2007 Blue Planet Prize
Commemorative Lectures

財団法人 旭硝子財団

THE ASAHI GLASS FOUNDATION

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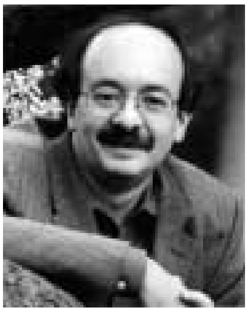
Supplementary volume
Dr. Amory B. Lovins
Slides for Lecture
“Profitable, Business-Led Solutions to the Climate, Oil, and Proliferation Problems”



Dr. Amory B. Lovins (U.S.A.)

Chairman and Chief Scientist, Rocky Mountain Institute

Selection rationale: For his contributions to leading global energy strategy for protection of the global environment by efficient utilization of energy through his advocacy of the concept of the "soft energy path" and invention of the Hypercar.

Education and Academic and Professional Activities

1947	Born in Washington DC
1964-67	Harvard University
1967-69	Magdalen College, Oxford, England
1969-71	Junior Research Fellow, Merton College, Oxford, England Received a master of arts (M.A.) degree 1971
1982	Co-founded Rocky Mountain Institute; currently Chairman & Chief Scientist
1999	Established Hypercar, Inc. (Chairman 1999-2007), now Fiberforge, Inc.
1968-present	Consulted for governments and the industries in the U.S. and worldwide

Major Awards Received

1982	Mitchell Prize
1983	Right Livelihood Award
1989	Delphi Prize
1993	Nissan Prize, ISATA; MacArthur Fellow
1997	Heinz Award for the Environment
1998	Lindbergh Award
1999	World Technology Award
2000	*Time* Heroes for the Planet Award
2001	Shingo Prize
2005	Jean Meyer Award
2006	Benjamin Franklin Medal and Life Fellow, Royal Society of Arts (London)
2007	Honorary Member, American Institute of Architects

Dr. Lovins was born in Washington, DC in 1947. From his high-school days, he showed talent in physics, music, classics and mathematics. He entered Harvard College, and transferred to Magdalen College, Oxford, England. He became a Junior Research Fellow of Merton College, Oxford, in 1969, receiving a master of arts (M.A.) degree in 1971.

During his stay in the U.K., Dr. Lovins was fascinated by Snowdonia National Park in North Wales, and wrote a book about these endangered Welsh wildlands. Dr. Lovins then served for ten years as British Representative for Friends of the Earth. While taking interest in nature and environment, he became involved increasingly in energy strategy, initially through his research on climate. He wrote his first books on energy "*World Energy Strategies*" in 1974.

The energy crisis in 1973 drew more people to Dr. Lovins's ideas, and in 1976, he published a groundbreaking essay "*Energy Strategy:* The Road Not Taken?" It redefined the energy problem from "how to supply more energy" to how to provide just the amount, type, and scale of energy that would do each task in the cheapest way, and there he put forward the concept of the "soft energy path." The concept points out to a new system with efficient use of energy and the use of "soft energy technologies" based on such resources as solar, wind force, bio-fuel and geothermal heat. This is opposite to the "hard energy path" which points out to an existing huge centralized power generation system utilizing fossil fuel and nuclear power. He envisaged this approach as a "master key" to unlock the intertwined puzzles of energy, environment, resources, development, and security. Dr. Lovins suggested that soft energy paths are possible, profitable, environmentally benign, and supportive of fair global development without the hard path's prohibitive costs and risks.

The soft-path concept initially attracted huge criticism from traditional energy suppliers. But nowadays, efficient use and soft energy technologies are being adopted worldwide through competition in the marketplace, and it can be said that his pioneering views have been proven.

Dr. Lovins continued to write books and consulted widely to industry, and was active in energy affairs in some 15 countries as a policy advisor. He and his first wife L. Hunter Sheldon co-founded Rocky Mountain Institute in 1982 to foster the efficient and restorative use of resources. They built their home and the original headquarters of Rocky Mountain Institute, still one of the world's most efficient buildings. The essence of its construction is that in order to thoroughly utilize the solar heat, it uses high performance insulation and glass, and takes notice on the heat intake and prevention of its dissipation, and through integrative design optimizing the whole building as a system for multiple benefits rather than isolated components for single benefits.

Radical energy efficiency has always been a key goal at Rocky Mountain Institute, examining in great detail nearly every use and emphasizing the most important ones. In 1991, Dr. Lovins invented the Hypercar , integrating two known and demonstrated techniques in a radically simplified, software-rich vehicle design. Compared to then-existing cars, Hypercar-class vehicles could triple fuel economy with equal or better performance, safety, and affordability.

In 1997, the Lovinses and Prof. E.U. von Weizsaecker wrote "*Factor Four: Doubling Wealth—Halving Resource Use*," and in 1999, with Paul Hawken, the Lovinses published the book "*Natural Capitalism: Creating the Next Industrial Revolution*." In 2004, Dr. Lovins published "*Winning the Oil Endgame*" which provided a detailed roadmap for eliminating U.S. oil use by the 2040s.

Dr. Lovins with his remarkable foresight has consistently proposed and implemented pioneering concepts since the 1970s in the energy field and many others. Inefficient energy use has created many economic and security issues and most of the world's environmental problems, so he has designed compelling technological, business, and policy innovations to solve them. At the same time, he has shown how to achieve a society where high energy efficiency and sustainable energy supplies can lead to a safer, environmentally healthier, climate-stabilized, and more rewarding future.

Profitable, Business-Led Solutions to the Climate, Oil, and Proliferation Problems

Dr. Amory B. Lovins

[slide 1] I appreciate the great honor of suggesting here some integrated and profitable solutions to three of the world's biggest challenges—climate change, oil dependence, and the spread of nuclear bombs—in the spirit of Raymond Williams's remark that "To be truly radical is to make hope possible, not despair convincing."

[slide 2] Until my "*Foreign Affairs*" article in 1976, the energy problem was generally thought to be where to get *more energy*—more, from any source, at any price, increasingly in the costliest and highest-quality form (electricity), made from depletable resources in ever bigger facilities. Instead, I redefined the energy problem around "end-uses"—the tasks that we want energy *for*, like hot baths, cold beer, comfort, mobility, cooked food, and smelted alumina. I asked how much energy, of what quality, at what scale, from what source, would do each end-use task in the cheapest way. This question reveals what happens when all ways to save or produce energy can compete fairly, at honest prices, no matter which kind they are (savings or supply), what technology they use, how big they are, where they are, or who owns them. Of course, that hypothetical world is far from today's actual energy policies in any country, but it remains a sound goal.

