ENVIRONMENTAL CONCERNS AND SUSTAINABLE DEVELOPMENT

by

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Abstract

This paper reviews a number of issues related to sustainable economic growth, with reference to the so-called "developing countries". Among the issues considered is the question raised by L. Summers when he was at the World Bank, namely whether there is not a good economic case for encouraging "dirty" industries to migrate from high-wage countries to low wage countries. The paper then reviews the global, regional and local environmental implications of agricultural and industrial development, including a number of tables. Implications for emissions and associated health and other problems are reviewed.

The paper then discusses technological opportunities for "win-win" solutions, especially by utilizing new technologies to "leapfrog" beyond capital and materials intensive Western developmental patterns, such as centralized electric power generation and distribution systems. It briefly considers the impact of pressures on developing countries to adopt "clean technology" in the light of international trade and competitiveness concerns. Finally, it discusses approaches to environmental regulation, concluding with a discussion of the need for a global regulatory authority.

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Background

In recent decades, Asia, Africa, Latin America and the former USSR have undergone significant economic liberalizations which hold forth the promise of accelerating economic growth. East Asia, where the reforms have been in place for the longest time, is currently the fastest growing region on earth. Petroleum and natural gas played a major, but now declining, role for Indonesia. Forest products and natural rubber did the same for Malaysia and Brazil. However, material-intensive processing industries will grow rapidly as the developing regions pursue value-added strategies and shift from raw material exports to intermediate material exports and increase regional demand for capital goods and building materials, especially for infrastructure. This implies an increasing emphasis, especially in China, on so-called "heavy" industry.

Based on considerations of economic geography alone, the most likely pattern of future global industrialization would see much of the basic petrochemical industry moving to the Persian Gulf and North Africa, where most of the world's gas and oil reserves are located. The heavy concentration of petrochemical operations in Texas-Louisiana, and West European port cities (such as Rotterdam, Antwerp, Hamburg and Le Havre) would gradually be phased out as Texas-Louisiana and North Sea oil (and gas) are exhausted in coming decades. Ammonia, urea, nitrate fertilizers and methanol-based chemicals should also be produced near sources of cheap gas, rather than near the consumers.

Similarly, the integrated steel mills still operating in the midwestern U.S. and in the Ruhr area of Germany would gradually be closed down in coming decades. By 2020 or so ferrous metallurgy in North America and western Europe would be almost exclusively based on recycling scrap through so-called mini-mills. The large iron/steel complexes in Japan and Korea would also be phased out a decade or two later. The basic iron and steel industry would tend to concentrate increasingly to the Ukraine, Russia, and China, where both coal and iron ore reserves are large, labor costs are low and an enormous over-capacity was left over from communist era central planning. Much of this capacity is based on obsolescent technology, but modernization would nevertheless be easier and cheaper than new construction elsewhere. The proportion of iron produced by direct reduction, using natural gas, should also grow, mainly in the Mid-East, Indonesia and Venezuela.

Similar considerations suggest that primary aluminum operations should be concentrated in Canada, Australia, Brazil and Russia, while copper and other non-ferrous metal smelting, refining and would increasingly be concentrated in southern Africa, western South America and parts of Russia. Western Europe and the U.S. will increasingly depend on secondary recovery of aluminum. Phosphate fertilizers should increasingly be produced in North Africa from locally mined phosphate rock, rather than being produced in Europe from imported concentrate. Russia and the U.S. will continue to be major suppliers for a long time, however.

Economic geography also suggests that humid tropical regions, Canada and Siberia, will increasingly dominate the world's supply of forest products, including paper and lumber. The dry desert regions, on the other hand, could become major sources of exportable electric energy, either directly or as products of electrolysis (especially hydrogen) as photovoltaic electric generating technology becomes competitive with conventional fossil-fuels in another decade or two. Unfortunately, photovoltaic technology will be very capital intensive, and many of the Mediterranean desert countries where solar arrays could most easily be deployed, like Algeria, and Egypt, are particularly unstable. On the other hand, Morocco, Tunisia and Israel are reasonable candidates for such investments. (The same is true of southern Italy and Greece.)

Yet, for socio-political reasons — among others — there is still great uncertainty with regard to the future development of some of these regions, especially the middle East, the former USSR, and Africa. Political instability and nationalism will undoubtedly slow down the tendencies that pure economic considerations would suggest, especially in the former USSR and Africa. This is partly because instability is anathema to investment; the most unstable regions will receive little or no investment. It is also partly because many developed countries will continue to subsidize agriculture and declining industries (like coal mining and steel), and block imports, notwithstanding free trade agreements. Protectionist pressures will be especially strong if economic growth in the industrialized countries slows further and unemployment continues to rise.

There are other impediments, also. One is the growth of environmentalism in the developing countries (especially India). The environmental NGOs are locally potent sources of resistance to change, especially where they perceive industrial development occurring without pollution controls that are required in industrialized world. The transport and dumping of toxic wastes is a particularly sensitive issue.

Sustainable Development

The phrase "sustainable development" was popularized in the Report of the UN Commission on Environment and Development (UNCED), entitled "Our Common Future", published in 1987 [Brundtland 1987]. The original implication that economic development along traditional lines is *not* compatible with environmental imperatives, and therefore *not* sustainable in the sense of preserving options for future generations, has been lost in much of the recent discussion. This report introduced the term "sustainable development" as a goal. But it failed to define sustainable industrial development in specific operational terms. In particular, it left open a crucial question: the extent to which natural capital can be substituted for by man-made capital.

There are those who think the very notion of sustainable development is an oxymoron, since "development" in conventional terms is based largely on the use of exhaustible resources. How then, can development be sustainable? This argument must be rejected. The mainstream economist's response is that economic growth, in effect, converts natural resources into man-made capital that can be as productive as the original natural resources were. The standard assumption is that it is essentially always possible to substitute man-made capital for natural capital.

Environmentalists, for the most part, dispute the latter contention, however. They argue that human technology cannot now — and never will be able to — substitute for many of the essential functions of the biosphere. Among those functions are the creation and replacement of topsoil, maintenance of climatic stability, the hydrological cycle, the carbon cycle and the nitrogen cycle. Detoxification of industrial wastes by natural decay processes is among the more valuable services of the biosphere. Here the environmentalists have a valid point that must be taken into account.

A detailed list of non-substitutable functions would be too long to include here. Suffice it to say that there is no firm agreement yet among experts on the limits of substitutability, or the extent to which humans can safely intrude on "environmental space". But one thing is beyond dispute, namely that human activities disturb the environment mainly in two ways. The first damage mode is by occupying the land surface, changing land-use by cultivation, animal husbandry, forestry and mining. This reduces agricultural productivity, destroys habitats for many species and reduces biological diversity, which is an important factor in maintaining environmental stability. In fact, potentially irreversible degradation is already occurring in some vulnerable ecosystems, such as semi-arid grazing lands, coastal wetlands and tropical forests. Inappropriate agricultural practices are causing deterioration of farmlands in many areas, through salination of soils, destruction of soil micro-flora and fauna by chemicals and, especially, by erosion and silting. Damage of the first type tends to be comparatively localized. For Asia and Africa, in particular, the most important threat to humans will be the increasing difficulty of feeding a growing population.

The second damage mode arises by converting natural resources into industrial commodities and, eventually, into industrial or consumption wastes. Wastes are inevitably disturbing to the natural environment, to some degree, although some forms of wastes are far less dangerous than others. The potential of the natural environment for absorbing and detoxifying industrial and consumption wastes is quite large but not unlimited. Anthropogenic rates of mobilization of "nutrients" (N, P, S), and toxic chemicals, especially organo-chlorines and heavy metals, are already significantly beyond natural levels and — in some industrialized regions of the world (especially eastern Europe and the former USSR) — beyond tolerable levels. Damage of the second type is not necessarily localized. In some cases it is regional or global in scope.

The key point, for purposes of this article, is that the environmental impacts of industrialization tend to be mostly of the second type rather than the first. Thus, environmental considerations will definitely have an impact on the actual evolution of future industrialization patterns.

To complicate matters, there is also a continuing disagreement with regard to the implications of sustainability for "developing" countries. There are at least four sources of disagreement. The first set of disagreements is based on different interpretations of the scientific evidence. Questions that may not be resolved, even among scientists, for several years — if not decades — to come include: How certain is global warming? How fast will it occur? What consequences will result and who will be affected?

