Annual Report Essay:
Toward a Radical Transformation of the Automobile

Cars and the Power of Technology

The twentieth century witnessed profound transformations in the way we live. Extraordinary scientific and technical advances have given society greater health, mobility, and knowledge. They have greatly improved the quality of life for most people. At the same time, those advances have created problems ranging from an exploding world population to the proliferation of nuclear arms. One of the great challenges of public policy today is to extract the good from new technology while limiting the harm it does.

The automobile is a special case. The car is surely the greatest force multiplier of our time: it expands the individual domain a thousandfold, but brings with it in burnt fossil fuels the whiff of environmental catastrophe. The automobile makes a compelling case study because its pollution can be tamed. Over the past two decades, new technologies have reduced emissions of several automobile pollutants by three-quarters while doubling fuel efficiency. Technology can further reduce energy use by threefold and pollution by tenfold or better in new cars within a decade. The technologies are in reach, but their benefits will not be secured without real political courage.

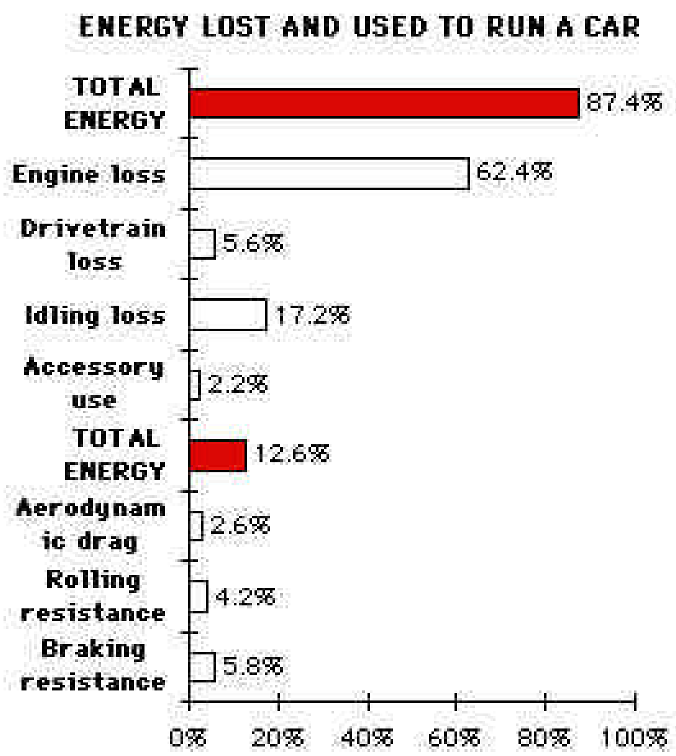
Several technologies that can transform the auto are nearing commercial reality. Early versions are being delivered to dealer showrooms today; others are expected to become viable within the next few years. But none will saturate the market anytime soon unless they are encouraged by aggressive, visionary public policy.

The history of public officials trying to reduce pollution and fuel waste in automobiles has been long and checkered. Their work has been quite successful but nonetheless riddled with inefficiencies, stops and starts, and even bad faith. The good news is that we have learned a great deal about how to speed technological transformation through public policy and, conversely, what sorts of policies produce perverse results.

This essay looks at the possibilities and the limitations of emerging automobile technologies and then discusses ways to speed those technologies into the marketplace. Because different countries have taken different routes to—and have had varying success in—controlling pollution and fuel waste, the essay then looks at global practices in cleaning up the automobile, highlighting the best ideas from each and synthesizing them into a long-term agenda for public officials.

A Tenfold Reduction in Environmental Harm

Today’s cars are modern-day manifestations of nineteenth-century technologies. The Model A Ford used a spark-fired internal combustion engine directly powering its drive train; that is what we use today. Spark-fired internal combustion is inherently wasteful, and today's cars, despite such advances as overhead camshafts and electronic ignition control, are still a pathetic 12 to 18 percent efficient in real-world conditions.



A typical midsize car loses 87% of its energy and uses only 13% of it to run.
(Source: Massa modification of diagram from PNGV, 1994) http://www.environment.volvocars.com/ch2-2.htm

Wasting more than 80 percent[1] of a fuel's energy makes it very difficult to meet any goals for energy sustainability. Not surprisingly, cars now account for almost a third of U.S. emissions of the dominant greenhouse gas, carbon dioxide (CO_2). In some states, such as California, the fraction is over 50 percent. What's more, the growth in CO_2 emissions from the vehicle sector is outstripping growth in other sectors.

