90 mpg cruising on the highway; at urban speeds, powered by its 573 pounds of batteries, it got the equivalent of 235 mpg.

Similar possibilities apply to larger vehicles, from pickup trucks to eighteen-wheelers. A small Florida firm has tested composite delivery vans that weigh less loaded than normal steel vans weigh empty, and has designed a halved-weight bus. Other firms are experimenting with streamlined composite designs for big trucks. All these achieve roughly twice normal efficiency with conventional drivelines, and could redouble that with hybrids.

Hypercars are also favorable to -- though they don't require -- ultraclean alternative fuels. Even a small, light, cheap fuel tank could store enough compressed natural gas or hydrogen for long-range driving, and the high cost of hydrogen would become unimportant if only a tenth as much of it were needed as would be to power cars like today's. Liquid fuels converted from sustainable farm and forestry wastes, too, would be ample to run such efficient vehicles without needing special crops or fossil hydrocarbons. Alternatively, solar cells on a Hypercar's body could recharge its onboard energy storage about enough to power a standard southern-California commuting cycle without turning on the engine.

Even if a Hypercar used conventional fuel and no solar boost, its tailpipe could emit less pollution than would the power plants needed to recharge a battery-electric car. Being therefore cleaner, even in the Los Angeles air shed, than so-called zero-emission vehicles (actually "elsewhere-emission," mainly from dirty coal-fired power plants out in the desert), ultralight hybrids should qualify as ZEVs, and probably will. Last May the California Air Resources Board Board reaffirmed its controversial 1990 requirement -- which some northeastern states want to adopt as well -- that two percent of new-car sales in 1998, rising to 10 percent in 2003, be ZEVs. Previously this was deemed to mean battery-powered electric cars exclusively. But, mindful of Hypercars' promise, the CARB staff is considering and in April 1995 finally announcing an intention of broadening the ZEV definition to include anything cleaner. This alternative compliance path could be a big boost both for Hypercar entrepreneurs and for clean air: each car will be cleaner, and far more Hypercars than battery cars are likely to be bought. By providing a large payload, unlimited range, and high performance even at low temperatures, Hypercars vault beyond battery cars' niche-market limitations.

This result brings full circle the irony of California's ZEV mandate. Originally it drew howls of anguish from auto makers worried that people would not buy enough of the costlier, limited-range cars it obliges them to sell. The business press ridiculed California for trying to prescribe an impractical direction of technological development. Yet that visionary mandate is creating the solution to the problems. Like the aerospace, microchip, and computer industries, Hypercars will be the offspring of a technology-forcing government effort to steer the immense power of Yankee ingenuity. For it is precisely the California ZEV mandate that radically advanced electric-propulsion technology -- thereby setting the stage for the happy combination with ultralight construction which we call the Hypercar.

Beyond the Iron Age

The moldable synthetic materials in the GM and Swiss prototypes have fundamental advantages over the metals that now dominate auto making. The modern steel car, which costs less per pound than a McDonald's quarter-pound hamburger, skillfully satisfies often conflicting demands (to be efficient yet safe, powerful yet clean): steel is ubiquitous and familiar, and its fabrication is exquisitely evolved. Yet this standard material could be quickly displaced -- as has happened before. In the 1920s the wooden framing of U.S. car bodies was rapidly displaced by steel. Today composites dominate boatbuilding and are rapidly taking over aerospace construction. Logically, cars are next.

Driving this transition are the huge capital costs of designing, tooling, manufacturing, and finishing steel cars. For a new model, a thousand engineers spend a year designing and a year making half a billion dollars' worth of car-sized steel dies, the costs of which can take many years to be recovered. This inflexible tooling in turn demands huge production runs, maroons company-busting investments if products flop, and magnifies financial risks by making product cycles go further into the future than markets can be forecast. That this process works is an astonishing accomplishment, but it's technically baroque and economically perilous.

