The New Yorker
December 20 and 27, 2010
The Efficiency Dilemma
By David Owen

In April, the federal government adopted standards for automobiles requiring manufacturers to improve the average fuel economy of their new-car fleets thirty per cent by 2016. The Times, in an editorial titled "Everybody Wins," said the change would produce "a trifecta of benefits." Those benefits were enumerated last year by Steven Chu, the Secretary of Energy: a reduction in total oil consumption of 1.8 billion barrels; the elimination of nine hundred and fifty million metric tons of greenhouse-gas emissions; and savings, for the average American driver, of three thousand dollars.

Chu, who shared the Nobel Prize in Physics in 1997, has been an evangelist for energy efficiency, and not just for vehicles. I spoke with him in July, shortly after he had conducted an international conference called the Clean Energy Ministerial, at which efficiency was among the main topics. "I feel very passionate about this," he told me. "We in the Department of Energy are trying to get the information out that efficiency really does save money and doesn't necessarily mean that you're going to have to make deep sacrifices."

Energy efficiency has been called "the fifth fuel" (after coal, petroleum, nuclear power, and renewables); it is seen as a cost-free tool for accelerating the transition to a green-energy economy. In 2007, the United Nations Foundation said that efficiency improvements constituted "the largest, the most evenly geographically distributed, and least expensive energy resource." Last year, the management-consulting firm McKinsey & Company concluded that a national efficiency program could eliminate "up to 1.1 gigatons of greenhouse gases annually."

The environmentalist Amory Lovins, whose thinking has influenced Chu's, has referred to the replacement of incandescent light bulbs with compact fluorescents as "not a free lunch, but a lunch you're paid to eat," since a fluorescent bulb will usually save enough electricity to more than offset its higher purchase price. Tantalizingly, much of the technology required to increase efficiency is well understood. The World Economic Forum, in a report called "Towards a More Energy Efficient World," observed that "the average refrigerator sold in the United States today uses three-quarters less energy than the 1975 average, even though it is 20% larger and costs 60% less"—an improvement that Chu cited in his conversation with me.

But the issue may be less straight-forward than it seems. The thirty-five-year period during which new refrigerators have plunged in electricity use is also a period during which the global market for refrigeration has burgeoned and the world's total energy consumption and carbon output, including the parts directly attributable to keeping things cold, have climbed. Similarly, the first fuel-economy regulations for U.S. cars—which were enacted in 1975, in response to the Arab oil embargo— were followed not by a steady decline in total U.S. motor-fuel consumption but by a long-term rise, as well as by increases in horsepower, curb weight, vehicle miles travelled (up a hundred per cent since 1980), and car ownership (America has about fifty million more registered vehicles than licensed drivers). A growing group of economists and others have argued that such correlations aren't coincidental. Instead, they have said, efforts to improve energy efficiency can more than negate any environmental gains—an idea that was first proposed a hundred and fifty years ago, and which came to be known as the Jevons paradox.

Great Britain in the middle of the nineteenth century was the world's leading military, industrial, and mercantile power. In 1865, a twenty-nine year-old Englishman named William Stanley Jevons published a book, "The Coal Question," in which he argued that the bonanza couldn't last. Britain's affluence, he wrote, depended on its endowment of coal, which the country was rapidly depleting. He added that such an outcome could not be delayed through increased "economy" in the use of coal—what we refer to today as energy efficiency. He concluded, in italics, "It is wholly a confusion of ideas to suppose that the economical use of fuel is equivalent to a diminished consumption. The very contrary is the truth."

He offered the example of the British iron industry. If some technological advance made it possible for a blast furnace to produce iron with less coal, he wrote, then profits would rise, new investment in iron production would be attracted, and the price of iron would fall, thereby stimulating additional demand. Eventually, he concluded, "the greater number of furnaces will more than make up for the diminished consumption of each." Other examples of this effect abound.

