ENERGY FOR A SUSTAINABLE WORLD

An End-Use Energy Strategy in the Global Context

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SUMMARY

If the energy problem is approached not as the challenge of expanding supplies but as one of providing energy services in cost-effective ways, it is possible to identify long term global energy strategies consistent with and supportive of solutions to other important global problems with strong links to energy. Because of ongoing structural shifts to less energy-intensive activities in industrial economies and opportunities for more efficient use of energy in industrialized and developing countries alike, it appears to be both technically and economically feasible to evolve a much more prosperous world over the next several decades with about the same level of global energy use as today. This implies that the availability of energy need not be a constraint either on the development of developing countries or on the continued prosperity of already industrialized countries. Also, much flexibility in energy supply planning is gained when demand is not too large; it thereby becomes possible to avoid many serious problems posed by heavy dependence on oil, fossil fuels generally, and nuclear power (1).

THE IMPLICATIONS OF CONVENTIONAL ENERGY PROJECTIONS

Most well-known projections indicate that 40 to 50 years from now the rate of global energy use will be some 2 to 4 times the 1980 level of 10 TW*, when allowance is made for both a substantial increase in standard of living and for an approximate doubling of the global population (see Figure 1). If these energy projections were realized, the result would be a serious aggravation of other global problems (2).

Because of high costs, energy supply expansion would divert major economic resources from other productive activities, as is already taking place. In the US, for example, capital expenditures on energy supply increased from $68 billion in 1973 to $125 billion** in 1982 -- i.e., from 26 to 39 percent of all new plant and equipment expenditures, with essentially no net increase in domestic energy production in this period. The effort to increase energy supplies is taking an even heavier toll in developing countries, which are being forced to spend a rapidly increasing fraction of GDP on domestic energy production (3). Also, on average, low and middle income oil-importing developing countries spent in 1981 61% and 37% of their export earnings on oil imports, respectively (4). In looking to the future, the World Bank has estimated that, in order to achieve a targeted increase in average per capita use of commercial energy from 0.54 to 0.78 kW between 1980 and 1995, investment in energy supplies for all

* Here 1 TW = 10^{12} Watts, an abbreviation for TW-years/year (equal to 31.5 EJ per year), is the unit used in this paper as a measure of global energy use rates. Similarly, per capita energy use rates are expressed in terms of kW, an abbreviation for kW-years/year.

** All costs in this paper are expressed in 1982 US dollars.

developing countries would have to average some $130 billion a year between 1982 and 1992. Half of this would have to come from foreign exchange earnings, requiring an average increase of 15% per year in real foreign exchange allocations to energy supply expansion (3). The Bank has also projected that between 1980 and 1995 oil imports by oil-importing developing countries would have to increase by 1/3, to nearly 8 million barrels per day (3). The staggering costs of providing these energy supplies would lead many to believe (but rarely to state) that it is not feasible to improve living standards substantially in developing countries.

The increased oil demand associated with these energy projections would make the current oil glut ephemeral. The US Department of Energy, for example, projected in 1983 that the world oil price will increase from $34 per barrel in 1982 to some $55 to $111 per barrel in 2010, associated with a 13 to 24% increase in non-Communist world oil demand in this period (5). Most of the projected net increase in demand would be met via an increase in OPEC production to nearly the 1979 level, when tight market conditions made possible the second world oil shock, with the outbreak of the Iranian Revolution. With even modest growth in world oil demand, a shift of oil power back to OPEC in this time frame would be inevitable, as more than half of the world's remaining oil resources outside the centrally planned economies lie in the Middle East/North African (ME/NAf) region, while the remaining resources in the rest of the world amount to only about a 40 years supply, at current consumption rates there (6).

The major shift to coal envisaged in most global energy projections would lead to climatic change associated with the "greenhouse effect," due to buildup in the atmosphere of carbon dioxide from fossil fuel combustion

-- with the prospect of a doubling of the carbon dioxide level and major climatic change by the latter half of the next century (7).

Most projections also involve a greatly expanded role for nuclear power. While in many parts of the world the reactor safety and radioactive waste problems posed by nuclear power have been a source of public controversy, these problems are amenable to technical fixes, at least in principle. An indissoluble link between nuclear weapons and nuclear power poses a more fundamental challenge. This link arises from the fact that plutonium, a nuclear weapons-usable material, is produced in large quantities in nuclear power reactors. If nuclear power were expanded to high levels, the recovery of plutonium from spent reactor fuel for recycling in fresh fuel would be inevitable -- and the likelihood of diversions of plutonium to weapons use would increase enormously. If a non-nuclear weapons state acquires plutonium recycle technology, it obtains nearly all the technology and materials needed to make nuclear weapons quickly, _without ever having to make an explicit decision to acquire nuclear weapons._ This route to nuclear weapons, which has come to be called "latent proliferation" (8), is particularly difficult to prevent, involving low risk to the would-be proliferator. An indication of the magnitude of the problem is that, at the level of nuclear power projected for the year 2030 in the 1981 energy study of the International Institute for Applied Systems Analysis (IIASA), some 2600 to 4400 GW(e) of installed nuclear generating capacity (9), there would be some 2.6 to 4.2 million kg of plutonium circulating _each year_ in global commerce -- enough to make some 1/2 million nuclear weapons. It is difficult to imagine international institutions capable of adequately safeguarding essentially 100% of this material against occasional diversions to nuclear weapons purposes.

APPLYING THE END-USE APPROACH TO THE LONG TERM ENERGY PROBLEM

The energy-related problems we have described above suggest a gloomy global outlook for the long term. The problem, however, may lie with the way projections are made and not with any inherent problems associated with providing for human energy needs.

Many long-term energy projections are derived by relating aggregated energy use variables to highly aggregated measures of economic activity and to average energy prices via historically determined correlations. This type of analysis may be adequate for looking to the future in a trouble-free world where only slow, continuous changes take place, but it is inadequate for understanding important dimensions of the energy problem when the energy system is being or could be perturbed in significant ways. It seems that a fundamental reexamination is needed of the methodologies used in making energy projections and their role in energy planning.

We adopt the obvious point of departure that the use of energy is not an end in itself. Energy is useful only insofar as it provides energy services like heating, lighting, cooking, refrigeration, mechanical work, etc., in ways that improve the overall quality of life.

The production and consumption of energy inevitably affect broad societal goals of economic efficiency, equity, environmental soundness, human welfare in the long term, and peace. If feasible, it would certainly be desirable to pursue energy strategies that are consistent with or even supportive of such goals, which are in essence the goals needed to bring about a sustainable society.

In the rest of this paper we present an alternative long range perspective on global energy, in which we examine the detailed patterns of energy end-use and explore the feasibility of modifying the evolution of the energy end-use system in ways that would be supportive of the pursuit of such goals. Our findings, some of which we report here, lead us to be optimistic that it is feasible to evolve long run global energy strategies that are consistent with the achievement of a sustainable world society.

We have been able to identify feasible energy outcomes far outside the range normally considered in making long term energy projections (see Figure 1), because the end-use approach facilitates the discovery of problems, trends, and opportunities that are obscured in analyses of the energy problem based on highly aggregated descriptors of the energy system. The end-use approach is useful in understanding better both the activities underlying energy use patterns and the opportunities for energy productivity improvement associated with these activities.

THE ACTIVITIES UNDERLYING ENERGY USE

Two of the most useful applications of the end-use approach have been in understanding the extent to which energy planning is being and can be effective in supporting development goals in developing countries and in understanding ongoing shifts away from energy-intensive activities in industrialized countries.

Energy and Development

Energy for Meeting Basic Human Needs: In the 1950s, when development strategies were first being articulated, it was generally felt that maximizing economic growth was the best way to eradicate poverty; but the the benefits of rapid economic growth have not trickled down to the poor to alleviate their plight. While rapid growth is a necessary condition for successful development, it is not sufficient. A more effective way of dealing with poverty is by allocating resources to the satisfaction of basic human needs, with emphasis on the needs of the poorest -- thereby ensuring that minimum standards for nutrition, shelter, clothing, health, and education are met (10). There is no empirical evidence that targetting the satisfaction of basic human needs would lead to slower economic growth (11), and even theoretical grounds for believing that a basic human needs policy leads to higher growth because of the resulting increase in worker productivity (12).

The allocation of sufficient energy to basic needs programs to ensure that the various needs are satisfied is therefore of crucial importance in energy planning.

Energy and Employment Generation: Employment generation is a development challenge closely related to the eradication of poverty. Because technologies used for industrialization today are far more labor-saving than the technologies which were used at the similar stage of development in now industrialized economies, the challenge is daunting. While there is no going back to the primitive industrial technologies of yesteryear, it is desirable to pursue those development strategies most capable of providing employment, which has acquired the status of a basic human need. Energy is a key factor in addressing this problem, as energy and labor tend to be substitutable inputs for industrial activity (13). The importance of employment generation has major implications for both the industrial mix and the choice of technologies for a given mix, both of which are often shaped by public policies. While in countries where labor is cheap, overall production costs could often be lower if labor-intensive technologies and industries are emphasized, planners are often tempted to use subsidies to attract large scale, energy-intensive industries that provide little direct or indirect employment.

