CHAPTER 2

# Reinventing the Wheels

## Hypercars and Neighborhoods

*The first automobile industry — Changing the world's industrial structure — Ultralight, hybrid-drive Hypercars — Starting at one percent efficiency — Making light cars safe — The hydrogen-fuel-cell revolution — The end of the Iron Age — Birth control for cars — From commuting to community*

THE LARGEST INDUSTRY IN THE WORLD, AUTOMOTIVE TRANSPORTATION, IS already well along the way to a Factor Four or greater breakthrough in resource productivity. It is also beginning to close its materials loops by adopting durable materials that can be continuously reused to make new cars, and to reduce dramatically its pressure on air, climate, and other key elements of natural capital by completely rethinking how to make a car move. This restructuring of so well established a segment of the economy is gaining its momentum not from regulatory mandates, taxes, or subsidies but rather from newly unleashed forces of advanced technology, customer demands, competition, and entrepreneurship.

Imagine a conversation taking place at the end of the nineteenth century. A group of powerful and farseeing businessmen announce that they want to create a giant new industry in the United States, one that will employ millions of people, sell a copy of its product every two seconds, and provide undreamed-of levels of personal mobility for those who use its products. However, this innovation will also have other consequences so that at the end of one hundred years, it will have done or be doing the following:

- paved an area equal to all the arable land in the states of Ohio, Indiana, and Pennsylvania, requiring maintenance costing more than $200 million per day;
- reshaped American communities and lives so as to restrict the mobility of most citizens who do not choose or are not able to own and operate the new product;
- maimed or injured 250 million people, and killed more Americans than have died in all wars in the country's history;

- be combusting 8 million barrels of oil every day (450 gallons per person annually);
- made the United States increasingly dependent on foreign oil at a cost of $60 billion a year;
- relied for an increasing percentage of that oil on an unstable and largely hostile region armed partly by American oil payments, requiring the United States to make large military expenditures there and maintain continual war-readiness;
- be killing a million wild animals per week, from deer and elk to birds, frogs, and opossums, plus tens of thousands of domestic pets;
- be creating a din of noise and a cloud of pollution in all metropolitan areas, affecting sleep, concentration, and intelligence, making the air in some cities so unbreathable that children and the elderly cannot venture outside on certain days;
- caused spectacular increases in asthma, emphysema, heart disease, and bronchial infections;
- be emitting one-fourth of U.S. greenhouse gases so as to threaten global climatic stability and agriculture;
- and be creating 7 billion pounds of unrecycled scrap and waste every year.

Now imagine they succeeded.

This is the automobile industry — a sector of commerce so massive that in 1998, five of the seven largest U.S. industrial firms produced either cars or their fuel. If this industry can fundamentally change, every industry can. And change it will. This chapter describes how the world's dominant business is transforming itself to become profoundly less harmful to the biosphere.

That transformation reflects, today partially and soon fully, the latest in a long string of automotive innovations. In 1991, a Rocky Mountain Institute design called the Hypercar[1] synthesized many of the emerging automobile technologies. To maximize competition and adoption, the design was put in the public domain (making it unpatentable), hoping this would trigger the biggest shift in the world's industrial structure since microchips. As revolutions go, it started quietly, with simple observations and heretical ideas.

The automobile industry of the late twentieth century is arguably the highest expression of the Iron Age. Complicated assemblages of some fifteen thousand parts, reliable across a vast range of conditions, and greatly improved in safety and cleanliness, cars now cost less per pound than a McDonald's Quarter Pounder. Yet the industry that makes them is overmature, and its central design concept is about to be overtaken. Its look-alike products fight for small niches in saturated core markets; they're now bought on price via the Internet like file cabinets, and most dealers sell new cars at a loss. Until the mid-1990s, the industry had become essentially moribund in introducing innovation. As author James Womack has remarked, "You know you are in a stagnant industry when the big product innovation of the past decade is more cup holders."[2] Virtually all its gains in efficiency, cleanliness, and safety have been incremental and responded to regulations sought by social activists. Its design process has made cars ever heavier, more complex, and usually costlier. These are all unmistakable signs that automaking had become ripe for change. By the 1990s, revolutions in electronics, software, materials, manufacturing, computing, and other techniques had made it possible to design an automobile that would leapfrog far beyond ordinary cars' limitations.

The contemporary automobile, after a century of engineering, is embarrassingly inefficient: Of the energy in the fuel it consumes, at least 80 percent is lost, mainly in the engine's heat and exhaust, so that at most only 20 percent is actually used to turn the wheels. Of the resulting force, 95 percent moves the car, while only 5 percent moves the driver, in proportion to their respective weights. Five percent of 20 percent is one percent — not a gratifying result from American cars that burn their own weight in gasoline every year.

The conventional car is heavy, made mostly of steel. It has many protrusions, edges, and seams that make air flow past it turbulently. Its great weight bears down on tires that waste energy by flexing and heating up. It is powered by an internal combustion engine mechanically coupled to the wheels. Completely redesigning cars by reconfiguring three key design elements could save at least 70 to 80 percent of the fuel it currently uses, while making it safer, sportier, and more comfortable. These three changes are:

1. making the vehicle ultralight, with a weight two to three times less than that of steel cars;
2. making it ultra-low-drag, so it can slip through the air and roll along the road several times more easily; and
3. after steps 1 and 2 have cut by one-half to two-thirds the power needed to move the vehicle, making its propulsion system "hybrid-electric."

In a hybrid-electric drive, the wheels are turned largely or wholly by one or more electric motors; but the electricity, rather than being stored in heavy batteries recharged by plugging into the utility grid when parked (as is true of battery-electric vehicles), is produced onboard from fuel as needed. This could be achieved in any of a wide range of ways: An electric generator could be driven by an efficient gasoline, diesel, Stirling (external-combustion) engine, or by a gas turbine. Alternatively the electricity could be made by a stack of fuel cells — solid-state, no-moving-parts, no-combustion devices that silently, efficiently, and reliably turn hydrogen and air into electricity, hot water, and nothing else.[3]

Electric propulsion offers many key advantages. It can convert upward of 90 percent of the electricity produced into traction. Electric propulsion uses no energy when a vehicle is idling or coasting. Electric motors are light, simple (they contain only one moving part), reliable, inexpensive in volume production, and able even at low speeds to provide high torque — several horsepower continuously, or about ten briefly, from a motor the size of a fist. Finally, a motor that uses electricity to accelerate a car can also act as a generator that recovers electricity by deceleration. Energy recovered by this "regenerative braking" can be reused, rather than wasted, as is the case with mechanical brakes.[4]

Ultralight hybrid-drive autos could be more durable, and could potentially cost less, than traditional cars. Blending today's best technologies can yield a family sedan, sport-utility, or pickup truck that combines Lexus comfort and refinement, Mercedes stiffness, Volvo safety, BMW acceleration, Taurus price, four- to eightfold improved fuel economy (that is, 80 to 200 miles per gallon), a 600 to 800 mile range between refuelings, and zero emissions. Such integration may require one or two decades to be achieved fully, but all the needed technologies exist today.[5]

Hypercars could also decrease by up to tenfold each of four key parameters of manufacturing. These are the time it takes to turn a conceptual design into a new car on the street, the investment required for production (which is the main barrier to new firms' or models' entering the market and the main source of automakers' financial risk), the space and time needed for assembly, and the number of parts in the autobody — perhaps even in the entire car. Together, such decisive advantages would give early adopters a significant economic edge in what is now a trillion-dollar industry.