[slide 3] The end-use/least-cost question led to a different answer about the energy future of, say, the United States over the next half-century. In 1975, all government and industry forecasts of U.S. energy use pointed to the upper right, along the red curve. I heretically suggested that this red curve could be flattened and then decreased, as in the dashed blue curve, by wringing more work from our energy—by substituting technology and brains for energy and money. That curve was within 4% of actual U.S. energy use in 2000, although the takeoff of "soft technologies"—diverse, renewable sources the right size and quality for their task—was delayed a quarter-century by largely hostile government policies that suppressed competition and even exported to Japan and Europe the fledgling solar industries that U.S. innovation had hatched. But now we can to do far better than my 1976 soft-path blue curve, especially in saving electricity and oil.

[slide 4] Of course, there are many important differences between energy systems in America and Japan, most obviously in prices, climates, and land-uses. But in many key ways, the similarities seem to me more important than the differences. Energy intensity—the energy used to make a dollar of GDP—is two to three times higher in America than in Japan, due substantially to bigger houses and travel distances and to more and bigger appliances. In some uses, especially in certain industries, Japanese industry is famously #1 in technical efficiency. But energy efficiency is improving much faster in America than in Japan, and some sectors in Japan, especially building, appear to be lagging. Japan is more conscious of the dangers of oil dependence, but America is catching up quickly. Of course, Japan never had its own oil resources; America had abundant oil, but its output peaked in 1970, has since fallen by half, to only two-fifths of U.S. supply; the rest is cheaper imports. Both countries have large and diverse renewable energy potential: Japan's is the largest per person of any major industrial nation. But this potential is badly underused and poorly understood in both countries. America's national energy policy is weak and fragmented (many states do far better); Japan's is strong and coherent but is less transparently formed and, as in America, sometimes reflects factional interests more than the national interest. Both countries have powerful engines of innovation — America's driven mainly by small businesses and independent inventors, Japan's mainly by giant companies and *keiretsus*. America's great strength is wildly diverse and chaotic entrepreneurship; Japan's is social cohesion and the wisdom of a long history. America's main energy weakness is its utterly dysfunctional national policy, but there are many ways to get around those roadblocks, mainly through the private sector. Japan's main energy handicap is the unfounded belief that the nation is poor in energy and can't become much more efficient than it already is.

[slide 5] A new McKinsey study reflects the growing official realization that global energy efficiency can be greatly and profitably improved beyond its normal spontaneously achieved levels. The potential energy savings costing less than the energy they save can nearly pay for all the costlier ways to reduce greenhouse gas emissions. Thus reductions totaling 46% of the total emissions projected for the world in 2030 would have an average cost of only about two Euros, or ¥325, per tonne of CO_2-equivalent avoided. I believe this encouraging result is still very conservative because it understates the amount and overstates the cost of available energy efficiency improvements, some of which I'll summarize here.

[slide 6] In Japan, a fascinating study is emerging from the National Institute of Environmental Studies thanks to support from the Ministry of the Environment. About 60 diverse experts have constructed two plausible scenarios for Japan in 2050 — one busy and urban, the other more traditional, serene, and community-centered. Both are consistent with the basic assumptions of government policy; both have growing wealth and technology; both have an extremely high standard of living and, in their different styles, quality of life. Strikingly, both scenarios reduce national CO_2 emissions by 70% below 1990 levels. **[slide 7]** This is achieved through a mixture of better land-use or societal organization, returning per-capita steel and cement production to Western norms (they're now twice that high due to exaggerated infrastructure investments), and switching to lower-carbon energy sources and more efficient end-use technologies. The extra cost of all these improvements in 2050 is estimated at roughly ¥1 trillion per year, or about 0.1% of GDP at that time. This is already a very impressive and encouraging result. But I'd like to explore whether, even in already rather energy-efficient Japan, end-use efficiency might be improved *even more* than the assumed 24 — 41%, and at even *lower* cost than assumed, thus making even bigger reductions in greenhouses gases both feasible and profitable. If Japanese people can do this, then others who are now less efficient can save even more.

[slide 8] It may seem odd to talk about "profitable" climate protection, because the whole political discourse is about how this will be costly, requiring us all to forego wealth, crimp lifestyles, bear burdens, and make sacrifices. But climate protection is actually like the Hubble Space Telescope. How? Both got messed up by a sign error — a confusion between a plus sign and a minus sign. In fact, climate protection is *not costly but profitable*, because saving fuel costs less than buying fuel. Every practitioner understands this; only some politicians and journalists, and therefore many citizens, do not. But once they do, especially in the United States, political resistance to protecting the climate will melt even faster than glaciers.

[slide 9] Many companies do understand this, so whether or not they worry about climate change, they are buying energy efficiency just to make money. For example:

b Two of the world's biggest chipmakers have been cutting their CO_2 emissions by 6% every year by improving their factories, recovering their investments in ~2—3 years.

b DuPont set an ambitious goal to cut its energy use per dollar of output by 6% a year, switch toward renewable fuels and feedstocks, and cut its greenhouse gas emissions by 2010 to 65% less than in 1990. By 2006, DuPont was 80% below 1990 emissions and had made $3 billion profit by substituting efficiency for fuel.

b Dow made an even bigger profit by cutting its energy intensity by 42% in 15 years.

b BP met its operational carbon-reduction goals 8 years early at a net profit of $2 billion.

b General Electric has promised to raise its energy efficiency 30% in 7 years to enhance shareholder value.

b Interface, a carpet and textile maker, has cut its greenhouse gas emissions by 60% in a decade (an average rate of over 9% per year) at a third of a billion dollars' profit. By 2020, the firm intends to eliminate *all* waste and all fossil-fuel input. Already it has the industry's strongest, least oil-dependent cost structure and much stronger profits.

b Texas Instruments is commissioning a new chip fab in Texas, not China, because my team was able to help reduce its capital cost by $230 million, or 30%, while saving a fifth of the energy and a third of the water. The next design should save over 50% via two additional energy-saving methods.

So while politicians keep lamenting the "costs" of climate protection, such smart firms are racing to grab the profits before their competitors do!

[slide 10] Yet the whole climate problem is caused by one percentage point. Here's what that means. Professor Youichi KAYA notes that how fast the global economy emits carbon by burning fossil fuel is the product of four terms: population, times per-capita GDP, times the rate of using primary energy per unit of GDP, times how much carbon each unit of energy supply releases. Economic theorists normally assume certain rates of change for these variables. Their net effect is a 1% annual increase in carbon emissions—enough to triple emissions by 2100. Those promoting their favorite forms of energy supply generally debate the rather small, green term showing carbon reductions per unit of energy. But the red term showing energy intensity—energy used per dollar of GDP—is normally assumed to change four times faster, even though that's only 1% per year. If we could double that modest pace, to 2% per year, it would offset population and economic growth, stabilizing global carbon emissions. If we could increase the rate of cutting energy intensity further, to 3% per year, we'd reduce carbon emissions and rather quickly stabilize the earth's climate, to the extent irreversible changes aren't already underway. So it is plausible that we could raise the world's energy productivity by 2—3% per year, whether by using energy more efficiently, making the mix of outputs less energy-intensive, or changing behaviors?