This waste has other environmental consequences. Gasoline and diesel fuels are complex hydrocarbons, and their combustion produces 75 percent of America's carbon monoxide emissions, 40 percent of nitrogen oxide emissions, half of all volatile organic compounds, and a veritable soup of other toxic and carcinogenic particulates and emissions. These pollutants can cause a variety of health problems (see Health Box, page TKTK), in addition to reducing crop yields and damaging natural ecosystems.[2]

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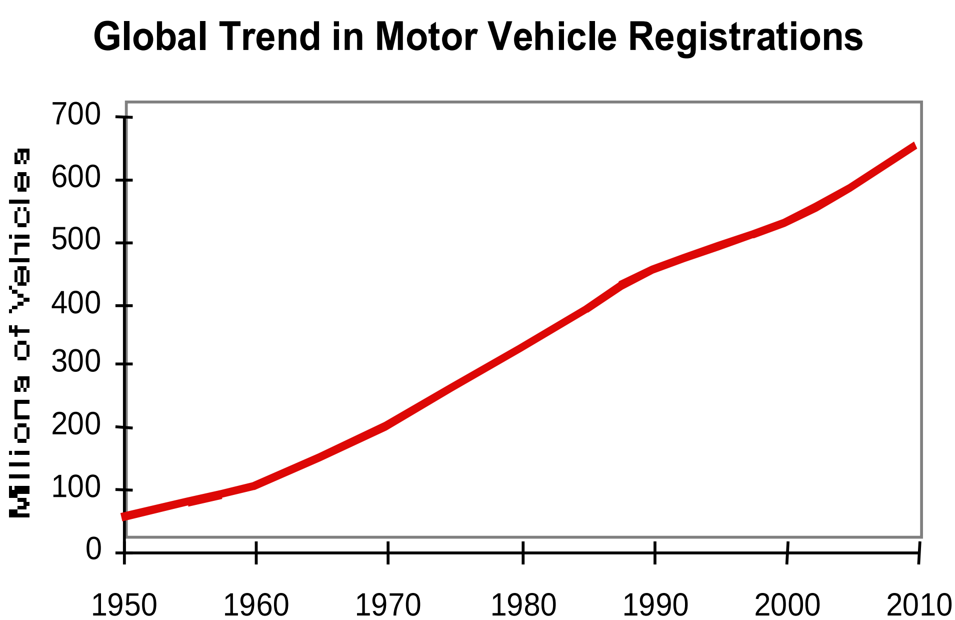
[1] This is, unfortunately, a conservative estimate of automobile inefficiency, since it does not count energy losses from extracting, refining, or transporting fuels, which together sap about 20 percent of the crude oil energy.

[2] *National Air Quality: Status and Trends,* published annually by the U.S. Environment Protection Agency, Office of Air and Radiation, Washington, D.C., December 1998.

The pollution from vehicles, combined with that from stationary sources, means that some 26 U.S. metropolitan areas need to make additional reductions in pollution to meet clean-air standards. These areas, distributed across most regions of the United States, have a combined population of more than 86 million. Twelve other areas, representing 25 million people, have a moderate to significant probability of needing additional reductions.

Air pollution is as bad or worse in other countries. Some 70 to 80 percent of 105 European cities surveyed exceeded World Health Organization (WHO) air quality standards for at least one pollutant. In developing nations, air pollution often exceeds WHO standards by a factor of 3 to 6. As many as 1.4 billion urban residents globally breathe air exceeding the WHO air guidelines.