To introduce Hypercars into the market successfully, new gasoline taxes or government standards are not required. Nor is it necessary to adopt many environmentalists' assumption, and oil drillers' hope, of sharply rising longer-term oil prices. (Such a price hike is unlikely for two reasons. First, there is intense competition from other ways to produce or save energy. Second, like any commodity, oil prices have been perfectly random for at least 118 years,[6] and no important social objective should be made to depend on a random variable.) Nor, finally, would Hypercars be small, sluggish, or unsafe; on the contrary, as an uncompromised and indeed superior product, they would sell for the same reason that people buy compact discs instead of vinyl phonograph records.

For these reasons, during the years 1993–98, the private sector committed roughly $5 billion to developments on the lines of the Hypercar concept — investments that produced an explosion of advances.[7] In April 1997, Daimler-Benz announced a $350 million joint effort with the Canadian firm Ballard to create hydrogen-fuel-cell engines. Daimler pledged annual production of 100,000 such vehicles per year by 2005, one-seventh of its total current production. Six months later, the president of Toyota said he'd beat that goal, and predicted hybrid-electric cars would capture one-third of the world car market by 2005.

In December 1997, a decade earlier than most analysts had expected, Toyota introduced its hybrid-electric Prius sedan. It dominated the innovation-driven Tokyo Motor Show, winning two Car of the Year Awards. Entering the Japanese market for just over $16,000, the Prius sold out two months' production on the first day. Ford meanwhile added more than $420 million to the Daimler/Ballard fuel-cell deal. The next month, GM riposted, unveiling at the Detroit Motor Show three experimental four-seat hybrid models (gas turbine–, diesel-, and fuel-cell-powered) of its EV-1 battery-electric car. GM promised production-ready hybrids by 2001 and fuel-cell versions by 2004. *Automotive News* reported that a marketable Ford P2000 — a 40 percent lighter aluminum sedan whose 60 to 70 mpg hybrid versions had been tested earlier that year — could be in dealerships by 2000. Chrysler showed lightweight, low-cost, molded-composite cars, one of them a 70 mpg hybrid.

In February 1998, Volkswagen's chairman, Ferdinand Piëch (whose grandfather Ferdinand Porsche had invented hybrid-electric propulsion in 1900), said that his company, about to start volume production of a 78 mpg car, would go on to make 118 and then 235 mpg models.

Indeed, by the spring of 1998, at least five automakers were planning imminent volume production of cars in the 80 mpg range.

By mid-1998, Toyota, still expanding Prius production to meet demand and prepare for its U.S. and European release in 2000, revealed plans to market fuel-cell cars "well before 2002." In October 1998, GM confirmed that the combination of fuel cells and electric drive has "more potential than any other known propulsion system." In November 1998, Honda announced that its 70-mpg hybrid would enter the U.S. market in autumn 1999, a year before the Prius.

These innovations are the forerunners of a technological, market, and cultural revolution[8] that could launch an upheaval not only in what and how much we drive but in how the global economy works. Such Hypercars could ultimately spell the end of today's car, oil, steel, aluminum, electricity, and coal industries — and herald the birth of successor industries that are more benign.

Eventually, Hypercars will embody the four different elements of natural capitalism. Their design reflects many forms of advanced resource productivity. Their materials would flow in closed loops, with toxicity carefully confined or designed out and longevity designed in. They are likely to be leased as a service, even as part of a diversified "mobility service," rather than sold as a product. Their direct and indirect transformation of the energy and materials sectors, as discussed below, makes them a powerful way to reverse the erosion of natural capital, particularly global warming — the more so if combined with sensible transportation and land-use policies that provide people mobility without having to own cars.

So what, precisely, is a Hypercar?

## ON THE ROAD TO EFFICIENCY

To correct the loss of 99 percent of the car's energy in between filling its tank and moving its driver, one must address two fundamental design flaws: The vehicle is about twenty times heavier than the driver, and its engine is about ten times larger than average driving requires. Both these flaws are the result of the pioneering choice that Henry Ford made in order to make cars mass-producible and affordable, namely, making them mainly from steel. To accelerate such a heavy vehicle quickly requires a large engine. But the car then needs only one-sixth of its available power to cruise on the highway and severalfold less in the city. The result is a mismatch not unlike asking a three-hundred-pound weightlifter to run marathons: The disparity between the engine's large output capability and its modest normal loads cuts its efficiency in half. Steel is a splendid material if weight is an unimportant or advantageous factor, but in a car, weight is neither. An efficient car can't be made of steel, for the same reason that a good airplane can't. And when cars are designed less like tanks and more like aircraft, magical things start to happen, thanks to the laws of physics.

Detroit has long focused on improving the efficiency of the driveline — the fraction of the fuel's energy that's converted by the engine into torque and then transmitted by the drivetrain to the wheels. But there is an even better approach. The Hypercar concept attacks the problem from the other end, by reducing the amount of power that is needed at the wheels in the first place. Because about five to seven gallons of fuel are required to deliver one gallon's worth of energy to the wheels of a conventional car, increasing energy efficiency *at* the wheels reverses those losses and hence offers immensely amplified savings in fuel.

The power required to move a car can be systematically reduced in three ways. In city driving on level roads, about a third of the power is used to accelerate the car, and hence ends up heating the brakes when the car stops. Another third heats the roughly six to seven tons of air that the car must push aside for each mile it travels — this is called "aerodynamic drag." The last third of the power heats the tires and road in the form of rolling resistance. The key to designing an efficient car, therefore, is to cut all these losses.