[slide 11] Some major countries already do this without even paying attention. The United States normally saves about 3% of its energy use per dollar of GDP each year; in 2006, that reached 4% per year, and total U.S. energy use went *down* 0.8% while GDP rose 3.3%. California generally saves energy about one percentage point faster than the whole United States—around 4% a year. China saved more than 5% a year for over 20 years, then nearly 8% a year for 5 years (until coming off the rails during 2001—06—this is now being fixed); energy efficiency is China's top strategic priority for national development, which otherwise becomes impossible. Attentive companies, some of which I've just named, routinely and profitably cut their energy intensity or even their absolute energy use or carbon emissions by 6—9% a year. So why should it be so hard for the world to achieve 3% a year? and since everyone who saves energy also makes money at it, why should this be costly?

Japan, having saved energy so inspiringly in the 1970s and early 1980s, then slowed down; the pace of saving energy per yen of GDP averaged only 0.7 per year from 1977 to 2004. The government's New National Energy Strategy calls for doubling that pace, and the National Institute of Environmental Studies' scenarios would speed it a little further, though nowhere near, say, the U.S. rate. Even so **[slide 12]**, the equitable vision of "contraction and convergence," where all countries have the same carbon emission rights per person and everyone continues to get richer (especially in developing countries), could head for carbon reductions around 90% over the next century. Could that grand vision of a richer, fairer, cooler, and safer world actually be feasible and profitable? And could Japan lead the way?

[slide 13] Some think not. *Yomiuri Shimbun* spoke for many when it remarked that "Japan's energy efficiency level is unlikely to improve much, since it is already the best in the world." Hmmm. Is that how Toyota thinks about making cars? Is it how Japan became such a mighty industrial power? Doesn't continuous improvement apply to energy as much as to manufacturing? Isn't Japan still the best in the world at this *kaizen*? As an admirer of Japan's scientific and technical genius as much as of its unique contributions to world culture, I believe Japan can lead this global leapfrog. And I know frogs leap also in Japan, because Bashô tells us so:

furu ike ya
kawazu tobikomu
mizu no oto

To see how this Japanese frog can leap ahead of the world, let's focus on oil and electricity, each of which is responsible for two-fifths of the world's CO_2 emissions.

[slide 14] First let's see where we're starting. Many of Japan's leading firms have already made impressive and exciting contributions to saving the climate: Toyota, Nissan, Honda, Ricoh, Kirin, and many more. But outside such pioneering companies, challenges have emerged.

[slide 15] The per-capita use of electricity is the most important indicator of climate progress, because classical power plants use roughly three or four units of fuel to make and deliver one unit of electricity, and worldwide, most of their fuel is coal, the most carbon-intensive kind. Notice how, since 1965, the orange line, for Japan, has been rising about as steeply as the purple line, for Texas, or the green line, for the whole United States. There are many causes: strong industrial growth until recent years, a reversal of previously falling energy intensity in some big industries since 1990, a 45% increase in household electricity per person. That rise in turn is due to more and bigger appliances and to a huge increase in lighting, which operates for much longer hours in Japanese homes than anywhere else, partly because of long commutes. Meanwhile, too, houses became a little better insulated, but indoor temperatures, traditionally around 15 ℃, rose even faster, the *kotatsu* gave way to bigger room heaters, and air conditioners to cool inefficient buildings continued to displace traditional architecture, attitudes, and customs.

Now compare the red line, California, where (as in New York State) the average citizen's total electricity use in all sectors is now slightly below that of the average Japanese person. In the past 30 years, while the average Japanese person's total electricity use doubled, the average Californian's total electricity use stayed flat even though her real income rose by 79%. Half of this dramatic efficiency gain came from strong and early efficiency standards for buildings and appliances. The other half came from rewarding utilities for cutting your bill, not for selling you more energy (as Japan and nearly all of the United States still do). Using electricity far more efficiently has saved California from building 65 billion watts of power stations, which with their grid investments would have cost upwards of $100 billion. Since Japan has 3.4 times more people than California, this implies that if Japanese people had held *their* electricity use flat for 30 years rather than doubling it, they wouldn't have needed tens of trillions of yen worth of electricity supply investments that help make Japanese electricity some of the costliest in the world.

[slide 16] But don't those doubled-efficiency hybrid cars pioneered in Japan, not to mention those amazing Japanese mini-cars, make Japan a leader in oil efficiency? Not exactly. If we compare different countries' household vehicles (cars, vans, SUVs, and pickup trucks) using the same test procedures, we're surprised to find that in the late 1990s, the average Japanese light-duty vehicle became as inefficient as its American counterpart, pulling only slightly ahead in the past two years.

These broad facts, plus the technical literature and my decades of observations of how energy is used in Japan, suggest that there are surprising parallels between our two countries' potential for further profitable gains in energy efficiency. My team's very detailed studies and practical experience illustrate that potential to be in the United States. **[slide 17]** There, if we fully adopted today's best efficiency techniques, we'd save over half the oil at a sixth of its price, half the gas at an eighth of its price, and three-fourths of the electricity at an eighth of its price. Implementing these radical efficiency gains would require extra investments equal to only one-sixth of the current direct price of the energy they'd save (at prices far below Japan's). This shift would also make energy cheaper, stabilize prices and keep them lower for longer, dramatically cut CO_2, enhance security, and buy time to learn more, choose better, and develop and deploy better techniques. While many details differ between the U.S. and Japan, I believe the Japanese potential for *percentage* reduction in energy use is not fundamentally different. The distinguished engineer KOMIYAMA Hiroshi-sensei, President of Tokyo University, agrees that about two-thirds of Japanese energy can be advantageously saved.

[slide 18] To illustrate what can be done in buildings, which in Japan are particularly underinsulated, let's visit my own house, indoor farm, and office high in the Colorado Rockies at 2200 meters (7100 feet) above sea level. There we have seen temperatures as low as −44℃ (−47 ℉), 39 days of continuous midwinter cloud, and frost on any day of the year. Yet if you come in out of the snowstorm into the central atrium, you're in a jungle where I've already harvested 28 banana crops and the new banana trees are growing 2 cm per day—and then you realize there's no furnace. The superinsulated house is 99% heated by the solar gain through the superwindows (which insulate as well as 12 to 19 sheets of glass, but look like 2 and cost less than 3), plus the heat from people, lights, and appliances. These heat-saving techniques *reduced* total construction cost by $1100, because they added less capital cost than I saved by not installing a heating system. I then reinvested that money, plus a further $6000—a net total of about ¥1900/m^2—in saving also 99% of the water-heating energy, half the water, and 90% of the household electricity. If I bought my home's electricity rather than making it with solar panels, it would cost only about ¥600 per month for 372 m^2. All these efficiencies together repaid their extra cost in ten months with 1983 technologies; today we can do much better.

