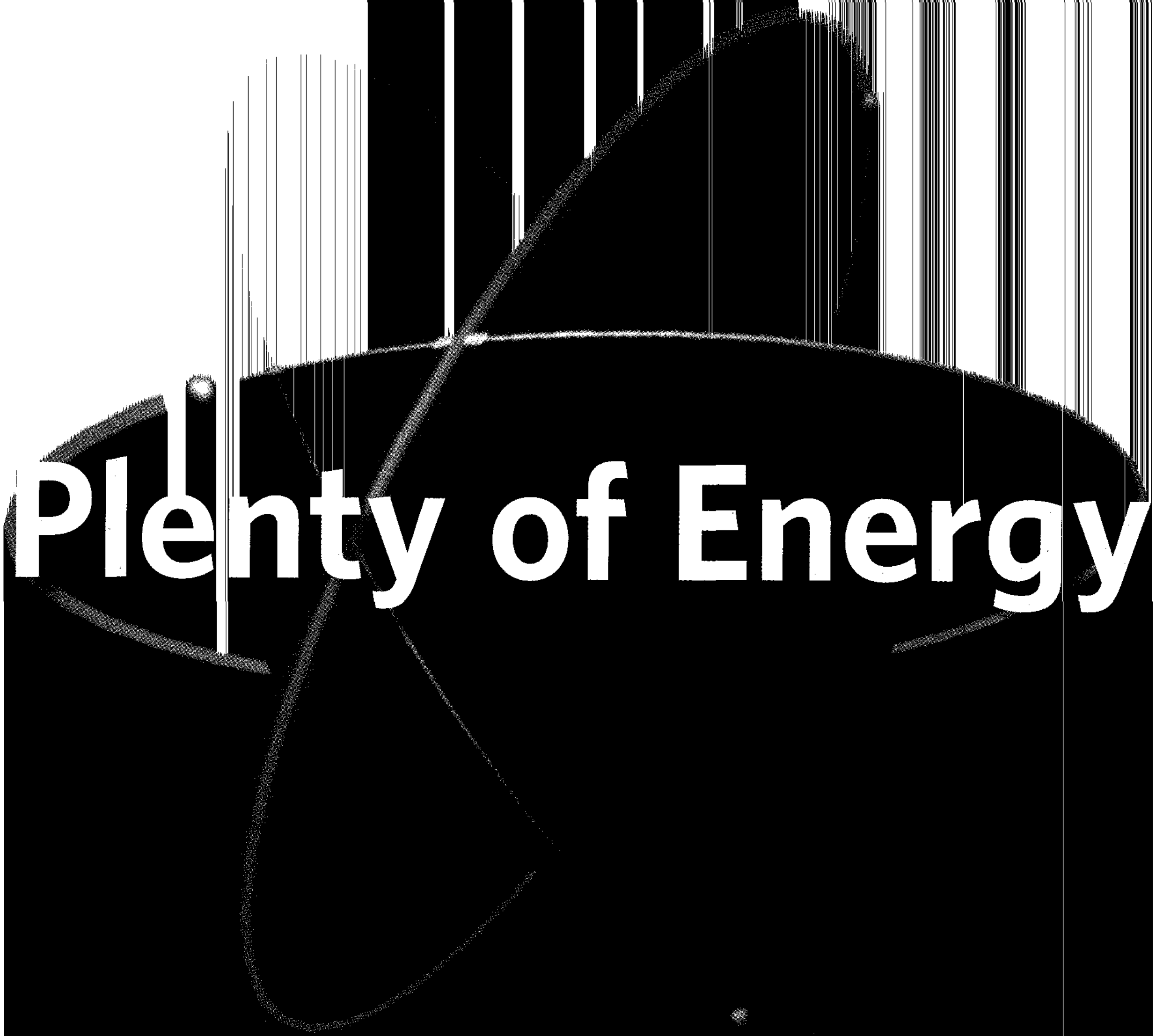
# There's Plenty of Energy at the Bottom



## Everyone's looking for energy fixes in all the wrong places.

By William Tucker

ON DECEMBER 29, 1959, on the threshold of the 1960s, Richard Feynman, "the best mind since Einstein" and interpreter of quantum mechanics, gave a lecture at the California Institute of Technology that is generally regarded to be the opening bell of the Information Age. It was titled, "There's Plenty of Room at the Bottom."

