Reflections on the 1974 APS energy study

Robert H. Socolow

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A participant in a study made in the wake of the oil-price surges asks: Have the events of the past decade vindicated the study's conclusion that greater well-being does not require more energy?

Robert H. Socolow

We physicists who worked together on the 1974 American Physical Society summer study entitled *Efficient Use of Energy: A Physics Perspective*[1] believed we were doing something important in questioning two beliefs strongly held by most people involved in problems of energy supply. One of the beliefs that we challenged concerned how energy relates to well-being, namely that only by ever greater use of energy can society achieve greater well-being. The other concerned how physicists relate to energy: that it is appropriate for physicists to work on problems of energy supply, but inappropriate for us to work on problems of energy use. The shared goal of the participants in the 1974 APS summer study was to overturn both of these majority positions—by creating counterexamples. In the first instance our counterexamples would be analyses that demonstrated the emptiness of the connection between various aspects of well-being—personal mobility and light to read by, for example—and the level of energy use required to achieve them (see figure 1). In the second instance our counterexamples would be ourselves.

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In this brief essay I would like to follow these two arguments over the decade since the study, and to address five questions:

▶ What kind of evidence supported the majority position in 1974?

▶ What was the source of our confidence that the majority position was misguided?

▶ To what extent have the events of the past decade vindicated our disbelief?

▶ What have turned out to be the major shortfalls in our 1974 analysis of the two areas?

▶ Finally, what new "wisdom" concerning energy and well-being and concerning physicists and energy ought physicists to be challenging now?

The wisdom of 1974

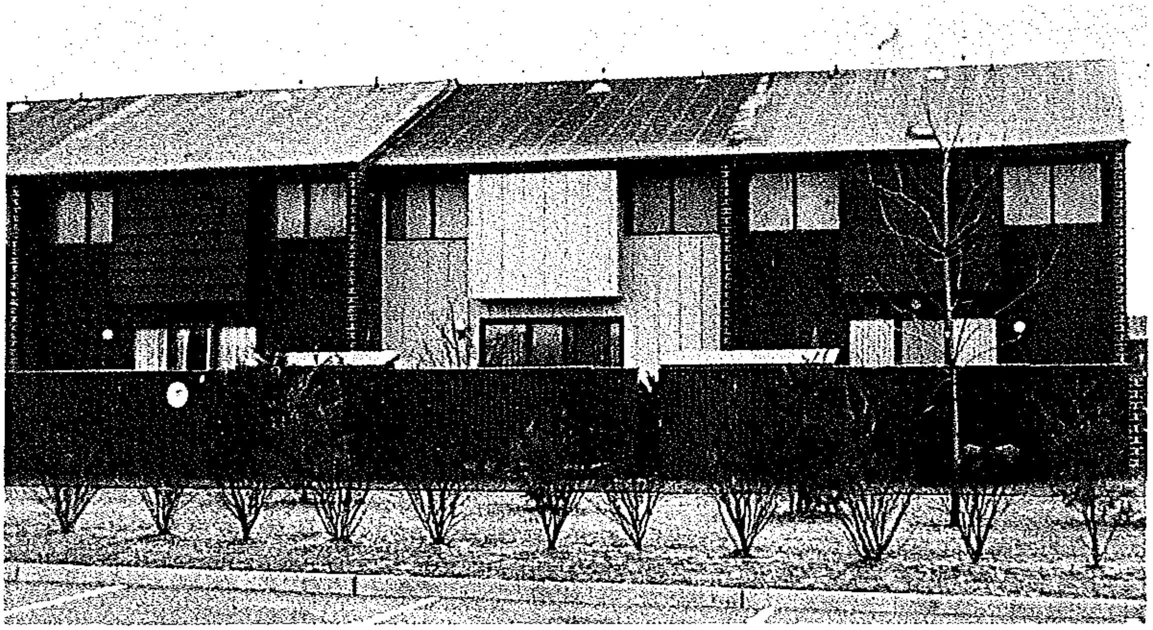
In 1974 it was easy to believe that improvements in societal well-being required continued expansion of the rate of use of energy in the economy. One had to be impressed with the strength of the data throughout the period after World War II, covering many countries, that showed two essentially unrelated aggregate variables moving together in eerie synchrony. The two variables were gross national product and use of commercial energy.

The gross national product is a carefully constructed measure of overall economic activity, traditionally expressed in units of inflation-corrected dollars. To be sure, it is a far from perfect measure of societal well-being. In fact, in the same mid-1970s period there was a flurry of activity among economists to explore other measures. However, no alternative gained enough adherents to become a serious challenger to GNP as the measure of choice in nontechnical discussions of societal welfare.

"Use of commercial energy" is a sum over the uses of coal, oil, gas, nuclear energy and hydropower, expressed in physical units such as exajoules (10^{18} J). To calculate this sum one uses physical measurements of the energy released to put the uses of different fossil fuels into common units. Figure 2 is one plot of these data, showing the variation in the ratio of energy use to real, or inflation-corrected, GNP over 130 years of United States history.