Autobodies molded from carbon-fiber composites can cut weight by two- to threefold. This proportionately reduces the losses from both braking and rolling resistance, as well as the size of the propulsion system required to achieve a given acceleration. Such simple streamlining details as making the car's underside as smooth as its top, and slightly smaller frontal area, can together cut air resistance by about 40 to 60-plus percent without restricting stylistic flexibility. The vehicle's lighter weight, combined with doubled-efficiency tires already on the market, can cut rolling resistance by about 66 to 80 percent.[9] Together, these changes can cut by half or more the power needed to move the car and its passengers — and can therefore cut by severalfold the amount of fuel needed to deliver that reduced power.

In the mid-1980s, many automakers demonstrated concept cars — handmade models for testing new ideas — that could carry four to five passengers but weighed as little as a thousand pounds, one-third as much as the average new U.S. car today. Conventionally powered, they were two to four times as efficient as today's average new car, but were made from light metals like aluminum and magnesium. The same results can now be achieved even better by replacing the stamped metal body with molded composite materials made by embedding carbon, Kevlar (polyaramid), glass, and other ultrastrong fibers in special moldable plastics. Such advanced-composite cars could weigh initially about 1,500 pounds for a six-seater comparable in volume to a 3,140-pound Ford Taurus, and could be trimmed to perhaps 1,300 pounds or less with further refinement. A typical four-to-five-seat sedan could weigh a few hundred pounds less.

Special attention devoted to making the car ultralight is important because saved weight multiplies. Making a heavy car one pound lighter actually makes it about a pound and a half lighter, because it needs lighter structure and suspension to support that weight, a smaller engine to move it, smaller brakes to stop it, and less fuel to run the engine. Saving a pound in an ultralight car saves even more weight, because the vehicle's components do not merely become smaller; some may even become unnecessary. For example, power steering and power brakes are not required for easy handling of such light vehicles. A hybrid-electric drive becomes small and cheap enough to be especially attractive in such a light car, and it can in turn eliminate the clutch, transmission, driveshaft, universal joints, axles, differentials, starter, alternator, et cetera. Special characteristics of the ultralight body and glazings can also combine with innovative techniques to reduce noise and to provide comfort, lights, and other accessory services with severalfold less energy and weight.

## MAKING A LIGHT CAR SAFE

Henry Ford said that a light man can outrun a heavy man: Weight is not a prerequisite for strength. Today's advanced-composite materials make this especially true: Crash tests have proven that innovative ultralight designs are at least as safe as standard cars, even in high-speed collisions with bridge abutments or with heavy steel vehicles. Composites are so extraordinarily strong that they can absorb five times more energy per pound than steel. About ten pounds of hollow, crushable carbon-fiber-and-plastic cones can smoothly absorb the entire crash energy of a 1,200-pound car hitting a wall at 50 mph. Such properties permit novel safety designs that can more than offset ultralight cars' disadvantage in mass when colliding with heavy sport-utility vehicles.

Millions have watched news coverage of Indy 500 race cars crashing into walls. These are ultralight carbon-fiber cars whose parts are designed to dissipate crash energy by controlled buckling or breaking away. Despite being subjected to crash energies many times those of highway accidents, the car's structure and the driver's protective devices typically prevent serious injury. Hypercars would combine this materials performance with a design that copes with the full range of possible accidents. Metaphorically, the approach could be described as "people, cushioned in foam, surrounded by a superstrong nutshell, wrapped in bubblepack." Ultralight cars, while protecting their own occupants, also pose less danger to passengers in the vehicles they hit — reversing the senseless "mass arms race" of ever heavier juggernauts. Additional safety features, ranging from all-wheel traction to blind-spot sensors, from always-dry electronic rearview mirrors to nimble handling, could make accidents less likely to happen in the first place.

### THE ECONOMICS OF ULTRALIGHTING

Hypercars gain much of their advantage by abandoning nearly a century of materials and manufacturing experience based on steel. This notion might at first appear quixotic. Steel is ubiquitous and familiar, and its fabrication highly evolved. The modern steel car expertly satisfies often conflicting demands — to be efficient yet relatively safe, powerful yet relatively clean. Most automakers still believe that only steel is cheap enough for affordable cars, and that alternatives like carbon fiber are prohibitively costly. Yet industrial history is filled with examples in which standard materials have been quickly displaced. U.S. autobodies switched from 85 percent wood in 1920 to over 70 percent steel in 1927. The same Detroit executives who think polymer composites will never gain much of a foothold in automaking may in fact spend their weekends zooming around in glass-and-polyester-composite boats: Synthetic materials already dominate boatbuilding and are making rapid gains in aerospace construction. Logically, cars are next, because new manufacturing methods, and new ways of thinking about the economics of producing an entire vehicle, suggest that steel is a cheap material but is costly to make into cars, while carbon fiber is a costly material but is cheap to make into cars.

Carbon fibers are black, shiny, stiff filaments finer than a human hair, and one-fourth as dense as steel but stiffer and stronger. In 1995, structural carbon fiber cost about twenty times as much per pound as did steel. By 2000, the ratio may fall to about twelve. But if aligned properly to match stress and interwoven to distribute it, the same strength and stiffness as steel can be achieved with two or three times fewer pounds of carbon fiber, embedded in a strong polymer "matrix" to form a composite material. Moreover, for many uses, such fibers as glass and Kevlar are as good as or better than carbon and are two to six times cheaper. Combinations of fibers offer vast design flexibility to match exactly the properties that a given part needs. Composites also make it possible to use the lightest-weight body designs, including truly frameless "monocoques" (like an egg, the body *is* the structure) whose extreme stiffness improves handling and safety. (If you doubt the strength of a thin, stiff, frameless monocoque, try eating a lobster or a crab claw with no tools.) Such designs economize on the use of costly materials, needing only about one hundred pounds of carbon fiber per car.

Carbon fiber, even if frugally used, still looks too costly per pound. But cost per pound is the wrong basis for comparison, because cars are sold by the car, not by the pound, and must be manufactured from their raw materials. Only about 15 percent of the cost of a typical steel car part is for the steel itself; the rest pays for pounding, welding, and finishing it. But composites and other molded synthetics emerge from a mold *already* shaped and finished. Even very large and complex units can be molded in a single piece. A composite autobody needs only about five to twenty parts instead of a steel unibody's two hundred to four hundred. Each of those hundreds of steel parts needs an average of four tool-steel dies, each costing an average of $1 million. Polymer composites, in contrast, are molded to the desired shape in a single step, using low-pressure molding dies that can even be made of coated epoxy, cutting tooling costs by up to 90 percent. More savings arise in the manufacturing steps after the autobody is formed, where assembly effort and the space to carry it out decrease by about 90 percent. The lightweight, easy-to-handle parts can be lifted without a hoist. They fit together precisely without rework, and are joined using superstrong glues instead of hundreds of robotized welds. Painting — the costliest, most difficult, and most polluting step in automaking, which accounts for one-fourth to one-half the total finished cost of painted steel body parts — can be eliminated by lay-in-the-mold color. Together, these features can make carbon-fiber autobodies competitive with steel ones.[10]

