Global Warming and Future Fossil Fuel Consumption

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This paper reviews the potential for reducing emissions of CO_2 by reducing the use of fossil fuels. Following a brief review of current data on greenhouse gas emissions and global warming, the author considers three ways of decreasing fossil fuel consumption: doing without; maximizing conversion efficiencies; and reducing the use of energy-intensive products through better design and extensive recycling of materials. He identifies a major potential for such reductions, but sees severe limits on their realization, even if the public's desire for them is intensified by a clear confirmation that significant global warming will occur. These limits centre around the diffuse nature of the measures necessary for dramatic energy conservation and the extreme cross-national inequalities in energy consumption. It is concluded that a reduction in population growth must be a major component of any attempt to reduce greenhouse gas emissions significantly.

Cet article examine le potentiel de diminution du dégagement de CO_2 en réduisant l'emploi des combustibles fossiles. A la suite d'une brève revue des données actuelles sur le dégagement des gaz à effet de serre et sur le réchauffement global, l'auteur considère trois façons de diminuer la consommation de combustibles fossiles: faire sans; maximiser l'efficacité des conversions; et diminuer l'emploi de produits qui consomment beaucoup d'énergie grâce à une meilleure conception et à un recyclage répandu de matériaux. Il reconnaît un potentiel majeur pour de telles réductions, mais entrevoit des limites importantes à leur réalisation, même si le public exprimait un désir de plus en plus intense pour ces réductions en face d'une confirmation plus claire d'un réchauffement global. Ces limites sont reliées à la nature diffuse des mesures qu'il faudrait prendre pour une conservation spectaculaire d'énergie et aux énormes inégalités entre nations en ce qui concerne la consommation d'énergie. Une baisse dans la croissance de la population devra former une composante majeure de toute tentative de diminution importante du dégagement de gaz à effet de serre.

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Risks of rapid CO_2-induced planetary warming have been among the most prominent of the rising concerns over global biospheric change. Many detailed surveys have extensively reviewed the past record of man-made emissions and steadily increasing atmospheric concentrations of the gas and have discussed the probabilities and consequences of ensuing climatic change (National Research Council, 1982 and 1983; Clark, 1982; US Environmental Protection Agency, 1983, 1989; Smil, 1985; US Department of Energy, 1985; Bolin *et al*, 1986; Trabalka and Reichle, 1986; Abrahamson, 1989; Schneider, 1989). This paper begins with a brief summary of these surveys and then focuses on the overall likelihood that a dramatic reduction in the emissions of greenhouse gases can be achieved by way of reductions in fossil fuel consumption. We shall see that there is great potential for the latter, but that there are also severe limits on the scope for achieving this potential.

Facts and Conjectures

We know with sufficient confidence that tropospheric concentrations of CO_2 have risen from their pre-industrial level (determined from air bubbles trapped in polar ice) of about 280 parts

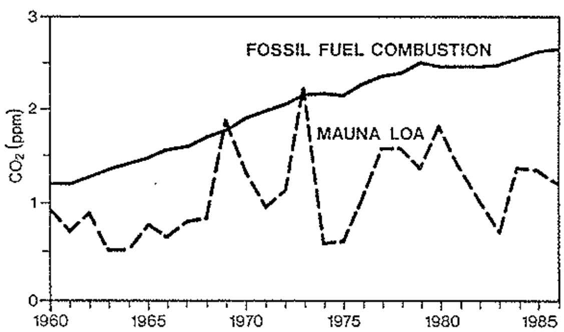

Figure 1: Recent annual increases of atmospheric carbon dioxide concentrations at Mauna Loa observatory (broken line) show fluctuations of 0.6-1.8 ppm (data from Bodhaine (1988)). In contrast, the solid line represents the increase in CO_2 levels that would result from complete atmospheric retention of the gas released from fossil combustion (calculated from UNO's annual *World Energy Supplies* for the period before 1980, and from UNO's *Yearbook of World Energy Statistics* for the period afterwards).

per million (ppm) to about 350 ppm by 1988, an increase of roughly 25% in less than 150 years. Moreover, the continuous program of Geophysical Monitoring for Climatic Change operated by the US National Oceanic and Atmospheric Administration (NOAA) shows recent annual increases fluctuating between 0.6 and 1.8 ppm, that is, 0.2-0.5% of the total level (Fig. 1). But we are much less clear about the make-up of anthropogenic emissions responsible for these increases.