The graph tells a number of stories. First, from 1850 to 1900 coal was replacing wood, and calculations for this period that do and do not include wood look very different. Today's less-developed countries are recapitulating this portion of the graph: Both a declining share of energy from wood and a downward trend in overall energy use per unit of GNP are now in evidence in much of the world. However, countries today have an option not available a century ago: conversion technologies that permit the high-effi-

Townhouses with and without additional attic insulation, distinguished by their early-morning frost patterns. Heat escaping from the conventionally insulated house at the center of this photograph prevents the accumulation of frost. The three units shown here are part of a group of 31 nearly identical townhouses built in Twin Rivers, New Jersey, in the early 1970s as part of a DOE project at Princeton University.[20] Figure 1



ciency transformation of wood and crop wastes to liquids and gases for use in cooking and transportation, again at high efficiency.[8] It may well turn out that today's developing countries will deploy these biomass-conversion technologies widely, in which case the share of biomass in total energy production will not fall to anything as low as the 3% contribution of biomass to total energy production now found in the United States.

A second story told by figure 2 is the 23% rise from 1900 to 1920 in energy use per unit of GNP, followed by a 40% fall from 1920 to 1945. The increasing intensity of energy use in an early stage of industrialization and the subsequent prevalence of energy efficiency are poorly understood phenomena worthy of further study.

The third story told by figure 2, however, is one that mesmerized many energy analysts in 1974: the constancy of the ratio from 1949 through 1973. For 17 of these 25 years the ratio was within 2% of its average value of 30 MJ (28 000 BTU) per 1983 dollar, while real GNP grew by a factor of 2.5.

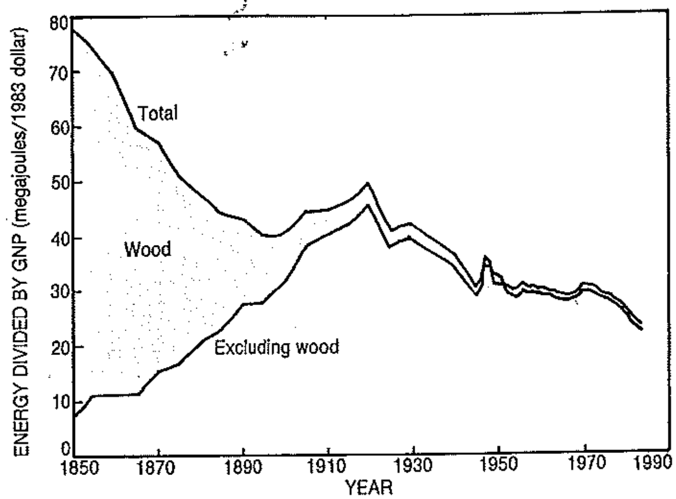
A quarter-century of steadiness is a long time, and data from 1949 to 1973 looked roughly similar in many other countries and also in subregions of countries. Such high correlations of two variables do not happen often in the social sciences. Moreover, all of us are predisposed to believe that the recent historical past is a useful guide to the near-term future. Thus it did not seem all that surprising that intelligent people could believe with considerable conviction that this value of 30 MJ per 1983 dollar had become an immutable fact of the US economy.

Physics, on the other hand, leads one to reason differently. It seeks models that preserve only the essentials of a problem. Here it forces one to ask, "What is energy being used *for*?" The APS study report placed strong emphasis on distinguishing *tasks* from *devices*, and on using the language of thermodynamics to restate a given task in terms of flows of work, heat and entropy. Such an inquiry establishes thermodynamic minimum energies for the performance of tasks, against which one can compare the actual energy use. Where the discrepancies are large, one concludes, tentatively, that society has not yet been particularly clever about providing the best devices to accomplish the task, and one predicts, again tentatively, that large energy savings will become possible—with no loss of amenity—as technology evolves. Far from seeming like a guide for prediction, the 25-year constancy in the ratio of energy use to GNP struck the summer-study physicists as a testament to the sustained inattention to energy use on the part of the technological community.

Such sustained inattention was easy to document and reflected the second belief with which the summer-study physicists had to contend. Although the book about quiche hadn't been written yet, a strong message in that period was that real men don't study how to use less energy. The "real" work of physicists, it was claimed, included realizing the promises of the breeder reactor and of controlled fusion, as well as helping to coax more oil out of underground reservoirs, converting a higher fraction of the carbon atoms in coal and shale into low-molecular-weight hydrocarbons and turning a higher fraction of the energy stream of solar photons into electric power. Energy demand, we were told, was "exogenous." This fancy word meant not only that energy demand was a variable that one could not determine from within a model of national energy accounts but also that it was an issue that lay outside the arena of discussions about energy by serious professionals.