In a paper published in 1998, the Yale economist William D. Nordhaus estimated the cost of lighting throughout human history. An ancient Babylonian, he calculated, needed to work more than forty-one hours to acquire enough lamp oil to provide a thousand lumen-hours of light—the equivalent of a seventy-five-watt incandescent bulb burning for about an hour. Thirty-five hundred years later, a contemporary of Thomas Jefferson's could buy the same amount of illumination, in the form of tallow candles, by working for about five hours and twenty minutes. By 1992, an average American, with access to compact fluorescents, could do the same in less than half a second. Increasing the energy efficiency of illumination is nothing new; improved lighting has been "a lunch you're paid to eat" ever since humans upgraded from cave fires (fifty-eight hours of labor for our early Stone Age ancestors).

Yet our efficiency gains haven't reduced the energy we expend on illumination or shrunk our energy consumption over all. On the contrary, we now generate light so extravagantly that darkness itself is spoken of as an endangered natural resource.

Jevons was born in Liverpool in 1835. He spent two years at University College, in London, then went to Australia, where he had been offered a job as an assayer at a new mint, in Sydney. He left after five years, completed his education in England, became a part-time college instructor, and published a well-received book on gold markets. "The Coal Question" made him a minor celebrity; it was admired by John Stuart Mill and William Gladstone, and it inspired the government to investigate his findings. In 1871, he published "The Theory of Political Economy," a book that's still considered one of the founding texts of mathematical economics. He drowned a decade later, at the age of forty-six, while swimming in the English Channel. In 1905, John Maynard Keynes, who was then twenty-two and a graduate student at Cambridge University, wrote to Lytton Strachey that he had discovered a "thrilling" book: Jevons's "Investigations in Currency and Finance." Keynes wrote of Jevons, "I am convinced that he was one of the minds of the century."

Jevons might be little discussed today, except by historians of economics, if it weren't for the scholarship of another English economist, Len Brookes. During the nineteen-seventies oil crisis, Brookes argued that devising ways to produce goods with less oil—an obvious response to higher prices—would merely accommodate the new prices, causing energy consumption to be higher than it would have been if no effort to increase efficiency had been made; only later did he discover that Jevons had anticipated him by more than a century. I spoke with Brookes recently. He told me, "Jevons is very simple. When we talk about increasing energy efficiency, what we're really talking about is increasing the productivity of energy. And, if you increase the productivity of anything, you have the effect of reducing its implicit price, because you get more return for the same money— which means the demand goes up."

Nowadays, this effect is usually referred to as "rebound"—or, in cases where increased consumption more than cancels out any energy savings, as "backfire." In a 1992 paper, Harry D. Saunders, an American researcher, provided a concise statement of the basic idea: "With fixed real energy price, energy efficiency gains will increase energy consumption above where it would be without these gains."

In 2000, the journal Energy Policy devoted an entire issue to rebound. It was edited by Lee Schipper, who is now a senior research engineer at Stanford University's Precourt Energy Efficiency Center. In an editorial, Schipper wrote that the question was not whether rebound exists but, rather, "how much the effect appears, how rapidly, in which sectors, and in what manifestations." The majority of the Energy Policy contributors concluded that there wasn't a lot to worry about. Schipper, in his editorial, wrote that the articles, taken together, suggested that "rebounds are significant but do not threaten to rob society of most of the benefits of energy efficiency improvements."

I spoke with Schipper recently, and he told me that the Jevons paradox has limited applicability today. "The key to understanding Jevons," he said, "is that processes, products, and activities where energy is a very high part of the cost—in this country, a few metals, a few chemicals, air travel—are the only ones whose variable cost is very sensitive to energy. That's it." Jevons wasn't wrong about nineteenth-century British iron smelting, he said; but the young and rapidly growing industrial world that Jevons lived in no longer exists.