The rates of current CO_2 generation from burning of fossil fuels can be calculated fairly accurately.[1] Annual releases during the late 1980s were nearly 20 billion tonnes (t), while releases due to natural gas flaring, cement production and combustion of wastes totalled less than 2 billion t/yr. But there is considerable uncertainty about the net annual CO_2 emissions from tropical deforestation and conversion of forests, grasslands and wetlands to fields. Recent estimates put these emissions at anywhere from 2 billion to 9 billion t of CO_2 (Smil, 1985; Trabalka and Reichle, 1986). Such a large range in estimates is attributable to the large variability of carbon content in plants and our poor knowledge of actual conversion rates.[2]

The best available historic data (summarized in Clark, 1982) translate into roughly 700 billion tonnes of cumulative emissions from fossil fuels in the period 1850-1990, while CO_2 releases from ecosystem changes caused by pioneer agriculture and deforestation total close to 600 billion t for the same period. Although these two cumulative totals are surprisingly similar, combustion of fossil fuels is now undoubtedly by far the more important source of anthropogenic CO_2.

But atmospheric concentrations of other greenhouse gases have also been increasing rapidly: methane concentration roughly doubled during the industrial era and levels of the principal chlorofluorocarbons have nearly doubled since their first measurement in 1977. The atmospheric concentration of these gases is only a small fraction of the CO_2 level, but since they are stronger absorbers of longwave radiation they are responsible for roughly one-half (US Environmental Protection Agency, 1989) of the overall absorption of outgoing longwave terrestrial radiation.[3] Still, combustion of fossil fuels remains the single largest source of anthropogenic

1/ Release of CO_2 during fuel combustion is a matter of complete oxidation of carbon. Coal has higher CO_2 emissions per unit of liberated energy than oils and natural gases, whose hydrogen contributes to energy release when its oxidation yields water. I have been using the following average conversion factors (all rates in grams of carbon per GJ): 24.2 for standard coal, 19.1 for liquid fuels, and 14.3 for natural gases (for a detailed justification of these values see Smil (1985)). The US Department of Energy uses very similar conversion rates of 23.8, 19.2 and 13.7 g C/GJ (Cheng *et al*, 1986). Global and national fossil fuel combustion totals are available in annual statistical compendia published by the United Nations, British Petroleum and the CIA. Inevitable errors arising largely from conversion of run-of-mine coal to standard fuel equivalent (an especially imprecise task in the case of the huge Chinese output originating in small rural mines) introduce uncertainty of about ±5%.

2/ Not surprisingly, the largest discrepancies are found among the estimates of tropical deforestation (Myers, 1980; Houghton, 1986). LANDSAT and SPOT satellite images help to make rough estimates but reliable totals can be assembled only by on-site inspection.

3/ Compared to 350 ppm of CO_2, the current atmospheric concentrations of other important greenhouse gases are two to five orders of magnitude lower: less than 2 ppm for CH_4, just over 300 ppb for N_2O, and less than 500 ppt for $CFCl_3$ (Bodhaine, 1988).

greenhouse gases and its reduction would have to be a critical part of any effective strategy to control overall emissions. How soon these efforts should start and how vigorous they should be remains a complex matter of conjecture.

One extreme opinion is that worrisome planetary warming induced by greenhouse gases is already happening; at the other extreme it is argued that any such future changes should be seen largely as a matter of overall biospheric and economic gains rather than one of feared losses.[4] In between is the bulk of the current scientific consensus, resting on a mixture of reliable atmospheric physics, uncertain palaeoclimatic analogies, and still very simplistic and hence dubious simulations of global climate. This view starts with the prediction that the doubling of pre-industrial CO_2 (i.e., a CO_2 concentration of 600 ppm, or its equivalent as a mixture of CO_2 plus the other greenhouse gases) will raise tropospheric temperatures by anywhere from 1-5°C.