One memorable event for me was a presentation about breeder reactors in 1972 at which the speaker asserted that the doubling time for fissile-material production from a commercial breeder system would have to be less than ten years, because the doubling time for use of electric power was well established to be ten years. (Indeed, the data for more than five previous decades did show this doubling time.) Such a de-

Energy divided by GNP for the United States, 1850–1984. Energy is defined here as primary consumption, with both hydropower and nuclear power treated as if the equivalent electricity had been produced by fossil fuels in average plants. (Sources of energy data: wood and nonwood, 1850–1948, reference 2; nonwood, 1949–83, reference 3; nonwood, 1984, reference 4; wood, 1949–84, reference 5. Sources of GNP data: 1850–1948, reference 2; 1949–81, reference 6; 1982–84, reference 7.) Figure 2



sign criterion, for a system that was being planned for the second decade of the 21st century, implied that the economy in which the breeder reactor would begin to function would use 16 times as much electricity as the world in which we in the audience were then living. I can date my personal commitment to full-time work on energy use to that event.

Reasons to doubt the wisdom

By 1974 environmentalism and economics had provided two quite separate reasons to doubt the claim that energy and GNP were destined to be coupled. Environmentalism is much like special relativity, subsuming a previous world view within a more inclusive one. The economic analog of Newtonian mechanics is what Kenneth Boulding called the cowboy economy, and the analog of relativistic mechanics is the spaceship economy. At low levels of energy use one does not have to consider planetary constraints, while at higher levels (as at velocities close to the speed of light) these constraints dominate. Because these constraints eventually affect prices, economics is, from this perspective, an elaboration of one aspect of environmentalism.

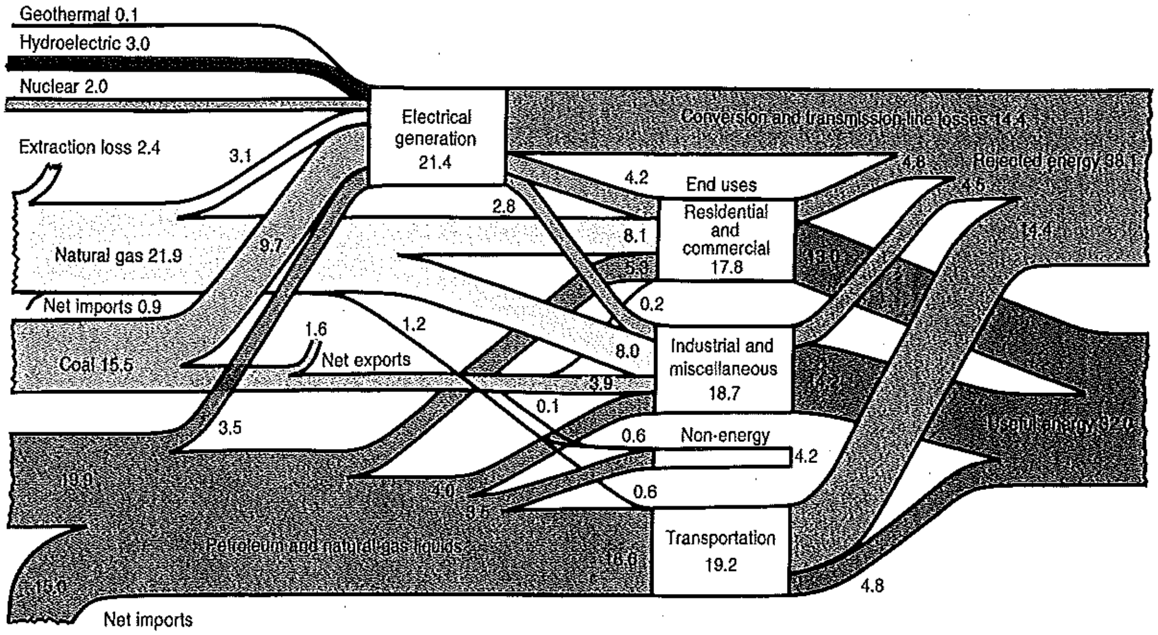
The list of planetary constraints is a long one. Many of these constraints are summarized in an interesting way by dimensionless ratios N/D, where the numerator N is an effect of people and the denominator D is an effect of nature. Such a formulation calls attention to vulnerable subsystems of nature, such as the stratosphere, the Arctic ice pack and the unbuffered mountain lakes, which are easily overwhelmed by deposition of, respectively, nitrogen oxides, albedo-changing particulates and sulfuric acid—each pollutant arising from technology and potentially appearing in quantities orders of magnitude greater than what nature generates without our help. The table on page 65 shows a few N/D ratios that are critical to discussions of energy. We see that the direct fractional effect on Earth's thermal balance due to human uses of energy is much smaller than the indirect fractional impact on the atmosphere's carbon dioxide balance due to the use of fossil fuels. The carbon dioxide increase threatens to have an overwhelming impact on climate, and is the Achilles heel of a multihundred-year future based on coal, oil shale and tar sands.

The table also shows what appears to be the Achilles heel of a future based on nuclear fission: the build-up of concentrations of plutonium on the Earth's surface, where only traces had existed in 1940. At an average rate of about 50 tons/year, about as much plutonium will be produced in the next decade from civilian nuclear power plants as was produced in the past four decades by the world's civilian and military programs combined. Plutonium is a material capable of eliciting many kinds of malevolent behavior; it is reasonable to wish that there be as little of it generated as possible, at least in the current epoch of disarray among nations. Perhaps someday international relations will have developed to the point where the world is safe for abundant nuclear power.

