transmission electron microscopy or scanning electron microscopy.

Nicolson proposes that cell agglutination with con A (or other proteins that induce cell agglutination) is a complex process that involves many factors, some of which favor and some oppose, agglutination. The factors include the number and location (distance from the membrane surface) of con A receptor sites, electrostatic charges on cell surfaces, structures such as microvilli, cell surface deformability, the mobility of con A receptors in cell membranes, and the control of that mobility by elements in the cytoplasm that are in turn controlled by cyclic AMP. Nicolson does not believe that cell agglutination can be explained by any single property of cell surfaces, although in certain systems some properties may be more important than others. He says that a given group of cells will agglutinate if the factors favoring this process outweigh the factors that oppose it.

Since dark-field microscopy has not been used previously to observe microvilli, many investigators are waiting to support the hypothesis of Willingham and Pastan until more cells have been observed in this way and until cells have been observed under a wide variety of experimental conditions. Others are enthusiastic about the hypothesis because of its simplicity and apparent generality. Still others agree with Nicolson's criticisms of it. Whether or not Willingham and Pastan turn out to be right, it now seems likely that microvilli will play a prominent role in future investigations of differences between normal and transformed cells.—GINA BARI KOLATA

Energy Conservation: Better Living through Thermodynamics

Modern fossil fuel generating plants have an efficiency of about 40 percent, typical household furnaces have an efficiency of 60 percent, and electric hot water heaters have an efficiency of about 75 percent.

Such a comparison seems to imply that 100 percent efficiency is the best theoretically possible, and that hot water heaters are more nearly perfect than generating plants. But closer study of the laws of physics shows that both of these implications are false. For fossil fuel generating plants the maximum theoretical efficiency is less than 100 percent, while for home heating devices it is considerably greater than 100 percent, just as it is for home cooling devices. The quantity that would otherwise be called efficiency for air-conditioners is so embarrassingly high that it is renamed the "coefficient of performance."

A number of studies of the energy economy have pointed out that the calorie content of fuel is not a very good index of wastefulness, since energy is not actually consumed (according to the first law of thermodynamics), but is rendered useless by an increase of entropy (according to the second law). A more important quantity is the ability of energy to do work, which is a more subtle thermodynamic quantity related to the concept of "free energy" introduced by J. W. Gibbs in 1878, and known to physicists and engineers as "available work." The second law of thermodynamics virtually guarantees that a quantity of high-temperature energy can do more work than an equal amount of low-temperature energy.

The shortcomings of the usual definition of energy efficiency are particularly apparent for tasks in which fossil fuels are used to produce low-temperature heat. Since fossil fuels burn at very high flame temperatures—up to 4000°F (2210°C)—the available work produced by fossil fuels is largely wasted when it is used for hot water heating, space heating, or even industrial steam production, since these are relatively low-temperature processes. For such purposes, the fuel could often be better used to raise the temperature of heat pumped in from another source rather than to produce heat directly by burning. Alternatively, the fuel could be used to do additional work, such as generating electricity, in the course of producing a low-temperature output.

Summer studies by the American Physical Society (APS) and the International Federation of Institutes of Advanced Study in 1974 have recommended that available work should be the measure of efficient energy utilization used for assessing wastefulness in various sectors of a national energy economy. The APS study,* for which the principal investigators were Robert Socolow at Princeton University and Marc Ross at the University of Michigan, proceeded further to recommend an improved definition of energy efficiency based on the minimum amount of available work needed for a task, and named it the "second-law efficiency." The more familiar measure would then be called the "first-law efficiency," and a comparison of the two measures estimated by the APS study is given in Table 1.

Table 1. Comparison of energy efficiencies derived from the first and second laws of thermodynamics. The familiar or first-law efficiency does not reflect the minimum theoretical energy needed for the task and so may be misleadingly high, especially for low-temperature heating requirements. [Source: "Efficient use of energy: A physics perspective," a report of an American Physical Society summer study of 1974]

Use	Estimated first-law efficiency (%)	Estimated second-law efficiency (%)
Space heating		
Furnace	60	6
Heat pump*	270†	9
Water heating		
Electric	75†	1–2
Gas	50	3
Air-conditioning	200†	5
Refrigeration		4
Industrial		
Process steam		~25
Direct heat		~30
Electric drive		30
Transportation		10

*Heat pump efficiency is here calculated for an indoor temperature of 110°F (before distribution) and an outdoor temperature of 40°F. Heat pumps are much less efficient in colder weather. †The first-law efficiency is smaller by a factor of 3 if stated in terms of the electric power plant fuel. Second-law efficiency must be based on power plant fuel.

The second-law efficiencies of space heating, water heating, air-conditioning, and refrigeration are all less than 6 percent. In other words, each of these processes requires almost 20 times as much as the minimum energy to do the task consistent with the laws of physics. Of course, any practical device will fall short of idealized performance, but "it is within reach of the present technology to come considerably closer to the ideal," according to the APS report. For relatively high-temperature processes, such as industrial direct heat, there is not so much difference between the first- and second-law efficiencies. However, low- and moderate-temperature processes account for 45 percent of the total U.S. energy usage.

