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HUMAN VALUES, AND SCIENTIFIC AND TECHNOLOGICAL MEANS

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Recently many thoughtful commentators are alarmed by the badly damaged relationship of humanity with its earthly environment, and the sobering list of unmet human needs ("State of the World," Worldwatch Institute Report, 1992, p. 3).

As examples of the damaged relationship, they cite:

- The protective ozone shield in heavily populated latitudes of the northern hemisphere is thinning twice as fast as scientists thought just a few years ago.
- A minimum of 140 plant and animal species are condemned to extinction each day.
- Atmospheric levels of heat-trapping carbon dioxide are now 26 percent higher than the preindustrial concentration, and continue to climb.
- The earth's surface was warmer in 1990 than in any year since recordkeeping began in the mid-nineteenth century; six of the seven warmest years on record have occurred since 1980.
- Forests are vanishing at a rate of some 17 million hectares per year, an area about half the size of Finland.
- World population is growing by 92 million people annually, roughly equal to adding another Mexico each year; of this total, 88 million are being added in the developing world.

As examples of unmet needs, the list includes:

- One in three children is malnourished.
- Some 1.2 billion people lack water safe to drink.
- Nearly 3 million children die annually from diseases that could be averted by immunizations.
- One million women die each year from preventable reproductive health problems.
- About 1 billion adults cannot read or write.
- More than 100 million children of primary school age are not in school.

The juxtaposition of these two sets of observations suggests a great dilemma of our times. People in scientifically and technically advanced countries live longer, are better fed, enjoy better health care, are more trained, and, as a result, use more energy per capita than people in developing nations. Thus, they cause the major damage to the relationship between humanity and its environment. People in developing nations do not enjoy the humanitarian benefits of science and technology and do not affect appreciably the relationship between humanity and its environment. However, they have many humanitarian needs that are unmet.

It seems to me that many well-coordinated efforts are necessary to alleviate the dilemma, including a more effective use of science and technology in developed nations, and an intensive use of scientific and technical means in developing nations.

To illustrate these points, I have selected the six countries listed in Table I. Three are not scientifically, technically, and economically developed, and three are. As a measure of development I use the gross national product per capita (GNP/CAP). I realize that any one index, in general, and the GNP/CAP, in particular, does not and cannot capture the richness and variety of characteristics that define a society. Nevertheless, we will see that, within broad limits, many humane goals are achieved in a country like Japan where the GNP/CAP in 1990 dollars was $32,680, but are sorely missed in a country like Ethiopia where the GNP/CAP in 1990 dollars was only $120.

TABLE I

GROSS NATIONAL PRODUCT PER CAPITA
(U.S. $ 1990)

BANGLADESH	210	JAPAN	25,430
BOLIVIA	630	SWITZERLAND	32,680
ETHIOPIA	120	USA	21,790

Source: World Bank, "World Development Report 1992," Oxford University Press, 1992

For example, as shown in Table II, the life expectancy at birth of people born in a developing country is much shorter than that of people in a developed country. The life expectancy at birth is 52 years in Bangladesh versus 78 years in Switzerland. On the human scale, the difference is enormous.

TABLE II

LIFE EXPECTANCY AT BIRTH
(YEARS, 1991)

BANGLADESH	52	JAPAN	79
BOLIVIA	60	SWITZERLAND	78
ETHIOPIA	48	USA	76

Source: World Bank, "World Development Report 1992," Oxford University Press, 1992

Of course, people do not live as long in developing countries as in developed countries because in the former they are not as well fed and do not enjoy the same health care as in the latter. The deficiency in nutrition is illustrated by the data in Table III. For example, the caloric intake in Ethiopia is one half that in Japan.

TABLE III

DAILY CALORIC SUPPLY PER CAPITA
(1989)

BANGLADESH	2021	JAPAN	2956
BOLIVIA	1916	SWITZERLAND	3562
ETHIOPIA	1667	USA	3671

Source: World Bank, "World Development Report 1992," Oxford University Press, 1992

The deficiency in health care is illustrated by the data in Tables IV and V which present statistics of population per physician and population per nursing person in each of the six countries under discussion. It is clear from these statistics that health care in developing countries is much less than in developed countries. For example, there are almost 80,000 persons per physician in Ethiopia versus only 470 in the United States. Again, there are about 5400 persons per nursing person in Ethiopia versus only 70 in the United States.