More specifically, it is predicted that this warming should be about two to three times more pronounced in higher latitudes than in the tropics and greater in the Arctic than in the Antarctic. It should intensify the global water cycle (manifested by higher circumpolar runoffs, later snowfalls and earlier snowmelts), which should be accompanied by a major redistribution of worldwide precipitation patterns, an intensification of extreme weather conditions (tropical and temperate cyclones, droughts), shifts in ecosystem boundaries (northward march of grasslands and forests), a poleward retreat of sea ice, and an appreciable rise in sea level (causing coastal inundation, greater erosion and storm damage and salt water intrusion). (See references cited in the opening paragraph.)

Complexities surrounding the genesis, identification, progression and effects of global warming have no simple, indisputable resolution. This guarantees that the coming decades will see a continuing clash of opinions regarding the existence and extent of the process and its effects. While it would be inadvisable to accept uncritically many untested claims about the dangers of future warming, a prudent risk-minimizing attitude requires that we start assembling and assessing effective strategies which would moderate the negative impacts of such a global change.

An essential ingredient of these efforts would be a substantial reduction in emissions of greenhouse gases. This would be impossible without reducing the global consumption of fossil fuels. The substitution of alternative energy sources — renewable energy conversions and nuclear electricity — will certainly contribute to these reductions. However, since a critical examination of the post-1973 record shows that long-range predictions of technical innovation are futile (Smil, 1987), I will not extend the list of embarrassing forecasts by offering estimates of global penetration rates for the alternative energy techniques that appear most promising for the coming two to four decades. (These are large-scale photovoltaics (Hubbard, 1989) and the second generation of nuclear systems.)

In any case, the well-documented slow pace of primary resource substitutions (Marchetti and Nakicenovic, 1979), the mismatch between the low power density of renewable conversions and the high power density of urban and industrial needs (Smil, 1985), and the massive post-Chernobyl distrust of nuclear generation, mean that alternative energies will not be able to take over more than a small fraction (most likely less than 10%) of the current global fossil fuel flow within the next 20 years. The need for relatively rapid reductions of CO_2, resulting from early confirmation of an unmistakable warming signal, would have to be met largely by energy conservation. The latter has a huge potential for impressive achievements, but also a multitude of limitations restricting its short and medium-term gains.

4/ These extremes are best exemplified by the contrast between James Hansen's congressional testimony in June 1988 — which attracted much attention because of its (indefensible) claim that the warm 1980s, a precursor of further rapid warming, can be ascribed with 99% certainty to the greenhouse effect (Kerr, 1989) — and Sherwood Idso's (1989) relatively benign view of possible climatic change.

Potential for Reduced Fossil Fuel Consumption

Although I agree with Rose (1986) that the term "rational and effective energy use" is preferable to "conservation", I will sweep all appropriate approaches under that imprecise but commonly used cover, the opportunities and benefits of which have been extolled in so many post-1973 publications (Ford *et al*, 1975; Lovins, 1977; Socolow, 1977; Gibbons and Chandler, 1981; Hu, 1983; Rose, 1986). These opportunities may be divided into a trio of broad strategies: doing without; maximizing conversion efficiencies; and reducing the use of energy-intensive products through better design and extensive recycling of materials.

Doing without is a much under-appreciated option in affluent societies which are habituated to the idea of growth. Its impact is obvious when one compares per capita energy use in the Western world of the early 1960s (a time chosen to allow the damages of World War II to be healed) with that of the late 1980s: was life with 10% (the US case), 30% (in Canada or West Germany) or even 40% less energy (nearly that much in France) so unbearable?

The potential for better conversion efficiencies — achieved directly by improving the performance of combustors and prime movers, or indirectly by adjusting their settings and emissions — remains large in every consumption sector and at every stage of economic development. Given the prevailing make-up of sectoral consumption, the largest savings in the rich world can come from buildings and transportation.