The table shows, as well, what is probably the Achilles heel of a solar-energy future based on biomass: a requirement for land that might equal what is required for agriculture. At an annual yield of 10 tons of dry biomass per hectare and an energy content of 15 GJ/ton, the output of a biomass plantation is 0.5 W/m^2, roughly 0.2% of the power of the incident sunlight. Perhaps advances in bioengineering and ecology will significantly increase this overall efficiency of conversion; perhaps cost reductions in the competitive technology of photovoltaics will propel this less land-intensive solar technology to a leading role in the supply of commercial electricity. At present, however, it appears that no road to a long-term energy future is free of severe environmental constraints.

Such an analysis of the human predicament based on a concatenation of environmental constraints motivated the first wave of energy-conservation researchers. However, the sudden prominence of another constraint—the finiteness of world oil reserves—gave the subject an urgency and generated a second, larger wave of researchers, which greatly accelerated the rate at which we gained insights. The 1974 APS summer study had been conceived some months before the first of the world's oil-price shocks, but the study occurred in its wake, giving great impetus to our work.

The first oil-price shock provided new insights into the apparent constan-



Spaghetti diagram. This conventional rendition of energy flows in the US economy shows where energy came from and how it was used in 1976. The numbers give energies in quadrillion BTUs, or "quads." The distinction between rejected and useful energy ignores thermodynamics. (From reference 9.) Figure 3

cy of the ratio of GNP to energy use. Might two economic forces have been accidentally canceling over the previous 25 years, we asked: a falling price of energy, which would have driven energy use up, and a steady stream of inventions of energy-saving technologies, which would have driven energy use down? Accidental cancellations of large terms with opposite signs are never as aesthetically pleasing as genuine constants; nonetheless, the cancellation hypothesis began to look plausible as responses to the rising oil price began to appear. Countless consumers of energy, whose decisions were routinely assisted by optimization procedures in which the current and expected prices of energy were input parameters, began reducing their consumption of energy almost immediately.

Suddenly, saving energy became important. For physicists to ignore the challenge on the grounds that their real work lay elsewhere began to seem irresponsible, at least to a few. Indeed, the argument that physicists interested in energy should concentrate exclusively on improving the prospects for new energy sources acquired a self-serving character, especially when it came from communities (such as breeder-reactor researchers) for which the prospect of reductions in future energy demand diminished the urgency of big programs.

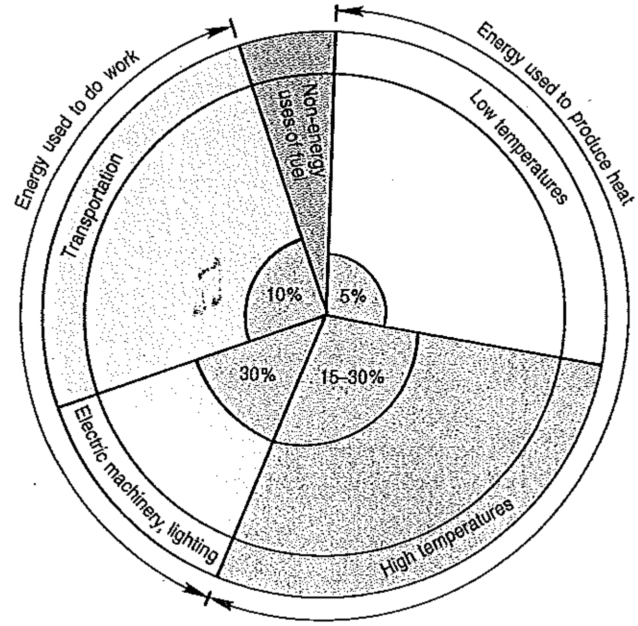
Physicists who insisted on taking a look at the problem of saving energy found quickly that the insights of their discipline were missing from some of the most widely used tools of analysis—for example, from the "spaghetti diagram" (see figure 3) that exhibited the transformation of all energy inputs into definite combinations of "useful" and "rejected" energy. On close inspection, it became clear that such diagrams claimed that residential and commercial end users convert a high percentage of energy inputs into useful energy (in figure 3, 13.0/17.8, or 73%), whereas for electrical generation the corresponding percentage was small (in figure 3, 7.0/21.4, or 33%). Were America's weakly engineered home furnaces and water heaters really, on average, more than twice as successful as her highly engineered power plants?

The resolution of this conundrum emerged from the second law of thermodynamics. Spaghetti diagrams, and energy accounting generally, systematically ignored any reference to the quality of energy, a horrendous omission. Why this omission is "horrendous" requires several sentences to explain. The assertion that 33% of the chemical energy delivered to an electric power plant becomes useful electricity while 67% becomes rejected heat is, of course, a reflection of the fact that the electricity is being generated in a thermal, usually Rankine, cycle, where the complete conversion of heat to work is not possible. Both the chemical energy and the electricity are high-quality forms of energy.