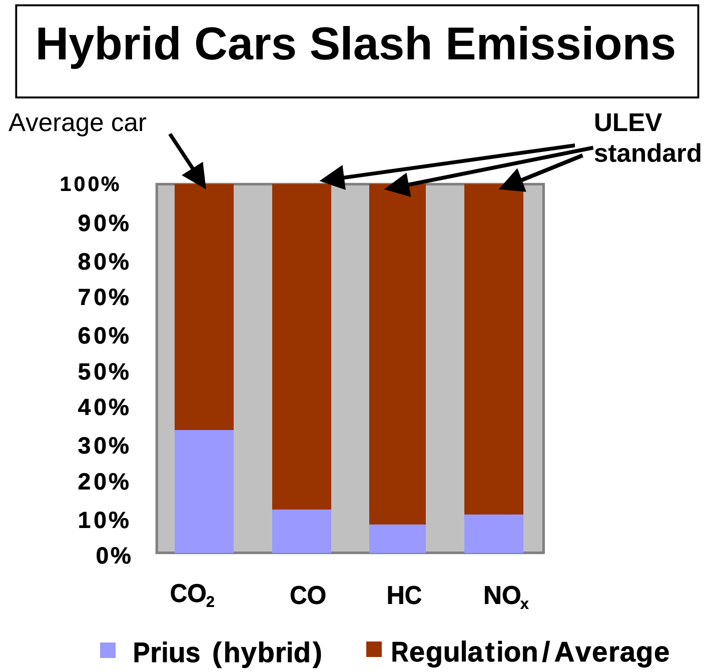
To exacerbate the problem, the world's auto fleet is growing at an extraordinary rate. In 1950, there were 53 million cars in the world. By 1990, the global fleet had increased more than eightfold to 430 million vehicles. If the trend continues, the world's population of cars will be 650 million by 2010.



The health and environmental consequences of urban air pollution simply cannot be solved without taming the automobile. Fortunately, just as conventional auto technologies are responsible for much of the problem, so advanced technologies can offer much of the solution.

New Technologies

A variety of new electric-drive vehicles is becoming commercially available. Powered by fuel cells, advanced batteries, or a combination of batteries and combustion engines, these vehicles have the potential to revolutionize the transportation sector. Terrific progress has been made in the last decade, spurred largely by air regulators' demands. Low-drag and low-weight vehicle designs, using advanced techniques and materials, could reduce fuel waste and emissions and further enhance performance.



Hybrid Cars

Hybrid gasoline-electric cars combine the compact energy storage and convenient refueling infrastructure of gasoline with the advantages of electric drive trains. Hybrids can increase fuel efficiency by 50 to 100 percent compared with conventional technologies, depending on configuration. Hybrids do not require any fundamental engineering advances, although they do require automakers to master new systems and develop sophisticated methods of optimizing the gasoline and electric components.

Several hybrid cars are entering the marketplace. They are expected to have wider market appeal than battery vehicles, which offer a limited range on each charge of electricity. Toyota has sold, in Japan, some 30,000 Prius hybrid gasoline-electric cars that get double the gas mileage of a conventional auto, with a commensurate drop in greenhouse-gas and toxic emissions. When the Prius is introduced in the United States, it will be outfitted with technologies to cut the emissions of other pollutants to only 10 percent of California's Ultra-Low Emissions (ULEV) level.

Honda introduced a hybrid two-seater in the United States in December 1999. This car, called the Insight, gets 60 to 70 miles per gallon. It is light, safe, aerodynamically efficient (with a lower drag than any other commercial car ever produced), and clean. The Prius and the Insight will both be competitively priced, especially considering fuel savings.

Fuel Cells

The fuel cell is a truly transformational technology. Some fuel cells combine hydrogen and oxygen to generate electricity, producing pure water as a byproduct. Fuel cell vehicle configurations are nearly 50 percent efficient, a threefold increase over today's cars. Electric-drive automobiles powered by fuel cells can slash pollution while increasing energy efficiency.

Automakers recognize the market potential of fuel cell vehicles and have begun to make serious investments in their development. Progress has been strong over the last eight years, with costs and weight dropping tenfold or more over the last decade.

But a billion dollars spent on R&D, globally, is a pittance for the auto and oil industries, and the population of companies working on these technologies is dangerously small. And fuel cell vehicles need more than cheap, small, reliable fuel cells. Fuel cells operate on hydrogen, which must be produced from a conventional fuel, such as methanol or natural gas. Thus, marketable fuel cell vehicles are likely to require advances in the fueling infrastructure, "reformers" to convert the base fuel to hydrogen, and, possibly, hydrogen storage. There are no intractable barriers to successful fuel cell commercialization, but current programs fall short of what is necessary.

