

Constraints on energy conservation

The scientific study of energy conservation is still beset with poorly defined goals. Conservation achieved through technology must be distinguished from conservation achieved through changes of lifestyle. In the technological approach, the objectives of energy-consuming activities are not questioned—thus, we accept that society needs a certain amount of aluminum, polymers, transport, and so on, per year. What is analyzed in this approach is how these materials and services can be provided more efficiently. On the other hand, in the change-of-lifestyle approach to conservation, the demand for energy is analyzed—do we need aluminum, can we decrease the temperature in our homes, do we need to travel?

To mandate sizable changes of lifestyle, limits must be placed on society's activities; in nonemergency situations, the implementation of these restrictions meets much resistance. The major problems in the technological approach, however, involve technology and economics, both of which can be addressed quite well within existing decision-making structures. It therefore appears worthwhile to evaluate the potential of the technological approach.

Thermodynamics is often used to estimate the potential for technological conservation. The concept of the availability of energy can be derived from the second law of thermodynamics, which gives a value for the amount of high-quality energy (that is, electrical energy or mechanical energy) equivalent to the quantity of energy under consideration. The concept of availability indicates how much high-value energy can be "obtained" at an infinitely slow rate when a reversible conversion device exists. Expressed in terms of the availability of primary energy resources, many present energy applications are very inefficient, and this observation is used by some people as evidence that there is a tremendous potential for conservation. These individuals would have us believe that all we have to do is improve technology to increase energy efficiency—in terms of availability—by, for example, 1 percent every year for many decades.

There is nothing wrong with the statement that we can never make a material with less energy than that corresponding



to the second-law value (the Gibbs-free-energy change of the process under consideration). But it is fundamentally wrong to suggest that the difference between the amount of energy used by the present process and the thermodynamic value can potentially be conserved through improvements in technology.

To prove this statement we refer to the thermodynamics of irreversible processes, which takes time into account. The irreversible heat production is proportional to the product of the rate of flow and the force. In the linear approximation the rate of flow is proportional to the force. Consequently, the irreversible heat production is proportional to the square of the rate of flow. This is the theoretical formulation for statements such as "haste makes waste" and "time can be substituted for energy."

In the technological approach to conservation we want to maintain the total production volume, but we want to reduce the rate of flow to decrease the irreversible heat production. The rate of flow is measured per unit equipment: for example, per unit surface of a heat exchanger or per unit volume of a reactor. Thus the size of the equipment must be increased to maintain the product volume at a lower specific rate of flow. There are

many examples of how the production volume per year can be maintained even though size is increased to decrease energy loss: a few examples include increasing the size of pipe diameters, the number of electrolysis cells (while decreasing the overvoltage), the number of effects used in evaporation processes, and the number of transport vehicles (while decreasing the speed of each).

The irreversible heat production often corresponds to the difference between the actual process energy and the thermodynamic limit. Thus, quite generally, one must move in the direction of thermodynamic equilibrium by using larger equipment. This trade-off between investment cost and energy cost is well known in engineering analysis, where the goal is to operate at the cost minimum.

Because energy is required to make and install equipment, a corresponding trade-off exists in energy accounting. A decrease of direct or process energy is accompanied by an increase of indirect or embodied energy in the equipment. Energy optimization leads to a real energy minimum for the production process that is higher than the thermodynamic limit. Thus the thermodynamic limit is not a real limit for conservation purposes for a certain production volume per year.

This general theory leads to other important conclusions. The energy minimum corresponds to higher cost per unit product than the cost minimum. As the price of energy increases, the cost minimum is brought closer to the energy minimum, but infinitely high energy prices are necessary for the two minima to coincide. This relationship explains why many large-scale industrial processes in Europe and Japan require 15–30 percent less energy per unit of production than they require in the US, where energy prices have been continuously lower.

The different goals between cost and energy optimizations bring about tensions in societies when both types of optimization are institutionalized. For example, shifting the operation away from the cost minimum in the direction of the energy minimum will increase the manufacturing cost. Because these costs increase considerably even for only 20–30 percent conservation, industry generally will not be interested in saving the extra energy.

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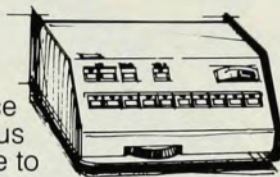
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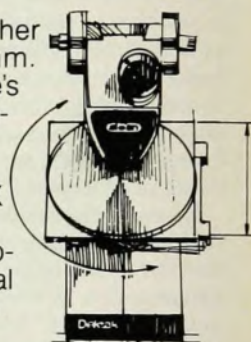
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Aiming for the maximum conservation is economically unacceptable.