Most economists and efficiency experts have come to similar conclusions. For example, some of them say that when you increase the fuel efficiency of cars you lose no more than about ten per cent of the fuel savings to increased use. And if you look at the whole economy, Schipper said, rebound effects are comparably trivial. "People like Brookes would say—they don't quite know how to say it, but they seem to want to say the extra growth is more than the saved energy, so it's like a backfire. The problem is, that's never been observed on a national level."

But troublesome questions have lingered, and the existence of large-scale rebound effects is not so easy to dismiss. In 2004, a committee of the House of Lords invited a number of experts to help it grapple with a conundrum: the United Kingdom, like a number of other countries, had spent heavily to increase energy efficiency in an attempt to reduce its greenhouse emissions. Yet energy consumption and carbon output in Britain— as in the rest of the world—had continued to rise. Why?

Most economic analyses of rebound focus narrowly on particular uses or categories of uses: if people buy a more efficient clothes dryer, say, what will happen to the energy they use as they dry clothes? (At least one such study has concluded that, for appliances in general, rebound is nonexistent.) Brookes dismisses such "bottom-up" studies, because they ignore or understate the real consumption effects, in economies as a whole.

A good way to see this is to think about refrigerators, the very appliances that the World Economic Forum and Steven Chu cited as efficiency role models for reductions in energy use. The first refrigerator I remember is the one my parents owned when I was little. They acquired it when they bought their first house, in 1954, a year before I was born. It had a tiny, uninsulated freezer compartment, which seldom contained much more than a few aluminum ice trays and a burrow-like mantle of frost. (Frost-free freezers stay frost-free by periodically heating their cooling elements—a trick that wasn't widely in use yet.) In the sixties, my parents bought a much improved model—which presumably was more efficient, since the door closed tight, by means of a rubberized magnetic seal rather than a mechanical latch. But our power consumption didn't fall, because the old refrigerator didn't go out of service; it moved into our basement, where it remained plugged in for a further twenty-five years—mostly as a warehouse for beverages and leftovers—and where it was soon joined by a stand-alone freezer. Also, in the eighties, my father added an ice-maker to his bar, to supplement the one in the kitchen fridge.

This escalation of cooling capacity has occurred all over suburban America. The recently remodelled kitchen of a friend of mine contains an enormous side-by-side refrigerator, and a drawer-like under-counter mini-fridge for beverages. And the trend has not been confined to households. As the ability to efficiently and inexpensively chill things has grown, so have opportunities to buy chilled things—a potent positive-feedback loop. Gas stations now often have almost as much refrigerated shelf space as the grocery stores of my early childhood; even mediocre hotel rooms usually come with their own small fridge (which, typically, either is empty or—if it's a minibar—contains mainly things that don't need to be kept cold), in addition to an icemaker and a refrigerated vending machine down the hall.

The steadily declining cost of refrigeration has made eating much more interesting. It has also made almost all elements of food production more cost-effective and energy-efficient: milk lasts longer if you don't have to keep it in a pail in your well. But there are environmental downsides, beyond the obvious one that most of the electricity that powers the world's refrigerators is generated by burning fossil fuels. James McWilliams, who is the author of the recent book "Just Food," told me, "Refrigeration and packaging convey to the consumer a sense that what we buy will last longer than it does. Thus, we buy enough stuff to fill our capacious Sub-Zeros and, before we know it, a third of it is past its due date and we toss it." (The item that New Yorkers most often throw away unused, according to the anthropologist-in-residence at the city's Department of Sanitation, is vegetables.) Jonathan Bloom, who runs the Web site wastedfood.com and is the author of the new book "American Wasteland," told me that, since the mid-nineteen-seventies, per-capita food waste in the United States has increased by half, so that we now throw away forty per cent of all the edible food we produce. And when we throw away food we don't just throw away nutrients; we also throw away the energy we used in keeping it cold as we lost interest in it, as well as the energy that went into growing, harvesting, processing, and transporting it, along with its proportional share of our staggering national consumption of fertilizer, pesticides, irrigation water, packaging, and landfill capacity. According to a 2009 study, more than a quarter of U.S. freshwater use goes into producing food that is later discarded.