Non-Commercial Energy: While there is poverty in urban slums, most of the poor live in rural areas, and a signficant fraction live outside the market economy. The importance of rural poverty reflects a population distribution between rural and urban areas very different from that in industrialized countries. In the latter only 30% of the population live in rural areas, whereas 70% live in rural areas in developing countries (4).

In rural areas people are largely dependent for energy on biomass -- mainly fuelwood, used mostly for cooking. But in parts of the developing world fuelwood demand is exceeding the rate of fuelwood regeneration via photosynthesis. Some 100 million human beings now suffer acute scarcity of fuelwood; about 1 billion a deficit (14). Fuelwood-gathering involves many hours of drudgery each day, particularly for women and children. The ecological effects of deforestation created by excessive fuelwood use are amplifying this human toil.

The vast scale of rural poverty, the weakness of market forces in being able to deal with it, and the central importance of cooking and its relation to the fuelwood crisis are all factors that must figure prominently in energy planning efforts.

Decentralized as Well as Centralized Energy: Inadequate attention to the problems of rural areas is causing the rural poor to flee to urban slums, which offer at least access to some services that are completely unavailable in rural areas. Because of the urban migration, the urban population in developing countries has been growing more than twice as fast as the population as a whole (4). The urbanization trend is becoming increasingly unmanageable, however, as the crowded and polluted cities are unable to offer enough jobs to support the number of job seekers. Urban migration could be slowed and the cities made more livable thereby if living conditions were improved in rural areas. In particular, rural-based, labor-intensive industries are needed. Providing the energy needed for such industries requires an emphasis in energy planning in which centralized energy production, which is essential for meeting urban energy needs, is complemented by decentralized energy production in rural areas, where it is often uneconomic or otherwise impractical to provide energy services from centralized sources. To this end biomass used renewably is a promising feedstock for providing solid, gaseous, or liquid energy carriers or for making electricity for many rural areas in small-scale operations.

It would be highly fortuitous if significant contributions to meeting development goals resulted from conventional energy planning, which involves mainly the engineering challenge of expanding conventional, centralized energy supplies to the extent suggested by energy/GDP correlations. Just as the trickle down approach to economic development has failed to improve the lot of the poor, we fear that an energy trickle-down approach to energy development is likely mainly to expand the energy services available to the affluent, while leaving the poor little or no better off.

To be supportive of development efforts, energy planning in developing countries must emphasize the provision of energy for the satisfaction of basic human needs, employment generation, cooking, and the general problems of rural areas, seeking an appropriate balance between centralized and decentralized energy sources.

Energy Implications of Post-Industrial Trends in Industrialized Countries

Production in the industrialized market economies is characterized both by an ongoing shift from goods to services and by a shift within the goods-producing sector from the processing of basic materials to fabrication and finishing activities.

The Shift to Services: The more familiar of these two structural changes is the growing importance of services (e.g., finance, insurance, education, communications, and marketing, information, medical and recreational services), which has been going on for decades (15). This shift has been reflected in slower growth of goods production than of GNP; for example, the output of the goods-producing sector [measured by gross product originating (GPO), or value-added] grew just 0.83 and 0.60 times as fast as GNP in the period 1970 to 1980 for the US and Sweden, respectively (1).

The Growing Importance of Fabrication and Finishing: Much less known is the on-going shift within the goods-producing sector from the processing of basic materials (in the petroleum refining; primary metals; chemicals; paper; stone, clay, and glass; and food industries) to fabrication and finishing.

The declining importance of several basic materials as contributors to economic growth has been identified in an analysis of future energy use in Sweden (16). In an analysis of the long-term history and future outlook for a representative sampling of basic materials in the US and some other industrialized market economies, strong evidence was found of saturation in consumption, expressed in kg per capita, as shown in Figure 2 (17). For both traditional materials (steel, cement, paper) and modern materials (aluminum, ethylene, ammonia, chlorine) per capita consumption stopped growing in the US in the 1970s and in most cases actually began to decline. Similar trends were found for steel, cement, and aluminum in France, W. Germany, Sweden, and the U.K. The trends appear to be due to a combination of factors including more efficient use of materials in providing essentially the same materials services, materials substitution, and market saturation. In all cases, the outlook for volume growth in consumption was found to be poor, in large part because of market saturation. Only markets for high value-added, specialty products appear to be promising. On balance, it is unclear at this time whether such growth will be adequate to offset the ongoing declines in markets for high-volume bulk products, but the evidence for at least saturation is strong.

The ongoing shift from basic materials, like the shift to services, implies a reduction in the amount of energy required to produce a unit of GDP. In US manufacturing, the basic materials processing industries in 1978 accounted for 87% of final energy use but only 32% of value added; for Sweden the figures were 92% and 51%, respectively. Thus shifts to fabrication and finishing, which typically require an order of magnitude less energy per unit of output, can have a profound effect on industrial energy use. For the US, such shifts accounted for an annual rate of decline in industrial energy use of 1.0 percent per year, 1973-1982, relative to the situation where there would have been no such shifts (18).

OPPORTUNITIES FOR ENERGY PRODUCTIVITY IMPROVEMENT

Technological opportunities for improving the productivity of energy use are also important in decoupling energy and economic growth, for industrialized and developing countries alike.

Industrialized Countries

The energy price increases of the 1970s have led to new energy-using technologies that are much more energy-efficient than those now in wide use and to major R&D efforts that will lead to even more efficient technologies in years to come. Opportunities exist for large improvements in energy productivity for all major energy-intensive activities. A full discussion of the opportunities in all energy-using sectors is presented in (1). Here we illustrate the possibilities for residential space heating, the automobile, and steel-making -- activities which account for about 30 and 40 percent of total final energy use, respectively, in the US and Sweden. In each of these areas, as in many others, the potential for reducing energy use via cost-effective investments in energy efficiency improvement is far greater than most people realize.

Residential Space Heating: For space heating, higher energy productivity can be achieved via improvements both in the building shell and in the heating equipment. Table 1 lists heating requirements corrected for floor area and climate for various groups of houses in the US and Sweden. The most energy-efficient units shown require an order of magnitude less heat than typical houses in the existing stock! While one would expect the very energy-efficient houses to be quite expensive, there is a growing body of evidence suggesting that the net extra cost of a very energy-efficient house may not be very large, because of synergisms whereby the added costs of shell improvement may be offset to a considerable degree by savings in the initial costs of the heat generation and distribution systems [see, e.g., (19) and note (j), Table 1].

The efficiencies of space heating equipment can also be much improved (19). For gas furnaces, conversion efficiencies have increased in the US from an average of about 69% for new units in 1980 to more than 90% for new condensing furnaces. Similarly, heat pumps with coefficient of performance (COP) up to 2.5 for air-to-air units and up to 3 for water-to-air or water-to-water units have also become available on the market, compared to an average COP of less than 2 for heat pumps and 1 or less for resistive heating units in the existing US stock.

Efficient heating systems installed in existing houses, together with building shell improvements, could lead to cost-effective fuel savings of some 50 percent on average, with presently commercial technology (19). Such retrofits could affect the entire existing building stock in 30-40 years.

<u>The Automobile:</u> There are opportunities to improve the fuel economy of automobiles from the present global average level of about 13 liters/100 km (18 mpg) to the range 4 to 2.3 l/100 km (60 to 100 mpg), both by increasing engine/drive train efficiency and by reducing vehicle weight and aerodynamic and rolling resistances. The technical possibilities with already commercial cars, prototypes, and advanced designs are indicated in Table 2.

One concern which has been raised about super-mpg cars is their safety. That a light-weight car need not be unsafe, however, is indicated by the safety features built into Volvo's LCP 2000 (20,21). Moreover, a light-weight design may not be needed to achieve high fuel economy. Researchers at the Cummins Engine Company and the NASA Lewis Research Center have described the design of a heavy super-mpg car [see (22) and Table 2].

Another concern is the air pollution from diesel engines. One solution is spark-assisted versions of diesel engines (e.g., the

Cummins/Lewis car) designed to use a wide range of fuels, including gasoline or methanol, without loss of efficiency.

Steel Industry: The thermodynamic minimum amount of energy required to produce a tonne of steel is 7 GJ from iron ore (23) and 0.7 GJ from scrap. At present, steel-making in Sweden and the US is based on a 50/50 mix of iron ore and scrap, so that the thermodynamic minimum is about 3.9 GJ per tonne of raw steel. For comparison, the actual energy used to produce raw steel was 27 GJ per tonne in the US in 1979 and 22 GJ per tonne in Sweden in 1976, where the evaluations are done on a comparable basis.

The large potential for practical energy productivity increases in steel production is illustrated with iron-making processes now under development in Sweden -- Plasmasmelt and Elred. Energy requirements are 8.7 GJ/tonne (of which 4.2 GJ is electricity) for Plasmasmelt and 11.9 GJ/tonne (1.3 GJ electricity) for Elred (16). Other promising advanced processes that attempt to integrate currently separate operations to save on capital, labor, and energy costs include direct reduction of iron, direct casting, direct steel-making, and dry steel-making (24).