TABLE IV

POPULATION PER PHYSICIAN
(1984)

BANGLADESH	6,390	JAPAN	660
BOLIVIA	1,530	SWITZERLAND	700
ETHIOPIA	78,780	USA	470

Source: World Bank, "World Development Report 1992,"
Oxford University Press, 1992

TABLE V

POPULATION PER NURSING PERSON
(1984)

BANGLADESH	8,530	JAPAN	180
BOLIVIA	2,470	SWITZERLAND	270
ETHIOPIA	5,390	USA	70

Source: World Bank, "World Development Report 1992,"
Oxford University Press, 1992

People do not only live longer and healthier lives in developed countries than in developing countries. They enjoy also more extensive formal training. This point is illustrated by the statistics in Table VI, especially by the comparisons of the percentages of the age groups that go to secondary schools, and to tertiary schools (colleges and universities). For example, only 4 percent of the relevant age group goes to college in Bangladesh versus 63 percent in the United States. A country must be very productive in order to afford the large investments required to have young people in school for almost a quarter of their lives. To be sure, these investments eventually provide a handsome social and economic return. Nevertheless, they cannot be out of step with the development of the country.

TABLE VI

EDUCATION (1989)
(PERCENT OF AGE GROUP)

	SCHOOL		
	PRIMARY	SECONDARY	TERTIARY
BANGLADESH	70	17	4
BOLIVIA	81	34	23
ETHIOPIA	38	15	1
JAPAN	100	96	31
SWITZERLAND	87	37	26
USA	100	100	63

Source: World Bank, "World Development Report 1992," Oxford University Press, 1992

There are many other important and desirable humanitarian features that correlate well with the GNP/CAP; that is, the larger is the GNP/CAP, the better the human needs are met.

An essential and unavoidable ingredient of a large GNP/CAP is energy consumption. This fact is clearly illustrated by the 1990 statistics listed in Table VII. The data show that the less developed the country the less the energy consumption per capita and, conversely, the more developed the country the more the energy consumption per capita. In 1990, the consumption of energy per capita measured in kilograms of oil equivalent was 20 in Ethiopia versus 7822 in the United States.

TABLE VII

1990 ENERGY CONSUMPTION PER CAPITA
(kG OIL EQUIVALENT)

BANGLADESH	57	JAPAN	3,563
BOLIVIA	257	SWITZERLAND	3,902
ETHIOPIA	20	USA	7,822

Source: World Bank, "World Development Report 1992," Oxford University Press, 1992

The large discrepancy in energy consumption per capita between developing and developed countries is not restricted only to the six countries selected for comparisons in Tables I to VII. It is universally valid, and is illustrated by the numerical data in Table VIII and the equivalent graph in Figure 1. Here, the World Bank has classified the countries of the world into four categories using as criterion the 1990 GNP/CAP. The categories are: low (less than $600), middle (between $600 and $6000), high (greater than $6000), and other. In each category, both energy consumption per capita and total population are reported. From both the table and the figure, it is abundantly clear that the greater the GNP/CAP the larger the energy consumption per capita. For a given GNP/CAP, energy consumption per capita may vary from developed country to developed country, such as the variation between Japan and the United States (see Table VII). However, no example exists of a country that consumes as little energy per capita as a low or even a middle GNP/CAP country and yet has no unmet humane needs.

TABLE VIII

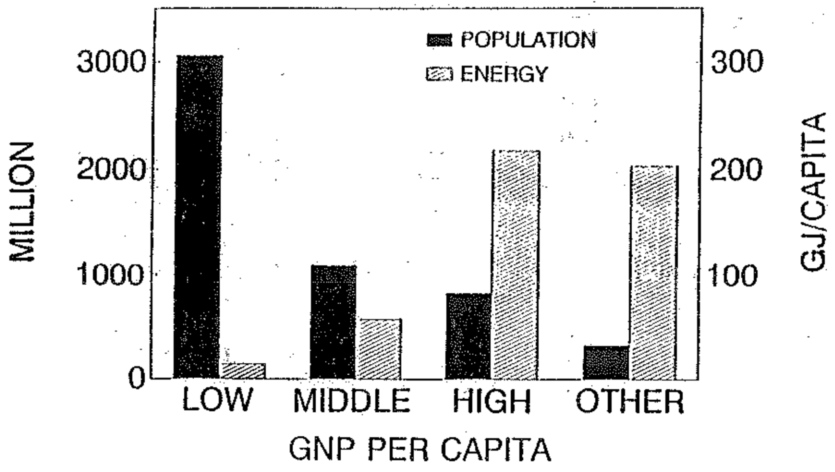
ENERGY CONSUMPTION (1990)