Perhaps the first example of a government order that incorporated the concept of second-law efficiency into a discussion of efficient fuel utilization was a recent action by the Federal Power Commission (FPC). In a request for permission to use offshore gas to fuel refineries in southern Louisiana, Exxon, Cities Service, and Continental oil companies argued for the energy efficiency of the plan by comparing the fuel value of the refined oil to the energy value of the crude oil feedstock plus the gas needed for refining. One witness at

*Summaries are available from Kurt Riegel, Federal Energy Administration, Room 5320, Washington, D.C. 20044.

the hearings testified that the petroleum industry had an efficiency of 84 percent by this measure. But the FPC granted only part of the gas volume requested, noting among other reasons for the decision that the true measure of the efficiency of the process is the minimum work theoretically needed to refine the oil. By this measure, which is the same as the second-law efficiency, the fuel efficiency of the petroleum industry is only about 9 percent. The FPC noted that "the petroleum refiners . . . do not outpace other industries in the overall efficiency of energy use." According to a report prepared for the Ford Foundation Energy Policy Project, the efficiency of other industries is comparable or higher (Table 2).

Table 2. The efficiency of fuel utilization in various industries. The measure of efficiency in each industry is the minimum amount of fuel theoretically needed to produce 1 ton of the product. The minimum fuel needed for the paper industry is very near zero because of the heating value of the waste products. [Source: E. P. Gyftopoulos, L. J. Lazaridis, T. F. Widmer, *Potential Fuel Effectiveness in Industry* (Ballinger, Cambridge, Mass., 1974)]

Industry	Second-law energy (%) efficiency
Petroleum	9
Steel	21
Aluminum	13
Cement	10
Paper	~0.3

One of the most promising suggestions for improved utilization of fuels by industry is the generation of electricity along with industrial heat or steam. Production of electricity at industrial plants was proved economically sound by several large paper companies during the 1920's, but was halted by the Justice Department [C. A. Berg, *Science* **184**, 264 (1974)]. Most industries would produce more electricity than they could use by cogeneration, at least during part of the year, and it is presently quite difficult for them to arrange for offsite sale of such electricity. But the technical capability is at hand, and the potential for energy saving is great. A study just being completed for the energy policy office of the National Science Foundation finds that as much as 700,000 barrels of oil per day could be saved by industrial cogeneration of electricity.

An alternative architecture for cogeneration of electricity and heat is a central power station redesigned so that its waste heat, which is now typically 100°F, can be used for domestic heating or industrial processes. Even though the amount of heat discharged in the cooling water of a power plant is large, the failure to use this water is not particularly wasteful because it typically contains only 1.5 percent of the available work represented by the fuel. To produce higher-temperature heat from a central power station requires modification of the design of the facility. The difficulties with a major project of this sort under way at Midland, Michigan, indicate that the institutional differences between power companies and potential industrial users are also serious problems. The Consumers Power Company is building a large nuclear facility in Midland to produce industrial steam at 360°F, in addition to electricity. However, the delays in starting this plant have apparently forced the largest potential customer, the Dow Chemical Company in Midland, to make other provisions. Dow has substantially reduced the amount of steam it was originally committed to purchase.

Combined systems can also be used to improve the efficiency of domestic and commercial energy usage. For instance, if a diesel motor is used to drive a generator, the efficiency is about that of a central station. But if much of the exhaust heat of the motor is recovered and used for space heating, significant amounts of fuel can be saved. According to a sample calculation in the APS report, in which a diesel generator provides the winter base-heating load for a sizable community and produces all the community's electricity plus more for sale, the overall second-law efficiency is 34 percent. This is so much higher than the typical efficiency of space and water heating that the fraction of the fuel saved by the combined system in the sample calculation was 31 percent. Another calculation, involving fuel cells with performance levels that should be available shortly, gave equal savings in energy without producing so much excess electricity.

For domestic and commercial energy needs, individual components such as heat pumps, fuel cells, and heat exchangers can also be greatly improved, according to the APS study. The efficiency of the heating system could also be greatly improved by plugging leaks and by using more sophisticated diagnostic instruments. The advances in infrared technology should make possible improved instruments for detecting heat losses in buildings, and the APS group noted that a small, easy-to-use heat flux meter, similar to a photographic light meter, would be very valuable.

Other sorts of badly needed instruments are gauges indicating energy consumption efficiency. One such meter could be a dial on the automobile instrument panel that would indicate the number of miles per gallon an automobile was getting over a short time interval, based on a comparison of the carburetor fuel flow and the speed. Empirical data could also be provided for the efficiency of home heating, with the use of the common predictor of energy consumption, the degree-day. Consequently, a meter that measures degree-days per gallon would be very useful.

Other parts of the three-part APS summer study dealt with windows and combustion, areas of interest to commercial and industrial designers that seem particularly well suited for physical modeling. The window study arrived at an important conclusion for the proper use of solar energy. While many inventors and scientists are trying to perfect collectors to attach to house roofs, the APS study found that windows themselves are excellent solar collectors which can provide a substantial amount of heating if properly designed.

Knowing that most scientists consider thermodynamics and fluid dynamics to be boring, "classical" subjects, the authors of the APS report urged fellow scientists to reconsider their importance. The overall second-law efficiency for consumption of U.S. energy resources is now only 10 or 15 percent.—WILLIAM D. METZ

Lasers in Biomedicine: Analyzing and Sorting Cells

At this time no one can say just how useful lasers will be for biomedical research. One area in which progress is already substantial, however, is the development of automated flow systems. These instruments, which are now becoming available commercially, use laser light to analyze cell characteristics; some can even sort or separate cells on the basis of differences in their characteristics. Flow systems promise to be powerful tools for studying basic cell biology. Moreover, they have potential clinical applications such as rapid screening of cell preparations for the presence of abnormal or cancerous cells.

Flow systems have several advantages over other techniques that may produce similar information. They examine individual cells with great rapidity. Some scan—and sort—cells at the rate of several thousand per second. Consequently, they can pick out cells that may be present as only a small minority in the population. The more advanced flow systems are de-