The differences between using steel and composites are profound at every level of manufacturing. For a conventional new car model, a thousand engineers spend a year designing and a year making more than a billion dollars' worth — a football field–full — of car-sized steel dies whose cost can take years, even decades, to recover. This inflexible tooling in turn demands huge production runs, and magnifies financial risks by making product cycles last far longer than markets can be reliably forecast. If the product fails, huge investments are effectively lost. Hypercars' soft tools, roughly shapable overnight, reverse these disadvantages. The Hypercar strategy exploits small design teams, low production runs, very low break-even volume per model, rapid experimentation and model diversification, and greater flexibility. The combination of low capital intensity and fast product cycles is less financially risky, combines processes that have been individually demonstrated, and should be cleaner and safer for workers.[11]

### HYBRID-ELECTRIC PROPULSION AND THE HYDROGEN-FUEL-CELL REVOLUTION

Hypercars share with battery-electric cars the use of very efficient electric motors to turn their wheels, and the ability to recover much of the braking energy for reuse. However, Hypercars differ from battery-electric cars not only in their much lighter weight but also in their source of electricity. Despite impressive recent progress, batteries recharged from the utility grid continue to be too heavy, costly, and short-lived a way to store enough energy for much driving range. Battery-electric vehicles, as Professor van den Koogh of the University of Delft put it, are "cars for carrying mainly batteries — but not very far and not very fast, or else they would have to carry even more batteries."

Since gasoline and other liquid fuels store a hundred times as much useful energy per pound as do batteries, a long driving range is best achieved by carrying energy in the form of fuel, then converting it into electricity as needed using a small onboard engine, turbine, or fuel cell. The hybrid drive system is small, can be sized closer to typical driving loads because the engine need not be directly coupled to the wheels, and runs very near its optimal conditions at all times. As a result, a modern hybrid-electric drive system weighs only about one-third as much as the half ton of batteries required for a battery-electric car, and its temporary energy storage capacity need be only a few percent as large. Hybrids thus offer all the advantages of electric propulsion sought and elicited by California's Zero Emission Vehicle requirement, but without the disadvantages of batteries.

Depending on the choice of onboard power plant, Hypercars could use gasoline or any clean alternative fuel, including liquids made from farm and forest wastes.[12] Enough such "biofuels" are available to run a very efficient U.S. transportation system without needing special crops or fossil hydrocarbons. Compressed natural gas or hydrogen would also become convenient fueling options in such efficient cars, because even a small, light, affordable tank can store enough gaseous fuel for long-range driving — especially if the fuel is hydrogen and it is used in a fuel cell whose very high efficiency further increases that of the vehicle itself.

But Hypercars' greatest impact may lie in their transformation not only of the automobile, oil, steel, and aluminum industries but also of the coal and electricity industries. If this takes place, it will be because the cleanest and most efficient known way to power a Hypercar is a hydrogen fuel cell — a technology invented in 1839 but only achieving in the 1990s the breakthroughs needed for widespread deployment.

You already know the principle of a fuel cell if in high-school chemistry class you did the experiment of passing an electric current through water in a test tube, splitting the water into bubbles of hydrogen and oxygen. That process is called "electrolysis." A fuel cell simply does the same thing backward: It uses a thin, platinum-dusted plastic membrane[13] to combine oxygen (typically supplied as air) with hydrogen to form electricity, pure hot water, and nothing else. There is no combustion. The electrochemical process, akin to a battery's but using a continuous flow of fuel, is silent, rugged, and the most efficient and reliable known way to turn fuel into electricity at any scale, from running a hearing aid[14] to a factory. Submariners and astronauts drink fuel cell's by-product water. Mayors are photographed drinking the water coming out the tailpipes of the fuel-cell buses being tested in Vancouver and Chicago.

To be competitively used in Hypercars, fuel cells need to become less expensive, which will occur if they are engineered for mass production and produced in sufficient quantities. The cells use a modest amount of relatively simple (though sophisticated) materials — and are potentially much easier to fabricate than, say, car engines, with their thousand-odd moving metal parts. It is a truism of modern manufacturing, verified across a wide range of products, that every doubling of cumulative production volume typically makes manufactured goods about 10 to 30 percent cheaper. There's every reason to believe fuel cells will be subject to the same trends. In 1998, fuel-cell prototypes handmade by PhDs cost around $3,000 per kilowatt. In early mass production — say, around 2000 to 2001 — a kilowatt will probably fall to $500 to $800, and over the following few years, to around $100 as production expands and design improves. That's only severalfold more than the cost of today's gasoline engine/generators (after more than a century of refinement), about tenfold cheaper than a coal-fired power station, and severalfold cheaper than just the *wires* to deliver that station's power to your building, where the fuel cell could already be located. When fuel cells are manufactured in very large volumes, they could become extremely cheap — probably less than $50 per kilowatt,[15] which is about a fifth to a tenth the cost of today's cheapest power stations. Most automakers assume they need to attain such low costs before fuel cells can compete with internal combustion engines. Hypercars, however, being so light and aerodynamic, need less power — fewer kilowatts — and so can tolerate costs around $100 per kilowatt, enabling them to start adopting fuel cells years earlier.[16]

A sufficient production volume to achieve $100 per kilowatt could readily come from using fuel cells first in buildings — a huge market that accounts for two-thirds of America's electricity use. The reason to start with buildings is that fuel cells can turn 50 to 60-odd percent of the hydrogen's energy into highly reliable, premium-quality electricity, and the remainder into water heated to about 170°F — ideal for the tasks of heating, cooling, and dehumidifying. In a typical structure, such services would help pay for natural gas and a fuel processor[17] to convert it into what a fuel cell needs — hydrogen. With the fuel expenses thus largely covered, electricity from early-production fuel cells should be cheap enough to undercut even the operating cost of existing coal and nuclear power stations, let alone the extra cost to *deliver* their power, which in 1996 averaged 2.4 cents per kilowatt-hour.[18] Electric or gas utilities could lease and operate the fuel cells most effectively if they initially placed them in buildings in those neighborhoods where the electrical distribution grid was fully loaded and needed costly expansions to meet growing demand, or where fuel cells' unmatched power quality and reliability are valued for special uses like powering computers.