The second source of disagreement arises from differing views on how to factor scientific uncertainties into risk assessment. In effect, the issue is: how much insurance should we buy, and when should we buy it? Questions that frequently occasion argument include: Is the "precautionary principle" really appropriate? Should the risk/benefit equation be different for rich and poor countries? Should one wait for "scientific proof" of harm? What evidence would constitute "scientific proof"?

The third source of disagreement has to do with arguments about the costs of adopting more environmentally friendly" technologies. Mainstream economists using equilibrium models assuming that all current technological choices are optimum, tend to conclude that any major change in technology must be costly and therefore that its adoption will necessarily reduce economic growth. Leaders in most countries, strongly influenced by neo-classical economics, tend to accept this view uncritically. Many engineers and scientists, on the other hand, see enormous opportunities for technological innovation that would be beneficial to the environment as well as profitable to the innovator. (The mainstream economists argue that if such opportunities did exist, somebody would have exploited them already; the technologists tend to reply that if that were so there would never be any profitable opportunity to innovate, which is clearly not the case). Everyone agrees that such opportunities should be exploited, insofar as they exist. The major dispute concerns magnitudes. This article takes the view that "win-win" opportunities for environmental improvement at little or no cost — or even at a profit — are actually quite widespread in the industrial world and probably even more so in the developing countries.

The fourth and last argument hangs partly on the third; namely: if there are major costs associated with adopting "green" technology, who should pay for them? On the other hand, it is undoubtedly true that some "end-of-pipe" retrofit technologies, such as wastewater treatment, smoke control, flue gas desulfurization (FGD), and catalytic convertors for motor vehicles do involve significant real costs. There are continuing arguments about who should pay those costs. Should the famous "polluter pays" principle (PPP) be upheld rigorously, or is there a case for "victim pays"?

Environmentalists in the industrialized world fear that "dirty" industry will move to newly industrializing countries in order to avoid strict environmental controls. This is not the major incentive for investment in newly industrializing countries, in most cases, as noted at the outset. But undeniably it does sometimes occur.[1] Many MNCs claim that they adhere to the same standards whether they manufacture in Europe or Africa, but small SMEs are not as closely scrutinized. Even Shell has been seriously criticized for operating its Nigerian facilities to a much less rigorous standard than in Europe or America. The case of the Union Carbide India Ltd. (UCIL) pesticide plant in Bhopal also raises similar questions, viz. whether the accident was due to design flaws, poor maintenance and/or inadequate procedures at the local level, or inadequate supervision from the higher level.

Some core issues were high-lighted by Lawrence Summers, when he was chief economist at the World Bank,[2] in his famous ("leaked") memo of December 1991. The hypothetical question he raised was: "shouldn't the World Bank be encouraging more migration of the dirty industries to the LDCs?" He offered three reasons "based on narrow-minded economic perspective", to "sharpen the discussion" [Summers, letter to the editor, *The Economist,* February 15, 1992]. They were as follows:

- Measuring health-related losses based on foregone earnings implies that the losses will be least in countries with the lowest wages. In fact, he remarked that "the economic logic behind dumping a load of toxic waste in the lowest wage country is impeccable".

- The costs of pollution control are non-linear functions of the degree of control, whence the greatest improvement can be obtained for the least cost in countries where there has been little pollution abatement so far.

- The demand for environmental amenities for aesthetic and health reasons is likely to have a high income elasticity, meaning that people living in rich countries will be willing to pay more to abate pollution than people in poor countries.

The Economist's editorial argued that Summers' first argument, which implies that the value of pain, illness and human life is less in low-wage countries, is morally unacceptable. However, it goes no to say that even if this argument is rejected, the other arguments deserve to be taken seriously. In fact, it concluded: "when a trade-off between cleaner air and less poverty has to be faced, most poor countries will rightly want to tolerate more pollution than rich countries do, in return for more growth. So the migration of industries, including "dirty" industries, to the third world is indeed desirable" [*The Economist* Feb 15 1992].

A senior economist of the African Development Bank arrived at a similar conclusion (also in an internal document). After reviewing all of the arguments, *pro* and *con,* he concluded: "While Summers' arguments may sound somewhat insensitive to the people of developing countries, his arguments are technically valid" [Shaaeldin 1993]. This author accepted the desirability of such a migration, provided it brings jobs and economic development. He only questioned the implication (that polluting industry could migrate to Africa) on operational feasibility grounds.

Yet this argument, too, is controversial. It assumes implicitly that economic growth along pre-1989 Russian lines, stressing "dirty" (i.e. materials/energy intensive) industry, is a feasible way to improve the welfare of the world's poorest people. In fact there is plentiful evidence that rapid economic growth, as it is now occurring in countries like Indonesia and China, is displacing large numbers of formerly self-sufficient rural people and creating a vastly larger (if not new) urban underclass that makes the problem of poverty even more intractable than it was before. China has admitted to an urban in-migration of the order of 180 million rural people in the past two decades. Another 500 million migrants to the cities of China can be expected in the next 55 years, if current demographic trends (toward urbanization) continue. Similar trends can be observed throughout the developing world.

It is very difficult to imagine how such large numbers of people can be fed, or supplied with clean water, sewage treatment and electrical energy under any circumstances. But it is almost inconceivable that such a dense population could (or would) exist in juxtaposition to high concentrations of `dirty' industries. In short, there is really no place on the earth's surface where such industries can safely be placed without careful attention to minimizing and treating wastes to eliminate harmful emissions. In the long run, for the sake of their workers and the families of the workers, all industries based on processing materials — whether primary or recycled — must be made far cleaner than they are now.

Waste Emissions in LDCs and NICs

Direct emissions data for most developing countries, especially the biggest (e.g. China, India, Indonesia, Pakistan), are virtually non-existent. The World Bank has derived emissions coefficients from USEPA data, as related to U.S. industrial output figures in monetary terms, then applied these coefficients to sectoral output figures in national currencies, converted to US $ equivalents. This procedure is unsatisfactory due to a combination of problems, including unreliable sectoral output data, use of market-based currency exchange rates, excessive aggregation, differences in raw material inputs, scale of production, level of technology, and degree of waste treatment.

Ideally it would be best to proceed by a completely different route, not using monetary data at all. In previous work, using a mass balance approach, we have derived aggregate wastes and emissions by sector for the U.S. for 1988. It is feasible to estimate comparable sectoral emissions for other regions of the world by deriving emissions coefficients directly in terms of major commodity outputs tracked by UN (and other) statistics, considering them as indicators. Using this approach it is also easier to take into account technological differences and other local factors, commodity by commodity, insofar as available data allows.

Sectors and key indicator commodities that can be considered for agriculture include fertilizer consumption, pesticide use, numbers of animals, area cultivated, area irrigated, etc. In the case of forest products, relevant commodities are roundwood, lumber, plywood, pulp, paperboard, and paper. In the case of fossil fuels we consider hard coal, lignite, oil, and natural gas, as well as various petroleum products (gasoline, aviation fuel, diesel fuel, heating oil, asphalt) and electric power generated. Other key commodities include metal ores and metals, non-metallic minerals and products (limestone, cement, clay, glass) and chemicals (sulfuric acid, ammonia, chlorine, methanol, ethylene, propylene, benzene, phenol, styrene, polymers, synthetic fibers, dyes, pesticides, etc).

As a practical matter, due to the number of countries to be covered and limited resources for the analysis, we consider only a few of the possible sectoral categories, namely agriculture, fossil fuel production and consumption (including electric power generation and transportation), and minerals/metals extraction and processing. We discuss other major polluting activities (e.g. pulp & paper and chemicals manufacturing) only briefly.

Agriculture related emissions:

The major mass flows and emissions associated with agriculture are nitrogen losses (as ammonia and nitrous oxide) via various processes, methane emissions from livestock, and soil erosion. Nitrogen losses must be made up by organic recycling, nitrogen fixation by legumes or the application of synthetic nitrogen fertilizers. Erosion is the major cause of phosphorus loss, which must also be made up by the application of phosphate fertilizers.

A detailed nitrogen and phosphorus balance for five regions, c. 1990, including world croplands, and all agro-systems for both the U.S. and China, has been prepared by V. Smil [Smil 1993]. According to Smil, biofixation only accounts for 17% of global crop nitrogen inputs (25% in the U.S., 11% in China) , with synthetic fertilizer supplying 43% of the nitrogen for world croplands (31% in the U.S., 52% in China). Smil also estimates the contribution from atmospheric deposition[3] (8.5% of global N-inputs, 6.2% of U.S. N-inputs and 3.7% of Chinese N-inputs).