"There is a device on the market, they tell me, that can write the Lord's Prayer on the head of a pin," Feynman began. "But that's nothing....It is a staggeringly small world below. In the year 2000, when they look back at this age, they will wonder why it was not until the year 1960 that anybody began seriously to move in this direction."

Feynman was talking about the storage of information. The smallest dot in a half-tone photo in the encyclopedia, he noted, if reduced by a factor of 25,000, would still contain in its area 1,000 atoms. Since electron microscopes could already scan pictures this small, why not store information at this level? Switching to the digital language of computers—1s and 0s—only made the possibilities even greater.

> It turns out that all of the information that man has carefully accumulated in all the books in the world can be written in this form in a cube of material one two-hundredth of an inch wide—which is the barest piece of dust that can be made out by the human eye. So there is plenty of room at the bottom! Don't tell me about microfilm!

It wasn't long, of course, before we began to fulfill this vision. In 1965, Gordon Moore, one of the founders of Intel, noted that the number of transistors that could be packed into an integrated circuit was doubling approximately every two years. This principle became "Moore's Law," which still holds to this day. Ultra-dense optical storage disks now hold 120 gigabytes, enough to hold an entire library floor of academic journals. In 2007, the world stored 161 exabytes, enough to pile twelve stacks of books reaching the sun. There is no indication that this revolution is slowing down. As we enter the quantum world, it may become possible to store a 1 or a 0 in the energy state of a single electron. There is still plenty of room at the bottom.

SPURRED BY THIS historical accomplishment, however, Silicon Valley has now decided to tackle the energy problem. Energy has become the "next big thing" in the land of information technology, with entrepreneurs who made their fortunes in computers now moving their investments into solar cells, biofuels-improved efficiency, and all forms of "renewable" and "alternate" energy. "My greatest hope is that Silicon Valley will solve the current energy problem with the same genius that it has solved the problems of commercializing the integrated circuit, biotechnology and the Internet," says T. J. Rodgers, founder of Cypress Semiconductor, who has now funded SunPower, a photovoltaics start-up. Legendary Silicon Valley investor John Doerr has hired Nobel Prize winner Al Gore to help select a number of wind and solar startups that he calls "cleantech." Adds Vinod Khosla, a co-founder of Sun Microsystems who has become the most active energy venture capitalist in California, "A crisis is a terrible thing to waste."

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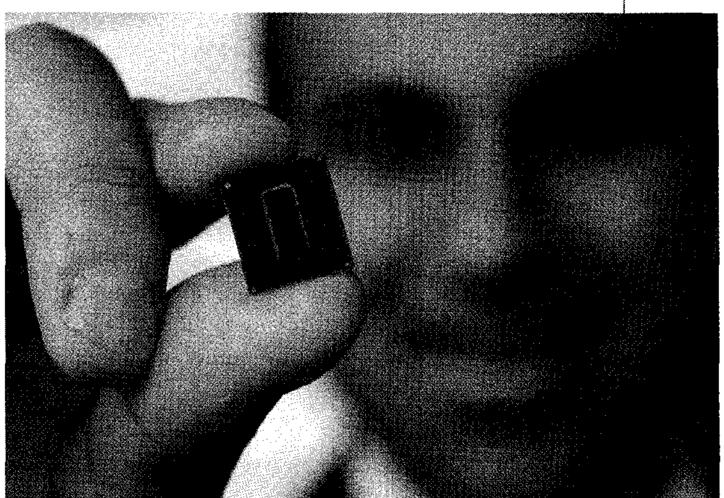
All this has raised great expectations among alternative energy enthusiasts of a world marriage between environmentalism and high tech. As Fred Krupp, CEO of the Environmental Defense Fund, says in his book, *Earth: The Sequel*:

> For investors who made their first fortunes from semiconductors and the Internet, the learning curve on photovoltaics is not terribly steep. Solar



power has grown up alongside the chip industry, borrowing its materials and processes and, increasingly, its talent. The geographies of the two industries overlap. Many of the solar startups are in California's Silicon Valley, in Cambridge, Massachusetts, in Phoenix, Arizona, and in Austin, Texas. And many have close relations with the same universities: Stanford; University of California, Berkeley; the California Institute of Technology; and MIT.