Once fuel cells become cost-effective and are installed in a Hypercar, the vehicle becomes, in effect, a clean, silent power station on wheels, with a generating capacity of around 20 to 40 kilowatts. The average American car is parked about 96 percent of the time, usually in habitual places. Suppose you pay an annual lease fee of about $4,000 to $5,000 for the privilege of driving your "power plant" the other 4 percent of the time. When you are not using it, rather than plugging your car into the electric grid to recharge it — as battery cars require — you plug it in as a generating asset. While you sit at your desk, your power-plant-on-wheels is sending 20-plus kilowatts of electricity back to the grid. You're automatically credited for this production at the real-time price, which is highest in the daytime. Thus your second-largest, but previously idle, household asset is now repaying a significant fraction of its own lease fee. It wouldn't require many people's taking advantage of this deal to put all coal and nuclear power plants out of business, because ultimately the U.S. Hypercar fleet could have five to ten times the generating capacity of the national grid.

For fuel-cell cars, the often-expressed concerns about hydrogen safety are misplaced. Although no fuel is free from potential hazard, carrying compressed hydrogen around in an efficient car could actually be safer than carrying an equivalent-range tank of gasoline.[19] The car's modest inventory of hydrogen[20] would typically be stored in an extremely strong carbon-fiber tank. Unlike spilled gasoline, escaped hydrogen likes nothing better than to dissipate — it's very buoyant and diffuses rapidly. While it does ignite easily, ignition requires a fourfold richer mixture in air than gasoline fumes do. Making hydrogen explode requires an eighteenfold richer mixture plus an unusual geometry. Moreover, a hydrogen fire can't burn you unless you're practically inside it, in contrast to burning gasoline and other hydro*carbons* whose white-hot soot particles emit searing heat that can cause critical burns at a distance. (Because of the gas's unique burning properties, no one was directly killed by the hydrogen fire in the 1937 *Hindenburg* disaster. Some died in a diesel-oil fire or by jumping out of the airship, but all sixty-two passengers who rode the flaming dirigible back to earth, as the clear hydrogen flames swirled upward above them, escaped unharmed.[21]

Another common objection to hydrogen-fueled cars — that the first such car can't be sold until the whole country is laced with hydrogen production plants, pipelines, and filling stations costing hundreds of billions of dollars — is equally misplaced. The fueling apparatus can instead be built up with existing methods and markets in a strategy that's profitable at each step, starting now. At first, fuel-cell cars could be leased to people who work in or near the buildings in which fuel cells have already been installed. Those cars can then refuel using surplus hydrogen that the buildings' fuel processors make in their spare time. Meanwhile, those same mass-produced fuel processors will start to be installed outside buildings too. Such "gas stations" can be more profitable than those that sell gasoline today, and they won't need a new distribution system because they'll exploit idle offpeak capacity in the existing natural-gas and electricity distribution systems. Competition between those energy sources will force hydrogen prices downward to levels Ford Motor Co. predicts will beat gasoline's present cost per mile.

Hydrogen production already uses 5 percent of U.S. natural gas, mainly in refineries and petrochemical plants.[22] As decentralized production expands the market for hydrogen to run fuel cells in buildings, factories, and vehicles, more centralized production methods and pipeline delivery will become attractive. An especially profitable opportunity will involve reforming natural gas at the wellhead, where a large plant can strip out the hydrogen for shipment to wholesale markets via new or existing pipelines. Professor Robert Williams of Princeton University points out[23] that the other product of the separation process, carbon dioxide, could then be reinjected into the gas field, adding pressure that would help recover about enough additional natural gas to pay for the reinjection. The carbon would then be safely "sequestered" in the gas field, which can typically hold about twice as much carbon in the form of $CO_2$ as it originally held in the form of natural gas. The abundant resources of natural gas — at least two centuries' worth — could thus be cleanly and efficiently used in fuel-cell vehicles, and in fuel-cell-powered buildings and factories, without harming the earth's climate. The hydrogen provider would be paid three times: for the shipped hydrogen, for the enhanced recovery of natural gas, and a third time, under future Kyoto Protocol trading, for sequestering the carbon. This opportunity is already leading several major oil and gas companies to move into the hydrogen business. Using electricity to split water to produce hydrogen can also be climatically benign if the electricity is derived from such renewable sources as solar cells or wind farms, which can often earn a far higher profit selling hydrogen than electricity.

The more widely hydrogen is used, the more its climatically benign production — from wind farms, natural-gas fields, biofuels, et cetera — will expand to meet the demand. Retail price competition will be strong, because the four main ways to generate hydrogen — upstream and downstream, from electricity and from natural gas — will all be vying for the same customers. The technology to accomplish this already exists; the main task remaining is to trigger this commercialization strategy by manufacturing enough fuel cells so they become cheap and ubiquitous. The companies aiming to do so over the next few years read like a *Who's Who* of formidable technological and manufacturing firms worldwide.

This combination of technologies can abate, at a profit, close to two-thirds of America's carbon-dioxide emissions while preserving the mobility, safety, performance, and comfort of traditional cars. But with or without fuel cells, successful Hypercars and their cousins, from superefficient buses and trucks[24] to hybrid-electric bicycles[25] and low-cost ultralight rail vehicles,[26] will ultimately save as much oil as OPEC now sells, making gasoline prices both low and irrelevant. Between Hypercars and other new ways to displace oil at lower cost in each of its main uses today, oil will most likely become uncompetitive even at low prices before it becomes unavailable even at high prices.[27] Like most of the coal and all of the uranium now in the ground, oil will eventually be good mainly for holding up the ground.

## BEYOND THE IRON AGE

A Hypercar, weighing two to three times less than a conventional car, would require about 92 percent less iron and steel, one-third less aluminum, three-fifths less rubber, and up to four-fifths less platinum. It typically would need no platinum unless it was powered by fuel cells, in which case it would use less platinum than is now in a catalytic converter. Further refinements would eliminate about three-fifths of the remaining other metals except copper.[28] The Hypercar design would double each vehicle's polymer content, but even if every U.S.-made automobile were a Hypercar, America's total use of polymers would rise by only 3 percent — less than a year's average growth.[29]

Initially, the manufacturing of Hypercars would reduce the U.S. steel industry's tonnage by about a tenth and raise carbon-fiber production volume by about a hundredfold. This level of demand should turn carbon fiber from a specialty product into a normal commodity, and reduce its cost by two- or even threefold from the 1998 bulk price of seven to eight dollars a pound. A drop in price would, in turn, make carbon fiber competitive with steel in most other industrial applications as well, from beams and girders to refrigerator shells to rebar. Hypercars would require about a tenfold lesser flow of such consumable fluids as oil, antifreeze, and brake and transmission fluids (fourteen kinds in all are used in a standard automobile), and there would be a similarly decreased flow of the twenty-one most routinely replaced automotive parts.[30] The rust-free, fatigue-free, nonchipping, nearly undentable composite body would last for decades until it was eventually recycled.[31] Together with reduced materials flows in the processing industries upstream, each Hypercar could thus represent a total saving of materials dozens of times its own weight — a total of billions of tons per year.