Efficiency improvements push down costs at every level—from the mining of raw materials to the fabrication and transportation of finished goods to the frequency and intensity of actual use—and reduced costs stimulate increased consumption. (Coincidentally or not, the growth of American refrigerator volume has been roughly paralleled by the growth of American body-mass index.) Efficiency-related increases in one category, furthermore, spill into others. Refrigerators are the fraternal twins of air-conditioners, which use the same energy-hungry compressor technology to force heat to do something that nature doesn't want it to. When I was a child, cold air was a far greater luxury than cold groceries. My parents' first house—like eighty-eight per cent of all American homes in 1960—didn't have air-conditioning when they bought it, although they broke down and got a window unit during a heat wave, when my mom was pregnant with me. Their second house had central air-conditioning, but running it seemed so expensive to my father that, for years, he could seldom be persuaded to turn it on, even at the height of a Kansas City summer, when the air was so humid that it felt like a swimmable liquid. Then he replaced our ancient Carrier unit with a modern one, which consumed less electricity, and our house, like most American houses, evolved rapidly from being essentially un-air-conditioned to being air-conditioned all summer long.

Modern air-conditioners, like modern refrigerators, are vastly more energy efficient than their mid-twentieth-century predecessors—in both cases, partly because of tighter standards established by the Department of Energy. But that efficiency has driven down their cost of operation, and manufacturing efficiencies and market growth have driven down the cost of production, to such an extent that the ownership percentage of 1960 has now flipped: by 2005, according to the Energy Information Administration, eighty-four per cent of all U.S. homes had air-conditioning, and most of it was central. Stan Cox, who is the author of the recent book "Losing Our Cool," told me that, between 1993 and 2005, "the energy efficiency of residential air-conditioning equipment improved twenty-eight per cent, but energy consumption for A.C. by the average air-conditioned household rose thirty-seven per cent." One consequence, Cox observes, is that, in the United States, we now use roughly as much electricity to cool buildings as we did for all purposes in 1955.

As "Losing Our Cool" clearly shows, similar rebound effects permeate the economy. The same technological gains that have propelled the growth of U.S. residential and commercial cooling have helped turn automobile air-conditioners, which barely existed in the nineteen-fifties, into standard equipment on even the least luxurious vehicles. (According to the National Renewable Energy Laboratory, running a mid-sized car's air-conditioning increases fuel consumption by more than twenty per cent.) And access to cooled air is self-reinforcing: to someone who works in an air-conditioned office, an un-air-conditioned house quickly becomes intolerable, and vice versa. A resident of Las Vegas once described cars to me as "devices for transporting air-conditioning between buildings."

In less than half a century, increased efficiency and declining prices have helped to push access to air-conditioning almost all the way to the bottom of the U.S. income scale—and now those same forces are accelerating its spread all over the world. According to Cox, between 1997 and 2007 the use of air-conditioners tripled in China (where a third of the world's units are now manufactured, and where many air-conditioner purchases have been subsidized by the government). In India, air-conditioning is projected to increase almost tenfold between 2005 and 2020; according to a 2009 study, it accounted for forty per cent of the electricity consumed in metropolitan Mumbai.

All such increases in energy-consuming activity can be considered manifestations of the Jevons paradox. Teasing out the precise contribution of a particular efficiency improvement isn't just difficult, however; it may be impossible, because the endlessly ramifying network of interconnections is too complex to yield readily to empirical, mathematics-based analysis. Most modern studies of energy rebound are "bottom-up" by necessity: it's only at the micro end of the economics spectrum that the number of mathematical variables can be kept manageable. But looking for rebound only in individual consumer goods, or in closely cropped economic snapshots, is as futile and misleading as trying to analyze the global climate with a single thermometer.