GNP/CAP	POPULATION MILLION	ENERGY GJ/CAP
LOW	3058	14.3
MIDDLE	1088	57.1
HIGH	816	218.0
OTHER	321	203.0

Source: World Bank, "World Development Report 1992," Oxford University Press, 1992

FIGURE 1

1990



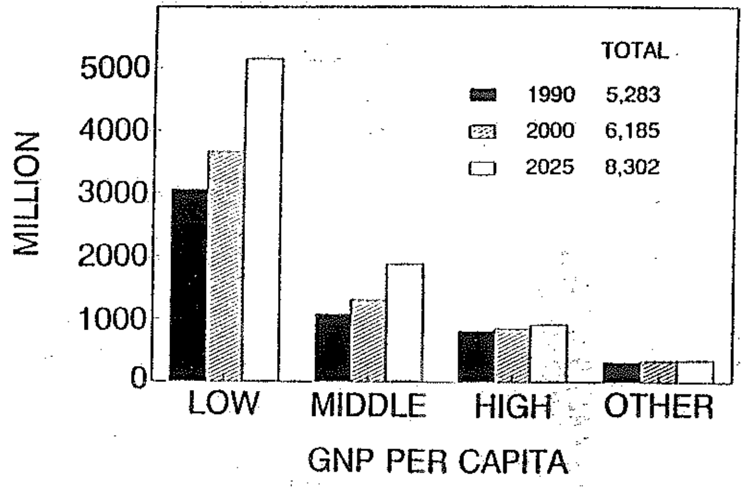
Source: World Bank, "World Development Report 1992," Oxford University Press, 1992

What is even more striking are the numbers of people that belong to each of the three main categories. In 1990, about three fifths of the population of the earth, that is, about 3 billion people, had a GNP/CAP less than $600, and consumed energy at the rate of about 14 gigajoules per capita, whereas about one third that many people had a high GNP/CAP and consumed energy at a rate about 15 times larger. These large differences between number of people and GNP/CAP of low income countries and the corresponding amounts of developed nations are among the most serious issues that humanity must face in the foreseeable future.

The differences become even more alarming if we look at forecasts of population growth over the next few decades. These forecasts are summarized in Figure 2. Over the next three decades, the world population is anticipated to increase by about 60 percent, and this increase will occur in the low and middle GNP/CAP countries. To be sure, forecasts do not necessarily coincide with what actually happens in the future. Nevertheless, it is disconcerting to note that to date all past forecasts of population growth have been underestimates.

FIGURE 2

POPULATION FORECASTS



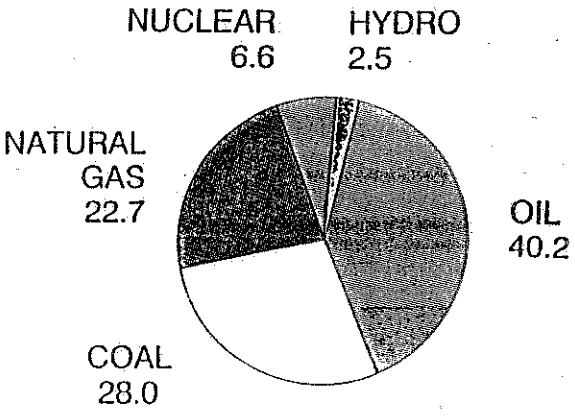
Source: World Bank, "World Development Report 1992," Oxford University Press, 1992

The differences are an illustration of the conflict that exists between the damaged relationship of humanity with its environment and the sobering list of unmet needs. In industrialized nations, the economic activity is high but the effects on the earthly environment are not sustainable. In developing nations, the economic activity is low and not so burdensome on the earthly environment but the conditions of life are inhumane and unbearable. I do not feel confident and competent to enumerate all the steps necessary to ameliorate the conflict. Instead, I would like to concentrate on energy production and energy consumption which are close to our professional expertise.

In 1991, over 90 percent of the world consumption of primary energy was accounted for by combustible fuels (Figure 3) such as oil (40.2%), coal (28%), and natural gas (22.7%). The remainder was provided by nuclear energy (6.6%), and hydroelectricity — solar energy (2.5%).