Buildings

Collectively, buildings are either the largest or second largest consumers of energy (behind all industrial conversions) in all rich societies. Space heating and cooling is the dominant demand in every rich nation (between 50-80% of all residential consumption), followed by lighting and electric appliances and water heating. The potential for efficiency improvements in all of these categories is impressive (Williams and Dutt, 1983; Baird *et al*, 1984; Schipper *et al*, 1985; Rosenfeld and Hafemeister, 1988).

The average consumption for North American housing stock (in units of kJ/m^2/degree-day) was about 160 in 1980. New buildings constructed during the 1980s rate between 100 and 120. Superinsulated houses decrease to 30-50 and the most efficient designs can use as little as 15-20 kJ/m^2/degree-day. Halving the total energy needs is not thus an exceptional performance. Further savings can come from structural changes. In comparison with the still much-favored three-bedroom single-story house, an equally-sized two-story building is 15%, a two-story duplex 30%, a two-story triplex 35%, and a low-rise condominium apartment 40% more energy-efficient (Burchell and Listokin, 1982).

Efficiencies of principal household energy convertors differ widely, from just 50% for solid-fuelled furnaces to 55-65% for well-adjusted traditional oil and gas furnaces with a standing pilot light and up to 91-96% for condensing non-vented gas-fired units (Macriss, 1983). Even greater differences separate heat losses of walls, windows, doors and roofs in typical poorly built pre-1973 dwellings from losses in new superinsulated houses with very low rates of air infiltration. Total energy requirements of such superinsulated structures are no more than 30 W/m^2 even on the cold Canadian Prairies, where most of the houses still average more than 80 W/m^2!

A similar trend has been evident for commercial buildings. Most of the multistoried glassy structures erected in North America between the early 1950s and the early 1970s average 110-140 W/m^2 of floor area (Fig. 2). By the mid-1980s the primary energy required by new office buildings was below 50 W/m^2 and many all-electric buildings have been designed for just around, or even below, 10 W/m^2, or less than 30 W of primary energy per square metre of occupied area.

Lighting can also become much more efficient. The most efficient incandescent light, a 10 kW source for film studios, puts out 33.6 lumens/W (lm/W) (Weast, 1989). Using 1.47 mW/lm as the standard mechanical equivalent of light, the 10 kW lamp is less than 5% efficient in converting

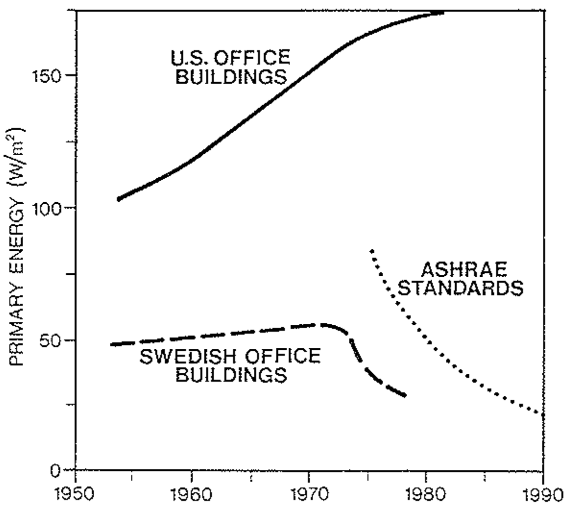

Figure 2: Comparison of energy intensities of Swedish and American office buildings with standards adopted by the American Society for Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) reveals the enormous potential for fuel and electricity conservation. In all cases electricity was converted to primary energy at a rate of 12.1 MJ/kWh. (Based on NRC (1986).)

electricity into light, while efficiency of the common 100 W bulb is a mere 2.6%. New techniques have boosted the performance: the standard 40 W warm white fluorescent tube has nearly 12% efficiency and it lasts at least 25 times longer (20,000+ hours) than a 100 W incandescent bulb. The best performers are high-intensity discharge metal halide (up to 110 lm/W) and high-pressure sodium lamps (up to 140 lm/W) whose efficiencies now near or even surpass 20%.