In a hot climate, up to 46℃ (115 ℉), this ordinary-looking California tract house, with the obligatory stupid dark roof, was designed to use one-tenth the normal U.S. amount of energy. It provided excellent comfort with no air-conditioner, yet if built in quantity, would have cost about $1800 less than normal to build and $1600 less over time to maintain, because it had no heating or cooling equipment. Or in steamy Bangkok, architecture Professor Soontorn BOONYATIKARN built this modern house, at exactly normal cost, providing superior comfort with one-tenth the normal amount of air-conditioning energy.

These three houses, spanning the range of the earth's climates, show how integrative design—getting multiple benefits from single expenditures—can make very large energy savings cost *less* than small savings!

[slide 19] That sounds odd to economic theorists who believe in "diminishing returns": the more energy you save, the more and more steeply the cost of the next unit of savings keeps rising, until it gets too expensive and you must stop. Insulation does work this way. If, like most engineers, you buy only as much insulation as will repay its extra cost from saved heating fuel over the years, then you will have thin insulation and a big furnace burning costly fuel. But if you remember to minimize *total* cost—construction cost as well as operating cost—then you'll discover a new part of the curve: **[slide 20]** you can add so much insulation that you eliminate the whole heating system—furnace, pipes, pumps, ducts, fans, wires, controls, and fuel-supply arrangements! This makes the capital cost come down to *less* than you started with, just as my house saves 99% of its heating energy, at a lower construction cost than if I'd tried to save little or nothing. **[slide 21]** And rather than getting there the long way around, we can "tunnel through the cost barrier" directly to that design destination—*muda nashi* (no waste). (For details on how to do this, www.rmi.org/stanford posts my five new Stanford University lectures on advanced energy efficiency.) And this isn't just some magic we do in Colorado. Central and northern Europe already have more than ten thousand "Passive Houses" that are comfortable with no heating systems, with zero extra construction cost.

[slide 22] Surprisingly, we can tunnel through the cost barrier not only in new buildings but also in retrofits (fixing up old buildings) if we properly coordinate with other major renovations that are happening anyway, such as renewing the façade or the mechanical equipment. For example, in 1994 we designed a retrofit for a 19,000-m^2 curtainwall office building in Chicago, which has both a hot and a cold climate. The 20-year-old window units had failing edge seals, so the whole curtainwall needed reglazing. But rather than replacing the dark heat-absorbing glass with the same kind, we found superwindows that would be nearly perfect in letting in light without heat. They'd admit nearly six times more visible light and a tenth less unwanted heat, and would block the flow of heat and noise 3—4 times better, at a slightly higher cost. But adding glare-free daylight distribution all the way through the building, plus very efficient and well-controlled lights and office equipment, would cut the peak cooling load by 77%. Then replacing the cooling system with a new one four times smaller and nearly four times more efficient would cost $200,000 less than renovating the big old system (for age and to eliminate its CFCs [chlorofluorocarbons]). That capital saving could then pay for the superwindows and the lighting and daylighting retrofits, yielding a 75% energy saving with a payback of *minus* five months—that is, a lower capital cost—compared with the normal 20-year renovation that saves nothing.

[slide 23] We can tunnel through the cost barrier not just in buildings but also in vehicles and factories. For example, a loop to pump a heat-transfer fluid around a factory was designed by a noted European engineering firm to use 70.8 kW of pumping power. A Dutch engineer using our methods reduced this by 92%, to 5.3 kW, at lower construction cost and with better performance, via two changes in design mentality that resulted in using fat, short, straight pipes rather than thin, long, crooked pipes. This is not rocket science; it's just Victorian integrative design rediscovered.

[slide 24] I've offered you a pumping example because power plants release 40% of the world's CO_2, three-fifths of electricity runs motors, and pumps and fans, which have similar physics, are the two biggest uses of motors. If you feed ten units of coal into a classical power station, nine units get lost in the compounding losses of conversion, distribution, and then the motor and pumping systems. Only one unit of energy comes out of the pipe as flow. But if we reverse those compounding losses into compounding *savings*, then each unit of flow or friction saved in the pipe saves ten units of coal, climate change, and cost at the power plant. It also makes the motor about 2.5 units smaller (hence cheaper). All the upstream components become smaller, simpler, and cheaper. That's why we should always start saving at the downstream end.

[slide 25] For example, often a big pump, meant to send fluid up a pipe, has an adjacent helper pump or identical in-place spare pump. They're drawn and then built so that the flow must always go through two 90 °bends (friction) and two valves. A new design mentality could make the flow go through no bends and no valves (or one valve). **[slide 26]** When my colleague, engineer Peter RUMSEY, did this in retrofitting a pumping loop, his odd—looking piping layout saved 75% of the pumping energy and eliminated 15 pumps that will never again waste electricity and maintenance.

[slide 27] My team has lately redesigned more than $30 billion worth of facilities for radical energy efficiency. In motor systems, for example, 35 kinds of improvements can save about half the electricity (not counting any previous, and typically even cheaper, savings in the systems that the motor is driving, like pumps and pipes). But the cost is repaid within a year because you need to buy only 7 kinds of savings; the other 28 are free byproducts. We see similarly rapid returns when saving half the energy used to make chilled water and clean air in chip fabs. Whether we're retrofitting an oil refinery or platform, a naval vessel, a huge liquefied natural gas (LNG) plant, or a giant platinum mine, or designing a new Fischer-Tropsch plant, data center, chip fab, supermarket, two chemical plants, even a luxury yacht, we typically find that retrofits can save ~30—60% of the energy with a 2—3-year payback, while in new installations, we save more, generally 40—90%, and the capital cost almost always goes *down*. We have "tunneled through the cost barrier" in 29 diverse sectors of the economy—every one we've tried. Of course, none of this would be possible if the designs had been optimal to start with. I'm getting tired of retrofitting things that weren't designed right the first time. To get to the root of the problem, we must reform engineering practice and pedagogy fundamentally. I hope next summer to help leading practitioners write a casebook on *Factor Ten Engineering*, presenting in detail such vivid examples that they will irreversibly rearrange engineers' mental furniture. Our aim is the nonviolent overthrow of bad engineering. We warmly invite practitioners who think this way to share their most compelling case-studies via www.10xE.org.

[slide 28] Now let's turn to oil, whose burning releases 42% of the world's CO_2, and which has many other problems. (For example, two-thirds of Saudi oil flows through one processing plant that's already been attacked, and through two terminals of which the larger has already been attacked twice.) In 2004, my team published *Winning the Oil Endgame* (www.oilendgame.com) —an independent study, cosponsored by the Office of the U.S. Secretary of Defense and written for business and military leaders, for getting the United States completely off oil by the 2040s, with a much stronger economy, all led by business for profit.

[slide 29] Rather than always rising, U.S. oil use (the solid red line) and oil imports (the dashed red line) could be turned down along the green lines by redoubling the efficiency of using oil— already doubled since 1975—at an average cost of $12 per saved barrel (2000 $). We could then turn down even more steeply along the blue lines by replacing the other half of the oil with saved natural gas and advanced biofuels such as cellulosic ethanol, all at an average cost of $18 per barrel. Thus the average cost of eliminating U.S. oil use is only $15 per barrel, or about one-fifth the current world price—assuming that the hidden environmental, security, and other costs of oil are worth zero, a conservatively low estimate.