FIGURE 3

WORLD CONSUMPTION OF
PRIMARY ENERGY (PERCENT, 1991)

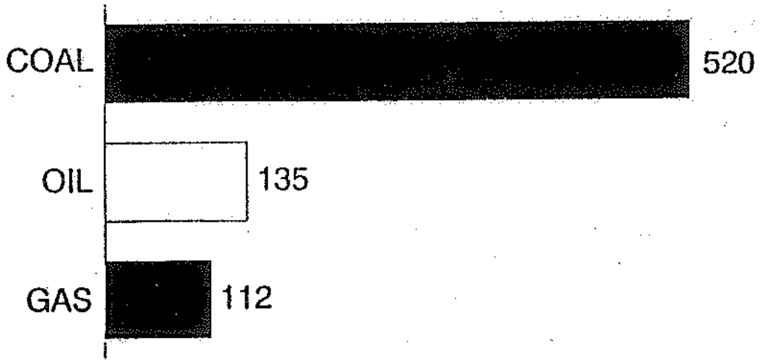


Source: British Petroleum, "Statistical Review of World Energy," 1992

Combustible fuels represent a nonrenewable source of energy. Disregarding questions of environmental pollution and climatic change, it is important to ask: "What are the remaining amounts of combustible fuels and how long will they last?" Nobody knows the answers to these questions with certainty. Different estimates are provided by different organizations. All the estimates, however, fall within the same order of magnitude. One organization that regularly publishes energy statistics is the British Petroleum Company. In 1991, the estimated remaining proved reserves are shown in Figure 4. They are expressed in billions of tons of oil equivalent (10^9 TOE). We see from this figure that we have about twice as much coal as oil and natural gas combined.

FIGURE 4

REMAINING PROVED RESERVES (1991)
(10^9 TOE)

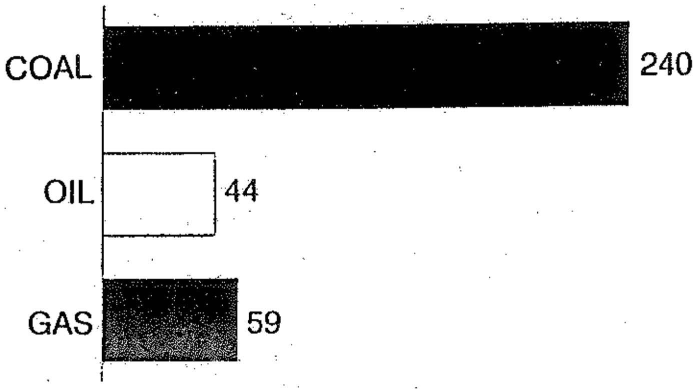


Source: British Petroleum, "Statistical Review of World Energy," 1992

At the rate at which each of the three combustible fuels was used in 1991, it is estimated that coal will last for 240 years, oil for 44 years, and natural gas for 55 years (Figure 5). For energy, a commodity of universal utility, such life spans are very short.

FIGURE 5

PROVED RESERVES/PRODUCTION RATE (1991)
(YEARS)



Source: British Petroleum, "Statistical Review of World Energy," 1992

We cannot be sure that the estimates are accurate, and that other economically affordable energy resources will not be identified in the future, thus altering the outlook for proved reserves. In the last few decades, however, no one has argued that we can expect hundreds more years of oil and natural gas, and hundreds and hundreds more years of coal. So, even though the estimates in Figure 5 are inaccurate, it is prudent to conclude that combustible fuels will become economically unavailable during the next century.

In the light of the unmet needs of low and middle GNP/CAP countries, and the estimates of population growth over the next few decades, the necessity to respond to the implications of the conclusion just cited acquires even greater urgency. During the next few generations, if the developing countries were to improve their present condition, the demand for energy will become much greater than today both because the current energy consumption per capita is very small, and because it is doubtful that the population growth will substantially decrease.

What are the challenges and opportunities in addressing the multifaceted energy issue? We have two ways to approach it and both are necessary and important: develop one or more major new energy supplies that are affordable, environmentally benign, and safe, and use energy and other resources more cost-effectively and more intelligently.

The only possible major new energy supplies are the sun, controlled nuclear fusion, nuclear fission, and hot dry rocks deep under the surface of the earth. Each of these major energy sources has its specific set of problems.

