Energy Vol. 6, No. 7, pp. 585–589, 1981
Printed in Great Britain.

0360-5442/81/070585-05$02.00/0
Pergamon Press Ltd.

CONSERVATION WILL ALWAYS BE WITH US

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(*Received* 18 *February* 1981)

Abstract—The rapidly changing energy situation has led to new analyses of energy conservation from both physical and economic perspectives. A physics perspective suggests that the technical prospects for improved efficiency remain very great. An economics perspective suggests that conserved energy may be used to offset new energy supplies. Together, they suggest a continuing and important role for energy conservation.

DISCUSSION

Statements such as "We have conserved just about all the energy we can" or "The full potential of energy conservation has virtually been realized" are frequently heard, even from people who should know better. Is energy conservation a dead-end field because it has a finite potential? The answer is emphatically "no". Energy conservation will always be with us.

Why did the discipline of energy conservation develop? Its origins can be traced to the late 1960s and early 1970s when the marginal cost of new energy supplies began to increase. During this time, the long-term, fixed-price energy supply contracts that had been written years earlier kept the average prices down. Still, a few far-sighted persons recognized that, as energy prices climbed, investment in energy conservation would become increasingly attractive and possible critical.

The 1973 oil embargo and subsequent price increases led to the renegotiation of many long-term contracts of all fuels, leading to a sharp increase in energy prices. Nationwide, conservation policies were suddenly no longer a theoretical possibility but a real economic alternative, even to the homeowner.

These were the golden years for energy conservation. With greatly increased energy prices, there was "energy fat" to trim any place one looked. Trivial investments led to tremendous savings. Sometimes, conservation measures were attractive even at pre-embargo prices, although nobody had bothered to look for them until the crises. A good portion of energy conservation consisted of rediscovering old tricks such as building efficient motors, shading windows and weather-stripping. It was embarrassing to find that modern technology often meant inefficient technology.

Accurate estimates of the potential for energy conservation required completely new types of information. While we knew very precisely where our energy came *from*, we had only the crudest idea of where it *went*. How much of the nation's energy went to heating water, to operating refrigerators, to lighting? How many refrigerators were there in America and what was their average energy consumption? In a remarkably short time estimates of energy consumption by end use were developed.[1] Admittedly, these were crude estimates, but they were sufficiently accurate to indicate where significant energy savings on a national scale could be achieved.

Two other concepts also emerged: energy process analysis and embodied energy. Using energy process analysis, one could examine each stage in some industrial process to understand how energy was used. The processes could then be compared in different factories. One immediate result was the embarrassing discovery that many European factories used 10–50% less energy to produce identical output (e.g. a ton of steel).[2]

The concept of embodied energy was developed to estimate the energy intensity of activities or complex products, such as autos. This type of analysis, based on macroeconomic input-output analysis, is full of assumptions and simplifications. Still, it shows how energy policies could backfire. For example, if consumers spend the money they save by insulating their houses on midwinter jet trips to Florida, the net result could be a much smaller decrease in energy consumption than the insulation savings alone. In other words, we cannot be certain energy is really being saved until we know the fate of the dollars saved. Macroeconomic input-output analysis also shows how shifts in consumer spending can effect energy savings. For example, the boom in personal electronic gadgetry, with little embodied energy and low energy use, has diverted consumer spending from energy-intensive leisure activities.

In 1974, a group of physicists gathered at Princeton University to discuss energy conservation.[3] The topic seemed to attract physicists because it was a new and undefined area. Until that time, the identification of conservation measures was unclear to many people. Few appreciated what the ultimate conservation potential was. There was also confusion in comparing electrical and fossil fuel energy. According to conventional wisdom, a heat pump could supply two units of heat for each unit of electrical energy, while an oil furnace could provide two units of heat for every three units of energy (i.e. 66% efficient). Surely, heat pumps were better conservers than oil furnaces. Or were they? Heat pumps use electricity generated in a power plant that converts three units of heat to one unit of electricity; the *net* efficiency of the heat pump, including the power plant, is therefore 66%. On very cold days this efficiency may fall to a pitiful 33%, while furnaces continue at 66%. Which system is better?