Moldable composites must be designed in utterly different shapes. But their fibers can be aligned to resist stress and interwoven to distribute it, much as a cabinetmaker works with the grain of wood. Carbon fiber can achieve the same strength as steel at half to a third of the weight, and for many uses other fibers, such as glass and polyaramid, are as good as or better than steel and 50-85 percent cheaper. But composites' biggest advantages emerge in manufacturing.

Only 15 percent of the cost of a typical steel car part is for the steel; the other 85 percent pays for pounding, welding, and smoothing it. But composites and other molded synthetics emerge from the mold already in virtually the required shape and finish. And large, complex units can be molded in one piece, cutting the parts count to about one percent of what is now normal, and the assembly labor and space to roughly 10 percent. The lightweight, easy-to-handle parts fit together precisely. Painting -- the hardest, most polluting, and costliest step in auto making, accounting for nearly half the cost of painted steel body parts -- can be eliminated by laid-in-the-mold color. Unless recycled, composites last virtually forever: they don't dent, rust, or chip. They also permit advantageous car design, including frameless monocoque bodies (like an egg, the body is the structure), whose extreme stiffness improves handling and safety.

Composites are formed to the desired shape not by multiple strikes with tool-steel stamping dies but in single molding dies made of coated epoxy. These dies wear out much faster than tool-steel dies, but they're so cheap that their lack of durability doesn't matter. Total tooling cost per model is about half to a tenth that of steel, because far fewer parts are needed; because only one die set per part is needed, rather than three to seven for successive hits; and because the die materials and fabrication are much cheaper. Stereolithography -- a three-dimensional process that molds the designer's computer images directly into complex solid objects overnight -- can dramatically shrink tooling time. Indeed, the shorter life of epoxy tools is a fundamental strategic advantage, because it permits the rapid model changes and continuous improvement that product differentiation and market nimbleness demand -- a strategy of small design teams, small production runs, a time to market of only weeks or months, rapid experimentation, maximum flexibility, and minimum financial risk.

Together these advantages cancel or overturn the apparent cost disadvantage of the composites. Carbon fiber recently cost around forty times as much per pound as sheet steel, though increased production is leading manufacturers to quote carbon prices half to a quarter of that. Yet the cost of a mass-produced composite car is probably comparable to or less than that of a steel car, at both low production volumes (like Porsche's) and high ones (like Ford's). What matters is not cost per pound but cost per car: costlier fiber is offset by cheaper, more agile manufacturing.

Shifting Gears in Competitive Strategy

Ultralight hybrids are not just another kind of car. They will probably be made and sold in completely new ways. In industrial and market structure they will be as different from today's cars as computers are from typewriters, fax machines from telexes, and satellite pagers from the Pony Express.

Many people and firms in several countries are starting to realize what Hypercars mean; at least a dozen capable entities, including auto makers, want to sell them. This implies rapid change on an unprecedented scale. If ignored or treated as a threat rather than grasped as an opportunity, the Hypercar revolution could cost the United States millions of jobs and thousands of companies. Auto making and associated businesses employ one seventh of U.S. workers (and close to two fifths of workers in some European countries). Cars represent a tenth of America's consumer spending, and use nearly 70 percent of the nation's lead, about 60 percent of its rubber, carpeting, and malleable iron, 40 percent of its machine tools, 15 percent of its aluminum, glass, and semiconductors, and 13 percent of its steel. David Morris, a cofounder of the Institute for Local Self-Reliance, observes, "The production of automobiles is the world's number-one industry. The number-two industry supplies their fuel. Six of America's ten largest industrial corporations are either oil or auto companies. . . . A recent British estimate concludes that half of the world's earnings may be auto- or truck-related." Whether the prospect of Hypercars is terrifying or exhilarating thus depends on how well we grasp and exploit their implications.