The holy grail of this venture—a new Moore's Law—will be discovered in the field of energy. As reporter G. Pascal Zachary wrote in the *New York Times* in February 2008:

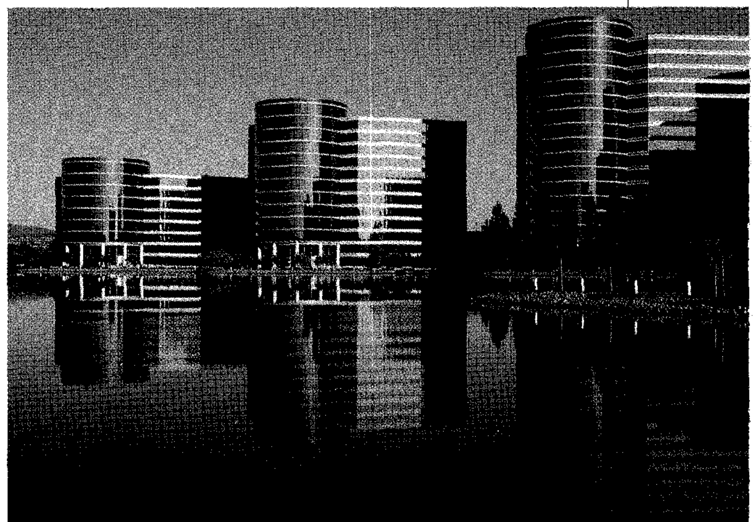
> There is, after all, a precedent for how the Valley tried to approach such tasks, and it's embodied in Moore's Law....A link between Moore's Law and solar technology reflects the engineering reality that computer chips and solar cells have a lot in common.

Or as Oliver Morton, chief news and features editor of *Nature,* has expressed it, "If Silicon Valley can apply Moore's Law to the capture of sunshine, it could change the world again."

Unfortunately, we can say with absolute certainty: "It ain't never gonna happen." There is absolutely no chance that all the money in Silicon Valley is ever going to discover a "Moore's Law" that will allow us to miniaturize the generation of energy the way it has miniaturized the storage of information. Why? The answer is simple: *energy and information are not the same thing.*

The marvelous miniaturization embodied in Moore's Law was accomplished by using *less and less* energy to store each individual bit of information. Think of an abacus. The position of each bead represents a 1 or a 0, and the amount of energy required to move the bead across the wire frame is the cost of storing that information. If we move down into the microcosm so we are storing information by the energy used to change the state of a logic gate or a group of molecules or a single molecule or even a single *electron,* we are using less and less energy at every level. That is the essence of Moore's Law.

BUT WHAT IF WE ARE SEEKING TO *generate* energy? We cannot move down the molecular scale in the same way. At each and every stage we



will encounter *less* energy. There is only so much energy stored in a chemical bond or in a flow of photons or electrons. This is easy enough to calculate. The amount of energy stored in a single carbon-hydrogen bond in a fossil fuel is about 1 electron volt (eV). The amount of energy in a photon of visible light is in the range of 1.7–3.3 eV. When we break one of those chemical bonds—through the process of "combustion"—or capture a photon in a photovoltaic cell, we can generate about 1 to 3.3 eV of energy.

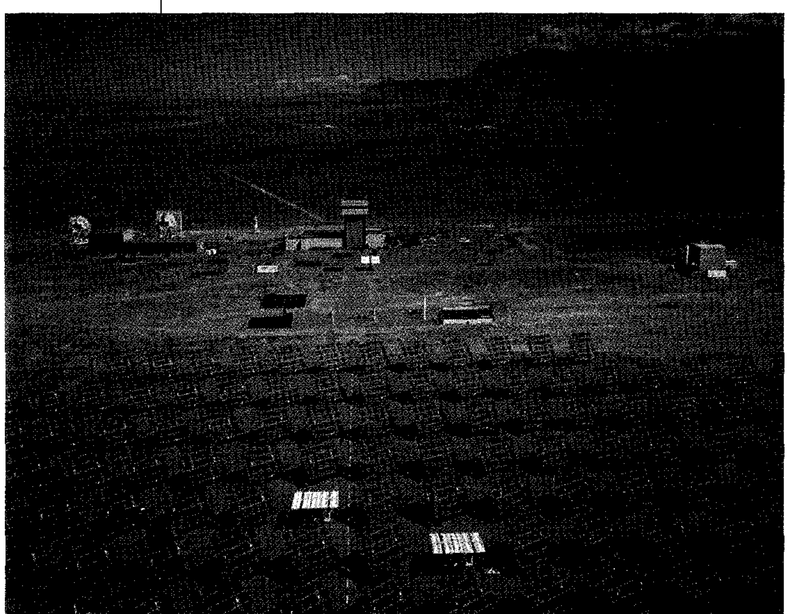
In fact, we already do a pretty efficient job of capturing and converting these sources of energy. A liter of gasoline, for example, can produce 9.7 kilowatt-hours (kWh) of power—probably the densest form of chemical energy we will ever encounter. Anthracite coal produces 9.4 kWh, liquid natural gas 7.2 kWh, methanol 4.6 kWh, and wood around .5–.9 kWh, depending on its moisture content. "Biofuels"—crops that are less dense and more saturated than wood—produce even fewer kilowatt-hours per liter.