The opportunities for process improvement in the steel industry are typical of the prospects in many industries (1,24). While the objective of such process innovation is not to reduce energy use *per se*, but to minimize the total cost of production, the history of modern industry shows that new processes are most likely to be able to overcome the resistance to technical change and displace existing processes if they offer opportunities for *simultaneous* improvements in several factors of production -- reduced labor, capital, materials, and energy requirements (25). This has been such a powerful phenomenon that energy requirements have often been reduced via technological innovation even during periods of declining energy prices.

Developing Countries

The Modern Sector: Most of the opportunities for more efficient energy use relevant to industrialized countries are relevant to the modern sectors of developing countries as well -- in buildings (except for space heating, which is not needed in most areas), transportation, and industry. Such opportunities may often be even more attractive to developing countries, for the following reasons.

First, capital generally tends to be scarcer in developing countries. While energy efficiency improvements usually require increased investment at the point of end-use, the required investments are often less than the investments in an equivalent amount of new energy supply, so that total capital requirements are reduced via investments in energy efficiency.

Second, the severe strain on export earnings in developing countries caused by oil import bills provides a powerful incentive to reduce oil import requirements and thereby become more self-reliant. Energy efficiency improvement (e.g., for cars and trucks) can be an especially cost-effective way of doing this.

Third, the potential for major growth in energy-intensive activities (e.g., the processing of basic materials) is a condition conducive to major process and product innovations. In the new era of high cost energy, technologies introduced to reduce total cost will often be far more energy-efficient than the corresponding technologies now in place in industrialized countries, most of which were introduced in the era of low cost energy. Because of saturated markets and thus a less favorable climate for innovation in the stagnating basic materials processing industries of industrialized countries, it could turn out that in some areas major industrial innovations will take place first in developing countries. The successful Brazilian programs (i) to shift cars from gasoline to ethanol derived from sugar cane and (ii) to produce high quality steels using charcoal derived from eucalyptus instead of coal, are existence proofs that such <u>technological leapfrogging</u> is possible.

<u>The Traditional Sector:</u> There are also major opportunites for energy efficiency improvements in the traditional sector, where fuelwood or other forms of biomass dominate energy use, mainly for cooking. The inefficiency of present woodstoves is highlighted by comparing the energy use for cooking via fuelwood stoves in developing countries today -- some 0.25 to 0.6 kW per capita [0.4 to 1.0 tonnes of wood per capita per year] -- with the corresponding rate of using LPG or natural gas for cooking in developing countries, and in Western Europe and the US as well, some 0.05 to 0.10 kW (26).

While as recently as 1983 only marginal gains were being made in stove efficiency improvement programs (27), recent successes in applying scientific principles of heat transfer and combustion to stove design, combined with standardized testing methods and production techniques, have made it possible to introduce a variety of high-efficiency, low-cost wood cooking stoves that appeal to users in a wide range of cultural contexts. With such stoves fuel requirements for cooking can be reduced by 1/3 to 1/2, and the fuel savings are complemented by other important benefits such as reduced cooking time and reduced labor requirements for fuelwood gathering (28).

Looking ahead, further improvements would be feasible if gaseous energy carriers (LPG, natural gas, biogas, or producer gas) were made available for cooking, as simple gas stoves can be 50% efficient, while even the best wood stoves have efficiencies of only 30-40%. Still further improvements would be possible via the use of advanced 70% efficient stoves that have been developed recently (29).

All such opportunities could free biomass resources for other purposes (30), such as energy for transport, agriculture and rural industry.

A GLOBAL ENERGY SCENARIO

We now construct a long-term global energy demand and supply scenario to illustrate how the end-use approach can be utilized to identify energy futures compatible with the achievement of a sustainable world.

The first step is to understand present and future needs for energy services -- requirements for cooking, lighting, domestic hot water, passenger and freight transport, basic industrial materials, etc. Fortunately, most energy use is concentrated in just a few activities in each energy-using sector (residential, commercial, transportation, and industry), so that the list of important end-use activities that must be scrutinized is readily manageable in most instances. Estimated levels of energy services associated with alternative economic development paths can be based on extrapolations of historical trends, taking into account ongoing shifts and saturation effects [as we have done for Sweden (16) and the US (31)], or departures from historical trends specified to conform to feasible societal goals (e.g., the satisfaction of basic human needs).

With energy service levels specified, the next task is to obtain estimates of the energy intensities for these service activities, i.e., the energy required per unit of service provided (e.g., kJ of kerosene per pass-km of air travel), associated with the cost-effective ways of providing these services. Here consideration is given both to potential improvements in energy efficiency and to the use of alternative energy carriers.

With these assumptions, future aggregate demand estimates are obtained by summing (over all activities) the products of the activity levels for energy services and the corresponding energy intensities. Then the demand levels so obtained can be matched to estimated available energy supplies.

Because of resource, climatic and cultural variations from one country and region to another, a comprehensive perspective on future energy demand/supply should be constructed "from the bottom up," with an aggregation of country studies into regional studies, which are then aggregated into a global picture. While to date detailed country studies and end-use strategies have been developed for only a few countries (32), it is nevertheless feasible to formulate a preliminary global perspective.

In constructing a global energy scenario we focus on the year 2020. By this time: (i) it would be feasible both to satisfy basic human needs and to bring about considerable additional improvements in living standards in developing countries; and (ii) there would be time for the widespread adoption of improved energy-using technologies. Yet 2020 is sufficiently close that it has an important bearing on long-range energy planning today.

A Global Energy Demand Scenario

Future Per Capita Energy Demand in Industrialized Countries: Our analysis of both ongoing structural changes in the economy and major opportunities for energy efficiency improvement for two countries, Sweden (16) and the US (31), indicates that a large reduction in the energy intensity of economic activity is feasible. Specifically, we have found that in the time frame of interest, it would be technically and economically feasible to reduce final energy use: for Sweden, from 5.4 kW in 1975 to 2.8 (3.3) kW, and for the US from 9.0 kW in 1980 to 4.0 (4.4) kW, along with a 50% (100%) increase in per capita GDP.

In light of the broad applicability of both the ongoing structural changes in these two countries and the technologies involved in these analyses, we believe it would be feasible to achieve comparable reductions in energy use associated with comparable increases in GDP in virtually every other industrialized country as well. We thus assume for our energy demand scenario that average per capita final energy demand in industrialized countries can be reduced in half, from 4.9 to 2.5 kW, 1980 to 2020.

Per Capita Energy Demand in Developing Countries: The challenge for energy planners in developing countries is to assure that energy services needed for satisfying basic human needs, for building infra-structure, and generally for bringing about a much higher standard of living than at present are available in affordable, environmentally sound, and sustainable ways.

To indicate how emphasis on energy efficiency improvement would facilitate the achievement of these goals, we present in Table 3 an energy budget for a hypothetical future developing country with an activities mix similar to that for Western Europe* in the 1970s (excluding space heating, which is not needed in most developing countries) but matched to much more efficient end-use technologies than those now in common use in Europe. The

* Strictly speaking, most of the data discussed here and shown in Table 3 as being characteristic of Western Europe are average values for the WE/JANZ region (Western Europe, Japan, Australia, New Zealand).

activity levels for this scenario are far in excess of present values in developing countries. For an "average" developing country to retrace a historical development path to such a state by 2020 might require per capita GDP to increase, 1975 to 2020, 10-fold (the ratio of the average per capita GDP in Western Europe to that in developing countries in 1975), or at an average annual rate of about 5 percent per year. To achieve by 2020 the indicated levels of consumption of those basic materials explicitly highlighted in Table 3 (steel, aluminum, cement, paper, nitrogen fertilizer) would require sustained per capita growth rates of 4 to 6 percent per year. These are ambitious but not inconceivable growth schedules. A number of developing countries achieved average per capita GDP growth rates of the order of 5 percent per year or more in the period 1960-1982 -- including China, Thailand, South Korea, Brazil, Yugoslavia, and Singapore (4). And in the US, per capita consumption grew at average rates in the range 5 to 10 percent per year for each of the above-mentioned basic materials during the 20 to 40 year initial rapid growth period, while per capita GDP was growing at an average rate of only about 2 percent (17).

To illustrate what can be achieved with efficiency improvements, we have multiplied these activity levels by energy intensities corresponding in energy efficiency to best available technologies on the market today or to advanced technologies that could be commercialized over a period of about a decade. The result (see Table 3) is that total final energy use per capita would be only 1.0 kW, or only slightly more than the actual 0.9 kW average final energy use rate in 1980!

It is possible to achieve such large improvements in living standards without increasing energy use in part because enormous increases in energy efficiency arise simply by shifting from traditional, inefficiently used, non-commercial fuels (which at present account for nearly half of all energy use in developing countries) to modern energy carriers, as the above comparison of cooking with fuelwood and with gaseous fuels shows clearly. The importance of modern carriers is also evident from the fact that for Western Europe in 1975 per capita final energy use for purposes other than space heating was only 2.3 kW, about 2 1/2 times that in developing countries, even though per capita GDP was 10 times as large.