Solar energy is abundant almost everywhere around the globe, and can be captured by many methods, such as photovoltaics, wind mills, hydroelectric installations, biomass, and exploitation of thermal gradients. However, for high-quality energy production, such as generation of electricity, solar energy is prohibitively expensive — the total cost of the electricity is more than an order of magnitude larger than from other power plants. Reduction of this cost is very difficult. Solar energy arrives on the surface of the earth very diluted — it takes about 25,000 acres of land to generate the electricity produced by an average oil- or coal-fired power plant. The cost of the structures to capture and transform the insolation is very high despite the fact that the materials used for these structures are ordinary and very cheap. For example, the materials used are steel, aluminum, copper, glass, lumber, and insulation. In industrialized societies, the unit cost of each of these materials is very low, and reducing it by more than an order of magnitude is an almost impossible task.

The present limitation of solar electricity is not an argument against continued efforts to improve the technology and cost of high-quality solar energy, such as photovoltaics. We cannot afford to disregard any of our limited possibilities. I mention it to stress the difficulty of the task before us.

Controlled thermonuclear fusion holds the promise of another abundant and safe source of electricity. However, its achievement has not yet been proven in the laboratory. The first step in this proof is to reach the break-even point — the production of as much energy from fusion as is consumed to create the thermonuclear plasma. A number of experiments around the world are close to the break-even point but not there yet. It is the hope of all involved in fusion research that this milestone will be reached soon.

Even after the milestone is achieved, however, the development of a commercially viable thermonuclear fusion power plant will be an arduous and complicated task. Experts do not know even how the design will look, let alone all the problems that may arise. If all goes well, and that is a big "if," the scientists and engineers working in the field say that an affordable fusion power reactor will not be built before 50 years after the proof of scientific feasibility. Needless to remind ourselves how hard it is to make predictions about the immediate future, let alone about what might happen more than 50 years later.

Nuclear fission power plants represent the best known technology. Light water nuclear reactors supply about 75 percent of the electricity in France, about 60 percent in Belgium, about 50 percent in Sweden, over 40 percent in Taiwan, about 40 percent in Switzerland, and smaller but appreciable fractions in Bulgaria, Finland, Spain, Germany, Japan, the United States, and the republics of the ex-Soviet Union. Nuclear fission power plants are continuously under study, and many improvements in design, operation, safety, and economics are accomplished. Despite many actual and perceived shortcomings, when properly managed fission power plants continue to be less costly, more environmentally benign, and safer than any other known source of electricity, including solar electricity (see B. L. Cohen, *The Nuclear Energy Option*, Plenum Press, New York, 1990).

The last remark may be surprising. It does not mean that solar electricity is unacceptably dangerous. It simply states the fact that nuclear fission involves fewer fatal accidents per unit of electricity generated than solar electricity. The reason, of course, is the huge difference between the amounts of materials required per unit of electrical energy generated in solar versus nuclear installations. Well documented statistics exist about fatal accidents per ton of material mined, transported by one kilometer, processed, manufactured, installed, maintained, and permanently disposed. When all these accidents are accounted for, nuclear fission power plants prove to be the least harmful. Of course, the harm done by any of the known types of electric power plants is completely overshadowed by the immense benefits that society derives from the use of electricity.

The exploitation of hot dry rocks lying deep under the surface of the earth is perhaps another possible major energy source, available throughout the globe. The idea is relatively new, and its technology and commercial viability are currently under study.

The second approach to the energy issue — cost-effective energy use or rational improvement in energy-use efficiency — offers the largest opportunity of all alternatives to meet the energy requirements of a growing world. A universal one percentage point improvement in end-use efficiency, a perfectly doable short term objective, would be equivalent to discovering every five years forever a new oil supply equal to the 1990 oil proven reserves of the entire United States.

Presently, the satisfaction of the residential, commercial, transportation, and industrial energy needs of developed and developing societies is very inefficient. Correct use of all the laws of thermodynamics discloses that the average efficiency of energy utilization — the so-called second-law efficiency — is less than 20 percent in industrialized nations, and less than 10 percent in non-industrialized countries. From the engineering standpoint this is a very low efficiency, and the theoretical potential for improvement is enormous. Of course, energy end-use efficiency will never approach 100 percent. Nevertheless, the present low value underscores the opportunity for large savings. No scientific barriers exist to prevent overwhelming improvements. For example, changing the average efficiency by a factor of 2, not an unreasonable goal over the next few generations, would reduce energy consumption by one half without curtailing energy services.