From the Princeton conference emerged a theoretical framework for physicists to study energy conservation founded on the second law of thermodynamics. The efficiency of a device is measured with respect to the minimum energy needed to do that task as determined by the second law. The second law efficiency indicates device efficiency relative to the thermodynamic minimum required. A typical furnace has a second law efficiency of only 6%, a car 10%, and a water heater 3%. Curiously, a steam electrical power plant has a second law efficiency of 80%, showing that engineers have obtained very nearly the maximum electricity from this process.

The concept of energy quality was also developed. Electrical energy, because it can produce very high temperatures, is high-quality energy. The task of heating a home requires energy delivered at only 50°C, i.e. low-quality energy. To use high-quality electrical energy to heat a home is therefore wasteful, a mismatch of energy quality, because the task of heating can be done just as well with lower-quality energy (such as that provided by the sun).

Around 1976, the environmental benefits of energy conservation became clear: less pollution, less mining, less nuclear waste, etc. All this at lower costs than new energy supplies! Careful estimates of conservation potentials became powerful arguments against the construction of new energy facilities. In California, it was shown that merely requiring consumers to purchase the most efficient refrigerators available (as old units wore out), would create sufficient energy savings to negate the need for a proposed nuclear power plant. The total cost to consumers would be lower than otherwise since the additional cost of the new refrigerator would be offset by lower electricity rates and lower energy use.

Early on, conservation experts recognized that there existed two types of energy conservation. The simplest kind occurs when the consumer invests to reduce energy use, and the savings pay back the investment in a reasonable time. Insulating a house and buying an efficient refrigerator are examples. A second kind occurs when the benefits of investments in conservation do not accrue so much to the individual consumers as to the supplier or to society as a whole. Air conditioning is the classic example.

Air conditioning places uneconomic demands on utilities. The utilities must construct sufficient generating capacity to meet the demands of every operating air conditioner, even though they may operate only a few hours each year. After the summer peak, these expensive generating facilities lie idle until the next year. In the Southwest, as much as 50% of the generating capacity of some utilities lies idle for nine months of the year. Thus, although the individual consumer saves in energy bills by buying an efficient air conditioner (a unit that supplies the same amount of cooling for less energy), the utility saves even more because it need not build as much capacity. These savings are eventually (hopefully) passed on to consumers in the form of lower electricity rates. Simply put, it is currently cheaper to conserve a kilowatt than to install a kilowatt of capacity. The utilities are only now beginning to realize this fact.

Recognition of the interdependency of supply and demand is forcing experts to analyze the benefits of conservation in terms of the consumer, the supplier and the nation. Ordinarily, consumers pay an average price of energy which is now far below the marginal cost a utility must pay to provide it. The average price is, in part, kept low by the long-term supply contracts that were written in an era of lower energy prices. If the consumer paid the marginal price, much more conservation would occur, thereby reducing the need for new supplies.

Recognition of the national (or at least regional) benefits of energy conservation forced researchers to develop new ways to express the economics of new energy supplies and conservation on a similar scale. Only large-scale aggregation of energy savings could rebut the arguments that conservation was a small effect, a stopgap measure, and often expensive. One technique was to express the conservation potential in terms of the cost of conserved energy. Once the cost of conserved energy was calculated for several measures, one could compare them to the cost of energy from new sources. By estimating the cost of conserved energy and the aggregate savings for many measures, one can establish a sequence for the measures, starting with those with the lowest cost of conserved energy. This procedure yields a supply curve of conserved energy, i.e. a schedule showing the energy available through conservation measures, expressed in cost per unit energy.[4] A supply curve of conserved electricity for California's residential sector is shown in Fig. 1.[5]

Conserved energy is not perfectly analogous to conventional supplies. It can be exploited at two times. First, conserved energy can eliminate increased demand caused by growth. For example, by improving the efficiency of the nation's ninety million refrigerators, we need not build any additional power plants for the additional twenty six million refrigerators expected by the year 2000. Second, supplies of conserved energy can substitute for a depleted resource, instead of replacing it with a much higher cost energy source. One solution to the dilemma of our dwindling natural gas supplies is imported liquified natural gas. The conservation alternative, however, is to invest in measures cheaper than the LNG, thereby obviating the need for all or a part of the LNG.