In addition to the savings associated with the shift to modern energy carriers, considerable further savings can be gained by adopting more energy-efficient technologies that have recently become available. With such technologies, indicated in in Table 3 and described in detail elsewhere (1), per capita energy use would be reduced from 2.3 to 1.0 kW. Attaining such a high level of average performance in end-use technology could in principle be achieved much more quickly in a developing country than in an industrialized country. In the former there is such a large demand for new energy-using capital stock that the rate of introducing new efficient technology is not limited by the rate of turnover of the existing stock, as would be the case in industrialized countries.

The set of activities indicated by this scenario should not be construed as targets to be achieved by 2020 or any other date. The appropriate mix and levels of activities for, say 2020, may well have to be different to be consistent with overall development goals. But this analysis suggests that it is possible to provide a standard of living in developing countries anywhere along a continuum from the present one up to a level of amenities typical of Western Europe today, without departing significantly from the average energy use per capita for developing countries today.

That development goals can be achieved with little change in the overall per capita level of energy use should not obscure the challenge of bringing this about. As in the case of development generally, large amounts of capital are required to bring about a shift to modern energy carriers and to efficient end-use technology. But our analysis for a wide range of end-use technologies suggests strongly that for almost every plausible set of activity levels, it would be less costly to provide energy services using the more efficient end-use technologies than to provide the same services with conventional, less-efficient end-use technologies and more energy supplies.

On the basis of such considerations we assume for our global energy scenario an average level of per capita final energy use of 1 kW for developing countries in 2020 -- a level which, with emphasis on energy efficiency improvement and modern energy carriers, would be adequate both to ensure that basic human needs are satisfied and to allow for considerable further improvements in living standards. With per capita energy use at this level, there should be no fundamental energy constraint on development, as our energy supply analysis will show more clearly.

Total Global Energy Demand: Global final energy use in the year 2020 would be 8.8 TW, differing only slightly from the 1980 level of 8.4 TW, with the per capita energy use values indicated above and population levels of 5.71 billion and 1.24 billion for developing and industrialized countries, respectively (33). But the demand distribution would be markedly different: the per capita levels of energy use of the North and the South would converge, and developing countries would account for about 2/3 of total world energy use, up from 1/3 in 1980. Figure 3 shows our scenario in terms of primary energy use, and places it alongside the corresponding projections made by the International Institute for Advanced Systems Analysis (IIASA) (9) and the World Energy Conference (WEC) (34)*. The latter studies envisage that the increment in energy use by industrialized countries, 1980-2020, will be 1.2 to 1.5 times as large as that for developing countries in this time period; we believe a world with such disparities would suffer intolerable North/South tensions.

A Global Energy Supply Scenario

When energy demand is not too large, there is flexibility in planning the energy supply mix -- in particular, a welcome flexibility for dealing with problems associated with overdependence on fossil fuels generally, oil specifically, and nuclear power.

Of the many possible energy supply futures that can be matched to the demand patterns described above, one future, involving only very minor shifts from the present situation, is shown in Figure 4, alongside the supply projections made in the IIASA and WEC studies. The primary energy use level in 2020 for our scenario would be 11.2 TW, only slightly higher than the 1980 level of 10.3 TW, but less than half the levels projected in the IIASA and WEC energy studies.

* In a longer companion paper (48) a detailed comparison is made of the global energy scenario presented here with eight other projections of global energy use, and it is shown how the present scenario can be expressed in terms of a simple model relating energy use to incomes, energy prices, and a non-price-induced energy efficiency improvement rate.

The construction of our energy supply mix begins with the assumption that that the overall level of fossil fuel use in 2020 is the same as in 1980, with the mix of oil, natural gas, and coal adjusted to reflect considerations of the atmospheric carbon dioxide build-up from the burning of fossil fuels, global security and the world oil price, and the relative abundances of oil and gas resources. Biomass is considered the "swing fuel," providing solid, liquid, and gaseous fuels needed in excess of what is provided by fossil fuels.

Electricity's share of global final energy demand would increase from 10% in 1980 to 18% in 2020, reflecting a continuation of the ongoing electrification of the global energy economy. Despite this emphasis, requirements for new electricity supply would grow far more slowly (1.6% per year on average, 1980-2020) than in most government and industry forecasts -- so that there would still be considerable flexibility in putting together an electricity supply mix. With proliferation-related constraints on nuclear power, an expansion of hydropower, and a contribution from cogeneration comparable to that from nuclear power, there would be no need to expand fossil-fuel-based central station power generation beyond the present level.

In what follows we describe how considerations of various supply constraints motivated the supply mix we have chosen to illustrate the flexibility gained with relatively low energy demand levels.

<u>Atmospheric Carbon Dioxide and the Burning of Fossil Fuels:</u> The need to adjust to a dramatically changed global climate in less than a century could be greatly reduced by reducing dependence on fossil fuels. Such efforts must focus on coal. While using <u>all</u> the remaining ultimately

recoverable oil and gas resources would lead to an atmospheric carbon dioxide level of 440 ppm, or nearly 1.5 times the pre-industrial level, using half of the remaining 9 trillion tonnes of coal resources would increase the CO2 level to four times the pre-industrial level.

We have modeled future levels of fossil fuel use by assuming that: (i) half of the released carbon dioxide remains in the atmosphere; (ii) all estimated ultimately recoverable oil and gas resources are eventually used; and (iii) coal production falls exponentially over time. The one free parameter then is the rate of exponential decline, which depends on the ultimate CO2 ceiling level. If the ceiling were as low as 1.5 times the pre-industrial level, coal must be phased out very rapidly, falling to 1/2 the present level before the turn of the century -- which is not a practical target. We assume instead a ceiling of 1.7, which implies that coal use would have to decline only 20%, 1980-2020. Coal use in 2020 with this scenario would be only 0.2 to 0.4 times as large as the levels projected in the IIASA and WEC scenarios (see Figure 4).

<u>The World Oil Problem:</u> In light of the facts that there is about as much recoverable gas left in the world as oil, and the present rate of gas use is only 2/5 that for oil (see Figure 4), we assume a shift to gas to the extent that by 2020 gas and oil production rates become equal (see Figure 4). Global oil use would be reduced thereby from 59 to 46 million barrels per day, 1980-2020. At this demand level there would probably be adequate oil supplies available outside the ME/NAf region at production costs less than $30 per barrel (1982 $) to sustain dependence on the ME/NAf region at the 1983 glut level of 15 million barrels per day (35). This scenario would provide a hopeful outlook for oil-related global security problems

and perhaps stable oil prices for the entire period till 2020.

The Nuclear Weapons/Nuclear Power Link If nuclear power growth were sufficiently slow that the economic incentive to pursue plutonium recycle remained low everywhere (by avoiding uranium scarcity), the risks of *latent proliferation* in non-nuclear weapons states and of merging weapons and civilian nuclear power programs in weapons states could be greatly reduced.

Avoiding reprocessing and plutonium recycle technologies, though politically challenging, should in principle be much easier to accomplish today than was thought possible just a few years ago, since the economics of reprocessing and recycle are not now favorable and would become only marginally favorable at very high uranium prices (36).

Since even a ban on nuclear fuel reprocessing and plutonium recycle would not *prevent* proliferation via the clandestine recovery of plutonium from spent fuel -- the risk of which increases with the extent of world-wide nuclear power development -- it would seem desirable to go further and make nuclear power an *energy technology of last resort*, limited to those situations where viable alternative energy technologies are not available. With this perspective we assume that installed nuclear generating capacity increases from the 1980 level of 120 GW(e) to some 460 GW(e) (approximately the level generally expected for the year 2000) and then levels off (see Figure 4). This implies that beyond the turn of the century the only nuclear power plants that would be built are those that would replace retired units.

Renewable Energy Resources: One way to cope with the global risks posed by over-dependence on conventional supplies would be to shift to greater dependence on renewable resources. While the costs of such resources in large amounts are far more speculative at present than the costs of more efficient end-use technology, renewables can play at least a minor role in the time frame of interest. We have singled out hydropower, windpower, photovoltaic power, and bioenergy as promising options, which we assume provide for energy needs in excess of what is provided by fossil fuels and nuclear power.

Hydropower is especially promising in developing countries, where only 7% of economical reserves have been developed (37). We assume that by 2020 the hydro share of global electricity increases from 20% in 1980 to 25% in 2020, by which time about 40% of the global economic hydro potential would be developed (37). We limit wind and photovoltaic power combined to 5% of total power production.

We assume that biomass is provided via a 50/50 mix of organic wastes and biomass grown for fuel on energy plantations or farms, and that efforts are made to use biomass energy renewably. Such efforts would be facilitated by the fact that the need for biomass, as the swing fuel, would be only slightly higher in 2020 than in 1980 (see Figure 4). But there would be an enormous increase in the useful energy services obtained from this biomass, because we have emphasized efficient biomass conversion and end-use technologies.

Supply Flexibility: We do not claim to have put together here an energy supply mix that is optimal in an economic sense or otherwise. Rather we have chosen a mix, not obviously constrained by costs or other factors, with which we hope to show that at or near present global energy demand levels plausible energy supply mixes can readily be identified that would not lead to the troublesome problems which appear to be unavoidable at higher demand levels.