Dramatic changes in efficiency are not unprecedented in the history of technology. An excellent illustration is provided by the improvement of efficiency of engines over the past two centuries (A. Bejan, *Advanced Engineering Thermodynamics*, Wiley, 1988, Figure 2.1, p. 51). In the late 1760s, engine efficiencies were less than one percent. Since that time, they have been steadily increasing. Today, the efficiency of engines manufactured by General Electric, Brown-Boveri, and other manufacturers exceeds 50 percent, and is still rising.

Many cost-effective, energy-saving technologies exist for use in space lighting, heating, and air-conditioning, in new designs of large and small vehicles, and in manufacturing processes. Examples are more luminous fluorescent lamps, 60 to 100 miles per gallon automobiles, cogenerators of heat and motive power or electricity, computerized process controls, novel uses of less energy intensive materials, and reduction and recycling of wastes.

Over the past two decades, cost-effective, energy-saving technologies have contributed large energy reductions in many countries. For example, in the United States, energy consumption per $ 1982 of industrial output has been steadily decreasing (U.S. Energy Information Administration, "Energy Conservation Indicators 1986 Annual Report," February 1988). From 1973 to 1985, the decrease was about one third or, equivalently, about 35 percent more industrial output was generated by the U.S. economy without an increase in energy consumption. It is estimated that about one half of the improvement in energy consumption per constant dollar of industrial output was due to cost effective efficiency improvements made by industry in response to higher energy prices. The other half was due to structural shifts in U.S. demand such as reduced consumption of energy-intensive products, and reduced production of energy-intensive goods — steel and automobiles. The reduced production was achieved by substituting imports for goods that were previously manufactured in the United States. The substitution was beneficent only to the extent that the exporting countries, like Germany and Japan, were more energy-efficient than the United States.

Past achievements by no means have exhausted the currently available opportunities for continued improvements in cost-effective energy utilization. In fact, the opportunities become broader and larger and more challenging when considered in conjunction with the problems created by wastes, both with respect to the environment, and the impact on resources. Waste streams are potential feedstock sources. Transforming wastes into usable feedstocks can reduce energy requirements, improve the quality of the environment, and reduce the use of natural resources.

Two more aspects of cost-effective energy use deserve special comment because they are at the frontiers of technology and science. One is the development of radically new technologies which may be even less efficient than current practices and yet save energy. An example of this concept is surface hardening of metal parts, such as gears and shafts. The current method of hardening is through heating and cooling the entire part in order to achieve the desired surface molecular structure. An alternative to this method is to use radiation which affects only a few atomic layers at the surface of the part and achieves the desired surface molecular structure. The production of radiation may be very inefficient. However, the amount of energy required to affect the structure of a few atomic layers at the surface is many orders of magnitude smaller than the energy required to heat-treat the entire part. So the loss in efficiency may be overshadowed by the reduction of the required amount of energy.

The other aspect of cost-effective energy use refers to our understanding of the foundations of thermodynamics. As it is very well known, the reason processes are inefficient is the spontaneous increase of entropy, that is, the generation of entropy by irreversibility. This generation is a time-dependent phenomenon, and yet we do not know the complete equation of motion of physics that describes this generation. Neither the equation of motion of classical mechanics — Newton's equation — nor the equation of motion of conventional quantum mechanics — either the Schroedinger or the von Neumann equation — describes all known reversible phenomena of thermodynamics, let alone any of the irreversible phenomena. The discovery of the complete equation of motion that describes all physical phenomena — zero entropy and nonzero entropy physics — remains a subject of research at the frontier of science — one of the most challenging and intriguing problems in physics. Some progress has been made (G. P. Beretta, E. P. Gyftopoulos, J. L. Park, and G. N. Hatsopoulos, "Quantum Thermodynamics: A New Equation of Motion for a Single Constituent of Matter," *Il Nuovo Cimento*, 82B, 2, pp. 169-191, 1984; and G. P. Beretta, E. P. Gyftopoulos, and J. L. Park, "Quantum Thermodynamics: A New Equation of Motion for a General Quantum System," *Il Nuovo Cimento*, 87B, 1, pp. 77-97, 1985), but more fundamental work needs to be done.

History teaches us that if we are successful in understanding and explaining the foundations of the dynamic phenomena of thermodynamics, we will be better guided in developing applications that are closer to reversible and, therefore, less burdensome to our natural resources and earthly environment.