Battery Electric Cars

Battery electric cars have been sold in the United States for 70 years, and modern battery-powered vehicles have been sold in limited numbers in the past few years, but their popularity has been limited by the poor energy density of batteries. Batteries are heavy and hold only about 1 percent as much energy per pound as gasoline. Nonetheless, significant advances have been made in battery electric cars and in batteries themselves. The General Motors EV-1 is a fast, sophisticated car, with impressive driving performance. New nickel-metal hydride and lithium-ion batteries store as much as twice the energy of conventional lead-acid batteries. And new drive technologies make the whole package more efficient.

Electric cars offer other advantages: They are virtually silent. They consume no energy at idle, they maintain their efficiency throughout the range of driving conditions, remain essentially impervious to driver behavior, and recapture the energy of braking as electricity instead of wasting it as heat. Electric car sales will grow as batteries improve and as system efficiencies grow. Equally important, the core electric car technologies—in electric drive systems and power control—will be used in hybrid and fuel cell cars.

Inherently Clean Characteristics

Just as manufacturers learn to make toys that are safe despite the malign intentions of children, so they need to make cars that are clean despite variations in driver behavior, maintenance, age of vehicle, or operating conditions. Such a vehicle—one that would emit very modest emissions throughout its lifespan no matter how used—would be "inherently clean." One of the most significant benefits of advanced hybrid, fuel cell, and battery electric cars is that they can be designed to be inherently clean.

To understand this goal, it is useful to consider the antithesis: today's car. Our automobiles run on engines that do not attain even their limited potential to be clean or efficient unless they are operated at the right temperature, with the right load, under proper maintenance. A deviation from *any* of these conditions results in vastly greater pollution and energy waste. In real-world conditions, our autos rarely reach the sweet spot of optimal performance. As a consequence, pollution from today's fleet is as much as six times higher than that predicted on federal tests. Tighter tests have recently narrowed the gap between predicted and actual performance, but the internal combustion engine naturally tends to operate suboptimally, so it always needs ongoing corrective action. An inherently clean vehicle would be efficient throughout the operating regimen.

Public Policy and Technological Innovation

The potential benefits of inherently clean, efficient vehicles powered by electric-drive technologies are clear, but the path to their wide use is murky. The interactions between automakers and public officials over such issues as air pollution and safety have historically been unpleasant. Indeed, virtually every one of the regulations that now govern our tailpipes was promulgated despite automakers' predictions of doom. The history of air pollution is, in short, one of political antagonism followed by extraordinary technological achievement.

Automakers and oil companies are clearly capable of significant long-term technological innovation. In areas where they perceive significant consumer value, such as vehicle reliability or electronic entertainment options, they have made extraordinary progress. But in reducing pollution and energy use, which are *public* values and thereby not promoted by private market transactions, automakers have been reluctant innovators. When compelled by public policy, they have proven their ability to rise to the challenge, but they have resisted almost every step of the way.

Regulation has nonetheless resulted in major improvements. Even as vehicle miles traveled increased by 120 percent between 1970 and 1996, emissions of every major pollutant, save CO_2 and NO_x, dropped by a third or more. Fuel efficiency laws have had similar, if less widely acknowledged, success. The U.S. Corporate Average Fleet Efficiency (CAFE) law, passed in 1975, helped double the fuel efficiency of autos in the United States even as cars grew in speed and size.

But this progress is reaching its limits. The growth in vehicle miles traveled is fast overcoming reductions in tailpipe emissions. Further improvements are needed to protect public health and ecosystems. Only inherently clean vehicles will enable the world's large cities to reach the clean-air standards required to protect human health. And the energy efficiency of the transportation sector must improve dramatically to meet any reasonable goal of reducing greenhouse gases.

Air regulators are consequently looking for technological innovations that can ensure we have healthy air in the coming two decades. In a bold, visionary move, the California Air Resources Board set a rule requiring automakers to produce 10 percent of their automobiles with *zero* emissions by 2003.[3] The zero-emission vehicle (ZEV) mandate has been the subject of intense attacks by the auto and oil industries since it

[3] Maine, Massachusettes, New York, and Vermont have joined California.

was adopted in 1990. Only fuel cell vehicles and battery electric vehicles have zero local emissions, although the Air Resources Board has allowed very clean hybrids to qualify for some credit toward the mandate.