Generally, the first savings in capital cost are less expensive per megajoule than the investments necessary to produce 1 MJ of energy from new resources. In our society there is a financial structure to raise capital for the production of secondary energy carriers from primary resources, but there is not yet a structure to finance only conservation. Industrial companies, for example, might reject conservation investments with a return on capital of 25 percent, while investments necessary to improve the main product line are accepted with a lower rate of return. Utilities can raise capital for new power plants, but they have to be pushed to be bankers who finance the insulation of homes. In the domestic sector we see corresponding problems: conservation requires that the fraction of spendable income going into investments rather than into consumption of commodities and services should increase with respect to the present situation. The final result is that the rate of return on the conservation investments generally has to be much larger than that of the usual business to provoke large-scale conservation.

The conservation path as described earlier represents a trade-off between capital and energy used to get a constant production level. In terms of economics this corresponds to an isoquant of the production function. The technological information of the conservation theory can be fed directly into the economic theory. This is important since in many macro-economic models the price elasticity of energy demand occurs only as a parameter to which rather arbitrary values are assigned.

Until recently the study of embodied energy dealt mainly with the supply side, such as nuclear reactors and solar installations. In the static analysis the question addressed is whether or not the installation will produce more energy than was used to construct it. Even when the net effect is positive, the total output can be zero or negative for a certain period when the building program increases too quickly (dynamic analysis).

Exactly the same arguments hold when conservation measures are based upon capital (and thus energy) investments. The conservation potential quoted in the literature is normally the gross effect, since the energy necessary to produce the conservation devices is assumed to be available from elsewhere in society. Relevant to a national energy policy, however, is the net energy conserved. Here too the problem is that although a conservation device as such may have a reasonable payback time in energy, it may have decreased short-term net effects—as shown by the dynamic theory—when in-

troduced rapidly. The nature of democracies is to postpone actions as long as there are no emergencies and to react to crises with emergency programs. We must determine the energy embodied in conservation and supply options to judge whether such emergency programs have any useful near-term effect.

The energy embodied in materials and equipment is also relevant in the study of future energy technologies based more or less upon decentralized solar-energy philosophy. Not only capital, but also materials and energy will be required to build such a supply system. Obviously, the present production systems must be maintained for several decades to produce the new system. The promise of other energy supplies in the future is sometimes used as an argument to deter further applications of options now available. But when a more detailed analysis of the materials, devices and embodied energy necessary for the future system is still needed, it seems imprudent to impede the utilization of present options: it would seem to be the most direct way of preventing the construction of a new energy structure.

How does one handle the requirement for indirect energy? The easiest way to estimate it is to use the payback time in energy for the proposed measures. The payback time in energy is the ratio of the amount of the primary energy necessary to make and install the energy-conserving equipment to the annual saving of energy, also counted as primary fuels. For example, we wish to heat water with solar systems to save 25×10^{12} MJ (about 25 quads) of fossil fuel by the year 2000. With the estimated payback time of at least 5 years for these solar installations, about 125×10^{12} MJ (or 125 quads) is necessary to produce and install the equipment in the period 1980–2000. This is an important amount of energy when compared to the annual US energy use of about 80×10^{12} MJ (or about 80 quads).

The calculation of payback times in energy is not without methodological problems. The payback time in terms of money invested and saved is always larger than the payback time in energy. For most practical cases, a payback time in energy of five years generally leads to unacceptable economics. Findings such as these emphasize the need for further analysis to evaluate the net effect of large-scale conservation programs.¹

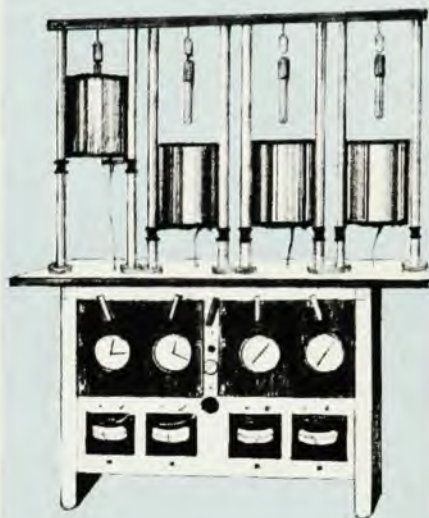
Reference

1. Detailed information about the issues under discussion is available in reports by the author from the Institute for Energy Analysis, Oak Ridge Associated Universities, Oak Ridge, Tennessee 37830; see report numbers ORAU/IEA-78-6(M), 78-17(M) and 78-20(M).

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