Sunup to sundown, the sun's rays shed about 400 watts per square meter of ground in the United States. By theoretical limits, only about 25 percent of this can be converted into electricity. This means that solar electricity can light one 100-watt bulb *for every card table.* Covering every square foot of every building in the country with solar panels would be enough to provide our indoor lighting—about 4 percent of our total electrical consumption—during the daytime. Other forms of solar energy flows—wind, hydroelectricity, or biofuels—are more dilute.

The only way to make up for the relatively low density of solar flow is to *use more land* in gathering

it. There is no Moore's Law waiting to improve the process. Solar cells, windmills, and other forms of solar flow may be made *cheaper*—which is where most of the research is going right now—but *land requirements* will never be reduced. Those requirements, when confronted, turn out to be staggering.

In a 2007 essay that is becoming a classic, Jesse Ausubel, of the Program for the Human Environment at Rockefeller University, calculated the amount of land that would be required to equal the output from fossil fuels using so-called "renewable" energy. Running a 1,000-megawatt electrical station—the standard size—for example, would require 1,000 square miles of forest. A hydroelectric dam generating 1,000 MW usually backs up a reservoir of about 250 square miles. T. Boone Pickens's plan to generate 4,000 MW of electricity from wind in west Texas will cover around 1,200 square miles. In the January 2008 issue of *Scientific American,* three solar energy theorists presented a "grand plan for solar energy" that would involve powering the entire country by covering 30,000 square miles of Southwest desert with solar collectors.



No amount of technical ingenuity or venture capital flowing out of Silicon Valley is ever going to change these parameters. Cool Earth Solar, for example, a company in Livermore, California, has invented an eight-foot balloon whose surface acts as a magnifying glass to concentrate solar energy on a small photovoltaic cell at its center. This will cut down on the requirements for expensive solar cells. But it will not reduce the space required by the balloons. Bob Metcalfe, co-founder of the Ethernet, is heading GreenFuel Technologies, a Massachusetts company developing photosynthetic algae that will convert the carbon exhausts from a coal plant into biofuel. But the algae pools for a single 1,000-MW coal plant will cover 40 square miles.

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Both fossil fuels and solar flows have their limitations. Fossil fuels can produce only so much energy from their chemical bonds. Solar flows can be increased only by covering more land. So is there any other source of energy that can surpass these limitations?

IT TURNS OUT THERE IS. We just haven't gone down far enough down into the microcosm. If we go down one step further, we encounter the greatest storehouse of energy in the universe: the nucleus of the atom.

To understand the dimensions of the energy stored in the atomic nucleus, it is best to begin with Einstein's formula $E = mc^2$. Almost everyone has heard of it (it is the title of one of Mariah Carey's recent albums), yet how many people understand exactly what it means?

Einstein's formula says that matter and energy are interchangeable. They form a continuum. Energy can be converted to matter and matter can be converted to energy. The important thing is the coefficient—the *speed of light squared.* That is a very, very large number, on the order of one quadrillion. What it says is that a very, very *small* amount of matter translates into a very, very *large* amount of energy.

These transformations take place at the atomic level, both within the electron shells and in the nucleus. It is the distribution of matter between the two that defines the difference. More than 99.9 percent of the mass of an atom is within its nucleus. That translates into vast stores of energy, beyond anything we encounter in the "chemical" reactions of the electron shell. If producing energy comes from the conversion of matter, there is only one logical place to look for large amounts of matter: in the nucleus of the atom.

Over the course of the early 20th century, a generation of brilliant European scientists—Marie Curie, Niels Bohr, Werner Heisenberg, Enrico Fermi, Leo Szilard—gradually unlocked the secret of the vast quantities of potential energy in the nucleus of the atom. Then as World War II approached, many of these scientists migrated to America to help build the atomic bomb. Ever since, the idea of "nuclear power" has been fatefully intertwined with nuclear weapons.