Taking everything into consideration, these results imply that future growth in food production in Asia and Africa will be more dependent on synthetic ammonia production[4] than on either organic recycling or legumes. Recent capacity, production and consumption figures, by region are shown in *Table I.*

It is clear that there is currently a great deal of fertilizer overcapacity in the former communist states (eastern Europe and the USSR), but this is largely due to the economic changes that have occurred there. The World Bank's World Nitrogen Survey projected a 37% increase in consumption in Asia from 1992 to 2000, but a 5.5% decrease in the former Comecon countries and a 12% decrease in Western Europe, due to reduction of agricultural subsidies [Constant & Sheldrick 1992].

Long-term projections of population growth and food production in the developing world suggest huge increases in fertilizer use. To put the problem in perspective, FAO data for 1989 suggests that, in the wealthiest countries (Western Europe and North America), grain yield is about 4.4 metric tons/ha with an input of 270 kg/ha of fertilizer [cited in Huq 1994, Figure 8]. For Eastern Europe and the former USSR, yields averaged 3.5 metric tons/ha with fertilizer inputs of 145 kg/ha. East Asia had yields of 3.3 t/ha with inputs of 135 kg/ha. Latin America had yields of 2.3 t/ha for fertilizer inputs of 90 kg/ha. South Asia got 2.25 t/ha with inputs of 77 kg/ha. Finally, Sub-Saharan Africa enjoyed yields of 1.3 t/ha with only 26 kg/ha of fertilizer inputs.

These data can be plotted, resulting in a very significant relationship between yields and inputs (*Figure 1*). The curve shows clearly that fertilizer use increases non-linearly with yield.[5] Thus, to raise grain yields in East Asia by 25% — to current West European or U.S. levels — fertilizer use in that region would have to double. For South Asia to double its grain yields, fertilizer use can be expected to increase by 350%. In the case of Sub-Saharan Africa, grain yields might conceivably increase by 350% but fertilizer consumption would probably have to rise tenfold. In summary, if the world population doubles in the next 55 years, as UN projections imply, most of the increase will be in the developing countries. To allow for urbanization, and increased food consumption per capita, fertilizer inputs in the developing world will almost certainly have to rise by 400% or more.

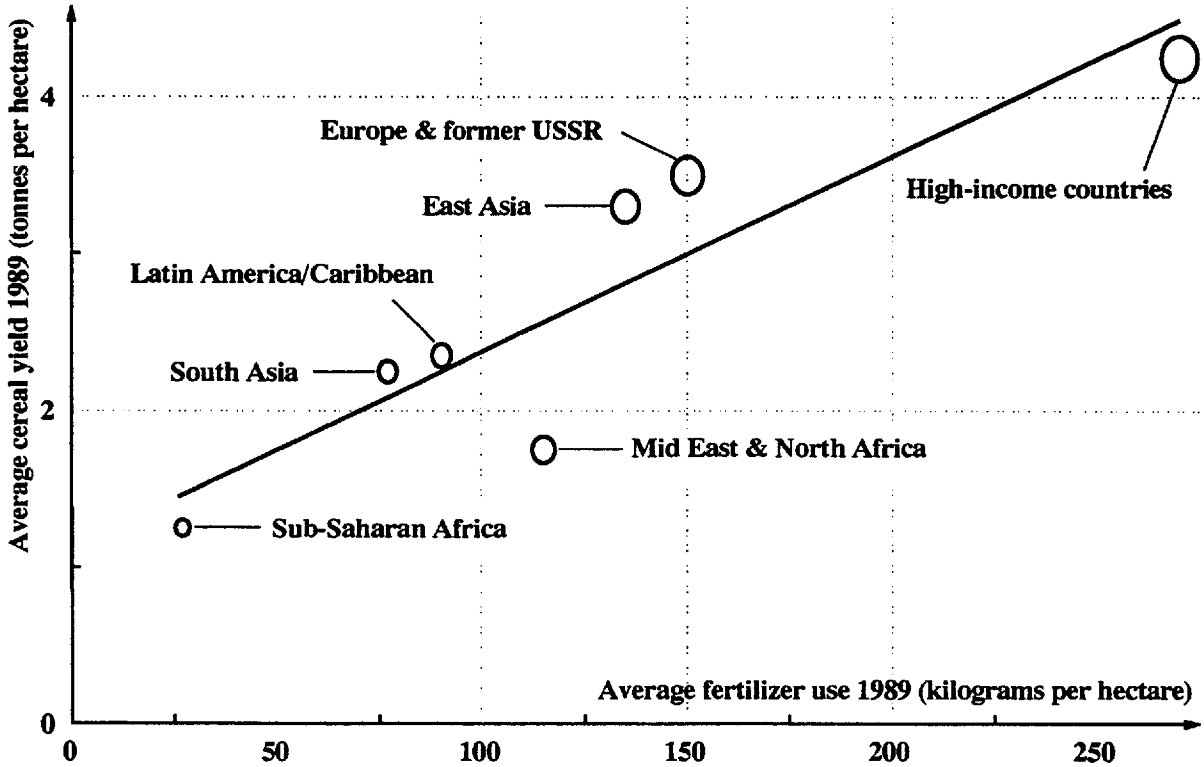

Figure 1: Fertilizer use vs. cereal yield (data source: FAO)

Nitrogen losses for the world c. 1990 were about 95 million metric tons (MMT) currently exceed synthetic nitrogen fertilizer inputs — around 75 MMT (N) — by 20 million metric tons. Smil assumes the balance is made up by "mineralization" of 30 MMT (from fossil biomass) and atmospheric deposition of 15 MMT. This seems unlikely. For instance, it is hard to see why the world average from atmospheric deposition should be higher than the U.S. average, considering that both ammonia emissions (from animals) and NO_x emissions from combustion sources are much higher in the U.S. than in the rest of the world. It seems more likely that Smil overestimated this source of nitrogen as a global input. Many experts believe the global system is out of balance and that the soils of the developing world, especially Asia and Africa, are being "mined" of nitrogen content — which must ultimately be replaced. This implies a growing worldwide nitrogen deficit. It also implies an enormous future demand for fertilizer.

Of the 95 MMT worldwide N-loss, estimated by Smil, the U.S. accounts for 14 MMT. Western Europe probably accounts for somewhat less, perhaps 10 MMT (in proportion to agricultural output). Evidently most of the global N-emissions (roughly 70 MMT) are occurring outside the OECD countries. Subtracting the probable OECD contributions, we estimate the non-OECD breakdown of losses to be roughly as follows:

• erosion losses	40 MMT	(57.0%)
• denitrification	15 MMT	(21.5%)
• leaching into soil	10 MMT	(14.5%)
• volatilization of NH_3	5 MMT	(7.0%)

The denitrification process (due to bacterial action) generates mainly di-nitrogen gas (N_2), but a small proportion of the nitrogen is released as nitrous oxide (N_2O), which is a greenhouse gas. The fraction released as N_2O is not accurately known, and is certainly a function of local soil conditions and humidity. However, the best available estimate of the ratio is 16:1, which implies a global N_2O production of about 1.25 MMT, of which about 3/4 now comes from non-OECD countries.[6]

This pattern of N-losses can probably be expected to continue for the foreseeable future, except that the totals can be expected to increase roughly in parallel with consumption of synthetic nitrogen fertilizer. (In other words, they may quadruple by 2050). It may be noted that global demand for nitrogenous fertilizers actually fell back in 1990 and 1991, largely due to the breakup of the communist regime in eastern Europe and the USSR. European consumption also dropped and North American consumption remained essentially steady. On the other hand, consumption in China and SE Asia has risen sharply and this trend continues. As noted above, most future increases in fertilizer production and consumption will come from developing countries.

Erosion, flooding and topsoil loss is a major environmental problem in all countries. Erosion losses in the U.S. have been carefully monitored (and have been gradually decreasing in recent years). However, despite this, annual losses in the U.S. average 1.5 billion metric tons. In Asia, Africa and Latin America the problem is not under control. Topsoil losses each year in the non-OECD countries, taken as a group, are at least 20-25 times the U.S. level. The fact that erosion accounts for a very large fraction of non-OECD losses of N is significant. It is also the only significant mechanism for loss of phosphorus. Evidently, erosion control would be a very potent tool for reducing demand for synthetic fertilizers. By extension, it would also reduce the very serious pollution problems that are caused by phosphate rock mining, beneficiation and fertilizer production.