The distribution of Hypercars could be as revolutionary as their manufacture. On average, today's cars are marked up about 50 percent from production costs (which include profit, plant costs, and warrantied repairs). But cheap tooling might greatly reduce the optimal production scale for Hypercars. Cars could be ordered directly from the local factory, made to order, and delivered to one's door in a day or two. (Toyota now takes only a few days longer than that with its steel cars in Japan.) Being radically simplified and ultra-reliable, they could be maintained by technicians who come to one's home or office (Ford does this in Britain today), aided by plug-into-the-phone remote diagnostics. If all this makes sense for a $1,500 mail-order personal computer, why not for a $15,000 car?

Such just-in-time manufacturing would eliminate inventory, its carrying and selling costs, and the discounts and rebates needed to move existing stock that is mismatched to demand. The present markup could largely vanish, so that Hypercars would be profitably deliverable at or below today's prices even if they cost considerably more to make, which they probably wouldn't.

America leads -- for now -- both in start-up-business dynamism and in all the required technical capabilities. After all, Hypercars are much more like computers with wheels than they are like cars with chips: they are more a software than a hardware problem, and competition will favor the innovative, not the big. Comparative advantage lies not with the most efficient steel-stampers but with the fastest-learning systems integrators -- with innovative manufacturers like Hewlett-Packard and Compaq, and strategic-element makers like Microsoft and Intel, more than with Chrysler or Matsushita. But even big and able firms may be in for a rough ride: the barriers to market entry (and exit) should be far lower for Hypercars than for steel cars. Much as in existing high-tech industries, the winners might be some smart, hungry, unknown aerospace engineers tinkering in a garage right now -- founders of the next Apple or Xerox.

All this is alien to the thinking of most (though not all) auto makers today. Theirs is not a composite-molding/electronics/software culture but a diemaking/steel-stamping/mechanical culture. Their fealty is to heavy metal, not light synthetics; to mass, not information. Their organizations are dedicated, extremely capable, and often socially aware, but have become prisoners of past expenditures. They treat those historical investments as unamortized assets, substituting accounting for economic principles and throwing good money after bad. They have tens of billions of dollars, and untold psychological investments, committed to stamping steel. They know steel, think steel, and have a presumption in favor of steel. They design cars as abstract art and then figure out the least unsatisfactory way to make them, rather than seeking the best ways to manufacture with strategically advantageous materials and then designing cars to exploit those manufacturing methods.

The wreckage of the mainframe-computer industry should have taught us that one has to replace one's own products with better new products before someone else does. Until recently few auto makers appreciated the starkness of the threat. Their strategy seemed to be to milk old tools and skills for decades, watch costs creep up and market share down, postpone any basic innovation until after all the executives' planned retirement dates -- and hope that none of their competitors was faster. That's a bet-the-company strategy, because even one superior competitor can put a company out of business, and the company may not even know who the competitor is until too late. The PNGV is stimulating instead a winning, risk-managed strategy: leapfrogging to ultralight hybrids.

It is encouraging that some auto makers now show signs of understanding the problem. In recent months the PNGV has sparked new thinking in Detroit. The industry's more imaginative engineers are discovering that the next gains in car efficiency should be easier than the last ones were, because they will come not from sweating off fat ounce by ounce but from escaping an evolutionary trap. Although good ultralight hybrids need elegantly simple engineering, which is difficult, one can more easily boost efficiency tenfold with Hypercars than threefold with today's cars.

Little of this ferment is visible from the outside, because auto makers have learned reticence the hard way. A long and unhappy history of being required to do (or exceed) whatever they admit they can do has left them understandably bashful about revealing capabilities, especially to Congress. And firms with innovative ambitions will hardly be eager to telegraph them to competitors. Corporations share a natural desire to extract any possible business and political concessions, and to hold back from extending to traditional adversaries (such as the media, politicians, and environmentalists) any trust that could prove costly if abused or not reciprocated. Thus automakers are more likely to understate than to trumpet progress. Also, the Big Three are progressing unevenly, both internally and comparatively: their opacity conceals a rapidly changing mixture of exciting advances and inertia. Only some executives appreciate that Hypercars fit the compelling strategic logic in favor of changing how their companies do business, especially by radically reducing cycle times, capital costs, and financial risks. It is difficult but vital for harried managers to focus on these goals through the distracting fog of fixing flaws in their short-term operations. But signs of rapid cultural change are looming, such as General Motors' announcement, last February 3, that its corporate policy now includes the CERES (Coalition for Environmentally Responsible Economies) Principles, formerly known as the Valdez Principles -- a touchstone of environmentalists.