The ZEV regulation is unpopular with automakers because, they argue, battery and fuel cell technologies suffer from insufficient performance and excessive cost. But while there are serious technological challenges, the rule has spurred great innovation—and led to the hybrid, fuel cell, and battery electric vehicles described above. There is little question that the environment demands such technologies. The ZEV mandate is not perfect, but it is so far the only policy to produce such innovation.

Automakers and oil companies alike are starting to understand the importance of selling products that are compatible with public health and a clean environment. For the ZEV program to succeed, it must be bolstered by programs to reward innovators and to smooth the paths to market for these new technologies. This is a crucial next step for legislators concerned with clean air. When more public officials summon their courage, the transition to clean technologies will be irreversible.

Combining Energy Efficiency and Air Quality Goals

This essay has so far argued for fuel efficiency (leading to lower CO_2 emissions) and reduced air pollution as a natural pair of goals, both of which can be achieved with advanced technologies. But few government agencies are equipped to pursue both, and many support one goal at the expense of the other.

For example, U.S. Department of Energy officials have been touting the benefits of diesel engines in reducing fuel consumption and have helped steer Detroit toward increasing the use of diesel. At the same time, the Environmental Protection Agency and the California Air Resources Board, recognizing the toxic and carcinogenic qualities of diesel exhaust, have been working to tighten standards on diesel engines. Neither the Department of Energy nor the auto companies have paid sufficient attention to the health effects of diesel fuel despite increasing evidence of the danger it poses. As a result, they have invested hundreds of millions of dollars in diesel technologies that may have little chance of commercial application. Europe has put considerable reliance on diesel engines to meet its CO_2 reduction goals; meeting those goals will come at serious cost to air quality and public health.

In the end it makes little sense to pursue energy solutions that savage air quality, or environmental solutions that lower fuel efficiency. No serious long-term plan should include technologies whose health effects or greenhouse-gas emissions are worse than those of current technologies.

Toward Global Best Practices in Environmental Performance

The foregoing discussion outlines the dilemmas facing public officials charged with cleaning the air. Automakers have resisted even incremental technological change, but long-term air and energy goals demand a radical transformation. Conventional approaches to air pollution have been extremely successful, but they must be replaced with more aggressive and holistic programs. And greenhouse-gas emissions must be brought into the equation quickly and intelligently.

Fortunately, when one looks around the world, one can see successful public policy programs addressing each of these dilemmas—although none addresses them all at once. It is clearly possible to transform the auto without destroying the auto industry, and it is also possible to avoid most of the unintended consequences and gaming that early regulation suffered. The following section describes the best auto regulations from different parts of the world and integrates them into an agenda for the future. The recommendations are derived from current best practices and the opinions of scientists and public policy experts who follow and influence the field.

1. Insist on Real-World Performance

There is a useful axiom in business: What you measure is what you get. It has certainly been true with auto pollution regulations. For decades, air quality officials have tried to build decent tests to measure pollution from cars, and auto companies have built cars to pass those tests.

Unfortunately, the practice has led to considerable gaming. Cars were designed to perform well under test conditions, but only under test conditions. Real-world performance was much worse.

Consider the following example: With the onset of electronic control systems for heavy-duty diesel trucks, it became possible to program engines to perform differently in use than they did on the U.S. EPA heavy-duty test cycle. Manufacturers could increase fuel economy under highway driving conditions by modifying the injection timing; unfortunately, this also increased NO_X emissions substantially. After an extensive investigation, the U.S. Justice Department and the EPA recently ordered seven manufacturers of heavy-duty diesel engines to pay more than $1 billion to settle charges that they illegally poured millions of tons of pollution into the air. The seven companies compose 95 percent of the U.S. heavy-duty diesel engine market. It was the largest environmental enforcement action in U.S. history.

The affected engines emitted more than 1.3 million tons of excess NO_X in 1998 alone, 6 percent of NO_X emissions from all sources in that year. It was equivalent to the NO_X emissions from an additional 65 million cars on the road.

One way to break the cycle of test-making and test-foiling is to make auto manufacturers liable for the real-world performance of their vehicles, regardless of what test is used. This is the basis for most civil law applied to other products; surely it can apply to cars as well. If Ford, say, was responsible for the lifetime emissions of its Taurus line (measured per mile, since Ford has no way controlling the total number of miles driven), it is highly likely Ford would equip that car with reliable, durable, and robust emissions-control equipment.