When chemical energy or electricity is delivered to residential and commercial buildings, on the other hand, the dominant conversion device is a furnace, boiler or water heater, and the output is not a high-quality form of energy but rather *heat* at a temperature close to the temperature of the environment. Traditionally, one rates the heating system by an efficiency equal to the fraction of the incident chemical or electrical energy that is transferred to the water or air that flows through a heat exchanger. These efficiencies generally range from 60% to 100%—at the low end for older furnaces, and at the high end for electric resistive heating. This measure of efficiency is deeply imbedded in the rivalry between gas heat and oil heat, and it is an excellent measure of the quality of furnaces, boilers and water heaters.

However, another way to heat water or an indoor space is by running a heat pump between some environmental source, such as outdoor air or groundwater, and an indoor heat sink. A window air conditioner, for example, reversed in its mounting, is such a heat pump; it can supply more heat than does an electric heater that consumes the same power, even though the electric heater is 100% efficient at converting electrical energy to heat. With today's heat pumps, one unit of electrical energy input brings roughly three units of heat indoors while removing two units of heat from the outdoor source. By the conventional measure, this is like having a 300%-efficient furnace, or a system with a coefficient of performance of 3.

All this is perfectly fine, and has never led to the misdesign of heating



Heat wheel showing the thermodynamics of US energy use by task. Percentages and shaded fractions of sectors indicate the second-law efficiencies of energy use. The second-law efficiency is the minimum energy required to accomplish a task divided by the energy used today to accomplish that task. Space heating, for example, which dominates the low-temperature sector, could be accomplished by ideal heat pumps with 1/20 the energy currently used. Radial angles indicate fractions of national energy use. Non-energy uses of hydrocarbons include their use in asphalt, plastics and pharmaceuticals. Figure 4

systems. The problem is in the spaghetti! Many an unsuspecting banker or Congressman, seeking to gauge the relative promise of alternative means of energy conservation, was led to conclude that 73%-efficient water heating and space heating could scarcely be improved, while 33%-efficient electricity production was ripe for a major breakthrough. The ubiquitous spaghetti diagrams pointed the investor and legislator away from the distinction between heat and work, which would have enabled them to comprehend a heat pump four or more times more effective than common furnaces or boilers at using fuel or electricity to heat air or water.

The APS study reminded its audience that thermodynamics led naturally to the concept of "available work," and thence to a "second-law efficiency" by means of which one could evaluate all tasks, including space and water heating and electricity generation, without distorting comparisons across tasks. "We strongly recommend," the study group said early in its report, "that this formulation, or a similar one, be widely adopted by the scientific and technical community as a standard from which all tasks should be measured, and against which all devices should be evaluated."

The APS study, moreover, estimated the second-law efficiency with which modern society accomplishes each of its major energy-using tasks. Figure 4 shows the study's conclusions in the form of a heat wheel. One can see that heating and cooling near environmental temperatures are done least well and that electricity generation is done best.

Moreover, the banker and Congressman *are* right: 33% conversion for electricity is not very impressive. Cogeneration, the joint production of marketable heat and electricity, now widely appreciated but in 1974 little known and much disliked, is one way to do better. Advanced gas cycles may be another.

The main point I want to make here is that physicists saw quickly that they could add discipline to the discussion of efficient energy use.[10] Moreover, we perceived that even our own special contribution, the second law of thermodynamics, could well stand some deep thought to allow it to be generalized to processes occurring in finite time rather than infinitely slowly and reversibly. (In the past decade such work has begun; see the article "Thermodynamics in finite time," by Bjarne Andresen, Peter Salamon and R. Stephen Berry, PHYSICS TODAY, September 1984, page 62.) With such evidence of their value and intimations that there was even some good physics to be done, all doubts vanished about the appropriateness of physicists in the enterprise.

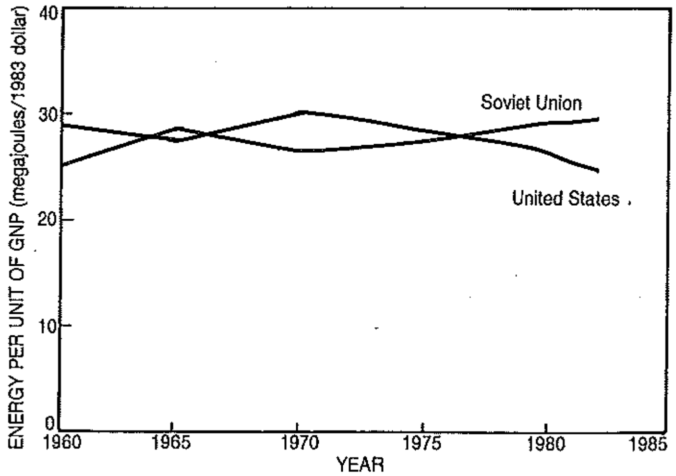
Degree of vindication

The United States used 1% less energy in 1984 than in 1973, yet the GNP grew 31% in constant dollars in that period. There was a similar decoupling of energy from GNP in Japan, Australia, New Zealand, Canada and the countries of Western Europe.