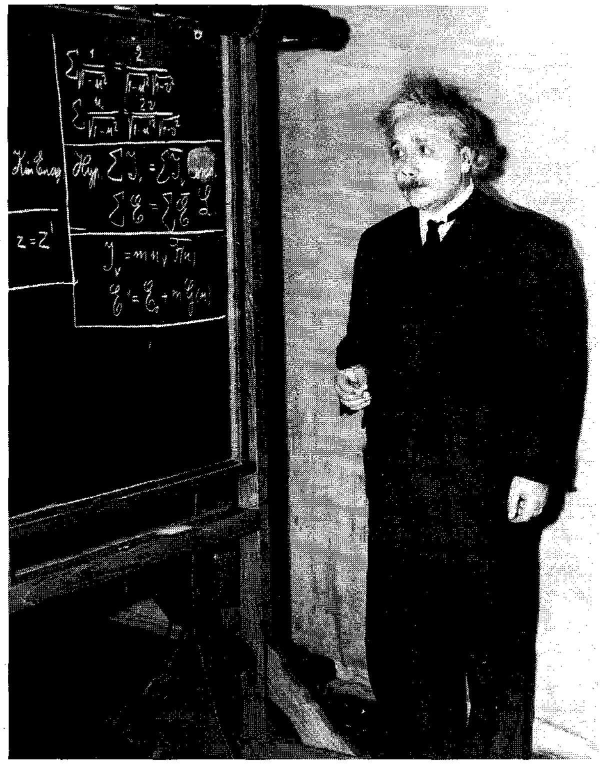
A far better way to think of nuclear power, however, is as "terrestrial energy," because that is where we encounter it. As Einstein said to his fellow scientists when he signed the letter to President Roosevelt, "For the first time in history, mankind will be using energy not derived from the sun."

Terrestrial energy—"nuclear energy"—is derived from the breakdown of the uranium and thorium atoms, two of the three heaviest atoms. They are so large that they are unstable and therefore "radioactive." Radioactivity is a release of energy. When uranium and thorium break down in the earth's crust, they release enough energy to raise the earth's core temperature to 7,000 degrees Fahrenheit—*hotter than the surface of the sun.* Although no one has ever calculated the exact portion, anywhere from 50 to 90 percent of the earth's internal heat is believed to come from these two elements.

When we mine uranium or thorium and accelerate their breakdown in a controlled environment, we have what is called a "nuclear reactor." In doing this, we are simply borrowing terrestrial energy from nature—just as we borrow solar energy in the form of photovoltaics, hydroelectric dams, and fossil fuels.

The only difference is the energy *density.* You will recall that the breaking of a carbon-hydrogen bond in coal or oil produces 1 electron volt. The disintegration of the nucleus of a single uranium atom produces *200 million* electron volts. This extraordinary concentration of matter means that vast amounts of energy can be generated from very small quantities of this natural resource.

For example, a 1,000-MW coal plant is fed by a 110-car "unit train" of coal cars arriving at the plant every 18 hours. (Such a unit train now leaves the Powder River Basin of Wyoming to distribute coal around the nation every six minutes. In 1999 it was



every 25 minutes.) A 1,000-MW nuclear reactor, on the other hand, is supplied by a single tractor-trailer that arrives at the reactor with a new supply of fuel rods every *18 months.*

This extraordinary concentration of energy occurs on the back end as well. The same 1,000-MW coal plant will release three million tons of carbon dioxide exhausts into the atmosphere every year, while the reactor's emissions are zero. The only "waste" is the highly radioactive fuel rods that—properly reprocessed—can produce even more energy. France, which has a complete nuclear cycle, gets 30 percent of its reactor fuel from spent fuel rods. All the remaining "waste" from 30 years of producing 75 percent of its electricity from nuclear power is stored beneath the floor in a single room at the La Hague plant in Normandy.

So there is plenty of energy at the bottom. We just haven't realized where it is yet. The place to look for both for an abundant supply of energy and the answer to our environmental problems from generating energy is in the nucleus of the atom.