IMPLEMENTATION

By focussing on ongoing and needed changes in energy end-use activities and on opportunities to make more efficient use of energy, it is possible to identify long-run energy strategies that are consistent with and even supportive of the achievement of a sustainable world society. But are such energy strategies, which differ so radically from conventional supply-oriented strategies, practically achieveable? It is unlikely that market forces can be relied upon to bring about the kind of energy future described here. Market intervention is needed both to make markets work better than they do today and to correct inherent market shortcomings (1).

In the case of developing countries, energy policies need to be closely coordinated with development policies generally, ensuring in particular that adequate energy is allocated to basic human needs programs and to rural needs -- especially for cooking, agriculture, and rural industry.

For industrialized and developing countries alike, important policies needed at the national level are: the elimination of all subsidies for energy supply; pricing policies that sensitize consumers to long run marginal costs for new energy supplies; stabilization of the world oil price seen by consumers via a variable oil tax that is adjusted with changes in the world oil price and inflation; the provision of better information to consumers about cost-effective opportunities for investments in energy efficiency; the redirection of capital toward consumer investments in energy efficiency; the regulation of energy performance for activities such as automotive fuel economy, where energy performance is readily measurable and easily understood; changes in the incentive structures for energy utilities so that they will provide energy services to their customers (via investments in energy conservation as well as supply), and not simply energy supplies; subsidies to the poor -- for the provision of energy services associated with the satisfaction of basic human needs in developing countries, and for investments in energy efficiency in industrialized countries; and support for research and development on end-use energy.

At the global level policies are needed both to provide support for national policies in developing countries of the type just outlined (support for institution building, the provision of capital, etc.), and to deal with global externalities associated with oil, the nuclear weapons/nuclear power connection, and the carbon dioxide problem.

Since each oil importer would gain from the lower world oil price that would result from the oil import reduction efforts of others, and from some coordination of internal oil prices, it may be desirable to coordinate national oil import reduction efforts with some kind of oil import reduction agreement (38). While such an agreement would lead to lower revenues for oil exporters, exporters would benefit in the long run from the resulting reduced uncertainties about future world oil demand.

To deal with the nuclear power/nuclear weapons link, a denuclearization treaty may be useful -- involving both the avoidance of nuclear fuel reprocessing technologies (on the part of nuclear weapons states as well as non-weapons states) and real commitments by the superpowers to move away from dependence on nuclear weaponry (39).

The gradual coal phase-out described here is one of the most significant policy challenges implicit in the energy strategy outlined here. The CO_2 ceiling we have assumed would require limiting coal use in the long run to about 1/4 of the amount of coal available at prices less than 1/2 the world oil price in 1982. However, coal is a dirty fuel requiring much more capital investment than either oil or gas to use in environmentally acceptable ways. The prospect of stabilizing the world oil price (and thereby natural gas prices as well) by pursuing energy efficiency improvements world-wide would make coal a much less desirable fuel than in energy futures with growing energy demand. Still, a carbon dioxide control treaty, involving perhaps agreed upon coal taxes or other control mechanisms, may be needed. The fact that nearly 90% of the world's geological coal resources lie in just three countries -- the USSR, the US, and China -- suggests that an agreement among these countries may lead to a solution of the problem.

There remain many unanswered questions as to how best to implement end-use energy strategies. But the kinds of policies most likely needed involve the coordinated use of familiar policy instruments. We do not believe that a pre-condition for bringing about what may be construed as a radical energy future is the creation of a radical new world order.

CONCLUSION

The global outlook associated with providing energy for the long term would be far more hopeful than what is implied by conventional energy projections if there is a shift in emphasis in energy planning from supply expansion to improvements at the point of energy use.

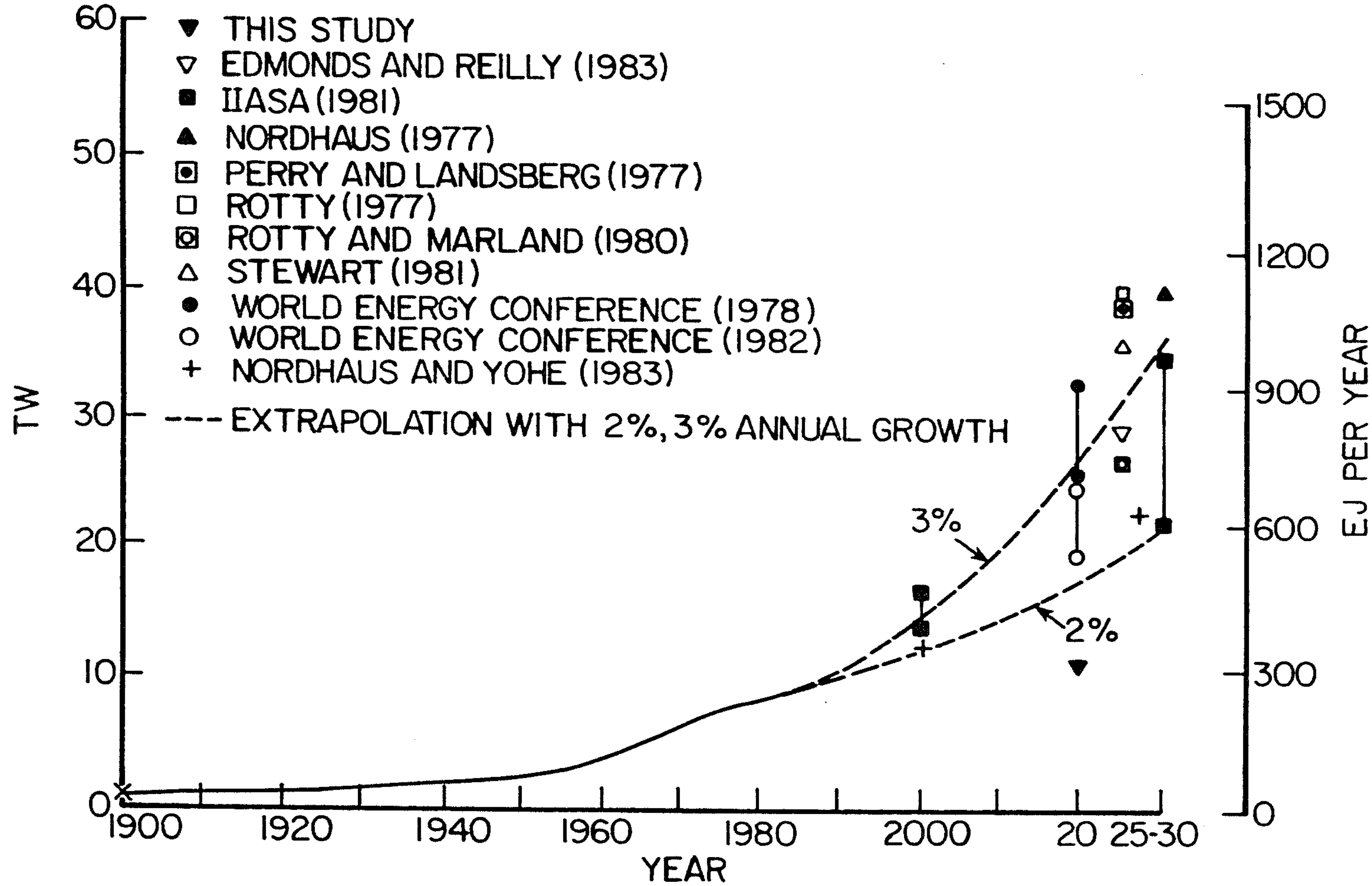
Such end-use energy strategies would lead to less expenditures for providing energy services than with supply-oriented energy strategies, freeing up economic resources for other purposes. North/South tensions would be eased because of the resulting more equitable use of global resources. It appears that with such strategies energy supply availability would not be a constraint on the development of developing countries, that basic human needs could be met, and that living standards could be increased considerably beyond the satisfaction of basic human needs in the course of the next several decades. And finally, end-use energy strategies would provide considerable flexibility in the choice of energy supplies, so as to be able to mitigate greatly the global problems posed by expanded use of oil, fossil fuels generally, and nuclear power. In short there are hopeful prospects for evolving a global energy future compatible with the achievement of a sustainable world society.

There are reasons to be optimistic that end-use energy strategies can be implemented on a wide scale. First, a good track record has already been established in decoupling energy and economic growth: between 1973 and 1982 there was no net increase in energy use in OECD countries, even though GDP increased 20 percent. Second, much more can be accomplished with existing technology. Third, the pace of technological change is swift -- indeed most of the technical opportunities upon which the major findings of the present analysis are based emerged only in the last few years, as part of a world-wide "quiet revolution" of innovation in end-use technology. And finally, while market forces acting alone will not likely lead to the kind of of energy future we have described here, we do not believe that radical, unprecedented institutional changes are needed.

Since our institutions for managing energy supply have evolved over many decades, while the energy crisis which first focussed attention on energy demand occurred but a decade ago, it is premature to make judgments as to precisely what institutional changes would be best. We should be prepared to try new approaches, learn from our mistakes, and take pride in our successes.

Figure 1.

Historical global energy use data and alternative projections. This figure is from (7), except for the additions of the 1982 World Energy Conference projection (34) and our own scenario. All other projections, except the IIASA projection (9), are listed in (40).