Pesticide use in the developing world is also rising faster than agricultural production, as measured in monetary terms [WRI 1994-95 Figure 6.11]. The reasons for this are similar to the reasons for expecting fertilizer use to increase faster than food production. Many pesticides banned or tightly restricted in the OECD countries are being used, and in some cases manufactured, in developing countries. Chlordane and DDT are two cases in point. Pesticide use in the OECD countries has levelled off or even declined in recent years. By contrast, pesticide use in many countries of the Asia-Pacific region has been growing at 10% per year or more, notwithstanding some progress toward integrated pest management (IPM). In India, treated cropland increased from 6 million hectares in 1960 to 80 million in 1985; pesticide production in that country increased 13-fold from 1970 to 1980 and now meets 90% of domestic demand (not to mention exports). India, Indonesia and Russia are major producers of DDT, for instance, though use of that chemical was supposedly ended in the early 1970s [Ayres *et al* 1995].

Agriculture is a major consumer of carbon dioxide and producer of oxygen. For instance, annual above-ground production of harvested crops in the U.S. is between 500 and 600 MMT, plus a slightly smaller amount of above-ground residues, making a total of 1100-1400 MMT but not including grass consumed directly by animals (another 200 MMT). About half of this mass is water; the rest is a combination of carbohydrates, proteins and fats, and a small percentage of mineral substance (ash). Year to year variation depends on rainfall and climate factors. Much of the unharvested crop residue in the U.S. is left on the land and recycled, but in Asia and Africa as much as 2/3 of it is collected and burned — rather inefficiently — for cooking [Smil 1993].

For each 100 units of dry biomass — taken as sugar (ribose) — produced by photosynthesis, 146.7 units of CO_2 are extracted from the atmosphere and 106.7 units of oxygen are returned thence. However, it must be recognized that biomass fed to animals for metabolic purposes reverses the photosynthesis process, consuming oxygen and generating carbon dioxide again. In principle, agriculture and forestry need not affect the global carbon cycle in equilibrium. However, in present practice, they do.

Despite increasing efforts to develop alternative modes of cultivation — especially "no till" agriculture (now strongly promoted in the U.S.) — world dry-land agriculture, as currently practiced, involves extensive plowing of the soil, mainly for weed control. Plowing exposes humus (partially decayed organic material) to rapid oxidation. On a net basis, global agriculture is losing humus faster than it is being replaced. No-till methods have a considerable potential to reduce this loss, but they require extensive re-education of farmers.

The other source of disequilibrium is deforestation. Deforestation (at present) occurs mainly in the tropics, either for logging or to open new land for cultivation or cattle grazing. Forests are major storehouses of fixed carbon. Cutting (or burning) forests releases this carbon to the atmosphere as carbon dioxide.

The rate of deforestation is variously estimated, and the larger estimates are somewhat disputed. However World Resources Institute (WRI) estimated several years ago that deforestation alone contributed 14% to global climate warming potential. Of this, 10% is attributed to carbon dioxide release and 4% to methane release [WRI 1990-1991, Table 2.4]. *(For purposes of comparison, this implies that global deforestation contributes as much CO_2 as all the fossil fuels burned by the US and the former USSR, combined.)*[7] The problem of deforestation is essentially limited to the tropical developing (non-OECD) countries of SE Asia, Africa and Latin America. In fact, Europe and the U.S. exhibit net reforestation, which partially counteracts the loss of tropical forests in terms of the global carbon cycle.

The other major pollutant emissions associated with agriculture are ammonia and methane. Ammonia is associated with livestock urine and manure, especially large-scale feedlots. Most of the ammonia released is volatilized and eventually returned to the land as nitrates and sulfates which are essentially fertilizers. Little if any harm is done, except that some of the nitrogen is lost to non-agricultural land or oceans. Contamination of ground water is a more serious problem, however, since ammonia itself and many organic nitrogen compounds are toxic. Grazing animals, especially ungulates, also produce methane in their stomachs — the work of anaerobic bacteria that help with the digestion of grasses. Methane is also generated in large quantities from wet rice cultivation; specifically, due to anaerobic decay bacteria in the mud. The OECD countries account for the great majority of cattle and sheep in the world, but wet rice cultivation is primarily an Asian phenomenon. Overall, methane from agriculture (wet rice cultivation) accounts for about 8% of global "greenhouse potential" [WRI 1990-1991 Table 2.4].

Fossil-fuel related emissions:

Most industrial and household emissions are direct consequences of the use of fossil fuels. Hence it seems reasonable to consider these sources together. Emissions result mainly from consumption, although significant emissions of methane result from both coal mining and natural gas production and distribution, especially via pipeline. This is important because each molecule of methane is ten times more potent as a Greenhouse gas than a molecule of CO_2. In the OECD countries, distributional losses of methane (i.e. natural gas) have been estimated at 2.9% of total production, not counting losses at the well or at the final destination, depending on the age and length of the pipeline system [OECD 1988]. The gas distribution system of the former USSR — the world's largest producer — is, unfortunately, much leakier. Some foreign experts have estimated losses as high as 10%. A detailed study by the Siberian Energy Institute for 1989 estimated the loss rate to be 3.3% -7% [Rabchuk & Ilkevich 1991]. The loss rate in more recent years is probably higher, due to uncertain maintenance.

Important emissions from fossil fuel consumption, in general, are carbon dioxide, carbon monoxide, sulfur and nitrogen oxides, methane (from coal mining, gas drilling and gas distribution), unburned hydrocarbons, tropospheric ozone and lead (mainly from motor vehicles), small particulates and fly ash (the last mostly from coal burning). Some basic statistics on fuel production and consumption for 1991/1992 in million metric tons are given in *Table II*.

Carbon dioxide generation is exactly proportional to the carbon content of the fuel. Fossil fuels range from 75% carbon (methane) to about 85% carbon (heavy petroleum fractions). Liquid fuels average about 80% carbon. Coal averages around 80 to 85% carbon, due to significant contamination by ash (10%-20%), sulfur (1%-3%), nitrogen (1%-2%), oxygen, water, etc. On an energy basis, however, gas combustion generates only about half as much carbon dioxide as coal, per unit energy output, with petroleum-based liquid fuels intermediate. Thus countries that are heavily dependent on burning coal (such as China, which is 76% coal-dependent) generate proportionally more carbon-dioxide than countries with, for example, access to natural gas. Carbon emissions by region have been estimated by the World Energy Council (WEC) for 1990 and 2020 (*Table III*).

Downstream energy use-efficiency is an important factor. For instance, Chinese industry uses 40% more energy per unit output than industrialized countries [Zhenping 1994]. The steel industry in China uses 78% more energy per unit output than Japan and 68% more than the U.S., for instance [ibid]. The ammonia and chlor-alkali sectors in China consume 43.3% and 35.8% more energy, respectively than western counterparts [ibid]. The electric power sector in China uses 26% more energy (coal) per unit of electricity produced than the Japanese [ibid]. These comparisons are typical, across the whole spectrum. India and other Asian countries suffer from comparable inefficiencies.

The inefficiencies of energy use in LDCs result largely from the fact that there are large numbers of small-scale local producers, as compared to the western pattern of few producers and large-scale integration. A secondary factor is that many of the smaller local producers also depend on older designs and less technologically advanced types of equipment. This, in turn, is a legacy of central planning and communism. Eastern European countries, including Russia, consume up to four or five times as much energy per capita as people with similar income levels elsewhere [*The Economist* "Survey of Global Economy", Oct. 1 1994 p. 36]. The basic reason is that, in Marxist-Leninist ideology, energy was viewed as the most potent driver of growth. All centrally planned countries historically put enormous emphasis on developing energy resources — from coal mines to hydroelectric dams — without imposing price discipline on energy. Energy prices are still subsidized in most of these countries, especially China [Gadgil 1994].

As a consequence of underpricing, lack of producer competition and small scale, only 15% of Chinese steel output uses the advanced continuous casting process for steel, as compared to 50% for the world average and 93% in Japan [Zhenping 1994]. Most Russian and Chinese steel producers still use open hearth furnaces, which have now been totally phased out in the rest of the world. Similarly the dry process for cement manufacturing accounts for only 27% of Chinese production, as compared to 98% in west Germany and Japan and 88% in France [ibid].

A closely related problem for the developing countries is the lag in electrification. Most coal in the OECD countries is used to generate electricity, where scale economies permit greater efficiency of operation and emissions control. By contrast, most of the coal burned in China is consumed directly by small-scale industry or final consumers. Efficiency is lower, and emissions per unit of energy consumed ar higher.