Modelers can only very imperfectly tease apart the role of the rising price of energy and the role of non-price effects, such as the effect of increased attention to efficiency, in bringing about the observed decoupling. However, most modelers agree that comparable roles for price and for non-price effects appear to be necessary to explain the data. The explanation matters, for if the entire cause of the decoupling were a price response, and if the price rises of the past decade turned out to represent a transition from one trajectory of gradually falling price to another, then one might expect a recoupling of energy and GNP.

Interestingly, in the Soviet Union and in Eastern Europe there has not yet been a decoupling of energy and GNP. Figure 5 compares trends in the ratio of energy to GNP in the United States and the Soviet Union, revealing a remarkable dance in which the US ratio falls when the Soviet ratio rises, and vice versa. In particular, between 1975 and 1982, annual GNP grew 16.3% in the Soviet Union and 20.6% in the United States, while annual energy use grew 28.0% in the Soviet Union and 3.9% in the United States.[11] The energy/GNP ratio, then, increased 8% in the Soviet Union over these seven years but decreased 14% in the United States.

Perhaps the steady increase of the energy/GNP ratio in the Soviet Union and Eastern Europe since 1970 reflects domestic economies better shielded by nonmarket policies from higher world energy prices, and perhaps the increase also reflects inactivity among their technologists, who have been less strongly drawn to the tasks of using energy efficiently than have their Western counterparts. My own guess is that there will be a decoupling of energy and GNP in Eastern Europe and the Soviet Union in the next decade. One reason I think so is that the Soviet physics community, in response to recent awareness in their government that the Soviet Union's own supplies of energy are severely constrained, is now enlarging the scope of its engagement with energy issues to include energy efficiency. In fact, energy efficiency may turn out to be an appropriate field for broad-scale East–



Comparison of US and Soviet ratios of energy to gross national product, 1960–83. Energy sources here do not include wood. Data are from the Central Intelligence Agency,[11] which determines the Soviet GNP and estimates a factor for converting rubles to dollars. Figure 5

West collaboration.

From the perspective of physics, there is enormous room for greater cleverness in providing more amenities with fewer resources. Indeed, not merely a constant level of energy use but more like a halving of the level of energy use in 30 years appears entirely feasible in the world's industrialized countries.[12] My own view is that such a reduction is not only feasible but likely, because technological change for the next several decades will be strongly driven by what I call[13] "molecular control." Building on the breakthroughs in quantum mechanics that tamed the atom in the first 40 years of this century, technologies of molecular control will replace sledgehammers with scalpels in task after task throughout the economy, with the inevitable consequence that inputs of natural resources will be sharply reduced.

As for the achievements of the insurgency that sought a more equal balance between physicists working on energy supply and physicists working on efficiency at end use, these have been much more spotty. The past decade has seen a "quiet revolution" in the efficiency of end uses of energy. This is the phrase that my colleague Robert Williams uses to describe the result of the transformation of the study of end-use efficiency from a sleepy backwater of engineering to an exciting enterprise. There is now a weekly publication called *Energy User News*, whose pages testify to continuing innovation in devices and systems, and a meeting in Santa Cruz every two years captures in its discussions and proceedings[14] the spirit of increasingly vigorous activities in the subspecialty of energy conservation in buildings. Groups such as the American Society of Heating, Refrigeration and Air Conditioning Engineers have been gradually transformed by newcomers into intellectually vigorous professional societies.

One measure of the number of physicists working on end-use efficiency is the ratio of the DOE budget for research on energy conservation to the DOE budget for research on fission, fusion, fossil fuels and solar energy. This measure is one of many that show that the level of involvement of American physicists in end-use issues grew rapidly for a while, then peaked and now has subsided somewhat. However, the current enterprise has considerable staying power. Every DOE national laboratory now has an end-use research program, and one, Lawrence Berkeley Laboratory, has in its applied-physics division a constellation of experienced researchers and coordinated programs that rivals in vigor anything the supply-research community can muster.

Shortfalls in our analyses

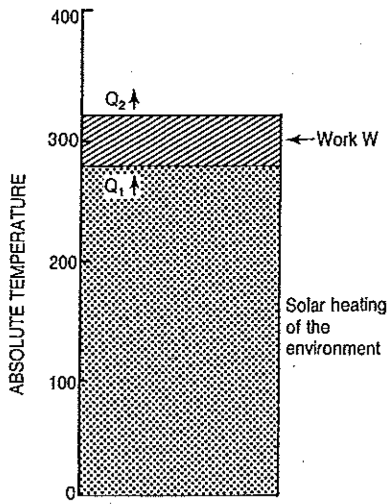
When one reads the APS study with a decade of hindsight, its omissions are more conspicuous, fortunately, than its outright errors. Foremost among the omissions is the lack of discussion of the adverse side effects that might accompany energy-conservation strategies. It was only one or two years after the 1974 summer study that researchers in end-use efficiency lost their naiveté about these side effects. We had not imagined that conservation strategies could possibly have negative consequences for safety or environmental quality comparable to those associated with the supply technologies that conservation was intended to displace. We came to understand, however, that there is *nothing* that cannot be done stupidly and that it was up to us to be at least as assiduous in identifying the negative aspects of energy conservation as we were asking proponents of coal, fission and solar energy to be of their conversion technologies.[15]