Only now are we able to integrate conventional energy supplies and conservation. By combining both conventional supplies and conservation, one obtains an energy alternatives

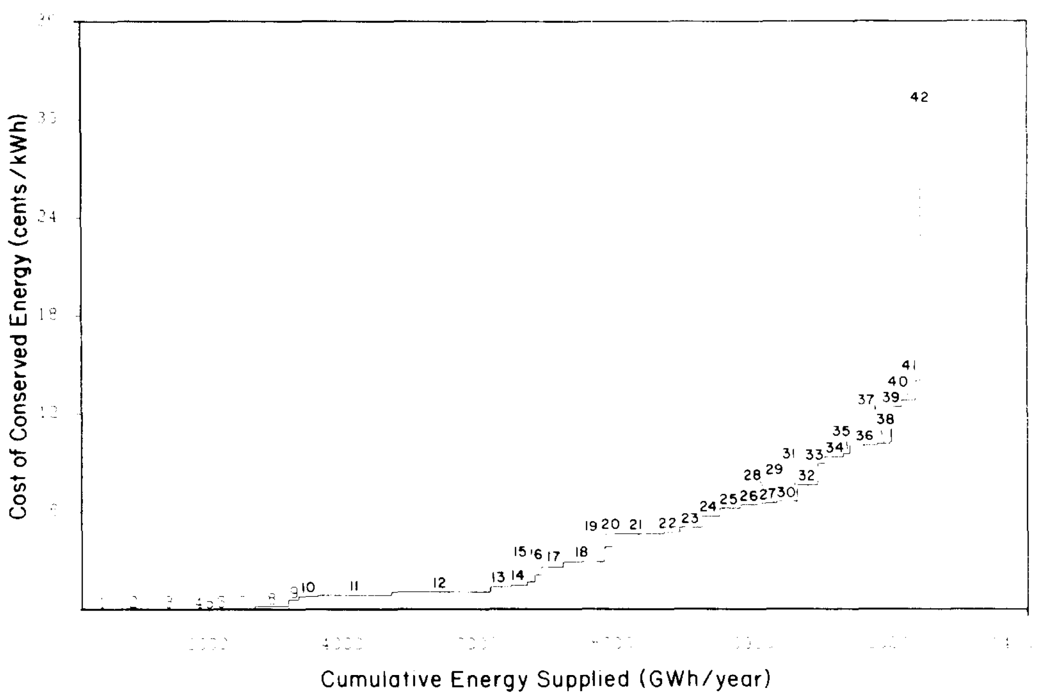

Fig. 1. A supply curve of conserved electricity for California's residential sector. Each step corresponds to a conservation measure; the y-coordinate is the cost of conserved energy and the x-coordinate the cumulative energy saved. We list each of the measures in Table 1. The calculations assume a consumer perspective, that is, costs, energy savings, and amortization times appropriate for consumers. A real discount rate of 5% was used. The results shown were obtained assuming a 10 yr time horizon. Measures with costs of conserved energy less than energy prices are economic. About 10.6 TWh per year could be supplied through conservation at costs of conserved energy below 7 cents/kWh (somewhat less than the maximum rate paid by California's residential customers). This energy is equivalent to the output of two standard 1000 MW power plants; adapted from Ref. 5.

Table 1. Table to supplement the supply curve of conserved electricity (Fig. 1). The conservation measures are listed in the order they appear on the curve; adapted from Ref. 5.