Nevertheless, because of far higher energy consumption, the OECD countries still produce most of the world's CO_2. In 1991 the U.S. consumed about 25% of the world's commercial energy, and generated 4931 MMT of CO_2. Japan consumed 5.4% of the world's commercial energy and generated 1091 MMT of CO_2. The CO_2 output per unit of energy consumed, in both cases, is about the same. In comparison, China consumed 8.5% of the world's commercial energy, but generated 2543 MMT of CO_2, or about 50% more CO_2 per unit of energy consumed than either the U.S. or Japan. The situation in south Asia (India, Pakistan) is probably similar.

There are several other important greenhouse gases, of course. Carbon dioxide accounts for only about half of the greenhouse effect; the other contributors are (in order of importance) chlorofluorocarbons (CFCs) 20%, methane 16%, ozone 8%, and nitrous oxide 6%. Nor does the energy sector, taken broadly, account for all of the greenhouse emissions — again, only about 49% (with agriculture and deforestation accounting for 13% and 14% respectively). An index of "greenhouse potential" has been computed by the Intergovernmental Panel on Climate Change (IPCC), based on measured physical characteristics of the various gases, namely their infra-red (heat) absorbtivities and atmospheric lifetimes. Using this index, the U.S. alone accounted for 19.1 % of the "greenhouse potential" emitted in 1992, followed by the former USSR (13.6%) and the European Community taken as a whole (12. countries), 12.4%. China was third (9.9%), Japan was fourth (5%), followed by Brazil (4.3%, mainly due to massive deforestation in the Amazon), Germany, sixth (3.8%) and India, seventh (3.7%).

The 26 OECD countries altogether accounted for about 42% of the global total in that year. In the short term, declining economic activity levels in Eastern Europe and the former USSR tend to skew the results (exaggerating the OECD share), but in the longer run these countries will presumably recover economically and utilize currently idle capacity. By the late 1990s OECD contributions to global greenhouse potential will be rapidly declining as a percentage of the global total, whereas the Asian contribution (especially) will be growing thanks to rapid economic growth and increasing fossil energy use in Asia and Latin America.

Other important pollutants related to fossil fuel combustion are sulfur dioxide (SO_2), nitrogen oxides (NO_x), carbon monoxide, unburned hydrocarbons, ozone, particulates and lead. The first two have regional as well as local significance; the latter group are primarily associated with urbanized areas.

The best way to estimate SO_2 emissions to the atmosphere is from the sulfur content of fuels, mainly coal, since there is essentially no flue gas desulfurization outside the OECD (and not much in it). Additional sulfur emissions are produced by non-ferrous metal smelters, especially copper smelters. Sulfur content of world hard coals range from roughly 0.5% to 1.1% [WEC 1992]. The two largest producers (China & USA) average 1% and 0.9% sulfur content, respectively. Russian coal is relatively low in sulfur (0.3-0.5%). Most others are in between. Brown coals have more variable sulfur content, but Polish brown coal ranges between 0.6%-0.9% sulfur. For the world as a whole the average is probably around 0.8%. On this basis, world sulfur emissions from coal combustion in 1991 would have been 0.008*4500 = 36 MMT (S) or 72 MMT (SO_2). This calculation must be regarded as uncertain by at least 10% either way. It is also probably an under-estimate, since it does not include sulfur from petroleum (both refineries and heavy fuel oil) or from copper, lead and zinc smelters where sulfur recovery is not complete.

The latest year for which relatively detailed sulfur dioxide emissions data are available, for (some) individual countries, is 1990 [WRI 1994-95, Table 23.5]. However, only Europe (E & W), North America, Japan, Turkey and the former USSR are included. The OECD total for 1990 was 38.5 MMT (19.25 MMT S) including Turkey but excluding E. Germany and Oceania. For the U.S. alone it was 21.1 MMT (10.55 MMT S). The former COMECON[8] total for that year was 24.8 MMT (12.4 MMT S). It is noteworthy that sulfur emissions for Japan, Europe (both west and east) and the former USSR declined quite sharply from 1980 to 1990, largely due to substitution of natural gas for coal. US emissions also declined, but only slightly, whereas emissions for other regions (such as Turkey) increased, reflecting accelerated economic activity.

The World Energy Council (WEC) has published global estimates of sulfur, nitrogen and carbon emissions for 1990 and 2020, with more detailed breakdowns for Africa, Asia and the Mid-East, and Latin America (see *Table III*) [EPRI 1994]. The WEC estimates for the former COMECON countries were much higher than the WRI figures, viz. 16.3 MMT (S). The WEC estimates for the rest of the world, Africa, Asia/Mid-East, Latin America, and Oceania add up to 25.8 MMT (S). By comparison, on the basis of coal consumption (1.6 billion metric tons) and sulfur content (assumed to be 1%, on average) one would have to estimate coal-related sulfur emissions of around 16 MMT (S) for Africa, Asia/Mid-East, Latin America, and Oceania in 1991, probably up about 1 MMT (6%) from 1990.

Data for NO_x is available for the same countries as above, also in 1990 [ibid]. For the OECD plus Turkey minus E. Germany and Oceania, the total was 35.5 MMT, of which the U.S. accounted for 19.4 MMT. For the former COMECON countries, the total was 8.5 MMT. Nitrogen emissions (in MMT N) as estimated by the WEC are also given in *Table III.*

Whereas the total emissions of the two gases are quite similar in the advanced industrialized countries (the SO_2/NO_x ratio is 1.1:1), this is not the case elsewhere. The ratio of SO_x to NO_x in former COMECON countries is nearly 3:1 according to the WRI data. The major reason for the difference is that motor vehicles are responsible for a major fraction of the NO_x emissions, with large power plants being responsible for most of the rest. On this basis, one would assume a similar or larger ratio for Asia, Africa and most of Latin America (except for the megacities: Buenos Aires, Rio de Janeiro, Sao Paulo, Lima, Bogota and Mexico City). Assuming a 3:1 ratio, as above, we conjecture that NO_x emissions in the other world regions would have been about 10 MMT in 1990. This will increase rapidly, however, if motor vehicle traffic increases as expected.

Data on other emissions (CO, HC, Pb, heavy metals particulates) is much scarcer. In fact it is available for only a few countries, mainly the U.S., and parts of western and eastern Europe. There is no way to estimate world totals, except perhaps in the case of coal fly ash, which can be estimated roughly from coal consumption and ash content [WEC 1992]. Even the best quality commercial coals average close to 10% ash content. Coals used in some countries (e.g. India and North Korea) have up to 40% ash content. Chinese coals average 13-14% ash.

Coal ash ends up either (10-30%) in solid form (clinkers) which are dumped or used for road paving, or (70-90%) in fly ash which goes up the stack. In the OECD countries the latter is mostly (up to 99%) captured and removed by electrostatic precipitators. But much less efficient means of fly ash removal — such as centrifugal separators or baghouses — are typically used in less advanced industrial countries. These technologies typically allow something like 20% of the ash to escape as particulates i.e. smoke. The most dangerous particles are the smallest ones, less than 10 microns in diameter. The rate of removal of these particles is not much better than 95% even with the most advanced electrostatic precipitators and probably no better than 50% otherwise.

Coal ash is mostly a mixture of light metal oxides, which are comparatively harmless, but coal ash also contains traces of almost every heavy metal, including significant amounts of arsenic, chromium and mercury. Coal and oil burning accounts for up to 15% of natural mercury emissions in the U.S. In China, where more coal is being burned in a smaller (and much more densely populated) area, it is likely that the mercury buildup is significantly more rapid. Arsenic and cadmium are also contained in ash. Fractions of all of these toxic metals are volatilized during the combustion process and escape as vapor, which only later recondenses in the atmosphere and is washed out by rain. Thus, toxic metals tend to build up, over time, in the soil and vegetation downwind from any coal burning power plant or industrial plant. Even when the ash is captured, something must be done with it. Usually it is used for road surfaces or landfill. In either case, heavy metals can gradually leach into surface or ground water. The leaching process is accelerated by acidification of rainwater, due to sulfur and nitrogen oxides.

Because of lower efficiency it is clear that, in the developing world, carbon monoxide, unburned hydrocarbons and particulates are all produced in significantly larger quantities in relation to fuel used (and even more so in relation to GNP per capita) than is the case in advanced industrial countries. The relative lack of emissions controls makes the problem far worse. Evidently, major investments in pollution controls for fossil fuel burning power plants and other industrial facilities cannot be long delayed in rapidly industrializing regions of the world.