Transportation

By far the greatest efficiency gains in transportation can come from improving motor vehicles, above all, the performance of passenger cars. In 1985, 27% of global oil refinery output was motor gasoline and just over 20% was diesel oil for land vehicles and ships (United Nations, 1987). Jet fuels accounted for about 3%. Everyday average vehicle performance is very low. The best practical First-Law efficiency of an Otto cycle engine is around 32%. Frictional losses bring this down to 26% and partial load factors, inevitable during the urban driving which constitutes most car travel, reduce it to 19-20%. Losses due to the use of accessories and automatic transmissions may nearly halve the total. Thus, effective efficiency is no more than 10-12%, and can be as low as 7-8% (Reitz, 1985).

Between 1974 and 1988 mean fuel consumption for the North American car fleet fell by almost 50% to 3.1 MJ/km (Fig. 3). However, this belated decline still leaves the new mean at over 8 l/100 km, at a time when there is no shortage of cars that average 6-8 l/100 km, even in city traffic, and when the best performers among gasoline-fuelled vehicles — including the Ford Fiesta, Daihatsu Cuore or Renault R5 — need just 4.3-4.8 l/100 km (1.7-1.5 MJ/km) when running at 90 km/h (Adler *et al*, 1986).

As with buildings, major improvements in automotive efficiency require no technical breakthroughs and can come from a combination of gradual adjustments and widespread applications of existing techniques (Reitz, 1985). To begin with, cars have been unnecessarily powerful: unless driving requires unusually rapid acceleration, travel on uncommonly steep roads or heavy towing, there is no reason to have any standard passenger cars rated over 35 kW. Even a VW Golf is overrated (40 kW) and the Honda Civic is nearly twice as powerful as necessary (63 kW). Lower weights obviously reduce power requirements: front wheel drive with transversely-mounted engines and replacement of steel by lighter materials are the key routes to take.

There remains much scope for reducing aerodynamic drag on automobiles. Other ingredients of a strategy which could yield national car fleets averaging below 1.75 MJ/km (5 l/100 km) before the end of 20th century are: lean-burn low-friction engines; continuously variable transmissions; and more use of the inherently more efficient diesel engine, especially better adiabatic low-friction kinds. This would correspond to drive train efficiencies around 20%.

Air transportation claims an increasing share of refined fuel output. Turbofan engines

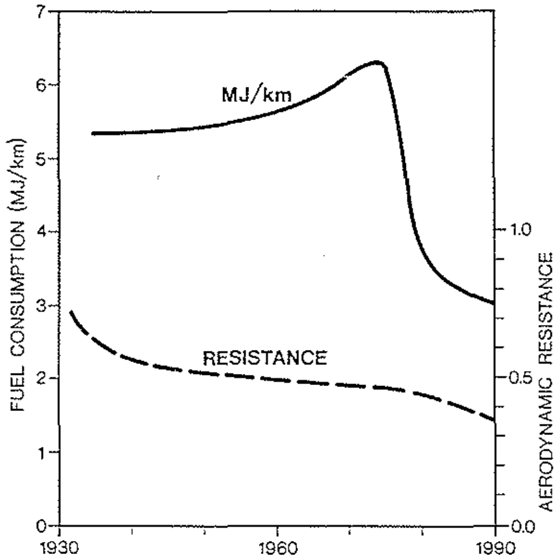

Figure 3: Fuel consumption of the North American car fleet (solid line) continued to increase until 1974. Since then a rapid decrease halved the average consumption rate; but huge potential for conservation remains — there are cars on the road consuming only half of this much-improved mean. Decreases in aerodynamic resistance of automobiles (broken line) have contributed somewhat to reduced fuel consumption, but further reductions are still possible. (Data recalculated from MVMA (1989).)

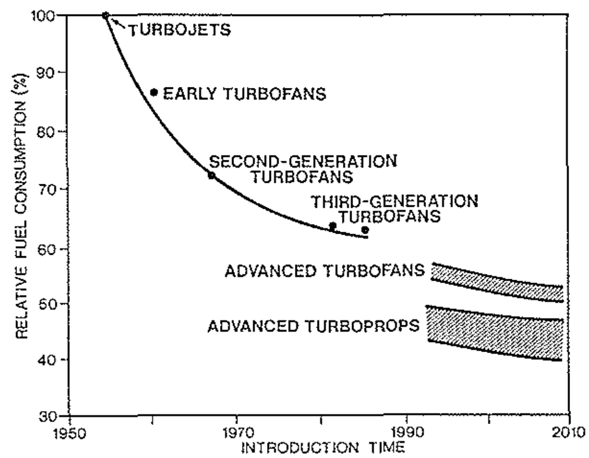

Figure 4: Impressive secular decline of aircraft fuel consumption: turbojets of the late 1950s used about 50% more fuel than will the advanced turbofans and turboprops in the year 2000 (Sampl and Shank, 1985).