Best of all for the owner, the complex mechanical systems of the traditional automobile would be largely replaced by solid-state electronics and software. The most immediate benefit would be that the twenty or so most frequent mechanical causes of breakdowns *would no longer be components of the car at all.* Instead, a wireless link with the factory could keep the car up-to-date, calibrated, and tuned, improving its reliability. An expanding range of intelligent software features would enhance safety, economy, security, convenience, and customizability.

## HOW DO YOU GET THERE FROM HERE?

The inherent advantages of Hypercars should make them a rapid success with drivers. However, the additional strategic advantages they offer of saving oil, protecting the climate, and strengthening the economy may justify giving automakers strong incentives to pursue their introduction into the marketplace even more aggressively. One powerful stimulus adoptable at the state level would be "feebates":[32] Whenever a customer bought a new car, he or she'd either pay a fee or receive a rebate. Which alternative and how large an amount would be involved would depend on how efficient the vehicle was. Year by year, the fees would pay for the rebates.[33] An even better strategy would involve basing the rebate for a new car on how much more efficient it is than the old car that's scrapped rather than traded in.[34] This plan would encourage competition, reward automakers for bringing efficient cars to market, and open a market niche into which to sell them — a series of benefits that has lately led GM to express interest in the concept.

Because ultralight hybrids are not just another kind of car, they will probably be made and sold in completely novel ways. Car-industry jobs will shift, though their total number could well be sustained or increased.[35] The entire market structure will change, too. Today's cars are marked up an average of about 50 percent from their production cost; more Americans sell cars than make cars. But inexpensive tooling might make Hypercars' optimal production scale as small as that of a regional soft-drink bottling plant. Cars could be ordered directly from a local factory, made to order, and delivered to a customer's door in a day or two. Such just-in-time manufacturing would eliminate inventory, its carrying and selling costs, and the discounts and rebates needed to move premade stock that's mismatched to current demand. Being simple and reliable, Hypercars could be maintained automatically by supplementing their wireless remote diagnostics with technicians' housecalls, as Ford does in Britain today. Since this market structure makes sense today for a $1,500 mail-order personal computer, why should it not work for a $15,000 car?[36]

America leads — for now — both in startup-business dynamism and in all the required technical capabilities to assume leadership in the Hypercar industry. The main obstacles are no longer technical or economic but cultural. As energy analyst Lee Schipper remarked, big automakers start with two major disadvantages, namely that they're big, and that they're automakers. Hypercars will more resemble computers with wheels than they do cars with chips. They will be driven more by software than by hardware, and competition will favor not the most efficient steel-stampers but the fastest-learning systems integrators and simplifiers. Manufacturers like Dell and systems companies like Sun Microsystems or Intel may fare better in the business than companies like GM or Mitsubishi. As Professor Daniel Roos of MIT told the 1998 Paris Auto Show, "In the next 20 years, the world automotive industry will be facing radical change that will completely alter the nature of its companies and products. . . . In two decades today's major automakers may not be the drivers of the vehicle industry; there could be a radical shift in power to parts and system suppliers. Completely new players, such as electronics and software firms, may be the real competitors to automakers."

**BEYOND EFFICIENCY: THE BEST ACCESS AT THE LEAST COST**

One problem that Hypercars cannot solve is that of too much driving by too many people in too many cars: Hypercars could worsen traffic and road congestion by making driving even cheaper and more attractive. U.S. gasoline is now cheaper than bottled water. Dr. Paul MacCready points out that in 1986 dollars, buying the fuel to drive an average new car 25 miles cost about $4 in 1929, $3 in 1949, $2 in 1969, and $1 in 1989. Extrapolation would reach zero in 2009. Hypercars could make that right within about a nickel. The fuel saved by the 1980s doubling of U.S. new-car efficiency was promptly offset by the greater number of cars and more driving: America has more licensed drivers than registered voters. Global car registrations are growing more than twice as fast as the population — 50 million cars in 1954, 350 million in 1989, 500 million in 1997.[37] Fifteen percent of the world's people own 76 percent of its motor vehicles, and many of the other 85 percent desire their own as well. Standard projections suggest that global travel (person-miles per year) will more than double from 1990 to 2020, then redouble by 2050, with world car travel tripling from 1990 to 2050.[38] The transportation sector is the fastest-growing and apparently most intractable source of carbon emissions (21 percent of the global energy-related total). In part this is because it is the most subsidized and centrally planned sector of the majority of the world's economies — at least for such favored modes as road transport and aviation. It has the least true competition among available modes, and the most untruthful prices.

For these reasons, it is even more important to extend Hypercars' gains in resource productivity by making any kind of car less necessary. This could multiply the cars' efficiency gains by reductions in cars and driving to yield Factor Ten or greater overall savings. The key is to promote effective community design to enable more access with less driving. You could still pile the family in the car whenever you wanted and drive from Los Angeles to a magnificent national park — but when you got there, you'd actually be able to see it.

With or without Hypercars, the problem of excessive automobility is pervasive.[39] Congestion is smothering mobility, and mobility is corroding community. People demand a lot of travel and have few non-automotive ways to do it. This effectively immobilizes everyone too old, young, infirm, or poor to drive — a group that includes one-third of all Americans, and whose numbers are rising. Street life and the public realm are sacrificed as we meet our neighbors only through windshields. As architect Andres Duany puts it, this stratification "reduces social interactions to aggressive competition for square feet of asphalt."

A fleet of 200 mpg, roomy, clean, safe, recyclable, renewably fueled cars might keep drivers from running out of oil, climate, or clean air, but they'd instead run out of roads, land, and patience — the new constraints *du jour.* Many of the social costs of driving have less to do with fuel use than with congestion, traffic delays, accidents, roadway damage, land use, and other side effects of driving itself. Those social costs approach a trillion dollars a year — about an eighth of America's gross domestic product. Because that figure is not reflected in drivers' direct costs, the expenses are in effect subsidized by everyone.[40]

Cars cause extensive pollution-induced illness and social problems. Road accidents cost about $90 billion annually by killing over 40,000 Americans, about as many as diabetes or breast cancer, and injuring 5 million more. Globally, car accidents are the fifth- and will soon be the third-largest cause of death: They currently kill a half million people and injure 15 million more every year.[41] If automobility were a disease, vast international resources would be brought to bear to cure it.