Mining and manufacturing emissions:

Wastes and emissions from these sectors are difficult to summarize briefly. Disregarding pollutants from fossil fuel production and consumption (discussed above), the major wastes remaining to be discussed are solid and liquid wastes from mining operations, air pollution from metallurgical operations, and chemical industry wastes. The latter industry is relatively undeveloped outside the OECD world, except in Eastern Europe, Russia and some NICs.

Regarding mining operations, it is primarily the tonnage of material handled and processed, and secondarily the technology used for concentration (beneficiation) of the ore that are of importance environmentally. Iron ore is produced in large quantities mainly because iron itself is used in large quantities: according to the US Bureau of Mines, approximately 900 MMT/y (million metric tons) of concentrated ore was shipped in 1991, not including about 325 MMT of gangue, plus comparable quantities of overburden left on site. See *Table IV*. The world's biggest iron ore producer (and consumer) is the former USSR (now the CIS), followed by Brazil, Australia and China. The average ore grade (world) is about 58% (Fe), which means that 525 MMT of Fe was contained in the ore that was shipped. Most of this was converted first into pig iron in blast furnaces, and subsequently into finished (cast or wrought) iron or steel.

Since iron ore is a mixture of iron oxides, mainly Fe_2O_3), the mass differential (375 MMT) consists mostly of oxygen, which combines with the carbon in coke producing carbon monoxide and carbon dioxide. A relatively small amount of other mineral impurities (mainly silica) is removed in the smelting process and, combined with limestone, producing a harmless mineral product, slag. In the US, blast furnaces consumed 57.4 MMT of ores in 1991, producing 13.3 MMT of slag. Assuming the same ratio worldwide, global iron slag production for 1991 was about 210 MMT. In the OECD countries slag is increasingly sold as a useful by-product for paving and other purposes. However old-style slag heaps are still a problem in some parts of the world.

Most blast furnaces use coke from coal.[9] Coking is probably the dirtiest process in the ferrous metal sector; modern coking plants in the industrial world emit only small amounts of pollutants. However facilities built under communist regimes, such as those in eastern Europe, CIS (former USSR) and China, emit significant amounts of pollutants: particulates, benzene, xylene, toluene and other aromatics, ammonia and hydrogen sulfide. Regarding coking emissions, no specific data is available for the countries where environmental controls are weak. However it is significant that Chinese authorities acknowledge that energy consumption in Chinese coking ovens ranges from 40% to 100% more than non-Chinese averages [Zhenping 1994, Table 1]. (This is a reflection of end-use inefficiencies noted earlier). Much of this excess energy loss is directly translated into pollutant emissions, which are largely uncontrolled in China and other developing countries.

Aluminum, like iron, is obtained from ores of relatively high grade. The mining itself is a surface (open pit) operation, since the bauxite, the only commercial source of aluminum, is normally found in a thin layer. Almost all of it is found in the tropics. See *Table V.* Overburden is removed by means of draglines and left on site. About 2.2 tons of crude bauxite ore yields one ton of dehydrated alumina (Al_2O_3), by means of the so-called Bayer process. This process consumes large amounts of lime and caustic soda, and generates a caustic waste called "red mud" (because of its iron-content) which is usually left in ponds near the alumina plant. Red mud is useless, corrosive and can pollute ground water, especially in wet climates.

The reduction of alumina to pure aluminum metal is done by electrolysis, and is invariably sited near a cheap source of electric power. About two tons of alumina and 0.5 tons of carbon anodes (made from petroleum coke), plus a small amount of aluminum fluoride, are needed to produce one metric ton of aluminum metal; the mass differential is converted into carbon monoxide and carbon dioxide, plus some toxic fluorides. (The latter are dangerous if not rigorously controlled). Apart from fluoride pollution, aluminum smelting is normally done in remote places to exploit cheap electric power, often subsidized. In general the aluminum industry is moving away from western Europe and North America. Recent smelting facilities have been built in Australia (using coal as a source of energy), Brazil and China.

But most metals come from ores of far lower grade. For example, zinc ore averages 4.4%, lead ore 3%, nickel ore 2%, copper ore averages 0.9%; uranium ore averages 0.002%, gold ore and platinum ore around 0.0003%. This means very large amounts of ore must be processed to produce a very little bit of the pure metal. Thus, to produce a ton of pure metal, on the average, 22 tons of zinc ore, 30 tons of lead ore, 45 tons of nickel ore, 110 tons of copper ore, 50,000 tons of uranium ore and 330,000 tons of gold or platinum ore must be extracted, concentrated — perhaps in several stages — and finally smelted. See *Tables VI-XI.*

In all of these cases concentration wastes, normally left near the mine, are very significant in absolute magnitude. In some cases, the concentration process is extremely dirty. Usually the ores are finely ground, screened, and then the useful fraction is separated from the waste fraction (gangue) by a chemico-physical process known as "froth flotation". Chemicals are added to the finely ground ore. These chemicals adhere preferentially to the surfaces of the desirable mineral fraction, encouraging clumping and coagulation and allowing the clumps to be captured in a chemical foam. The ore concentrate is then removed but the chemicals are simply left behind in huge impoundments near the mines. In dry climates (such as Arizona and Chile) probably no great harm results, but in wetter climates — as in Africa — there may be leaching into groundwater.

Most non-ferrous metals are obtained from sulfide ores. Prior to the actual smelting stage — which is very similar to iron smelting — most sulfide ore concentrates (including Cu, Zn, Pb and Ni) are first converted to oxides by heating in the presence of air to drive off the sulfur as SO_2, along with volatile metallic contaminants such as arsenic. This was one of the dirtiest of all industrial processes in the past, and there are still some old copper mining/smelting districts where literally nothing will grow, due to heavy arsenic contamination combined with erosion of denuded slopes. Certain valleys in Tennessee and Montana in the U.S., the Sudbury district of northern Ontario (where Canada's nickel mining/smelting industry is located), and parts of the Kola peninsula of northern Russia, are among the better known examples.

Modern practice in the non-ferrous metals sector is to recover the sulfur as sulfuric acid. In fact. recovered sulfur is now a significant fraction of total sulfur supply in some countries (12% in the U.S.) But this is a recent development. Even twenty years ago (1974) the US Bureau of Mines estimated that only 30% of the sulfur content of copper ore smelted in the U.S., and 43% of the sulfur in lead ore was recovered as sulfuric acid [USBuMines 1975]. Recovery from zinc ore was 81%. The remainder was driven off into the air as SO_2. The sulfur recovery rate in non-ferrous smelting in the U.S. today is 95% [USBuMines 1994]. This is also true for copper smelters located in Western Europe and Japan, where emissions regulations are tight.

However, sulfur recovery in major exporting countries is much lower. A study done in 1989 estimated sulfur control indices for major exporting countries as follows:
Australia (0%), Philippines (0%), Peru (0%), Chile (14%), Canada (26%), South Africa (39%), Zambia (70%) and Zaire (76%) [Chapman 1989, Table 3]. The average level of control for all exporting countries was estimated to be 32% [ibid]. Based on very sketchy information, admittedly, it is likely that emissions control for non-ferrous smelters in the former USSR and China is still very low if not zero.

Another kind of pollution problem arises in gold (and silver) mining. Modern large-scale gold mining operations use a process known as "heap leaching" using sodium or potassium cyanide as an agent to concentrate the gold ore. The cyanides remain in impoundments which can (and sometimes do) leak into groundwater. However an older and much more dangerous process was once standard practice., namely the use of mercury to amalgamate gold particles in low-grade ores (4-20 ppm). The gold-mercury amalgam is then heated, which vaporizes the mercury and leaves the gold. The vaporized mercury is probably oxidized in the atmosphere, but it ultimately condenses on soil or vegetation, washes into the rivers, and is taken up by plankton and aquatic food chains in the most toxic form, namely methyl mercury (CH_3Hg), which is biologically concentrated by fish and birds and is the cause of "Minimata disease".

This process was extensively used for gold and silver mining in the past, leaving large areas — such as the famous Potosi mines of Bolivia — as virtually uninhabitable "moonscapes". The mercury amalgamation process is still being used by small-scale illicit gold miners in the Amazon basin (known as "garimpos") who account for roughly half of Brazil's gold production (*Table IX*). Illicit gold mining is not limited to the Amazon basin, of course, but occurs in remote regions of many less developed countries. There is evidence that gold mining is now one of the major uses of mercury, and causes of mercury pollution, in the world (after chlorine manufacture).