Even faster oil savings are possible, because the U.S. actually achieved them when it last paid attention to oil. During the eight years 1977—85, America's GDP grew 27%, oil use fell 17%, oil imports fell 50%, and oil imports from the Persian Gulf fell 87%. (They'd have been gone in the next year if this had continued.) The world, including Japan, saved so much oil that OPEC's exports fell 48%, breaking the cartel's pricing power for a decade. We customers—especially in America, the Saudi Arabia of "negabarrels"—had more market power than the suppliers, because we could save oil faster than they could conveniently sell less oil. That was practice; this is real. Today we could re—run that old play much better, using our far more powerful technologies.

Suppose that by 2025 the United States invests $180 billion in the journey beyond oil—half to retool its car, truck, and plane industries, half to build an advanced biofuels industry. Suppose that the world oil price were then just $26 a barrel (2000 $)—which might be true if we saved that much oil! But even against this low oil price, the $180—billion investment would earn a handsome net return of $70 billion per year. As a free byproduct, CO_2 emissions would fall 26%. America would also get a million new jobs (three-fourths rural) and could save a million jobs now at risk, mainly in automaking, where the choice is whether to continue importing efficient cars to replace oil or to *make* efficient cars and import neither the cars nor the oil.

Our study's competitive-strategy analysis for the car, truck, plane, fuel, and military sectors found a business logic so compelling that public policy need only support, not distort, the business logic. Rather than needing government to force us to commit unnatural acts in the marketplace, the profit motive could implement this off-oil transition without new energy taxes, subsidies, mandates, or national laws—though a compatible policy framework would speed the transition, and we did suggest new policies more effective and attractive than traditional ones.

[slide 30] Technologically, the key is transport, which uses 70% of U.S. oil. But making trucks, cars, and planes lighter-weight, lower-drag, and with advanced propulsion could triple their efficiency, with uncompromised comfort and performance and better safety, and repay the buyers' extra cost in 1, 2, and 4—5 years respectively at low U.S. fuel prices. Often performance would improve too, as in the Opel Eco-Speedster carbon-fiber diesel hybrid car that gets 250 km/h (155 mph) and 40 km/L (94 mpg), although not at the same instant! Surprisingly, the ultralighting that doubles the efficiency of these carbon—fiber concept cars doesn't raise their production cost, because the costlier material is offset by simpler automaking and a 2—3-times smaller powertrain.

[slide 31] This opportunity emerges from the physics of a typical car. Each day it burns ~100 times its weight in ancient plants (very inefficiently converted to gasoline). But where does that energy go? Seven-eighths of it never reaches the wheels, but is lost first in the engine, idling, driveline, and accessories. Of the one-eighth that does reach the wheels, half heats the tires and road or heats the air that the car pushes aside. Only the last 6% of the fuel energy accelerates the car and then heats the brakes when you stop. But since only one-twentieth of the mass being accelerated is you—the rest is the car—only 5% of 6%, or 0.3%, of the fuel energy ends up moving the driver! After 120 years of devoted engineering effort, this is not very gratifying.

But there's good news. Three-fourths of the energy needed to move the car is caused by its weight, and every unit of energy we save at the wheels saves seven more units we needn't waste getting it to the wheels, so there's huge leverage in making the car radically lighter-weight.

[slide 32] Traditionally this meant light metals like aluminum, which cost more but work well. I drive a 27-km/L (3.56 L/100 km, 64 mpg) Japanese aluminum hybrid car. New ultralight steels are starting to compete too. The strongest, lightest solution is composites reinforced by carbon fiber. This Mercedes *SLC McLaren* supercar, handmade for a half-million dollars, is made of such "advanced composites." It was hit by a VW Golf, which was totaled, but the *McLaren* only lost a side-panel, which they'll snap back on and fix the scratch later. At the front corners, under the hood, is a pair of 3.5-kg carbon-fiber crush cones that can absorb the entire crash energy of this car's hitting a wall at 105 km/h, because such materials in the right shapes can absorb 6—12 times as much crash energy per kg as steel, and do so more smoothly. Such light-but-strong materials let us make cars big (which is protective and comfortable) without also making them heavy (which is hostile and inefficient), so we can save oil, lives, and money all at the same time.

[slide 33] Of course, advanced composites' challenge is cost. They're used in military and aerospace applications at about a thousand times higher cost and lower volume than automakers need. But I became encouraged about bridging that gap when I met a young Lockheed-Martin Skunk Works engineer who had led the development of a 95%-carbon fighter plane that was one-third lighter, yet two-thirds cheaper, because it was optimally designed for manufacturing from carbon, not metal. It was so unusual that he couldn't find a military customer, so in due course I was able to hire him to do the same for cars, which we did in 2000 with two European Tier One auto engineering firms (www.rmi.org/images/PDFs/Transportation/T04-01_HypercarH2AutoTrans.pdf).

Meanwhile, a new manufacturing method for making cost-competitive advanced-composite automotive structures is being rapidly commercialized by a small firm I chaired; for example, this test piece for an ultralight helmet, tougher than titanium and able to withstand a sledgehammer, can be made in less than a minute. Cars made of similar materials would weigh half as much as today's steel cars, save half the fuel, be safer, yet cost the same to make. Making American cars this way would be like finding an inexhaustible Saudi Arabia under Detroit.

[slide 34] Here's the car we designed in 2000 that could be made with such a process. It's an uncompromised midsize SUV that can carry five adults in comfort and up to 2 m^3 of cargo, haul a half-ton up a 44% grade, accelerate 0—100 km/h in 7.2 seconds, yet increase efficiency by 3.6-fold to 28 km/L (3.51 L/100 km, 67 mpg) using a *Prius*—like gasoline hybrid powertrain. Such a car would have an extra retail price of $2511 (2000 $), repaying its extra cost from one year's fuel savings in Japan or two years' in America. Or if run on a hydrogen fuel cell, it would achieve 6.2-fold higher efficiency, 48.5 km/L (2.06 L/100 km, 114 mpg), and could compete one or two decades sooner than heavy steel cars. That's because needing two-thirds less energy, the car's hydrogen tanks would become small enough to fit and its fuel cell would become small enough to afford early. Most interestingly, such vehicles would have ~99% lower tooling cost than today's steel cars, would need no body shop or paint shop (the two hardest and costliest stages in automaking), and would need at least two-fifths less capital than the industry's leanest plant today.