In fact, a cure has already been broadly defined, but it is a complex solution made of many details that will take time to implement. Creative public-policy instruments can introduce market mechanisms that would reconfigure a transportation system long dependent on subsidies and central planning. Three mutually supportive types of solutions are emerging that:

1. Make parking and driving bear their *true costs.*
2. Foster genuine *competition* between different modes of transportation.
3. Emphasize sensible *land use* over actual physical mobility — a symptom of being in the wrong place.

Ever since ancient Rome suffered from chariot congestion,[42] urban congestion has been abetted by the overprovision of apparently free roads and parking — that is, by underpricing or not pricing road and parking resources.[43] However, instead of today's nearly universal U.S. practice of providing "free" parking occupying up to several times as much area as workers' office space, employers could instead charge fair market value for parking and pay every employee a commuting allowance of equal after-tax value. Workers — a third of whose household driving miles are for commuting — could then use that sum to pay for parking, *or* find access to work by any cheaper method — living nearby, walking, biking, ridesharing, vanpooling, public transit, or telecommuting.[44] Users of alternatives could pocket the difference. This "parking cash-out" concept is now the law in California for firms of fifty-plus people in smoggy areas. Reportedly, many of the firms that have implemented it are extremely pleased with the results.[45] In 1997, Congress encouraged its wider use.

Most American building regulations require developers to provide as much parking for each shop, office, or apartment as people would demand *if parking were free.* This misconceived rule diverts investment from buildings into parking spaces, making affordable housing scarcer.[46] In contrast, a San Jose, California, city council member once proposed that developers of workplaces and multi-unit downtown housing be forbidden to provide a parking place but instead be required, at far lower cost, to provide a perpetual transit pass with each unit. In Frankfurt, Germany, an office cannot be built with associated parking: Workers must buy their own. Britain is authorizing local taxation of firms that provide free or below-market employee parking.[47] Metropolitan Sydney taxes many nonresidential parking spaces to fund suburban railway-station parking and other transit improvements. In Tokyo, you can't buy a car without proving that you own or rent a place to park it. Stockholm even proposed issuing a monthly permit to allow residents to drive downtown — but the same permit would also serve as a free pass to the regional transit system (which it funds). In many American cities, allowing residents to rent out their daytime parking spaces could yield enough income to pay their home property tax.[48]

Excessive Western automobility is analogous to the extravagantly wasteful use of energy in the former Soviet Union, where it was typically priced at less than one-third of its production cost. Of course, people used it lavishly. But once true social costs began to be reflected in prices, people began to consume energy far more efficiently and sensibly. Pretending that driving is free has imposed a comparable tide of unsupportable costs.[49] Slowly, citizens and governments at all levels are realizing that drivers must start to pay the costs they incur.

Singapore's prosperity could have turned it into another bumper-to-bumper Bangkok, whose congestion — gridlocking the average driver the equivalent of forty-four full days a year — is estimated to reduce Thailand's entire GDP by about one-sixth. Yet Singapore is rarely congested, because it taxes cars heavily, auctions the right to buy them, imposes a US$3 to 6 daily user fee on anyone driving downtown, *and* channels the proceeds into an excellent transit system. Just the morning-rush-hour $3 entry fee cut the number of cars entering the city by 44 percent and solo trips by 60 percent, helping traffic move up to 20 percent faster. London now hopes to follow suit, expecting twice the speed gain from a $1 charge.[50]

Charging more to use roads, tunnels, bridges, or parking areas when they're most crowded[51] is easy with the kinds of electronic passes that already debit drivers' accounts as they whiz through tollgates in roughly twenty states. Accurate price signals can then be effectively augmented by physical redesign of roadways. Converting existing highway lanes to high-occupancy-vehicle lanes — and thus enabling faster driving — is one of many incentives for moving the same amount of passengers in fewer cars. From Europe to Australia, "traffic calming" — slowing cars with narrow streets set with trees and planters — is emerging as an effective means of slowing and discouraging driving so people can reclaim their neighborhoods.[52] It repays its cost twice over in avoided accidents alone: Contrary to a traffic-engineering dogma now being belatedly abandoned, properly designed narrow streets are actually safer than wide ones.[53] In America, where most streets are wide and most driving on them is fast, "people are more likely to be killed in the suburbs by a car than in the inner city by a gun."[54] In contrast, safety and quality-of-life concerns spurred Amsterdam to ban cars gradually from its central district: The city has begun by introducing wider sidewalks and new bike lanes, much scarcer and costlier parking, and an eighteen-mile-an-hour urban speed limit. Four other Dutch cities are developing similar plans. Such initiatives tend to be self-reinforcing. In a country like Denmark, where bikes outnumber cars two to one (four to one in current sales) and where walking and buses are widely used, there's no need for "huge roads and parking lots. This keeps towns and villages walkable, bikeable and transit-reachable."[55] Danes are thus reversing the dynamics of more cars, more sprawl, and more driving — a vicious circle that increased the average U.S. commute by over 30 percent during the years 1983–90.[56]

Reducing traffic dangers and removing barriers to walking and biking can help these individual methods of "individual mass transit,"[57] which already account for as much as 30 to 40 percent of all trips in some major European cities.[58] Yet around 1990, although some 54 percent of working Americans lived within five miles of their workplace, only 3 percent biked to work and even fewer walked. The stakes are high: A Canadian analysis found that if only 5 percent of non-rush-hour mileage in North America were shifted from cars to bikes, the social savings could top $100 billion.[59] In pursuit of those benefits, some communities are becoming more bicycle-friendly. Pasadena, California, has even found it cost-effective to give free bicycles to city workers who promise to commute with them, and plans to expand this to the general public, imitating the heavily used 2,300-free-bike ($3 deposit) program in Copenhagen. Palo Alto, California, requires office buildings to offer lockers and showers for bike commuters. A big boost for U.S. bicycling may prove to be the police departments whose bike units are reporting greater policing effectiveness, better community relations, and 10- to 25-fold lower equipment costs.[60]

As land-use and transportation choices improve, alternatives to single-family car ownership also start to become attractive. Carsharing in Berlin, now spreading across Europe, cuts car ownership by three-fourths and car commuting by nearly 90 percent, yet retains full mobility options.[61] In Canton Zürich and in Leiden, collaboration between regional public transit and car rental firms guarantees unimpaired mobility at lower cost than owning a car if you drive fewer than about 6,000 miles a year. Internet bookings integrate rental city cars with Swiss railways. Even individual carsharing can be beneficial: One enterprising immigrant to the United States leased his car to a taxi company during the day while he was attending college classes, earning him enough to pay for a new car every two years plus the cost of his education.