THIS STUDY
EDMONDS AND REILLY (1983)
IIASA (1981)
NORDHAUS (1977)
PERRY AND LANDSBERG (1977)
ROTTY (1977)
ROTTY AND MARLAND (1980)
STEWART (1981)
WORLD ENERGY CONFERENCE (1978)
WORLD ENERGY CONFERENCE (1982)
NORDHAUS AND YOHE (1983)
EXTRAPOLATION WITH 2%, 3% ANNUAL GROWTH
TW
EJ PER YEAR
YEAR
3%
2%
0
10
20
30
40
50
60
300
600
900
1200
1500
1900
1920
1940
1960
1980
2000
20
25-30

Figure 1

Figure 2.

Basic Materials Use in the U.S. From (17). The data are for apparent consumption (production plus net imports, corrected for stock changes), except in the case of ethylene, for which the data are for production. Five year year running average are plotted in all cases except for steel and cement, where ten year running averages are plotted.

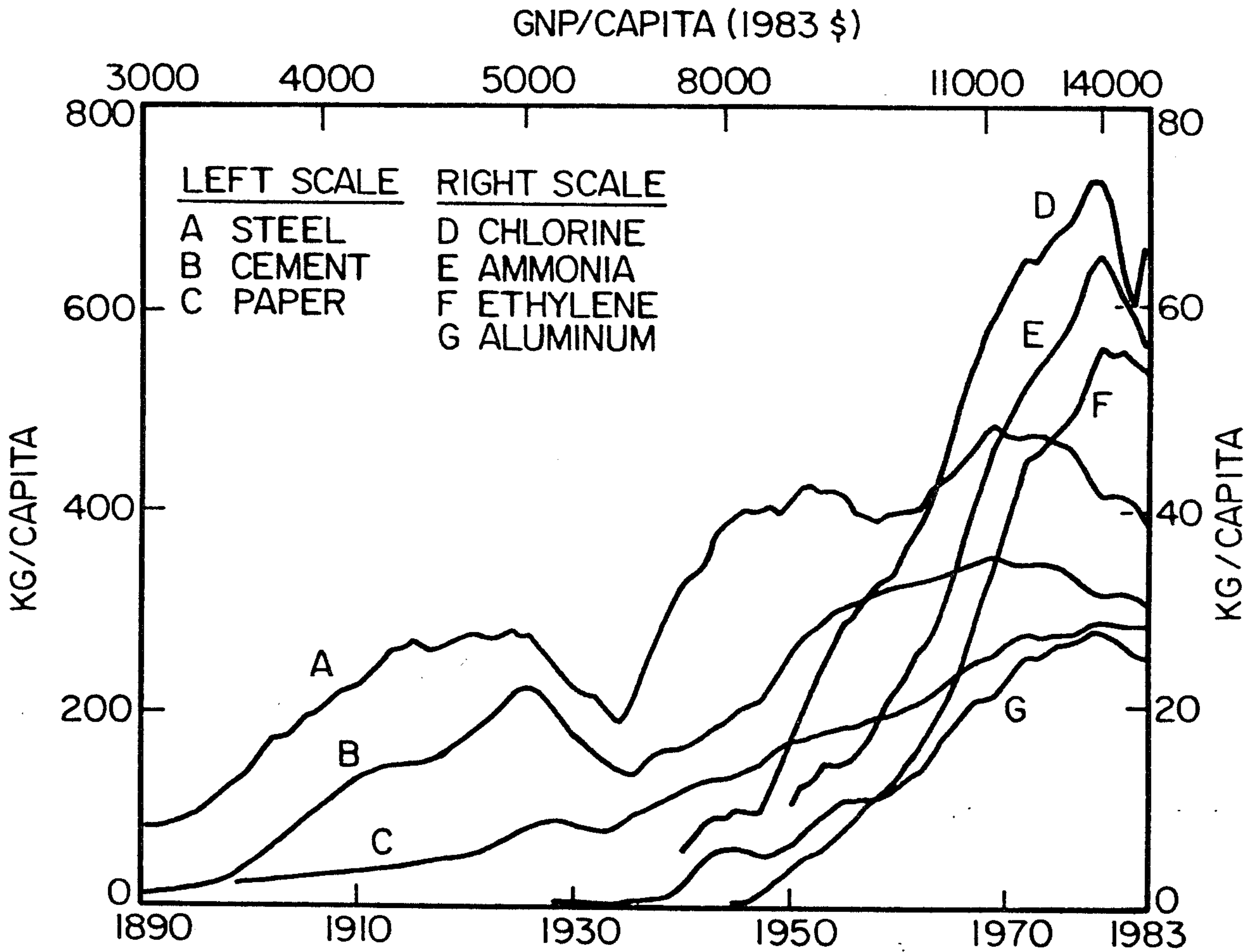

GNP/CAPITA (1983 $)
3000
4000
5000
8000
11000
14000
800
600
400
200
0
80
60
40
20
0
KG/CAPITA
KG/CAPITA
LEFT SCALE
A STEEL
B CEMENT
C PAPER
RIGHT SCALE
D CHLORINE
E AMMONIA
F ETHYLENE
G ALUMINUM
A
B
C
D
E
F
G
1890
1910
1930
1950
1970
1983

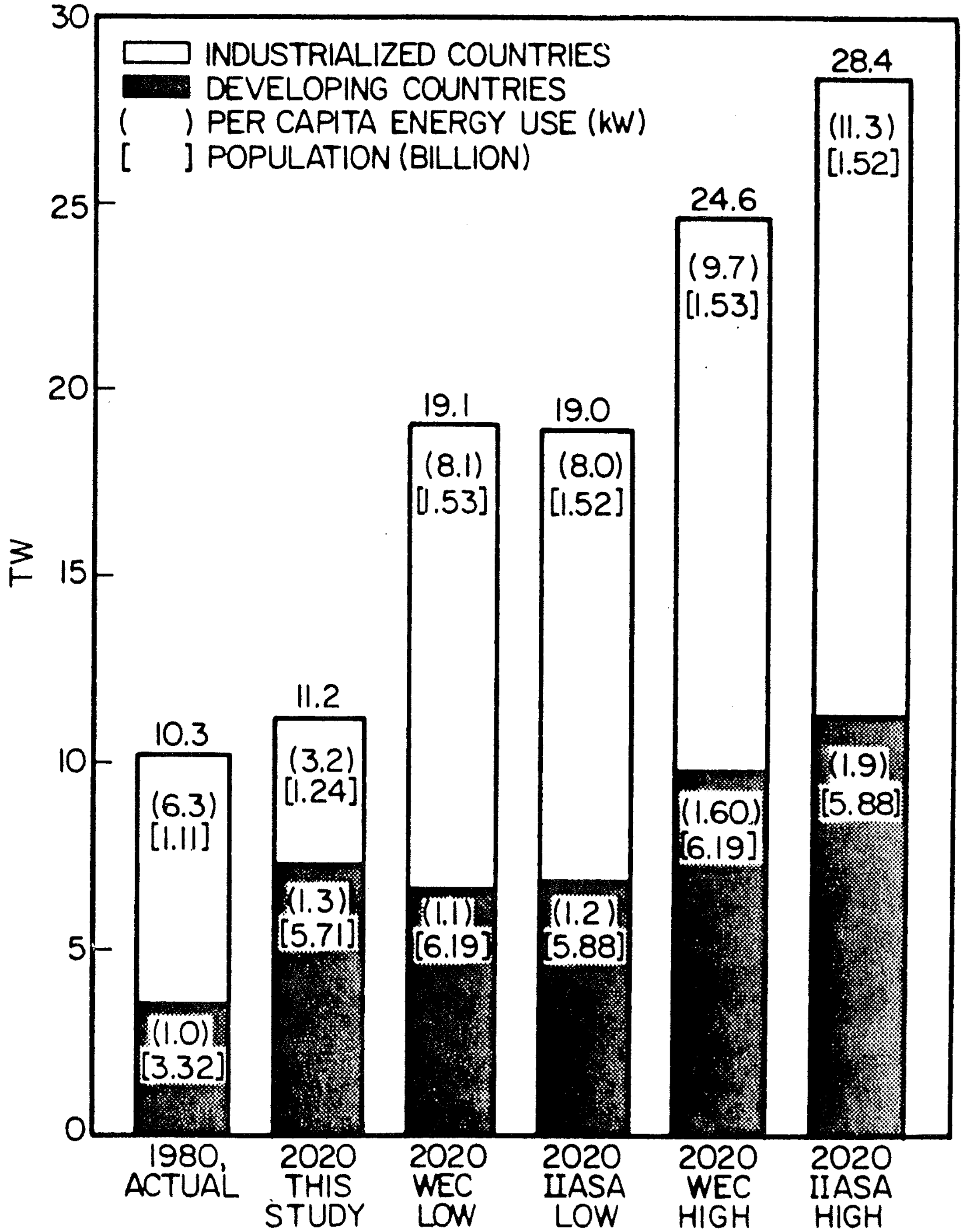
Figure 2

Figure 3.

Global primary energy consumption, disaggregated into developing and industrializd country components. Commercial energy consumption data for 1980 are based on U.N. statistics (46). The primary energy consumption values shown here for our scenario are the final energy consumption values discussed in the text, corrected for losses in generation, transmission, and distribution.