Chemical manufacturing is a major source of pollution in the western world. Up to now, the chemical industry — with some exceptions — remains largely concentrated in the most highly industrialized countries, especially western Europe and the U.S. One exception is ammonia production (for fertilizer) which is spreading rapidly into areas of the developing world where fertilizer use is increasing. This spread is limited, however, by the availability of natural gas, which is the primary feedstock. Thus, new ammonia production facilities are clustering particularly in the middle east, and Indonesia, where gas is available, as shown in *Table I*. The ammonia synthesis process is relatively benign, environmentally, except for its high energy intensity; the major pollution problems arise from careless use, not production, as discussed earlier.

Phosphate fertilizers are also increasingly in demand in the developing world. However, in this case, processing into fertilizer (via phosphoric acid) is likely to move in coming decades to the countries where phosphate rock is mined. At present there is a great deal of phosphate mining in North Africa, but relatively little production of phosphoric acid. (See *Table XII*). Most of the African ore now seems to go to Western Europe for processing into fertilizer and other chemicals (such as detergents). North Africa would be a logical location for this industry, in conjunction with petroleum refining. Sulfuric acid could be made from sulfur recovered from local petroleum refineries and natural gas processing plants and used for processing phosphate rock mined in the same region. Unfortunately, the political instability of North Africa, together with territorial quarrels between Algeria and Morocco, are undoubtedly holding back this natural evolutionary development.

Apart from the fertilizer-related chemicals and sulfuric acid, the modern chemical industry is largely built on or around petrochemicals. The basic feedstocks for this industry are chlorine, together with methanol, ethylene, propylene, butylene and butadiene. Here again, new refinery capacity is mainly being added in the middle-eastern countries, and Indonesia, largely to exploit large petroleum and gas reserves. The latter, especially, are difficult to utilize as fuel, whence chemical uses are strongly indicated. The new facilities in these industries are generally highly efficient and utilize the most advanced technology. They do not create significant pollution problems.

Chlor-alkali production is a partial exception. In the first place, chlor-alkali plants (based on electrolytic cells) are not necessarily very large in scale. There are many small scale chlorine plants around the world, including China. Only electric power and salt (brine) are needed. The most modern electrolytic cells— known as the diaphragm cell and the membrane cell — are now used almost exclusively in the U.S. and Japan, mainly due to environmental regulation. These cells are relatively benign. However an older type of cell, known as the de Nora cell, uses mercury as an electrolyte, and some mercury escapes. Most European chlorine production still uses mercury cells and many chlorine plants in Asia and elsewhere in developing countries also use the mercury process. (It is difficult to document, but probably a number of the mercury cells in the U.S. and Japan were exported to Asia and still operate there). In any case, this single process probably accounts for the largest fraction of worldwide mercury use.[10] Moreover, whereas in western Europe and the U.S. the remaining mercury cells are carefully controlled to recover the lost mercury (mainly in wastewater sludge), in the developing world it is likely that most of the mercury lost in the process simply escapes into the air or water.

It is not possible in a short article to discuss in detail all the significant sources of pollutant emissions. One of the major polluting industries in the west in past decades has been the pulp and paper sector. This sector is likely to grow in importance in the humid tropics, especially in Brazil, Indonesia, Malaysia and Russia. Even the cleanest pulp and paper mills in Scandinavia do not recycle all of the chemicals they use; significant amounts of chemicals end up in water treatment sludge or fly ash. In Russia, by contrast, a pulp and paper plant dumps (or did until recently) enormous quantities of untreated wastes into Lake Baikal, one of the ecological treasures of the world. Pulp and paper mills in remote areas have been resistant to installing expensive treatment facilities.

The same is true of other classic polluters, such as leather tanning, and electroplating. Leather tanning, an extremely dirty industry, which uses large quantities of toxic chromic acid, has been moving rapidly out of Europe and North America, where strict pollution standards are required. Brazil and India are the two chief "beneficiaries" of this particular shift. (Shoe manufacturing is a rapidly growing industry in both countries). However, the bulk of the chromium chemicals — not to mention organic wastes — ends up in the rivers. Electroplating is another industry dominated by small firms that use toxic heavy metals — especially chromium and cadmium — much of which ends up in the rivers. Tough environmental controls in western countries are rarely enforced in the developing countries. The rapid growth of light manufacturing in Asia and Latin America is sure to increase pollution from such sources.

Environmental Impacts of Emissions

There are three clearly distinguishable sorts of environmental problems. These three categories have very different implications for economic development and should be dealt with in different ways. The most contentious issues are not necessarily the most difficult to resolve from a scientific perspective. The three categories of problems are global, regional and local. A brief characterization follows:

Global impacts

The environmental problems of truly global significance are: (1) the buildup of greenhouse gases in the atmosphere with (probable) climate warming effects, resulting in shifts in precipitation patterns, shifts in storm tracks, increased probability of large storms (resulting from increased temperature gradients between oceans and continents), reduced snowpack at higher elevations, faster and earlier spring runoff with more damaging floods, increased probability of summer droughts, increased stress on forests and other natural ecosystems, (2) sea level rise, which is a consequence of climate warming, but a serious threat to low lying coastal areas and estuaries, (3) damage to the stratospheric ozone layer allowing more short-wave ultra-violet radiation (UV–II) to reach the earth's surface — with adverse impact on many marine organisms that reproduce in shallow water, not to mention causing skin cancer and eye damage to humans, and (4) loss of biodiversity as a storehouse of potentially valuable genetic information, especially for purposes of plant breeding for insect and disease resistance. The loss of genetic resources due to tropical deforestation is also a global problem as well as a regional one.

The potential impact of sea-level rise on coastal provinces of China has been considered in detail in a recent report prepared jointly by UNEP, the World Bank and China's National Environmental Protection Agency. Based on a scenario of continued CO_2 buildup and climate warming, an increase of 70 cm in mean high tide level is envisioned off Shanghai and 60 cm off the Pearl River delta (Canton) by the year 2050. A one meter rise in sea level would result in storm flooding and inundation of areas below the 4-meter contour line, which includes a number of major cities and 92,000 square km of fertile agricultural land with a projected population of 76 million people. These are the areas of China currently experiencing the most rapid economic growth, and protective dikes and river barrages are probably feasible to counter the threat via conventional engineering techniques such as the Dutch have developed (at great cost, however).

But the countries most seriously threatened by increased storminess and sea level rise are the countless islands, estuaries and coastal zones of southeast Asia, from Bangladesh, Indonesia, Indo China and the Philippines, not to mention Melanesia and Polynesia. These are areas that are still mostly rural and poor, but not necessarily unpopulated. While the Chinese coast may be protected, it is doubtful that tens of thousands of small islands can be protected. Since evacuation in advance of perceived and immediate need is highly unlikely, the people living in threatened locations are very much at risk.

Similarly, the possibility of changing atmospheric circulation patterns is most threatening to densely populated tropical countries adapted to, and dependent on the annual monsoon. By contrast, the potential beneficiaries of climate warming (if any) would be the unpopulated northern lands of Canada, Scandinavia and Siberia.

Conceivably, disturbances to the carbon, nitrogen and sulfur cycles could be beneficial by increasing the biological productivity of the earth. However storminess and sea-level rise help nobody; nor is there any gain from loss of genetic resources, except short-term gains to cattle ranchers, loggers, miners or other resource extractors.

Regional impacts

The major environmental problems of regional significance are: (1) acidification and toxification of soils and surface waters resulting mainly from emissions of combustion products (SO_x and NO_x) and fly ash, but also to some extent from other industrial processes, such as mining and smelting as discussed above; (2) deforestation, desertification and erosion, and (3) loss of natural biodiversity as a protection against catastrophic outbreaks of diseases and/or pests affecting trees and crops.

Regional environmental problems mainly affect people downwind or downstream from sources of pollution, regardless of level of industrialization. For instance, the Rhine, Elbe, Vistula, Po, Rhone, Danube and other big rivers of Western Europe drain mostly into shallow seas (North Sea, Baltic Sea, Adriatic Sea, Black Sea), with limited regenerative capacity. All countries bordering on the Baltic Sea suffer from high levels of pollution generated by industry in Germany, Poland and the former USSR. The Black Sea and the Adriatic Sea are now very nearly dead, and other parts of the Mediterranean seem to be not far behind.