One good example is indoor air quality, which, for those pollutants whose sources are largely indoors, worsens in first approximation with the reduction of the flow of outdoor air through a building. The 1974 APS study scarcely mentions this problem. Yet within two years researchers on energy use in buildings had inserted indoor air quality into the country's research agenda, and the single objective of cost-effective saving of energy was replaced by a more sophisticated program with multiple objectives. It has since become clear that the application of scientific thinking to the energy performance of buildings will have benefits in terms of

Effects of people vs. effects of nature

Numerator (An effect of people)	Denominator (An effect of nature)	Ratio
Thermal output (10 TW)	Solar input	0.0001
Annual oil production	Economically recoverable oil in the ground	0.01–0.02
Annual CO_2 from burning fossil fuels	CO_2 in the atmosphere	0.01
Annual plutonium from reactors, 1980	Pu on Earth in other than trace concentrations, 1940*	∞
Land for 1 TW from biomass plantations (10 tons/hectare)	Arable land (0.1 of surface)	0.04

*This quantity, which was zero in 1940, has now reached roughly 500 tons, ten times the current annual rate of production.



Ideal heat pump:

$$W_{\min} = \frac{\Delta T}{T_1} Q_1$$

$$\frac{\Delta T}{T} \approx 10\%$$

Heat-pump modeling of tasks of everyday life—a suggested figure for elementary physics textbooks. Many important tasks of everyday life require the transfer of heat Q from a lower to a higher temperature, where the absolute temperatures before and after transfer differ by only 10% or so. Examples are space heating, water heating, air conditioning and refrigeration. Comparison of ideal heat pumps with actual systems such as furnaces and water heaters reveals very large opportunities for energy savings. Figure 6

both economy and health: The control of pollution sources, controlled air exchange through heat exchangers, monitoring with advanced sensors, and an improved understanding of health effects are all going to emerge from this research, along with improvements in the efficiency with which energy is used. Similarly, one has come to expect that each year's cars will be both more fuel-efficient *and* more crashworthy.

Of the many other areas of naiveté and ignorance that one could discover in the 1974 APS study, one that is still with us is the issue of the durability of conservation investments. In thousands of analyses that purported to establish the periods in which conservation investments would pay for themselves, conservation researchers failed to insist that the number of years over which savings could be expected be *measured,* not guessed. We still know pitifully little about the determinants of hardware durability and even less about the determinants of durability of attitudes and behavior.

Shortfalls of our analysis of the physics profession were perhaps most glaring insofar as they concerned physics education. The report says:

> One realization we shared during our study is the importance of classical physics, notably areas such as fluid mechanics and classical physical and chemical thermodynamics. Despite the power and scope of these subjects, and despite their practical importance, they have been neglected in our educational enterprise. Academic physicists, while witnessing with satisfaction the adoption and adaptation of these subjects within other disciplines, have counseled their students, openly or subtly, to put their efforts elsewhere. This lack of breadth and diversity is a disservice to our science.

To restore this "breadth and diversity" apparently will require much more of an assault on physics education than what is currently engendered by a concern for energy efficiency and environmental quality, for freshman physics textbooks have scarcely changed in the past decade. In particular, heat pumps continue to get short shrift. I am still waiting for standard texts to include a diagram like figure 6 in the chapter containing the discussion of Carnot cycles.

Part of the mismatch between physics and societal concerns is the striving for generality in the one and the need for specificity in the other. Even the concept of available work in thermodynamics, mentioned above, requires a descent from universality. Available work is the maximum amount of work that can be done by a system enclosed within a much larger system with fixed temperature and pressure. Introducing the concept becomes worth the trouble only when one is considering processes on or near the surface of this particular planet, with its particular environmental temperature near 300 K and its particular surface pressure near 100 000 pascals. Earth is fascinating to many of us, but it is, after all, just a special case. Its radiative balance, its atmospheric concentrations, its oceanic salinity, its magnetic field—these are all just particular conditions on a continuum to which physics applies with indifference.