mounted on wide-bodied jets have already brought major efficiency gains (Sampl and Shank, 1985) and there are further considerable opportunities to continue this commendable trend (Fig. 4).

Industrial Energy Use

Industrial energy conservation since 1973 has been very successful in most OECD countries, with efficiency gains in the use of electricity being most impressive. For example, by 1985 American industries cut their electric intensity (kWh/$GNP) to one-half of their 1971 rate (Ross, 1989). But even here the potential savings are far from exhausted, especially in replacing older AC-polyphase induction electric motors rated from 750 W to 100 kW, which are the most important (for pumping, compressors, fans, blowers, machine tools). Potential efficiency gains are as large as 68% to 85% for motors rated below 1 kW. Even relatively small potential improvements for larger machines (a mere 2% for motors with efficiencies already exceeding 90%) translate into large aggregate gains when multiplied by millions of operating units. New high-efficiency motors are readily available and payback periods for their installation are a mere year or two.

Utilization of waste heat offers enormous conservation potential in power plants and industrial enterprises requiring high-temperature steam or dry heat. Cogeneration — the use of a single primary heat source to produce electricity and thermal energy simultaneously — uses 10-30% less fuel than if electricity and heat were produced in two separate facilities (Clark, 1986).

Reducing the use of energy-intensive materials is an approach applicable equally well to soft-drink cans and jumbo airliners, but these design improvements yield limited energy savings compared to the recycling of most metals and paper. Ferrous metallurgy is still the largest consumer of fossil fuels among principal material-producing industries and using scrap in steelmaking saves 10-25 MJ/kg compared with the 25-50 MJ/kg used for steel made from orederived iron. Typical reductions in recovering nonferrous metals from scrap, as opposed to smelting them from ores, are at least 250 MJ/kg for aluminum, around 50 MJ/kg for copper and zinc and 30 MJ/kg for lead (Wilson, 1979).

Overall Gains

These examples are sufficient to demonstrate the breadth and the level of possible gains from energy conservation. What the actual combined savings during the next 20-40 years will be is no less conjectural than the forecasts of planetary warming. Rather than adding to a large number of dubious long-term energy forecasts, the potential enormity of future energy savings can be best illustrated by simply observing that, in my view, the 1990 level of final energy services could be provided with up to 25% less primary energy within 20 years. A cut of close to 50% should not be seen as unrealistic within two generations. Indeed, a global study by Brookhaven National Laboratory has concluded that, by the middle of the next century, gains achievable by the use of more efficient energy conversions could add up to 500 EJ, or nearly 60% of the fossil fuel demand in the year 2050 without technical improvements (Cheng *et al*, 1986).

The highly skewed global distribution of fossil fuel combustion would seem to be helpful in bringing about such major gains. Only three countries are responsible for 50% of all CO_2 from fossil fuel combustion: the USA produces 22%, the USSR 18% and China 10% of the global total. Comparable to the case of strategic arms negotiations, an agreement among the handful of energy-consuming superpowers (adding Japan and West Germany to the group) would not eliminate the global risk — in this case, the accumulation of fossil fuel-derived CO_2 emissions — but it could lead to its substantial reduction.

But neither the impressive conservation potential nor the highly concentrated use of fossil fuels are guarantees of speedy and extensive progress: a variety of constraints will reduce the highest possible gains to a fraction of the best technical potential.