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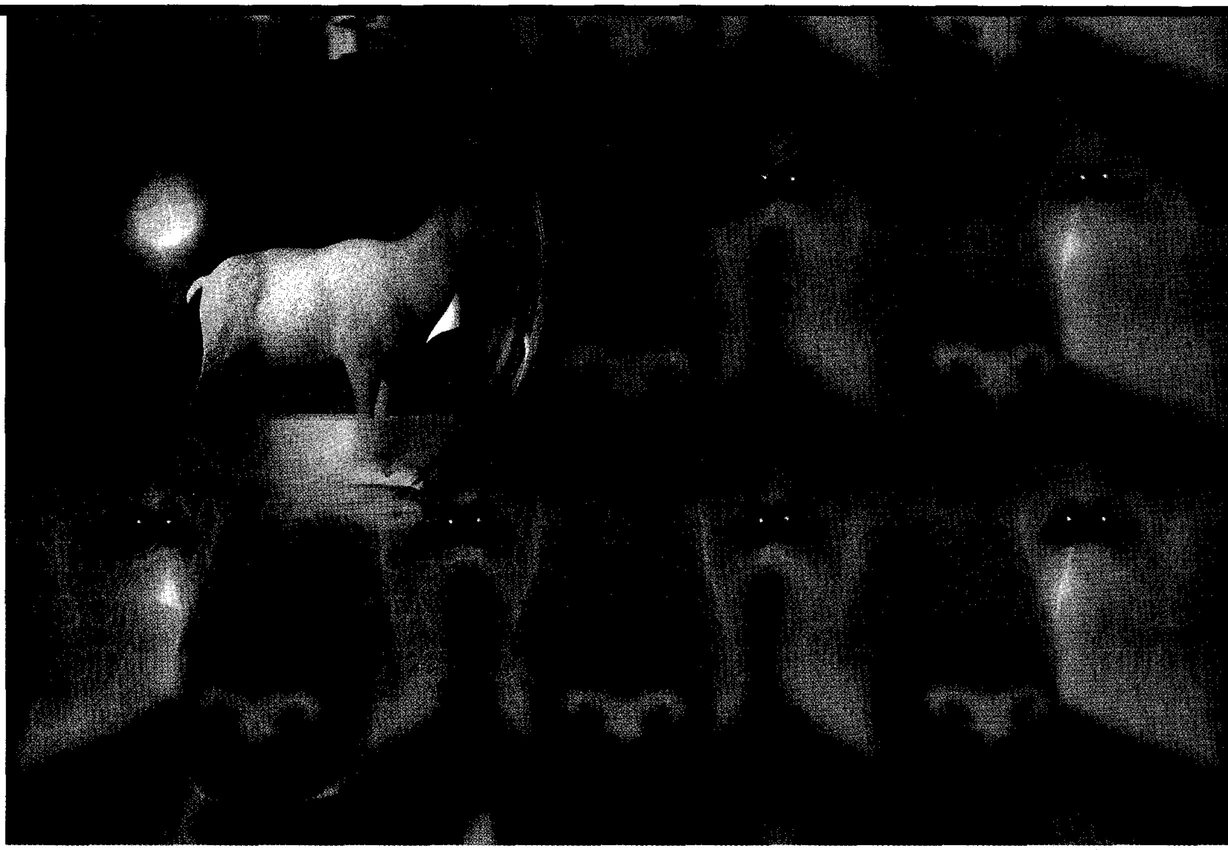
**William Tucker** *is most recently the author of* Terrestrial Energy: How Nuclear Power Will Lead the Green Revolution and End America's Energy Odyssey *(Bartleby Press).*



# Scientific Pretense vs. Democracy

**Arrogance and intolerance in the name of superior expertise are antithetical to popular governance and the requirements of honest argument. But that hasn't stopped them from becoming a central feature of our political life.**

**By Angelo M. Codevilla**

*"We will restore science to its rightful place..."*

—Barack Obama

UNPACKED, THIS SENTENCE MEANS: "Under my administration, Americans will have fewer choices about how they live, and fewer choices as voters because, rightfully, those choices should be made by officials who rule by the authority of science."

Thus our new president intends to accelerate a trend a half-century old in America but older and further advanced in the rest of the world. There is nothing new or scientific about rulers pretending to execute the will of a god or of an oracle. It's a tool to preempt opposition. The ruler need not make a case for what he is doing. He need only reaffirm his status as the priest of a knowledge to which the people cannot accede. The argument "Do what we say because we are certified to know better" is a slight variant of "Do what we say because we are us."

## An Old Story

THE FRENCH REVOLUTIONARY INTELLECTUALS and merchants who founded the modern state spoke of political equality. But they knew that if the masses governed, they might well have guillotined them rather than nobles and priests. And so