[slide 35] Such gamechanging technologies make me wonder if U.S. automakers might use radical energy efficiency as a competitive strategy, much as Japanese automakers did in boldly introducing and then selling more than a million hybrid-electric cars and building up a formidable lead in that technology—in which GM was once 18 months ahead of Toyota but then stumbled. Such an American leapfrog, in airplanes, is now getting attention in Detroit. In 1997, Boeing was in a crisis much like Detroit's today. The Toyota Manufacturing System and other wrenching changes at Boeing Commercial Airplanes brought costs under control, but there was little viable innovation in the pipeline after the *777*. In 2003, Airbus outsold Boeing, and some serious analysts were starting to doubt Boeing's longevity. But in 2004, Boeing's riposte was the *787 Dreamliner*—one-fifth more efficient at the same price, 50% carbon-fiber composites by mass (up from 9% in the *777*), with many customer and operator advantages and with assembly time cut from 11 days to 3. It's now sold out into 2014. Its order takeoff has been the fastest of any airplane in history. Now Boeing is bringing those innovations to every commercial airplane it makes, before Airbus can even steer itself out of the ditch. This stunning success naturally makes U.S. automakers wonder: if you're in the ring with the world champion *sumo* wrestler, do you just keep training to become a little faster and stronger—or do you quietly shift the game to *aikidoh*?

[slide 36] My team is two-thirds of the way through an effort to make America's journey off oil irreversible, via "institutional acupuncture": we figure out where the business logic is congested and not flowing properly, and we stick needles into it to stimulate the flow. I think we're already past the tipping point—with much more work to do, but it gets easier from now on—in three of the six sectors we must influence. In aviation, Boeing's efficiency leapfrog has won, and will doubtless finance rapid development of even more efficient airplanes to make its lead unassailable. In heavy trucks, based on our analysis, Wal-Mart (the world's largest company) is requiring doubled-efficiency trucks from its suppliers; that "demand pull" drags the trucks into the market where everyone can buy them, saving 6% of U.S. oil use (ultimately 8% with the next step—tripled-efficiency trucks). The U.S. Department of Defense is rapidly becoming the most important part of the Federal government in leading the country off oil, so ultimately they needn't fight over oil. Military leaders really like the idea of nega-missions in the Persian Gulf—Mission Unnecessary. There is also gratifying progress in the fuel and finance sectors: in 2006 alone, the "clean energy" space received $71 billion of new private investment.

Obviously the slowest and hardest sector to transform is automaking, but here too, progress is quickly accelerating. In 2004, our study proposed that Detroit follow Boeing's competitive strategy based on breakthroughs in ultralight materials, advanced propulsion, and integrative design. Two years later, Ford Motor Company hired the head of Boeing Commercial Airplanes, who had led that revolution, as its new CEO; he is now in Detroit with transformational intent. The United Autoworkers' Union and the car dealers are keen for such innovation to save their industry. The tsunami of "creative destruction" (as economist Joseph Schumpeter called it) sweeping over the global auto industry—plus emerging competition from India, China, and others—is now the greatest since the 1920s. It will change automakers' managers or their minds, whichever comes first: both Ford and Chrysler now have turnaround-expert CEOs from outside the auto industry. Indeed, my team currently has two transformational auto projects underway, one at an automaker level and one at a Tier One supplier level, and this spring, both surpassed expectations.

[slide 37] Japanese automakers' extraordinary achievements since the 1990s in commercializing hybrid-electric cars are just the first step. An excellent hybrid like Prius, properly driven, roughly doubles efficiency—much more if ultimately equipped with a diesel engine (if it can be clean enough) or its ~60%-efficient successor, the "digital engine" first tested by Sturman Industries, a small Colorado firm, in January 2007. Making today's hybrid cars ultralight, with better aerodynamics and tires, can redouble their efficiency at no extra cost with highly integrative design. Fueling such "Hypercars " with 85% sustainably grown cellulosic ethanol or butanol and only 15% gasoline quadruples again their kilometers per liter of oil, reducing cars' oil use to 1/16th the current level.

But then we can go further, beyond our oil-endgame analysis. For example, Toyota is to road-test in November 2007, and is rumored to be preparing to sell as early as Model Year 2008, a plug-in hybrid-electric car. Such vehicles could again at least redouble the efficiency of using oil, reduce carbon emissions, and require no new power stations. Moreover, a plug-in hybrid intelligently connected to the power grid when parked could exploit the "vehicle-to-grid" opportunity I invented in the early 1990s, selling electricity from its distributed storage capacity back to the electric companies when and where it's most valuable. This could justify utility financing for the costly batteries. Later, fuel-cell Hypercars could act as power plants on wheels, able when parked (~96% of the time) to earn impressive profits—for the first two million Americans to do so, roughly the whole cost of the car—by selling power back to utilities downtown on hot afternoons. This could readily put the coal and nuclear power plants out of business, since a full U.S. Hypercar fleet would have 6—12 times as much generating capacity as all the utilities now own. Thus Hypercar technology could end up profitably eliminating the majority of CO_2 emissions by addressing both their oil and electricity causes. But even without fuel cells, just biofueled plug-in ultralight hybrids could cut cars' oil use per km by 97%. Then hydrogen (and battery-powered pure-electric cars) could compete for the last 3% as well as for the biofuel market. Hydrogen fuel cells, practical and affordable when put in Hypercars, will reduce drivers' cost per km and will cut CO_2 per km by 2—6-fold, then become carbon-free with sequestration or renewable hydrogen.

[slide 38] Cars last about 14 years (except in Japan, where the government makes us scrap them prematurely), and planning and tooling new models takes years, so big automotive change is painfully slow. But U.S. automakers took only six years in the 1920s to switch from wood to steel autobodies, and at the start of World War II, converting all car factories to make war materiel took just six months. The last time the U.S. paid attention to oil, it cut oil intensity by more than 5% per year (like displacing a Persian Gulf's worth of imports every 2.5 years); the biggest saving came from a nearly 5% annual gain in the efficiency of new domestic cars—96% from making them smarter, and only 4% from making them smaller.

In recent years, Boeing has inverted the airplane industry's competitive ranking in just 2—4 years, with a breakthrough product a hundred-fold more complex and even more highly regulated than a car. General Motors's small team took the breakthrough *EV1* battery-electric car from concept to street in three years. Thus even big organizations can move quickly if the efficient new product is simpler than the inefficient old one. Of course, normal S-curve diffusion of new technologies normally takes 12—15 years to take the stock of product from 10% to 90% adoption, but the kinds of innovative competitive strategies and public policies we suggest in *Winning the Oil Endgame* can reach the 10% "takeoff point" three years earlier and then spread much faster.

[slide 39] The oil industry views its global extractable resource base as a supply curve with rising costs. One trillion barrels have already been burned. The International Energy Agency says the world will need about that much again through 2030—about the amount that OPEC countries in the Middle East officially claim they can provide at a price far above the competitive free-market price of about \$5—14 per barrel. After that, oil or its conventional substitutes become rapidly more difficult, remote, costly, and disagreeable. **[slide 40]** But if we add the savings and substitutes documented in *Winning the Oil Endgame*, conservatively scaled from the United States to the world, the whole supply curve slides three trillion barrels to the right, saving probably tens of trillions of dollars. **[slide 41]** Since resources like tar sands, oil shales, and coal-to-liquids are not only costly but also far more carbon-intensive than conventional oil, not using them also keeps more than a trillion tonnes of carbon out of the air.