Schipper told me, "In the end, the impact of rebound is small, in my view, for one very key reason: energy is a small share of the economy. If sixty per cent of our economy were paying for energy, then anything that moved it down by ten per cent would liberate a huge amount of resources. Instead, it's between six and eight per cent for primary energy, depending on exactly what country you're in." ("Primary energy" is the energy in oil, coal, wind, and other natural resources before it's been converted into electricity or into refined or synthetic fuels.) Schipper believes that cheap energy is an environmental problem, but he also believes that, because we can extract vastly more economic benefit from a ton of coal than nineteenth-century Britons did, efficiency gains now have much less power to stimulate consumption. This concept is closely related to one called "decoupling," which suggests that the growing efficiency of machines has weakened the link between energy use and economic activity, and also to the idea of "decarbonization," which holds that, for similar reasons, every dollar we spend represents a shrinking quantity of greenhouse gas.

These sound like environmentally valuable trends—yet they seem to imply that the world's energy and carbon challenges are gradually solving themselves, since decoupling and decarbonization, like increases in efficiency, are nothing new. One problem with decoupling, as the concept is often applied, is that it doesn't account for energy use and carbon emissions that have not been eliminated but merely exported out of the region under study (say, from California to a factory in China). And there's a more fundamental problem, described by the Danish researcher Jørgen S. Nørgård, who has called energy decoupling "largely a statistical delusion." To say that energy's economic role is shrinking is a little like saying, "I have sixteen great-great-grandparents, eight great-grandparents, four grandparents, and two parents—the world's population must be imploding." Energy production may account for only a small percentage of our economy, but its falling share of G.D.P. has made it more important, not less, since every kilowatt we generate supports an ever larger proportion of our well-being. The logic misstep is apparent if you imagine eliminating primary energy from the world. If you do that, you don't end up losing "between six and eight per cent" of current economic activity, as Schipper's formulation might suggest; you lose almost everything we think of as modern life.

Blake Alcott, an ecological economist, has made a similar case in support of the existence of large-scale Jevons effects. Recently, he told me, "If it is true that greater efficiency in using a resource means less consumption of it—as efficiency environmentalists say— then less efficiency would logically mean more consumption. But this yields a reductio ad absurdum: engines and smelters in James Watt's time, around 1800, were far less efficient than today's, but is it really imaginable that, had technology been frozen at that efficiency level, a greater population would now be using vastly more fossil fuel than we in fact do?" Contrary to the argument made by "decouplers," we aren't gradually reducing our dependence on energy; rather, we are finding ever more ingenious ways to leverage B.T.U.s. Between 1984 and 2005, American electricity production grew by about sixty-six per cent—and it did so despite steady, economy-wide gains in energy efficiency. The increase was partly the result of population growth; but per-capita energy consumption rose, too, and it did so even though energy use per dollar of G.D.P. fell by roughly half. Besides, population growth itself can be a Jevons effect: the more efficient we become, the more people we can sustain; the more people we sustain, the more energy we consume.

The Model T was manufactured between 1908 and 1927. According to the Ford Motor Company, its fuel economy ranged between thirteen and twenty-one miles per gallon. There are vehicles on the road today that do worse than that; have we really made so little progress in more than a hundred years? But focussing on miles per gallon is the wrong way to assess the environmental impact of cars. Far more revealing is to consider the productivity of driving. Today, in contrast to the early nineteen-hundreds, any American with a license can cheaply travel almost anywhere, in almost any weather, in extraordinary comfort; can drive for thousands of miles with no maintenance other than refueling; can easily find gas, food, lodging, and just about anything else within a short distance of almost any road; and can order and eat meals without undoing a seat belt or turning off the ceiling-mounted DVD player.