An important benefit of holding auto manufacturers accountable for real-world results is that over time they will move away from technologies that end to behave suboptimally and toward those that perform well regardless of vehicle age, driver behavior, or maintenance. This will speed the introduction of such technologies as hybrid gasoline-electric, battery electric, and fuel cell cars. Real-world improvements in air quality demand real-world performance by automakers.

2. Set Aggressive Requirements, but Give Manufacturers Flexibility

Regulators generally avoid setting technology standards, and this practice should be maintained. No one, whether from industry or government, can adequately foresee the opportunities and problems of deploying new technologies.

Instead, regulators should set ever tightening long-term standards. These would pose a clear challenge to both fuel suppliers and auto manufacturers, and they could set R&D and production plans accordingly.

California pioneered such an approach with the so-called NMOG curve, which requires automakers to meet successively more stringent standards for nonmethane organic gases. The California standards are averaged over all the sales of a company for the model year, allowing some cars to be better and some to be worse. Similarly, the NMOG curve lets auto companies do better in one year and worse in another.

Finally, the NMOG curve sets standards for a decade or more at a time, making them progressively tighter. One car company may pursue an incremental cleanup, and another may go for more radical change, depending on their independent assessments of risks and cost. These are terrific attributes of the NMOG, ones that drastically cut the cost of compliance while encouraging private sector innovation.

3. Build Programs, including Zero Emission Vehicle Requirements, That Transform Technology

Modestly tightening controls on conventional technologies will not enable the mega-cities of the world—such as Tokyo, Beijing, Hong Kong, Los Angeles, or Houston—to meet long-term air quality goals. These cities need zero and near-zero emissions technologies. Such technologies will not emerge through a simple reliance on the private market, since their benefits are largely public. They are also unlikely to arise from an incremental tightening of pollutant standards for conventional vehicles. California has recognized the inevitable requirement through its Zero Emissions Vehicle (ZEV) regulations, which require 10 percent of all cars sold in 2003 to emit zero local emissions.

The California Air Resources Board used the ZEV regulation to ask automakers to design cars anew. Despite protests, the auto companies and other private sector firms have responded with extraordinary innovation. Battery and fuel cell costs, size, and weight have dropped as performance has improved, with more gains in the past decade than in the previous four. All the major manufacturers launched electric or fuel cell programs, and investments in these technologies grew to over $2 billion.

Other jurisdictions need to match California’s boldness; if they do, long-term improvement is possible.

4. Reward Innovation and Early Adoption

The California Air Resources Board ZEV regulation allows some technology trading to bring advanced hybrid, if not zero-emission, vehicles into the program: this suggests a fourth principle for public officials. Automakers need to be recognized and rewarded for bringing risky technologies into the marketplace. A difficult performance standard—such as the 10 percent ZEV requirement—can be softened by giving back some credits to manufacturers who move early, or who offer technologies that get at least part of the way to zero.

Of course, regulators must be vigilant about what they trade away, and when. Advanced technologies meet several goals simultaneously: they slash air pollution; they improve reliability; and they cut fuel consumption. These characteristics all need to be built into any regulatory flexibility.

Similarly, to induce early market introductions, public agencies should offer incentive funds to help lower the cost of new technologies. A number of new policy mechanisms allow public funds to be used efficiently to bring new technologies to market. The Carl Moyer Program, in California, pays for diesel engine retrofits and for the incremental costs of alternative-fuel trucks, buses, and heavy-duty equipment. The program is successfully reducing emissions on a large scale and at modest cost.

Public officials charged with cleaning the air need to look more seriously at the demand side and transition paths for new technologies.

5. Regulate Carbon Dioxide (CO_2)

There is now little disagreement that global warming is under way. It is time for public officials to take accept this reality and begin to regulate CO_2 emissions. The sooner they do, the easier it will be for automakers and fuel providers to make long-term plans.

Both Japan and the European Community have set ambitious goals for CO_2 reduction; these deserve broad emulation. The Japanese standards were adopted in 1999. Based on the "top runner" (or best in class) method, they are as follows:

Percent improvement required (over best in class)	Gasoline	Diesel
Passenger cars	**23 %**	**15%**
Truck	**13%**	**7%**
Total average improvement	**21%**	**13%**

The European vehicle industry has recently pledged voluntary reductions in vehicle CO_2 emissions. The target is to reduce such emissions in new cars by 25 percent as of 2008 (from 1995 levels).