Let me conclude with a few remarks about electricity—the other two-fifths of the CO_2 problem —and about Japan's unique opportunity to lead all these changes.

[slide 42] With electricity at least as much as with oil, efficiency is a rapidly moving target. In the early days of exploring America's "negawatt" potential, 1984—89, the efficiency resource became twice as big but three times cheaper in just five years. Since then, it has become still bigger and cheaper, thanks to mass production (often in Asia), innovation, competition, and the pervasive effects of the IT revolution. Consider refrigerators, for example—the biggest user of electricity in most U.S. houses that don't use electricity to heat space or water. The electricity used by a new refrigerator soared until the first oil shock, partly because refrigerators kept getting bigger. They stopped getting bigger around 1980 so they could still fit through the door and into the kitchen. But meanwhile, California and then Federal efficiency standards quadrupled their efficiency, saving energy by 5% a year, while refrigerators also became 64% cheaper. Japan's recent progress (though under a different test procedure) has been even faster. And there's still room for improvement, as illustrated by the custom-made refrigerator I've used since 1985 and the Dutch state of the art in 2000.

[slide 43] In the late 1980s, my team synthesized a decade of what is probably still the most detailed effort to assess how much electricity can be saved at what cost. Measured cost and performance data showed that fully applying ~1,000 efficiency technologies in new and existing buildings and factories could save ~75% of America's 1986 electricity use, at an average technical cost that in today's money would be about 1 U.S. cent per saved kWh. The North American utilities' think-tank, the Electric Power Research Institute (EPRI), found a somewhat smaller potential saving—only 40—60% by 2000—but still cheaper than the cost of just *operating* a coal or nuclear power plant and delivering its electricity. (Most of the differences between these two studies were due to methodology, not substance.) Our findings were also consistent with other studies in Europe. And as EPRI agrees, the efficiency technologies continue to improve in cost and performance faster than we're using them up, so saved electricity, or "negawatts," keeps on becoming an ever bigger and cheaper resource. The "low-hanging fruit" is mushing up around our ankles and spilling in over the tops of our waders while the innovation tree pelts our head with more fruit!

[slide 44] A similar but even less visible revolution is happening in electricity supply: low- and no-carbon decentralized generators are eclipsing central thermal power stations. These graphs show the electricity produced and the capacity installed, both worldwide, for what *The Economist* magazine calls "micropower." Real data are on the left side of the vertical line, industry projections on the right. Micropower has two components:

- The tan wedge is combined-heat-and-power ("cogeneration")—making electricity together with useful heat. It's very efficient and about two-thirds gas-fired, so it saves over half the carbon emitted by the separate power plants and boilers or furnaces that it replaces.
- The colored wedges are all the renewable sources of electricity except big hydroelectric dams (units over ten megawatts).

Astonishingly, micropower now provides a sixth of the world's electricity—slightly more than nuclear power—and a third of the world's additions of electricity. Micropower in 2005 provided from one-sixth to more than half of all electricity in 13 industrial countries. These graphs don't show "negawatts," which are probably about as big, so together, micropower and negawatts now provide the majority of the world's new electrical services. Because they're mass-produced, quickly built and installed, and bought by millions of dispersed market actors, they're more like cellphones than like cathedrals, so they can grow very quickly. For example, in 2005 (the last full data available), micropower added four times the output and 11 times the capacity that nuclear power added worldwide (both net of retirements). Moreover, even though it gets smaller subsidies and faces bigger obstacles than its traditional competitors, micropower won investments of more than $100 billion of private risk capital—$56 billion just for the distributed renewables—while nuclear got none (it's bought only in centrally planned power systems).

The simplest explanation for micropower's marketplace victory over central thermal stations is that its lower costs and financial risks make it more attractive to investors. **[slide 45]** Let's test that hypothesis by examining the best empirical U.S. data on what it costs to make and deliver (or to save) a new kWh of electricity at the retail meter. We'll examine both remote resources, which incur a delivery cost to reach the customer, and onsite resources, which are already delivered. Your actual costs may vary, but I've done the analysis in a way that favors central stations. For those I used the canonical 2003 Massachusetts Institute of Technology (MIT) study, whose costs included whatever subsidies central stations then got, but not the reserve margin needed to back up those big plants when they fail.

The MIT study found that a new nuclear kWh would cost 7.0¢ to make (2004 $), so adding a deliberately low, decade-old average delivery cost for U.S. investor-owned utilities would bring the delivered cost to nearly 10¢. The MIT study said that huge new subsidies might, if everything went well, cut that cost by nearly 3¢, though a 2007 industry consensus group found the base-case cost has since *risen* by up to 3¢. Meanwhile, the MIT study found that a coal plant would cost slightly less than best-case nuclear power might achieve, though coal plants too have lately become costlier. Yet a big ($100/tonne) carbon tax could make the coal plant look nearly as costly as the nuclear base case, and similarly for combined-cycle gas-fired plants.

So policymakers keep juggling taxes and subsidies to try to get the market to choose what they want. But meanwhile the market is shifting away from *all* central power stations. For example, let's assume that windpower costs slightly more than the median for the past eight years' U.S. installations. Let's include its delivery cost too, of course, and add more than the actual cost of "firming" the windpower so it's fully dispatchable whether the wind is blowing or not. Even if we took away its Production Tax Credit—smaller than the subsidies to coal and nuclear—windpower would still beat their cost. But they're becoming costlier while wind turbines' cost trends downward, and indeed the cheapest windfarms already cost less than the industry projection for five years from now.

Generally cheaper still is cogeneration—whether it's the normal industrial kind, or "trigeneration" of electricity, heating, *and* cooling in a building, or cogeneration from recovered industrial waste heat. Cheapest of all is end-use efficiency, which typically costs 1¢/kWh or less for industrial and commercial retrofits, up to a few ¢/kWh if you're not as skillful or also retrofit houses, and if you're very skillful in new installations or even for many retrofits, less than zero.

Comparing all these ways to save or make electricity, we can see why investors are losing their old enthusiasm for central stations: they simply cost too much. But the cheaper alternatives also offer better climate solutions. For example, based on the MIT numbers, you can make and deliver one new nuclear kWh for just ten U.S. cents. That nuclear kWh can displace one kWh of coal-fired electricity, helping to protect the climate. But if you'd spent the same money on distributed renewables, cogeneration, or efficiency instead, you'd displace two to ten times as much coal-fired electricity, and you'd do so faster. If climate is a problem, we must invest judiciously, not indiscriminately, to get the most solution per ¥ and the most solution per year. Buying anything costlier and slower will only reduce and retard the climate solution we need.