	Measure	Cost of conserved energy (cents/kWh)	Energy supplied per measure (GWh/yr)	Cumulative energy supplied (TWh/yr)
1	Solid-state color TV	0	599	0.6
2	Solid-state black-and-white TV	0	322	.9
3	CEC standard refrigerator	0	728	1.6
4	CEC standard room A/C	0	152	1.8
5	CEC standard central A/C	0	168	2.0
6	Water heater temp. setback	0	186	2.2
7	Cold-water laundry	0	407	2.6
8	Low-flow showerhead	.2	497	3.1
9	Night setback of 10°F	.6	153	3.2
10	Pool filter savings from cover	.8	287	3.5
11	Buy most eff. refrigerator	.9	1,092	4.6
12	Refrigerator package "A"	1.1	1,466	6.1
13	Buy most eff. freezer	1.4	306	6.4
14	Water heater insul. blanket	1.5	241	6.6
15	3-Way bulb to high efficiency	1.7	111	6.7
16	Seal attic bypasses	2.1	93	6.8
17	Freezer package	2.6	328	7.1
18	Kitchen fluorescent	2.9	609	7.7
19	Install R-19 in ceiling	3.7	10	7.8
20	Divert elec. clothes dryer vent	3.8	105	7.9
21	Switch to gas clothes dryer	4.6	767	8.6
22	Exterior fluorescent	4.7	239	8.9
23	100 W bulb to fluorescent (1)	5.0	335	9.2
24	Storm windows	5.7	258	9.5
25	Central A/C wall insulation	6.2	309	9.8
26	Buy most efficient central A/C	6.4	252	10.0
27	Manual refrig. improvement	6.5	208	10.2
28	Buy most efficient elec. dryer	6.5	62	10.3
29	Fireplace damper	6.5	13	10.3
30	100 W bulb to fluorescent (2)	6.6	290	10.6
31	Install R-11 in walls	7.4	9	10.6
32	3-way bulb to fluorescent	7.6	305	10.9
33	Caulking	8.9	102	11.0
34	Switch to gas range	9.3	274	11.3
35	Window shading for central A/C	9.5	95	11.4
36	Refrigerator package "B"	10.0	406	11.8
37	100 W bulb to fluorescent (3)	10.1	191	12.0
38	Buy most efficient room A/C	10.2	24	12.0
39	75 W bulb to fluorescent	12.4	156	12.2
40	Weatherize apartments	12.8	204	12.4
41	Additional R-19 in ceiling	14.0	69	12.4
42	Weatherstrip	30.8	48	12.5

supply curve. As energy prices rise, a mix of conventional supply and conservation measures will become economic. Developing such energy alternatives supply curves would require enormous effort; Exxon has difficulty creating its own oil supply curve! Nevertheless, even recognizing that such a curve is possible would have a tremendous impact on energy policy. For the first time, conventional energy supplies and conservation would be treated as equals. Energy alternatives supply curves also show that conservation is not something we need be concerned with for a limited time; rather, as energy prices rise, new measures will become economic.

Granted that there will always be some conservation measures available, will they always be large enough to justify deliberate policies? In other words, will we eventually exhaust our large reserves of conserved energy? Probably not. The second law of thermodynamics dictates the minimum energy needed to perform a process but, even this can change if we redefine the task. In baking, for example, the goal is to heat the food. However, we usually accomplish this by heating the air inside an oven which, through conduction, heats the food. In terms of delivering its energy to the air (the process), an electric oven is nearly 100% efficient. A microwave oven also heats the food, but with much less electricity by sidestepping the original process. In a similar manner, electric power generation (the goal) may be accomplished through processes not requiring steam (the task). One such technique uses fuel cells which, by avoiding high temperatures, produces electricity more efficiently. Examples like the microwave oven and fuel cells force us to redefine the task to one much closer to the goal rather than the process.

Task redefinition resulting from new technologies, as in the two cited examples, will undoubtedly serve as an important means of increasing conservation reserves. In this procedure, we avoid the increasingly sophisticated engineering needed to improve thermodynamic efficiency for a given process.

So what is the status of conservation and the future of research in conservation? It is very slowly gaining recognition as a legitimate alternative to the continued search for new conventional energy supplies. Problems remain, of course, particularly in the area of achieving the known technological conservation potentials. These may require the development of new institutions (whose cost should also be included in the cost of conserved energy). The crucial step is the realization that energy conservation is not a stopgap measure but rather a necessary part of the solution to energy shortages and increasing prices.

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