The World Energy Conference (WEC) projections (34) are for average per capita GNP growth rates, 1978-2020 of 1.4 (1.85) per cent per year for industrialized (developing) countries in the low growth scenario. The corresponding values for the high growth scenario are 2.2 (3.2) per cent per year.

The IIASA projections (9) are for average per capita GDP growth rates, 1975-2020, of 1.6 (1.7) per cent per year for industrialized (developing) countries in the low growth scenario. The corresponding values for the high growth scenario are 2.7 (2.9) per cent per year.



INDUSTRIALIZED COUNTRIES
DEVELOPING COUNTRIES
( ) PER CAPITA ENERGY USE (kW)
[ ] POPULATION (BILLION)
TW
30
25
20
15
10
5
0
10.3
(6.3)
[1.11]
(1.0)
[3.32]
11.2
(3.2)
[1.24]
(1.3)
[5.71]
19.1
(8.1)
[1.53]
(1.1)
[6.19]
19.0
(8.0)
[1.52]
(1.2)
[5.88]
24.6
(9.7)
[1.53]
(1.60)
[6.19]
28.4
(11.3)
[1.52]
(1.9)
[5.88]
1980, ACTUAL
2020 THIS STUDY
2020 WEC LOW
2020 IIASA LOW
2020 WEC HIGH
2020 IIASA HIGH

Figure 3

Figure 4.

Global primary energy consumption, disaggregated by energy source. Here primary energy use associated with hydropower, wind power, and photovoltaics is counted as the electricity produced. Nuclear power is counted as the heat energy released in the fission process. Commercial energy data for 1980 are based on U.N. statistics (46). Biomass data are from (46) and (47).

The supply mix for our global scenario was assembled as discussed in the text. Electricity production for our global scenario would be 1.9 times that in 1980 -- 37 percent central station fossil fuel, 26 percent hydro, 17 percent nuclear, 15 percent cogeneration, and 5 percent wind and photovoltaics.

The WEC (34) and IIASA (9) scenarios shown are averages for their low and high growth scenarios.

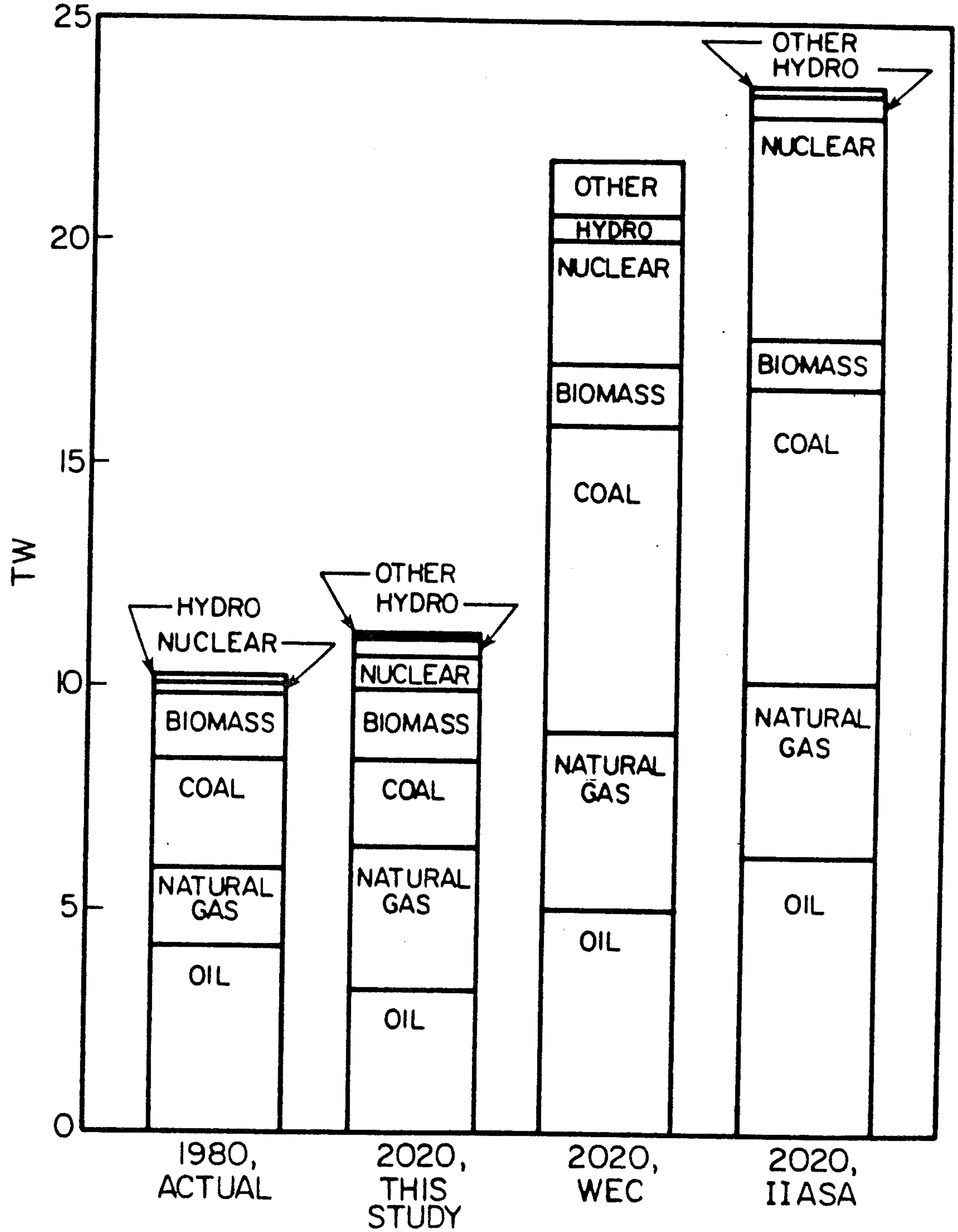

25
20
15
10
5
0
TW
HYDRO
NUCLEAR
BIOMASS
COAL
NATURAL GAS
OIL
OTHER
HYDRO
NUCLEAR
BIOMASS
COAL
NATURAL GAS
OIL
OTHER
HYDRO
NUCLEAR
BIOMASS
COAL
NATURAL GAS
OIL
OTHER
HYDRO
NUCLEAR
BIOMASS
COAL
NATURAL GAS
OIL
1980, ACTUAL
2020, THIS STUDY
2020, WEC
2020, IIASA

Figure 4

Table 1. Space Heat Requirements in Single Family Dwellings (kJ per square meter per degree day) (a)

United States	
Average, housing stock (b)	160
New (1980) construction in US (c)	100
Mean Measured Value for 97 Houses in Minnesota's Energy Efficient Housing Demonstration Program (b)	51
Mean Measured Value for 9 Houses Built in Eugene, Oregon, USA (d)	48
Calculated Value for a Northern Energy Home in New York City Area (e)	15
Sweden	
Average, housing stock (f)	135
Homes Built to Conform to the 1975 Swedish Building Code (g)	65
Mean Measured Value for 39 Houses Built in Skane, Sweden (h)	36
Measured value, House of Mats Wolgast, in Sweden (i)	18
Calculated Value for Alternative Versions of the Prefabricated House Sold by Faluhus (j)	
Version #1	83
Version #2	17

Notes to Table 1

(a) The required output of the space heating system (i.e., heat losses less internal heat gains less solar gains) per unit floor area per heating degree C day (base 18 degrees C).

(b) See ref. (19).

(c) As reported by the National Association of Home Builders (41).

(d) See ref. (19).

(e) The Northern Energy Home (NEH) is a super-insulated home design sold in New England and based on modular

Notes to Table 1, cont:

construction techniques with factory-built wall and ceiling sections mounted on a post and beam frame. The energy performance was estimated using the Computerized Instrumented Residential Audit computer program (CIRA) (42). The house has 120 sq. meters of floor area; triple glazed windows with night shutters; 20 cm (23 cm) of polystyrene insulation in the walls (ceiling); 0.15 ACH natural ventilation plus 0.35 ACH forced ventilation via 70% efficient air-to-air heat exchanger; and an internal heat load of 0.65 kW. The indoor temperature is assumed to be 21 degrees C in the daytime, setback to 18 degrees C at night.

(f) In 1980 the average values for fuel consumption, floor area, and heating degree days were 98.5 GJ, 120 sq. meters, and 4474 DD respectively, for oil heated single family dwellings (43). To convert fuel use to net heating requirements, a furnace efficiency of 66% is assumed.

(g) According to (43), and assuming a single story house with 130 sq. meters floor area, no basement, electric resistance heat, an indoor temperature of 21 degrees, and 4010 degree C days.

(h) The average for 39 identical, 4 bedroom, semi-detached houses (112 sq. meters of floor area; 3300 degree days).

(i) The Wolgast house has 130 sq. meters of heated floor space, 27 cm (45 cm) of mineral wool insulation in the walls (ceiling), quadruple glazing, low natural ventilation plus forced ventilation via air preheated in ground channels. Heat from the exhaust air is recovered via a heat exchanger. For 3800 degree days. See (16).