[slide 46] Of course, there's always a risk that any energy investment will be failure, like a "dry hole" when drilling for oil. So what can we learn from actual market behavior? An encouraging example comes from California during 1982—85, when all ways to make or save electricity could compete on a fairly level playing-field. During those four years, California's utilities bought or were firmly offered electrical savings and new decentralized supply (mainly renewables) totaling 143% of their total peak demand! The bidding had to be stopped, because in another year the power glut would have forced the shutdown of all the fossil-fueled and nuclear plants (which in hindsight might not have been such a bad idea). Thus letting everything compete will probably yield too many attractive options, not too few—all the more so with today's far more powerful and cost-effective technologies.

Those alternatives are also extremely large. For example, the U.S. potential for electric efficiency is 2—3 or 4 times nuclear power's output, but costs less than just *running* a coal or nuclear plant, even if building it costs nothing. Cogeneration can profitably provide a fifth of U.S. electricity from industry, still more from buildings. On- and nearshore windpower has a practical potential in the U.S. and in China that's over twice total electricity use; in Britain, six times; worldwide, using newer data at 80 meters hub height, about 35 times just from windy areas. Other renewables are even larger. And contrary to a widespread misconception, windpower and solar power don't need impractical amounts of land nor big investments in electricity storage. Diverse, dispersed, but variable solar power and windpower that are forecast and integrated into the grid will actually need *less* storage or backup than utilities have *already* installed to cope with the intermittence of their big thermal plants.

[slide 47] Meanwhile, a wide range of renewable sources is getting inexorably cheaper, and many are also likely to show discontinuous, "leapfrog" technological progress like the red examples I've added to these U.S. Government projections. And decentralized resources' economic advantage increases by typically about another tenfold when their 207 "distributed benefits," mainly from financial economics and electrical engineering, are properly counted (www.smallisprofitable.org).

[slide 48] Even seemingly costly renewable energy also becomes often cost-effective today when properly integrated with efficient use. For example, a California prison installed 1.2 hectares of photovoltaics on its roof. But first making the roof white (to reject solar heat) and the jail's lights, fans, and air conditioners more efficient reduced demand, so on the hot afternoons when the solar cells produce the most electricity, the jail has the most surplus to sell back to the grid at the best price. Thus this $9-million project, of which the state reimbursed $5 million through subsidies, would have been very profitable even without them, because over 25 years, it yielded $15 million of benefits. The same logic becomes even stronger with distributed generators cheaper than photovoltaics, and at the scale of a house. My own household, using an average of about 120 watts, is entirely powered by 3 m^2 of photovoltaics, which — installed with inverter and batteries — cost slightly less than connecting to the utility wires 30 m away, even if the saved electricity were worth zero. Today's state-of-the-art technology could reduce my home's usage to only about 40 watts, powered by 1 m^2 of photovoltaics, which would cost less than connecting to wires that were already on the side of my house and filled with free electricity. That is, an extremely efficient house can reduce to zero the breakeven distance beyond which it's cheaper to use solar power than to connect to the grid.

[slide 49] Thus efficient use, micropower, and substitutes for oil are all revolutionizing the way we get the services now provided by electricity and by oil. These profound market shifts are good for both climate and security. They profitably protect the Earth's climate, far faster and more effectively than other methods. Smarter choices can also free up huge energy investments to help finance other development needs. For example, building a compact fluorescent lamp factory in Mumbai or a superwindow coating factory in Bangkok needs roughly a thousand times less capital, repaid ten times faster, than supplying more electricity from central plants to run inefficient lamps and air conditioners to provide the same light and comfort. This ~10,000-fold reduction in the capital needed by the power sector, which now gobbles about one-fourth of global development capital, offers unique macroeconomic leverage for global development.

These innovations can also make energy no longer a source of conflict, corruption, and autocracy, but rather a powerful path to peace, transparency, and democracy. It can make today's brittle energy systems resilient, so major failures now inevitable by design (and easily caused by malice) become impossible by design. And taking seriously the verdict of the global marketplace can stop the main cause of the spread of nuclear bombs to such countries as Iran and North Korea. As I explained in *Foreign Affairs* magazine in summer 1980, civilian nuclear power makes widely available, in innocent-looking civilian disguise, the materials, equipment, knowledge, and skills for do-it-yourself bomb kits. But without today's big nuclear commerce, obtaining those ingredients would be harder, more conspicuous, and more politically costly, because the intention would *unambiguously* be to make bombs, not electricity. This unmasking would not make proliferation impossible, but would make it far more difficult and likely to be noticed in time, because intelligence resources could be concentrated on needles, not haystacks.

Both our countries' leadership right now is vital to global security. If the United States claims that despite all its wealth, technological prowess, and fuel resources, it needs nuclear power, it invites all countries lacking those advantages to draw the same conclusion. Conversely, if Japan, already the world leader in solar power and in some forms of energy efficiency, shows that despite having no fuels, its further efficiency potential and renewables could power its advanced industrial economy, then no other country could claim it cannot do likewise. Indeed, by offering wide access for developing countries to the same inherently nonviolent technologies we'd be adopting for ourselves, the U.S. and Japan could even return to the original purpose of Article IV of the Non-Proliferation Treaty — access to affordable energy for development. Our two nations, intertwined by fate in the only uses so far of these horrible weapons, could now join by choice to expose and penalize their proliferators. This would greatly lessen the risk that they will once again be used, while also helping fair global development and protecting the climate.

In short, using energy in a way that saves money can eliminate the supposed need to choose between dying by climate change, by oil wars, or by nuclear holocaust. All those choices are unnecessary and uneconomic.

[slide 50] So let me summarize how I see Japan's energy achievements and opportunities. Japan's industrial efficiency ranges from #1 in the world to more ordinary; even the best sectors and firms can make considerable further improvements. Japan's energy use in households and transport has more than doubled since 1970, including a doubling for trucks and more than a 6-fold increase for passenger cars. All the cars and trucks on the road have average efficiencies far below the best export models, so at least doubled efficiency is quickly and cheaply available. The biggest opportunities are in the rather inefficient stock of buildings, which need both mass retrofits and stronger efforts toward full adoption of highly integrated superefficient equipment and design. Japan is pioneering some excellent policy instruments, like "Top Runner," but it would be helpful to emphasize price less than ability to respond to price, via comprehensive barrier-busting. The most important reform would be to reward distributors of electricity and gas for cutting your bill, not for selling you more energy. And in a country obviously poor in fuels but astonishingly rich in renewable energy potential, the biggest barrier to fully exercising Japan's extraordinary opportunity for energy leadership is simply *not realizing* that the opportunities for efficiency and renewables are as large as they really are: more than large enough to power the whole country, more securely and more cheaply than present arrangements.

[slide 51] So what are we waiting for? *We* are the people we have been waiting for. And Japan is the leader the world is waiting for.

If anything I have said seems too good to be true, please remember Marshall McLuhan's remark that "Only puny secrets need protection. Great discoveries are protected by public incredulity."

It's your move.

Thank you for your kind attention.