The Cost of Inaction

The potential public benefits of Hypercars are enormous -- in oil displacement, energy security, international stability, forgone military costs, balance of trade, climatic protection, clean air, health and safety, noise reduction, and quality of urban life. Promptly and skillfully exploited, Hypercars could also propel an industrial renewal. They're good news for industries (many of them now demilitarizing) such as electronics, systems integration, aerospace, software, petrochemicals, and even textiles (which offer automated fiber-weaving techniques). The talent needed to guide the transition is abundant in American labor, management, government, and think tanks, but it's not yet mobilized. The costs of that complacency may be high.

Cars and light trucks use about 37 percent of the nation's oil, about half of which is imported at a cost of around $50 billion a year. We Americans recently put our sons and daughters in 0.56 mpg tanks and 17-feet-per-gallon aircraft carriers because we hadn't put them in 32 mpg cars -- sufficient, even if we'd done nothing else, to have eliminated the need for American oil imports from the Persian Gulf. Of course, more than just oil was at stake in the Gulf War, but we would not have sent half a million troops there if Kuwait simply grew broccoli. Even in peacetime the direct cost to the nation of Persian Gulf oil -- mostly paid not at the pump but in taxes for some $50 billion a year in military readiness to intervene in the Gulf -- totals nearly $100 a barrel of crude, making it surely the costliest oil in the world.

Had we simply kept on saving oil as effectively after 1985 as we had saved it for the previous nine years, we wouldn't have needed a drop of oil from the Persian Gulf since then. But we didn't -- and it cost us $23 billion for extra imports in 1993 alone. Gulf imports were cut by about 90 percent from 1977 to 1985 (chiefly by federal standards that largely or wholly caused new-car efficiency to double from 1973 to 1986). Yet they are now reapproaching a historic high -- the direct result of twelve years of a national oil policy consisting mainly of weakened efficiency standards, lavish subsidies, and the Seventh Fleet.

The national stakes therefore remain large. And even though the PNGV is starting to re-create Detroit's sense of adventure, Hypercars still face formidable obstacles, both culturally within the auto industry and institutionally in the marketplace. Whether or not their advantages make their ultimate adoption certain, the transition could be either unnecessarily disruptive, shattering industrial regions and job markets, or unnecessarily slow and erratic in capturing the strategic benefits of saving oil and rejuvenating the economy. Auto makers should be given strong incentives to pursue the leapfrog strategy boldly, and customers should be encouraged to overcome their well-known lack of interest in buying fuel-thrifty cars in a nation that insists on gasoline cheaper than bottled water.

Market Conditioning and Public Policy

The usual prescription of economists, environmentalists, and the Big Three -- though, it seems, a politically suicidal one -- is stiff gasoline taxes. After painful debate Congress recently raised the gasoline tax by 4.3 cents a gallon, leaving the price, corrected for inflation, the lowest both in the industrial world and in U.S. history. But in Western Europe and Japan taxes that raise the price of motor fuel to two or four times that in the United States have long been in place, with unspectacular results. Gasoline costing two to five dollars a gallon has modestly reduced distances driven but has had less of an effect on the efficiency of new cars bought. New German and Japanese cars are probably less efficient than American ones, especially when performance, size, and features are taken into account. Costlier fuel is a feeble incentive to buy an efficient car, because the fuel-price signal is diluted (in the United States today, by seven to one) by the other costs of owning and running a car. It is, as well, weakened by high consumer discount rates over a brief expected ownership, and often vitiated by company-owned cars and other distortions that shield many drivers from their cars' costs.