Limits to Reductions

The 1980s have been a decade of globally unprecedented consumption — in North America, consumption patterns have been increasingly ostentatious and economically debilitating. Voluntary frugality has clearly been in short supply throughout the rich Western world. Putting much faith into the option of doing without is illusory in the absence of acute social crises, the only time when affluent democracies are inclined to adopt proscriptive measures. What would a string of extraordinarily hot and dry years (which would not, of course, in itself necessarily mark the onset of pronounced long-term global warming) do to the willingness to sacrifice?

Doing with less is a more appealing alternative than doing without. But conservation has an important perceptual problem owing to its contrarian nature: in facing the energy dilemma, it springs from what Socolow (1977) appropriately labelled "inverted emphasis." Instead of concentrating all efforts on enlarging energy supply — the traditionally dominant way of development —the inverted approach focuses on deliveries of particular energy needs and inevitably discovers huge rationalization opportunities. Curiously enough, this continues to be viewed too often as much less important than even the most dubious quests for new sources of supply, a reality perfectly illustrated by the respective levels of mass media attention.[5]

Putting aside these perceptions of irrationality, there are two unavoidable practical limits to conservation. There is no equivalent of spectacular giant oilfield discoveries in energy conservation, no dramatic single-item short-cut. Particular conservation efforts — even when obviously so far-reaching as higher efficiency stan-

5/ Compare the frenzied coverage of the most recent non-event associated with energy supply — the story of cold fusion — with a virtual absence of reporting on aeroderivative turbines for stationary electricity generation (Williams and Larson, 1988). The latter is a fine technical innovation using well-established machines in a new configuration designed to improve substantially the efficiency of thermal electricity production.

dards for cars, air conditioners or refrigerators—cannot reduce national energy use by large margins. Only sustained accumulation of numerous improvements can add up to impressive reductions.

Successful conservation efforts thus require prodigious numbers of informed individual decisions and long-term commitment: both can be a problem in many rich Western societies. Higher energy inputs into conservation generate greater life-cycle savings but require longer amortization spans. Such commitments run against both the frequent preference for low initial cost and the still very high mobility of North American society. In many poor countries, where average conversion efficiencies are even more dismal than in the rich world, a lack of capital investment often precludes the adoption of even relatively simple measures.

Energy conservation is thus primarily a matter of important socioeconomic adjustments, rather than of technical innovation, and the progress of those changes is almost invariably far behind the engineering potential. But still more important is the fact that even some impossibly large CO_2 emission cuts by major offenders would translate into just minor reductions of overall growth rates in emissions of greenhouse gases. This is the consequence of a complex mixture of gases and sources contributing to the risk of planetary warming. In 1988 about 57% of the total burden was coming from fossil fuels (overwhelmingly as CO_2, but also as N_2O), 17% from chlorofluorocarbons, 3% from various industrial processes (largely CO_2), 14% from agricultural activities (as CO_2, CH_4 and N_2O), and 9% from land use changes, mainly CO_2 from deforestation (US Environmental Protection Agency, 1989).

Even an immediate (and unquestionably impossible) 30% reduction of CO_2 emissions in the US would cut global greenhouse emissions by less than 4%. If all rich countries did the same, the total would decline by about 1/10. Furthermore, in the coming decades national contributions to the global total of CO_2 flux will become less concentrated in a small number of countries. This will occur because of the combination of low population growth rates, major energy conservation gains and near-saturated per capita demand in the rich countries on the one hand, with high natalities, persistent gross energy conversion inefficiencies and huge unfilled fuel and electricity demand throughout the poor world on the other. Any effective long-term response will thus require a truly global agreement.

Such a consensus would also be essential in order to avoid highly disruptive economic effects as the countries with national consumption limits or with taxes discouraging fossil fuel combustion become less competitive or less well off than the producers and consumers in unaffected nations. Enormous difficulties facing such an agreement are best appreciated by recalling the endless rounds of the GATT negotiations aimed at liberalizing global trade, which, in some instances, were accompanied, in reality, by deepening trade restrictions.

Perhaps the most taxing task would be an equitable division of contributions to national control. Uniform cuts would be easier to apply in many energy-inefficient economies, which are currently the world's largest per capita offenders (Czechs at 20 t CO_2/capita/year, Canadians at 18 t, East Germans at 17 t, Americans at 15 t), than in the nations whose sustained energy conservation efforts have already achieved remarkably low per capita fuel consumption and hence CO_2 emission rates (obviously Japan, but also Sweden, France, Italy).