A modern driver, in other words, gets vastly more benefit from a gallon of gasoline—makes far more economical use of fuel—than any Model T owner ever did. Yet motorists' energy consumption has grown by mind-boggling amounts, and, as the productivity of driving has increased and the cost of getting around has fallen, the global market for cars has surged. (Two of the biggest road-building efforts in the history of the world are currently under way in India and China.) And developing small, inexpensive vehicles that get a hundred miles to the gallon would only exacerbate that trend. The problem with efficiency gains is that we inevitably reinvest them in additional consumption. Paving roads reduces rolling friction, thereby boosting miles per gallon, but it also makes distant destinations seem closer, thereby enabling people to live in sprawling, energy-gobbling subdivisions far from where they work and shop.

Chu has said that drivers who buy more efficient cars can expect to save thousands of dollars in fuel costs; but, unless those drivers shred the money and add it to a compost heap, the environment is unlikely to come out ahead, as those dollars will inevitably be spent on goods or activities that involve fuel consumption— say, on increased access to the Internet, which is one of the fastest-growing energy drains in the world. (Cox writes that, by 2014, the U.S. computer network alone will each year require an amount of energy equivalent to the total electricity consumption of Australia.) The problem is exactly what Jevons said it was: the economical use of fuel is not equivalent to a diminished consumption. Schipper told me that economy-wide Jevons effects have "never been observed," but you can find them almost anywhere you look: they are the history of civilization.

Jevons died too soon to see the modern uses of oil and natural gas, and he obviously knew nothing of nuclear power. But he did explain why "alternative" energy sources, such as wind, hydropower, and biofuels (in his day, mainly firewood and whale oil), could not compete with coal: coal had replaced them, on account of its vastly greater portability, utility, and productivity. Early British steam engines were sometimes used to pump water to turn water wheels; we do the equivalent when we burn coal to make our toothbrushes move back and forth.

Decreasing reliance on fossil fuels is a pressing global need. The question is whether improving efficiency, rather than reducing total consumption, can possibly bring about the desired result. Steven Chu told me that one of the appealing features of the efficiency discussions at the Clean Energy Ministerial was that they were never contentious. "It was the opposite," he said. "No one was debating about who's responsible, and there was no finger-pointing or trying to lay blame." This seems encouraging in one way but dismaying in another. Given the known level of global disagreement about energy and climate matters, shouldn't there have been some angry table-banging? Advocating efficiency involves virtually no political risk—unlike measures that do call for sacrifice, such as capping emissions or putting a price on carbon or increasing energy taxes or investing heavily in utility-scale renewable-energy facilities or confronting the deeply divisive issue of global energy equity. Improving efficiency is easy to endorse: we've been doing it, globally, for centuries. It's how we created the problems we're now trying to solve.

Efficiency proponents often express incredulity at the idea that squeezing more consumption from less fuel could somehow carry an environmental cost. Amory Lovins once wrote that, if Jevons's argument is correct, "we should mandate inefficient equipment to save energy." As Lovins intended, this seems laughably illogical—but is it? If the only motor vehicle available today were a 1920 Model T, how many miles do you think you'd drive each year, and how far do you think you'd live from where you work? No one's going to "mandate inefficient equipment," but, unless we're willing to do the equivalent—say, by mandating costlier energy—increased efficiency, as Jevons predicted, can only make our predicament worse.

At the end of "The Coal Question," Jevons concluded that Britain faced a choice between "brief greatness and longer continued mediocrity." His preference was for mediocrity, by which he meant something like "sustainability." Our world is different from his, but most of the central arguments of his book still apply. Steve Sorrell, who is a senior fellow at Sussex University and a co-editor of a recent comprehensive book on rebound, called "Energy Efficiency and Sustainable Consumption," told me, "I think the point may be that Jevons has yet to be disproved. It is rather hard to demonstrate the validity of his proposition, but certainly the historical evidence to date is wholly consistent with what he was arguing." That might be something to think about as we climb into our plug-in hybrids and continue our journey, with ever-increasing efficiency, down the road paved with good intentions.