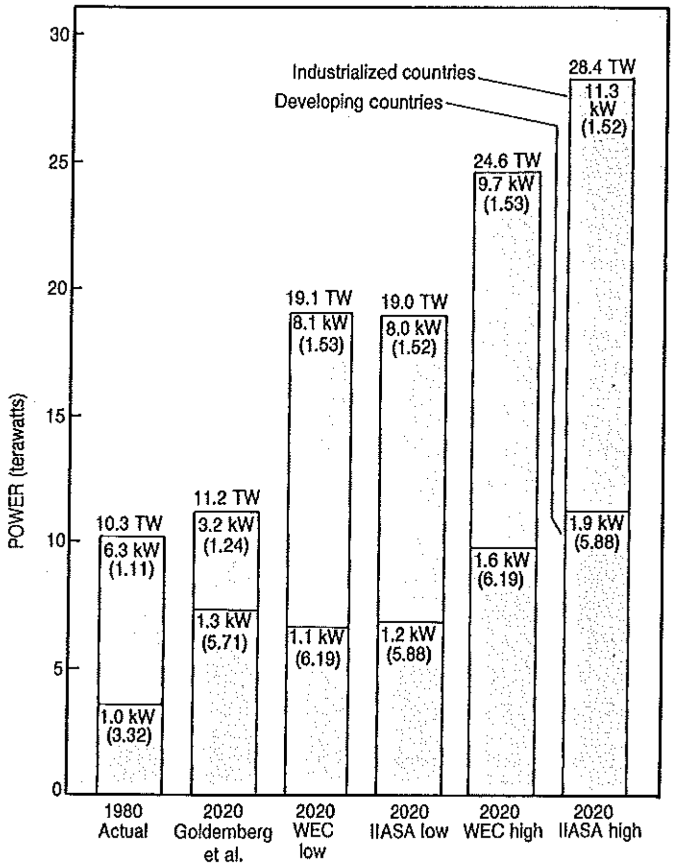
Shibboleths of 1985

Today's popular beliefs about energy and economics and about priorities for the attention of physicists are not the same ones as a decade ago, but they are at least as worthy of refutation. The heir to the belief that prosperity requires endless increases in the rate of energy use is the belief that the three-quarters of the world's population that live in the less-developed countries cannot achieve a level of well-being comparable to the current level in the industrialized countries without the environment being destroyed; in short, the developing countries are believed to be undevelopable. And the heir to the belief that physicists interested in energy should work on energy supply, not efficient use, is the belief that physicists interested in national security should work on weapons systems, not on civilian concerns.

Physicists who have been looking at energy use in developing countries have been learning that thermodynamic analysis of tasks, detailed modeling of devices and multiobjective modeling of performance are all at least as applicable in the setting of a poor village as elsewhere. The third-world cooking stove, the world's most important conversion device for harnessing the chemical energy in wood, is yielding its secrets to careful studies,[16] and it is becoming clear that more efficient cooking technology could permit enormous energy resources to be freed for redeployment in other tasks.

Moreover, when one examines each of the tasks requiring significant amounts of energy from the point of view that it should be performed with equal technical cleverness everywhere in the world, credible arguments emerge in defense of an attractive proposition much in need of close scrutiny: that the total rate of energy use by the world's population in 2020, expected to be between 7 and 8 billion people, need not be any greater than the current rate of use, even assuming substantial economic development everywhere.

A first cut at such a planetwide analysis, undertaken by Jose Goldemberg of Brazil, Thomas Johansson of Sweden, Amulya Reddy of India and Robert Williams of the United States, suggests[17] that a world with a wide distribution of 80-mile/gallon cars, 500 kW h/year refrigerators, superinsulated houses, variable-speed-drive fans and compressors, microprocessor-controlled rolling mills for sheet steel, and so on would be a livable, sustainable world. Figure 7 summarizes their vision of energy use in 2020 and compares it with more traditional analyses. Thirty-five years from now, according to this planetwide analysis, the devel-



World primary energy use in 1980 and various projections for 2020. The four projections on the right are high- and low-energy forecasts from two major studies that are representative of the conventional wisdom: the 1983 World Energy Conference study,[18] and the 1981 study by the International Institute for Applied Systems Analysis.[19] The numbers in kilowatts are per-capita energy uses; the numbers in parentheses are populations in billions. This chart is adapted from a recent study[17] that, like this article, emphasizes the potential of an aggressive effort to conserve energy. Figure 7

oping world could be using 65% of the world's energy, double its 32% share today, if the industrialized countries continue to introduce energy-efficient technology at a sustained, vigorous rate. An important conclusion of Goldemberg, Johansson, Reddy and Williams is that the current rate of per-capita consumption in the developing countries (about 1.0 kilowatt) is consistent with a broad range of standards of living—from the present one in those countries to one equivalent to that enjoyed in Western Europe—so that the total consumption of energy in a developing country that gives priority to efficient use of resources need grow only as fast as its population.

As for the argument that national security is equivalent to weapons systems, it can best be undermined by creative work in other areas that demonstrably improves society. If the United States and the Soviet Union lose ground to the rest of the world by engaging an ever increasing share of their most creative people in the production of modern arms, a cause and effect relationship between the deflection of talent from the civilian sector and the faltering of the civilian economy, although difficult to prove, may be strongly suggested. For those of us appalled at the present trends probably the best thing to do is to continue to make as attractive as possible several alternative ways of working as scientists on problems of concern to society. One such path, and an endlessly fascinating one, remains the career of physicist engaged in designing a resource-respectful world.

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