Modern information systems can markedly improve even old transit modes, permitting conveniently dispatched paratransit and "dial-a-ride" services. The information superhighway can also help displace physical highways in an era when half of Americans work in the information economy.[62] Bringing optical fiber into every home in America would cost less than what we spend every two years building new roads. For those tasks and jobs that can be "virtualized," ever better and cheaper telecommunications can move just the information in the form of electrons and leave the heavy nuclei in the form of human beings at home. This would offer a welcome saving in time, fatigue, energy, and cost. For many office jobs, the main benefit of such "virtual mobility" is more likely to be the increase in personal freedom and flexibility than the major traffic reductions, but both are important. A world-class Canadian firm of consulting engineers, which has sustained steady growth since it was founded in 1960, maintains staff in more than 70 locations worldwide yet has no central headquarters and hence low overheads. Wholly owned by its 1,700 employees and managed by a nine-member team that meets only electronically across three continents, Golder Associates exemplifies the emerging "virtual company" that is both nowhere and everywhere.[63]

## FROM COMMUTING TO COMMUNITY

In the 1970s, Portland, Oregon, estimated it could cut gasoline consumption 5 percent merely by resuscitating the concept of the neighborhood grocery store. Such concepts are the foundation for re-creating community. Zoning and land-use planning can provide comprehensive market-based incentives to reward the clustering of housing, jobs, and shopping, as is typical in Canada's denser, more homogeneous cities and towns. Density bonuses and penalties can be based on proximity to transit corridors, and since the 1950s have helped steer nearly all of Toronto's development to within a five-minute walk of subway or light-rail services. Recent California studies suggest that in little more than a decade, such incentives for clustering can so shift land-use patterns that every person-mile of mass transit in the form of buses or light rail can displace the need for four to eight person-miles of car travel.[64] Arlington, Virginia, has cut traffic by using Metro stations as development foci. Whenever a new Washington-area Metro station opens, its proximity boosts real estate values by 10 percent for blocks around, encouraging further private development — $650 million worth just in the system's first three years.

Sensible land use would make many trips unnecessary by clustering within walking distance the main places where people want to be. Developers who do this are actually succeeding in the marketplace. Many U.S. jurisdictions, however, prohibit clustering by enforcing obsolete zoning rules enacted, as the key 1927 Supreme Court decision put it, to "keep the pigs out of the parlor." Current zoning typically mandates land-use patterns that maximize distance and dispersion, forbid proximity and density, segregate uses and income levels, and require universal car traffic on wide, highly engineered roads. Such zoning, once designed to increase amenity and protect from pollution, now makes every place polluted, costly, and unlivable.

Mortgage and tax rules that subsidize dispersed suburbs are another long-standing cause of sprawl. Especially since 1945, when they were reinforced by subsidized cars and roads, such provisions have encouraged America's exodus to the suburbs. The suburbs thus have received roughly 86 percent of the nation's growth since 1970. Europe largely avoided this decentralization, and now has four times the central-city density.[65] In Europe, 40 to 50 percent of trips are taken by walking and biking, and about 10 percent by transit — versus America's 87 percent by car and 3 percent by transit.[66] U.S. sprawl imposes staggering costs. In 1992, Rutgers University's Center for Urban Studies found that if a half million new residents moved to New Jersey over the next twenty years, each new homeowner would have to pay $12–15,000 more because of such indirect costs of sprawl as roads and extended infrastructure than if development were more compact.[67] A recent Bank of America study warned of "enormous costs that California can no longer afford. Ironically, unchecked sprawl has shifted from an engine of California's growth to a force that now threatens to *inhibit* growth and degrade the quality of our life."[68]

A good start to correcting these costly distortions would be to make developers bear the expenses they impose on the community. Another would be "locationally efficient mortgages" that effectively allow homebuyers to capitalize the avoided costs of the car they no longer need in order to get to work. Existing Fannie Mae and Freddie Mac rules qualify energy-efficient American homes for a bigger mortgage on less income, because their low energy costs can support more debt service with less risk of default. Dr. David Goldstein, senior scientist at the Natural Resources Defense Council, suggested that including in the same formula a neighborhood's typical *commuting* costs (which are manyfold larger per household than direct energy bills) would make urban housing cheaper and suburban sprawl more expensive, better reflecting their relative social impact.[69] Fannie Mae launched a billion-dollar experiment in 1995 to see how this scheme worked; now it's being expanded nationwide. It may ultimately reduce driving dramatically, because studies in three cities have shown that, compared with sprawl, higher urban density reduces driving by up to two-fifths, proximity to transit by one-fifth.[70]

Making sprawl pay its way will further boost the market advantage of New Urbanist design, which seeks instead to put the places people live, work, shop, and play all within *five minutes' walk* of one another —

the pattern observed worldwide in human settlements that have grown organically. Pedestrian-friendly spatial arrangement in turn re-creates community. As Alan Durning of Northwest Environment Watch explains it, "Most people believe the alternative to cars is better transit — in truth, it's better neighborhoods."[71] That is the key to making the car "an accessory of life rather than its central organizing principle."[72]

In short, for personal mobility as also for freight, demand for traffic is akin to demand for energy or water or weapons: It's not fate but choice. Cost-minimizing methods are now emerging to enable us to select whether to invest more in cars, other modes of transport, substitutes for transport such as videoconferencing and satellite offices, or smarter land use and stronger neighborhoods. Meanwhile, the car is being reinvented faster than the implications of its reconception are being rethought. The recent history of computers, telecommunications, and other technological convergences suggests that the switch to Hypercars could come faster than the reconsideration of where people live, work, shop, and play or how people choose among means of mobility. Hypercars can buy time to address these issues but cannot resolve them. Unless basic transport and land-use reform evolve in parallel and in step with Hypercars, cars may become extremely clean and efficient before we've gotten good enough at not needing to drive them. This success might even undermine transport reform, because if the smog vanishes and struggles for oil control are no longer necessary, it may be hard to get excited about unbearable traffic and the more subtle and insidious effect of excessive automobility on equity, urban form, and social fabric.

Hypercars are quickly becoming a reality. If their technical and market advantages seemed speculative and controversial as late as 1995, by 1999 it's clear that one of the greatest adventures in industrial history is under way. Yet as in many other contexts, the powerful technologies of resource efficiency should coexist with a keen sense of social purpose: Means cannot satisfy without worthy ends. T. S. Eliot warned: "A thousand policemen directing the traffic / Cannot tell you why you come or where you go." Mobilizing the ingenuity to create a better car must be matched by finding the wisdom to create a society worth driving around in — but less often.