It is difficult to imagine how the economically wobbly Communist regimes of East Germany, Czechoslovakia, Poland or the USSR, all still heavily dependent on large-scale combustion of poor quality lignites, would be willing to adopt the same relative emission cuts as the two rich North American nations. On the other hand, if there were differentiated national targets which required the already highly efficient Japanese to do less cutting than, for example, the inefficient Canadians, Japanese competitiveness would further escalate, creating even greater trading imbalances and more unfavourable conditions for all kinds of global cooperative efforts.

The most fundamental obstacle to any substantial reduction in CO_2 emissions is the necessity of energizing the growing economies of the poor world. Looking just 30 years ahead, United Nations (1988) projections forecast a 15% larger population in the rich countries and 84% more people in the poor world. Current annual per capita primary energy consumption in the poor world averages about 20 MJ (the rich world's mean is close to 150 MJ). Merely maintaining this inadequate rate of primary energy consumption would then boost global use by 32%; even efficiency improvements, conservation and substitutions cutting away 1/3 of today's per capita use would not reduce overall global CO_2 emissions.

But maintaining the poor world's annual mean of 20 MJ/capita would be just extending the existing hardship to another 3 billion people. International comparisons of a wide variety of socioeconomic indicators show that an acceptable physical quality of life cannot be secured for populations consuming annually less than 40-50 GJ of primary energy per capita.[6] The quest for a more decent quality of life and a more equitable division of planetary wealth should thus involve at least a doubling of the poor world's consumption mean.

Even when it is assumed that a doubling of final useful energy flows could be achieved by just a 50% increase of primary consumption (a task requiring huge capital investment for the requisite boost of conversion efficiencies), and further assumed that this major transformation would be accompanied by a 25% reduction of average per capita energy use in all rich countries, the global rate of consumption in 2020 would still come up 33% higher than recent rates. Similarly, Gilland (1988) demonstrated in a detailed forecasting exercise that even stabilizing global CO_2 emissions roughly at the present level is not feasible if the poor world's living standards are to improve. Fundamental considerations of energy supply transitions, conservation limits and population growth make it clear that some widely publicized calls for cutting global CO_2 emissions by 1/3, or even by 1/2, by 2020-2025 are quite unrealistic.[7]

Maintaining the current rate of emissions could be bought only by continued impoverishment outside North America, Europe, Japan and Australia. Otherwise the poor world's expected population growth, coupled with just very modest increases of per capita consumption, will completely eliminate even some very large gains resulting from technical innovation, conservation and social adjustments.

Concluding Comments

An early confirmation of a clear warming signal would intensify the calls for a major global effort aimed at reducing the emissions of CO_2. Such emissions are still the leading contributor to changing radiative properties of the Earth's atmosphere. However, although we have an impressive arsenal of readily available technical improvements, which will be augmented by future innovative designs, as well as a choice of helpful socioeconomic adjustments, these changes would not be sufficiently effective without recognizing the critical necessity for the earliest possible stabilization of global population.

Avoidance of rapid, undesirable and potentially risky global climatic change will possibly be the most fundamental energy problem of the early decades of the next century. If it is, dealing with it will be primarily a matter of accelerating the transition to stationary populations throughout the poor world and moderating the consuming overindulgence of rich nations. Without these two critical ingredients, even the best and speediest realistic combination of technical fixes and economic incentives would be inadequate to achieve the desired cuts in CO_2 emissions.

6/ Four of the most telling quality-of-life indicators — infant mortalities, life expectancies, average daily food availability, and literacy — show sharply diminishing gains after annual primary energy consumption levels reach 40-50 GJ/capita (Smil, 1987).

7/ Perhaps the best example of these poorly thought out exhortations was the call of the Conference on the Changing Atmosphere (Toronto, June 27-30, 1988) for a 20% cut of global CO_2 emissions by the year 2005, and for their halving by 2025. Such shifts could by achieved only by a massive impoverishment of the already poor four-fifths of mankind.

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