(j) The Faluhus has a floor area of 112 sq. meters. The more energy-efficient Version #2 (with extra insulation and heat recuperation) costs US $508 per sq. meter compared to US $480 per sq. meter for Version #1. The annual electricity savings for the more efficient house would be 8960 kWh per year. The cost of saved energy [assuming a 6% discount rate and a 30 year life for the extra investment] would be US $ 0.026 per kWh. For comparison electricity rates for residential consumers in Sweden consist of a large fixed cost independent of consumption level (about US $150 per year) plus a variable cost of US $0.032 per kWh. Here we have used an exchange rate of $0.13 per SEK.

Table 2. Fuel Economy for 4-passenger Automobiles (a).

Car	Status	Fuel Economy [l/100 km (mpg)]	Engine power (kW)	Curb weight (kg)	Drag coefficient
1981 VW Rabbit (gasoline)	commercial	7.9 (30)	55	945	0.42
1981 VW Rabbit (diesel)	commercial	5.3 (45)	39	945	0.42
Honda City Car (gasoline)	commercial	5.0 (47)	46	655	0.40
VW Experimental Car 2000 (b)	prototype	3.8 (62)	33	786	0.25
Volvo LCP 2000 (c)	prototype	3.6 (65)	66	707	0.27
Volvo LCP (potential) (d)	design	2.75 (85)	--	--	--
Cummins/NASA Lewis Car (e)	design	3.0 (79)	51	1360	--
Pertran Car (diesel version) (f)	design	2.2 - 2.4 (100 - 105)	--	545	0.25

Notes to Table 2

(a) The 1978 World average automobile fuel economy was 13 l/100 km (18 mpg).

(b) 3-cylinder, direct injection, turbocharged diesel engine; more interior space than the Rabbit; engine off during idle and coast (44).

(c) 2-passenger + cargo or 4-passenger; 3-cylinder, heat-insulated, direct-injection, turbocharged engine with multi-fuel capability (20).

(d) The Volvo LCP 2000 plus continuously variable transmission (CVT) and engine off during idle and coast (21).

(e) 4-5 passenger; 4-cylinder, direct-injection, spark-assisted, multi-fuel capable, adiabatic diesel with turbo-compounding; CVT; 1984 model Ford Tempo body (22).

(f) pre-chamber diesel engine with supercharger; CVT; flywheel for energy storage in braking (45).

Notes to Table 3

(a) For a country in a warm climate, with a level of amenities (except for space heating) comparable to that in the WE/JANZ region (Western Europe, Japan, Australia, New Zealand, and South Africa) in the 1970s, but with currently best or advanced energy utilization technologies. Final energy use refers to site energy consumption.

(b) Activity levels for the residential sector are estimates, owing to lack disaggregated data for Western Europe.

(c) Here 30% of all p-km are via electric trains, for which the final energy intensity is 1/3 that of diesel trains.

(d) Here 40% of p-km is via electric systems, for which the final energy intensity is about 1/3 that of diesel buses.

(e) Here "other" is the difference between the manufacturing total and the sum of the items calculated explicitly. Energy usage associated with "other" for the non-manufacturing sectors is negligible and thus is not shown explicitly in this table.

Table 3 A Hypothetical Final Energy Use Scenario (in Watts per Capita) for an Affluent Energy-Efficient Developing Country[a]

	Activity Level	Technology, Performance	Electricity	Fuel	Total
Residential (b)	4 persons/HH				
Cooking	Brazilian cooking level w/LPG stoves	70% efficient gas stove		34	
Hot Water	50 l of hot water/capita/day	heat pump WH, COP = 2.5	29.0		
Refrigeration	1 315 l refrigerator-freezer/HH	Electrolux, 475 kWh/year	13.5		
Lights	New Jersey (US) level of lighting	Compact Fluorescent Bulbs	3.8		
TV	1 color TV/HH, 4 hours/day	75 Watt unit	3.1		
Clothes Washer	1/HH, 1 cycle/day	0.2 kWh/cycle	2.1		
Subtotal			51	34	85
Commercial	5.4 sq. m/capita floor space (WE/JANZ ave, '75)	Harnosand Building, Sweden (all uses, ex. space heating)	22	-	22
Transportation					
Automobiles	0.19 autos/capita, 15,000 km/car/yr (WE/JANZ ave, '75)	Cummins/NASA Lewis Car @ 3.0 l/100 km		107	
Intercity bus	1850 p-km/capita (WE/JANZ ave,'75)	0.45 MJ/p-km, 3/4 '75 ave.		26	
Passenger train	3175 p-km/capita (WE/JANZ ave,'75)	0.45 MJ/p-km diesel, 3/4 '75 ave (c)	4.5	32	
Urban Mass Transit	520 p-km/capita (WE/JANZ ave,'75)	0.85 MJ/p-km diesel, 3/4 '75 ave (d)	2.0	8	
Air Travel	345 p-km/capita (WE/JANZ ave,'75)	1.9 MJ/p-km, 1/2 US ave in 1980		21	
Truck Freight	1495 t-km/capita (WE/JANZ ave,'75)	0.67 MJ/t-km, 2/3 of Swedish ave		32	
Rail Freight	814 t-km/capita (WE/JANZ ave,'75)	Electric, 0.18 MJ/t-km, Sweden ave	5		
Water Freight (incl. bunkers)	1/2 OECD Eur ave, '78 (reduced reliance on oil)	60% of ave OECD energy intensity		50	
Subtotal			12	276	288
Manufacturing					
Raw Steel	320 kg/capita (OECD Eur ave, '78)	ave of Plasmasmelt, Elred Processes	28	77	
Cement	479 kg/capita (OECD Eur ave, '80)	Swedish ave in 1983	6	54	
Primary Aluminum	9.7 kg/capita (OECD Eur ave, '80)	Alcoa process	11	26	
Paper and Paperboard	106 kg/capita (OECD Eur ave, '79)	Ave of 1977 Swedish designs	11	24	
Nitrogenous Fertilizer	26 kg N/capita (OECD Eur ave, '79/80)	Ammonia via steam reforming of methane	-	36	
Other (e)			65	212	
Subtotal	Swedish industrial mix w/ '75 W. European level of GDP/capita (55% of Swedish level)	Energy intensity for Swedish industry w/ '75 level of goods and services and advanced technology (16)	121	429	550
Agriculture	WE/JANZ ave, '75	3/4 of WE/JANZ ave energy intensity	4	41	45
Mining, Construction	WE/JANZ ave, '75	3/4 of WE/JANZ ave energy intensity	-	59	59
TOTALS			210	839	1049

References

1. This paper is based on J. Goldemberg, T.B. Johansson, A.K.N. Reddy, and R.H. Williams, Energy for a Sustainable World (forthcoming book).

2. Recently there have been several global energy studies that depart from the traditional energy supply orientation. A 1979 study [U. Colombo and O. Bernardini, A Low Energy Growth Scenario and the Perspective for Western Europe (Report for the Panel on Low Energy Growth, Commission of the European Communities, July 1979)] explores an energy supply-constrained future for the year 2030 (16 TW of primary global energy use) as an alternative to the IIASA scenarios (9). The study shares a number of features with the present one, including an emphasis on energy efficiency; but our analysis indicates a greater potential for energy efficiency improvement. A 1983 study [D.J. Rose, M.M. Miller, and C. Agnew, Global Energy Futures and CO2-Induced Climate Change (Report MITEL 83-015, Massachusetts Institute of Technology, Cambridge, Massacusetts, 15 November, 1983)] exploring alternative energy strategies for coping with the CO2 problem found that improved energy efficiency offers the single most important opportunity to ameliorate the CO2 build-up, and described several viable scenarios with demand levels in the neighborhood of 12 TW for the year 2025. A 1981 study [A.B. Lovins, L.H. Lovins, F. Krause, W. Bach, Energy Strategy for Low Climatic Risk (Report for the German Federal Environmental Agency, June 1981)] is perhaps the first global study to stress the importance of pursuing alternative energy strategies, including energy efficiency improvement, as a means of coping with the CO2 problem. Its targetted global primary energy use

level for the year 2030 is only 5.2 TW, just half of value for the scenario presented in this paper for the year 2020. One of the main reasons this is so low is that the authors assume per capita primary energy use in developing countries can be reduced to 1/4 kW -- about 1/4 the 1980 level. We are skeptical that development needs can be satisfied with such a low level of energy use.

3. The World Bank, The Energy Transition in Developing Countries, Washington DC, 1983.

4. The World Bank, World Development Report 1984, Oxford University Press, July 1984.

5. Office of Planning, Policy, and Analysis, US Department of Energy, Energy Projections to the Year 2010: a Technical Report in Support of the National Energy Policy Plan (Report DOE/PE-0029/2, Washington DC, October 1983).

6. In Table 2.6, p. 57 of (9) it is estimated that the remaining ultimately recoverable oil resources of the world amount to 365 TW-years, of which 155 TW-years lie in the ME/NAf region.

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favorable for the poor (4). Since a quantification of the impact of such a policy on population has not been carried out, we reflect this effect by the adoption of the UN's 1980 Low Variant Projection of world population -- 7.0 million people by 2020 (vs. 7.8 million for the Medium Variant). See United Nations, World Population Prospects As Assessed in 1980 (United Nations, New York, 1981).

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