Certainly the market conditions in Japan and Europe support CO_2 reduction more so than those in the United States, since gasoline is at least three times as expensive there.

But the goals will nonetheless require automakers to deploy new technologies—and determination. Surely the U.S. market could make similar improvements.

6. Develop International Antipollution Policies

Because the auto and fuels industries are dominated by global companies, policy-makers must build a coordinated international response. The auto and oil companies have to meet the standards of dozens of countries and therefore often pursue different goals with different technologies in different countries. In Europe, for example, automakers work to fulfill the voluntary pledge to reduce CO_2, but they face lower air pollution standards than in the United States. They have responded to this challenge by deploying efficient but dirty diesel cars. In California, car companies work to make ultra-clean autos but pay virtually no attention to fuel efficiency.

It is time for air regulators from major cities and countries to work together. National environmental officials have a difficult challenge, and they need to reach across political boundaries to build a coordinated strategy. Officials in the world's large cities have to provide for the health of their residents. They cannot do this basic job without advanced auto technologies, but no city official has enough political power to force a transformation of the largest industries in the world.

Working together, the air regulators of Japan, Europe, China, and the United States could send a powerful signal to auto companies about the technologies they need to clean their air. Similarly, the mayors of Tokyo, Los Angeles, Beijing, Cairo, Bangkok, Paris, and Bonn could have a significant influence. They could ban two-stroke engines (see box, page TKTK), penalize dirty diesel technologies, set their own fleet purchase requirements to encourage clean technologies, and allow preferential access and parking to clean vehicles. If policy-makers link their plans together, manufacturers will have a strong incentive to deliver cleaner technologies.

Unless air regulators reach across political boundaries, they will fall victim industry trends, largely powerless to clean their air or reduce greenhouse-gas emissions.

In sum, effective regulation will:

- **Insist on real-world performance**
- **Set aggressive requirements, but give manufacturers flexibility**
- **Build programs that transform technology**
- **Reward innovation and early adoption**
- **Regulate carbon dioxide**
- **Form a coordinated, international antipollution front**

Conclusion

Providing citizens with clean air will ultimately become as clear and important a mandate as providing clean water or effective sewers. No big city can prosper without decent sanitation systems because the consequences are too ugly and too apparent. But as the epidemiology of air pollution grows ever more convincing, the public will demand the same standards for the air, and public officials will have to deliver.

Advanced technologies can solve the air pollution problem and substantially help reduce greenhouse gases. But auto companies will not push those technologies without unambiguous signals from public officials, and piecemeal regulation is insufficient. In fact, as auto fleets grow, current air pollution laws will only slow the rate at which the air becomes dirtier.

Those officials charged with cleaning the air and protecting the public health must take a more aggressive, holistic, and longer-term view of the world, and build a system that can actually win the day. Clearly, we can slash pollution and energy consumption; equally clearly, today's air quality and energy rules are not up to the task. Courage and vision can change that.

Health Box

Public health in the United States is determined in no small measure by environmental conditions. Long-term and acute exposure to ambient pollution can impair cardiopulmonary functions, exacerbate allergies and asthma, and contribute to bronchitis and emphysema. According to the American Lung Association:
[[We need a footnote giving the full citation for this quote]]

> Air pollution contributes to lung disease, including respiratory tract infections, asthma, and lung cancer. Lung disease claims close to 335,000 lives in America every year and is the third-leading cause of death in the United States. Over the last decade, the death rate for lung disease has risen faster than that of any of the top five causes of death. **[[Can we separate out smoking effects?]]**

These impacts are especially severe on children and the elderly, who are already more vulnerable to disease than the general population. The ALA states that some 27 million children are exposed to unhealthy air each year, of whom almost 2 million are asthma suffers.