This market failure could be corrected by strengthening government efficiency standards. But standards, though effective and a valuable backstop, are not easy to administer, can be evaded, and are technologically static: they offer no incentive to keep doing better. Happily, at least one market-oriented alternative is available: the "feebate."

Under the feebate system, when you buy a new car, you pay a fee or get a rebate. Which and how big depends on how efficient your new car is. Year by year the fees pay for the rebates. (This is not a new tax. In 1990 the California legislature agreed, approving a "Drive+" feebate bill by a seven-to-one margin, although outgoing Governor George Deukmejian vetoed it.) Better still, the rebate for an efficient new car could be based on how much more efficient it is than an old car that's scrapped (not traded in). A rebate of several thousand dollars for each 0.01-gallon-per-mile difference would pay about $5,000 to $15,000 of the cost of an efficient new car. That would rapidly get efficient, clean cars on the road and inefficient, dirty cars off the road (a fifth of the car fleet produces perhaps three fifths of its air pollution). The many variants of such "accelerated-scrappage" incentives would encourage competition, reward Detroit for bringing efficient cars to market, and open a market niche in which to sell them. Feebates might even break the political logjam that has long trapped the United States in a sterile debate over higher gasoline taxes versus stricter fuel-efficiency standards -- as though those were the only policy options and small, slow, incremental improvements were the only possible technical ones.

Perhaps people would buy Hypercars, just as they switched from vinyl records to compact discs, simply because they're a superior product: cars that could make today's most sophisticated steel cars seem clunky and antiquarian by comparison. If that occurred, gasoline prices would become uninteresting. Scholastic debates about how many price elasticities can dance on the head of a pin would die away. The world oil price would permanently crash as superefficient vehicles saved as much oil as OPEC now extracts. Feebates would remain helpful in emboldening and rewarding Detroit for quick adaptation, but perhaps would not be essential. The ultralight hybrid would sweep the market. What then?

Then we would discover that Hypercars cannot solve the problem of too many people driving too many miles in too many cars; indeed, they could intensify it, by making driving even more attractive, cheaper, and nearly free per extra mile driven. Having clean, roomy, safe, recyclable, renewably fueled 300 mpg cars doesn't mean that eight million New Yorkers or a billion still-carless Chinese can drive them. Drivers would no longer run out of oil or air but would surely run out of roads, time, and patience. Avoiding the constraint du jour requires not only having great cars but also being able to leave them at home most of the time. This in turn requires real competition among all modes of access, including those that displace physical mobility, such as telecommunications. The best of them is already being where we want to be -- achievable only through sensible land use.

Such competition requires a level playing field with honest pricing, so that drivers (and everyone else) will both get what they pay for and pay for what they get. But least-cost choices are inhibited today by central planning and socialized financing of car-based infrastructure, such as roads and parking, while alternative modes must largely pay their own way. Happily, emerging policy instruments could foster and monetize fair competition among all modes of access. Some could even make markets in "negamiles" and "negatrips," wherein we could discover what it's worth paying people to stay off the roads so that we needn't build and mend them so much and suffer delays and pollution. Congestion pricing, zoning reforms, parking feebates, pay-at-the-pump car insurance, commuting-efficient mortgages, and a host of other innovations beckon state, local, and corporate experimenters. Yet unless basic and comprehensive transport and land-use reforms emerge in parallel with Hypercars, cars may become apparently benign before we've gotten good enough at not needing to drive them—and may thus derail the reformers.

If the technical and market logic sketched here is anywhere near right, we are all about to embark on one of the greatest adventures in industrial history. Whether we will also have the wisdom to build a society worth driving in -- one built around people, not cars—remains a greater challenge. As T. S. Eliot warned, "A thousand policemen directing the traffic / Cannot tell you why you come or where you go."

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1739 Snowmass Creek Road
Snowmass, Colorado 81654-9199
970/927-3851
Fax: 970/927-3420