Jerome Goldstein, M.D., recent president of National Association of Physicians for the Environment, succinctly states: “The bottom line is that there is no question that air pollution is a serious public health problem. . . . It is also clear that much of this problem can be dealt with: *air pollution prevention is disease prevention*” [emphasis in original].
[[need a footnote with full citation]]
END HEALTH BOX

Diesel Box

The diesel engine runs at hotter temperatures and with higher compression ratios than its gasoline counterpart and, as a consequence, has higher fuel efficiency. That has made diesel fuel a favorite for trucks, ships, locomotives, and other vehicles that run for long periods. This efficiency also makes converting gas cars to diesel a tempting component of a strategy for reducing greenhouse gases, since emissions of CO_2 are between 10 and 30 percent less in diesel engines. Some very large government and industry programs have been built on this idea, including the Partnership for a New Generation of Vehicles, a venture of the U.S. Department of Energy and the Big Three automakers to build high-efficiency prototype automobiles.

Unfortunately, diesel soot is increasingly implicated as toxic and carcinogenic. According the California Air Resources Board (ARB): **[[need footnote for this quote, with full citation]]**

- Emissions from diesel-fueled engines are mainly composed of particulate matter and gases, which contain potential cancer-causing substances such as arsenic, benzene, formaldehyde, nickel, and polycyclic aromatic hydrocarbons.
- Emissions from diesel-fueled engines currently include over 40 substances that are listed by the U.S. Environmental Protection Agency (U.S. EPA) as hazardous air pollutants (HAPs) and by the ARB as toxic air contaminants.
- Research studies show that emissions from diesel-fueled engines may cause cancer in animals and humans.
- Studies show that workers exposed to higher levels of emissions from diesel-fueled engines are more likely to develop lung cancer.
- In 1990, the State of California . . . identified diesel exhaust as a chemical known to cause cancer.
- The International Agency for Research on Cancer has concluded that diesel engine exhaust probably causes cancer in humans.
- The U.S. EPA has proposed classifying diesel exhaust as a probable human carcinogen.

Diesel exhaust clearly poses a serious health risk. The unavoidable implication of the epidemiology of diesel exposure tells us that, without significant improvements, diesel fuel will be increasingly unacceptable to the public health. The ARB recognized this in insisting that future diesel engines for light duty vehicles meet the same standards as gasoline engines. Officials in Tokyo, Hong Kong, and Beijing are considering banning or severely restricting the use of diesel.

If diesel manufacturers expect to maintain their market share—or avoid becoming a moribund industry altogether—they will have to reinvent their engines and make them meet the most stringent air pollution standards. The current European trend toward a greater use of diesels will shortly run into this harsh reality.

Two-Stroke Box

If one technology exemplifies the need to overhaul air pollution laws—especially in the large cities in Asia—it is the two-stroke engine. Two-stroke engines are cheap, light, and powerful, but they mix their lubricating oils with their combustion fuel, meaning that a vast quantity of unburned hydrocarbons are released into the environment.

To get a sense just how dirty two-stroke engines are, consider:

- Seven hours of use of a two-stroke jet ski releases the same emissions as driving a new car 100,000 miles.[4]
- Using a snowmobile for one hour releases as much pollution as driving a car for a year.[5]
- 25 to 30 percent of the fuel and oil used in a conventional two-stroke engine passes through unburned.[6]
- Marine two-stroke motors spill 15 times more oil and fuel into waterways every year than did the Exxon Valdez.[7]

Two-stroke engines are used in the U.S. primarily in lawn equipment, off-road motorcycles, and jet skis. In developing countries, they are used for mopeds, small motorcycles, and tuk-tuks.

There is little justification for allowing such egregious polluters in cities where air pollution has become the primary health risk, especially since four-stroke engines are available as replacements. Eliminating two-stroke engines—or requiring them to meet the same standard as four-stroke engines—would be a quick way to slash pollution in many cities.

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[4] California Air Resources Board. **[[publication?]]**

[5] Ibid.

[6] Source: Bluewater Web site. **[[NEED URL]]** "One of the first studies was conducted in 1973 by R.E. Kollman, S.S. Lestz, and W.E. Meyer. They were members of the Society of Automotive Engineers, Inc., and Pennsylvania State University. The report is entitled 'Exhaust Emissions Characteristics of a Small 2-Stroke Cycle Spark Ignition Engine.' The report reads: 'it was determined that 25%-40% of the fuel air mixture was short-circuited to the exhaust in the scavenging process . . . [or] twenty-five to forty percent of the fuel leaves the engine as unburned HC's depending on load.'"

[7] Eric Nelson, "Polluting for Pleasure?" *Sail Magazine,* November 1994, 26. Cited on the Bluewater Web site.