Major river basins in Asia, Africa and Latin America, such as the Brahmaputra, Mekong, Nile and Parana, which pass through many countries almost inevitably generate conflicts over environmental issues. Downstream countries need flood control, electric power, fish, and water for irrigation; upstream countries are the sources of runoff, silt from erosion (due to mining and hillside deforestation), and pollution (from industry and mining); upstream countries also depend on the rivers for transportation purposes, which would be disrupted by large dams.

The Aswan High Dam project in Egypt illustrates the sort of problem that can arise. The Egyptians (encouraged by the Soviet Union) wanted the dam to be in their territory, under their control, despite warnings that the very dry air and porous ground surrounding the dam site would result in significant water losses (to evaporation and leakage), not to mention losing the benefits of the annual silt deposition that had formerly kept the Nile Valley fertile for over two millennia. Today the Aswan dam is generally regarded as an environmental disaster, for a variety of reasons, not least of which is the shortage of water downstream (necessitating the diversion of much of the electric power from the dam to pumping water) that has resulted.

Nevertheless, large dam projects are under way in China (e.g. Three Gorges) and India, among other places, despite warnings of likely problems. In the Chinese case, the flood control benefits downstream in the flood-prone Yangtze and Yellow River valleys may compensate for the loss of farmland in the to-be-flooded region upstream, and the large number of people who must be displaced and resettled.[11] In some other cases, however, the benefits appear to be much more limited. Western aluminum companies, in particular, have encouraged some developing countries (e.g. Ghana) to build large dams, flooding valuable agricultural land, to make cheap electric power available for aluminum smelting. The Akosombo dam on the Volta River in Ghana, which flooded 5% of the land area of the country, sells 3/4 of its power to an aluminum smelter at very low prices [Young 1992]. The Tucurui dam on the Tocantins River in the Amazon basin (part of the Carajas project) sells one third of its power output to an aluminum smelter, also at subsidized prices. The Brazilian government itself estimated that 60% of the value of its aluminum exports were subsidies [ibid].

Regional problems also arise from regional dispersion of air and water pollutants, both from industry and domestic activities. The dispersion of mercury from illicit gold mining in the Amazon basin was mentioned above. This mercury is showing up in fish and birds that eat fish. A number of native tribes in the Amazon region are at risk, not to mention the effects on other species, especially predators with high trophic levels.

Air pollution can cross national boundaries even more easily than water, and in any direction. (The movement of the cloud or radioactive contamination from Chernobyl, which travelled first Northwest into Sweden, and subsequently into western Europe, is a case in point). The problem of environmental acidification has been recognized (so far) mainly in northern and central Europe and eastern North America, but is already becoming severe in the industrializing coastal zones of China, due to the large amounts of coal being burned there.

The most publicized, and arguably most important, regional environmental problem is tropical deforestation. In this regard, the primary focus of world attention during the 1980s was Brazil. The Brazilian government, and the Amazonas state government had offered numerous financial incentives to "open up" the region, including road building, tax benefits for cattle ranchers, attempts to attract the electronics industry to Manaus (the state capital), and the enormous Carajas project (partially financed by the World Bank) which includes an iron mine, an electrified railroad to carry the ore, an iron smelter designed to use charcoal made from wood, an aluminum smelter (ALCOA) and the Tocantins dam which provides cheap (subsidized) hydro-electric power to the complex.

Throughout the 1980s fires burned throughout much of the Amazon region, mainly to clear land for cattle ranching (which can seldom be sustained for more than a decade before the soil becomes too degraded to support grazing fodder. The impact of tropical deforestation and resulting CO_2 global climate change has already been mentioned. There is also a potential for regional meso-climatic effects, since most of the rainfall that humidifies the Amazon basin also originates there, as evapo-transpiration from the dense vegetation. As larger and larger areas are denuded, the rate of evapo-transpiration falls and the rainfall over the rest of the region inevitably falls too. This would eventually result in changes in the species mix and could lead to widespread forest die-back in the drier areas. Then natural fires would become more frequent and more damaging and the remainder of the forest might become unsustainable in its present form. The natural succession cannot be predicted in this event, but it would have a devastating impact on biodiversity.

Among other impacts, formerly remote Indian tribes have been exposed to "civilization", including invasions of their ancestral territory by loggers, miners and others. There have been several well-documented (but unpunished) massacres. A significant fraction of the Amazon forest has already been destroyed (around 10% according to satellite surveys) and, even though the financial subsidies of the 1980s have generally been stopped, the floodgates seem to have been opened. The Amazon area is continuing to undergo rapid and irreversible "development". The same process has spread beyond Brazil to Colombia, Peru, Venezuela, Guyana, and now Suriname. Much the same thing has been happening in southeast Asia, especially Malaysia, Indonesia and Indo-China. During the past two decades much of the virgin forest of these areas, especially Sumatra and Borneo, have already been cut for logs, mostly shipped to Japan for plywood production. Now the south Asian logging companies, which don't bother about replanting or "sustainable" management, are looking for new forests to exploit. An Indonesian company was recently given a 50 year logging concession covering 15% of Cambodia's remaining forest [press reports, Oct. 1995]. The government of Suriname is proposing to offer concessions to logging companies to cut "selectively" 4.8 million hectares, or over 40% of the country's area. The proposed contracts would allow logging roads but prohibit clear-cutting. One of the first concessionaires (an Indonesian company called Mitra Usaha Sejati Abadi, or MUSA) has demonstrated how it interprets the contract: it cuts forest roads 45 meters wide, evidently to take all the trees it can [*International Herald Tribune*, Sept 6, 1995]. To enforce its rules, Suriname has a forestry service consisting of two professionals and one (broken) Jeep.

Local impacts

The major localized environmental problems are (1) exposure to toxic chemicals, especially pesticides, (2) urban air pollution (e.g. smog and smoke), (3) contamination of soils, rivers, streams and ground water with untreated sewage, pesticides, and other toxic industrial wastes. The majority of these problems are urban. However pesticide use is essentially a rural problem, except to the extent that some contamination of food may occur.

It is difficult to construct a meaningful numerical index of collateral damage to human health and the environment due to pesticide use. There are, of course, numerous examples of pesticide poisoning of workers due to improper use. There are also disturbingly many examples of pest species developing immunity to one or more pesticides (over 500 to date) or formerly secondary pests exploding. The case of cotton pests is the best documented. (Cotton consumes 10% of all chemical pesticides, worldwide). For instance, in Mexico, the tobacco budworm became a major cotton pest as a direct result of attempts to eradicate the cotton boll weevil. It devastated the Mexican cotton sector, which dropped from 300,000 hectares in the 1960s to 500 hectares in 1970. A similar episode occurred in Egypt, where attempts to eliminate the cotton bollworm using DDT caused a secondary pest, the white fly, to explode into major pest status [WRI 1994-95, p 113].

The health and other costs of pesticide use are not well documented. In the case of the U.S., a fairly careful — but incomplete — economic cost-benefit study recently published set the aggregate benefits of pesticide use to farmers at $12 billion, as compared to identified health and other costs of $8 billion [Pimental *et al* 1993]. This implies a small margin of benefits over costs, but it omits a number of items, including accidental poisonings, domestic animal poisonings, wildlife losses, and damage to soil microflora. The situation is probably less favorable for many of the LDCs. While quantitative data is extremely scarce, a number of country studies have concluded that pesticide use in agriculture actually cuts productivity, when associated health costs are counted. For example, one UN study estimated that use of insecticides resulted in measurable environmental and health costs for Nicaragua of $200 million in foreign exchange in 1973, while cotton exports earned a maximum of $141 million in the same year [cited by Swezey *et al* 1986, p.30]. Similar results have been reported in a number of other countries.[12]

The peculiarly urban problems of polluted air and water are becoming worse each decade. This is largely due to rural poverty and overpopulation resulting in massive migration to the cities. In fact, there is almost no scope for rural population increase, and virtually all future population growth in the developing (non-OECD) world will be urban. Urban air pollution in the major cities of the developing world is already far worse than anything to be found in the west. It arises from three sources, (1) direct use of low grade fuels — from animal dung to coal — for cooking and heating, (2) small scale industry (such as smelters and foundries) operating with essentially no environmental controls and (3) automotive traffic. While vehicle density is less than in European and American cities, many vehicles use low grade fuels, maintenance is poor, and emission controls are essentially non-existent. Improperly maintained diesel engines are particularly obnoxious sources of particulates.

Health problems arise especially from sulfur and fine particulates in the air, especially with diameters less than 10 microns. These particles (essentially "smoke") are not easily controlled.[13] The best solution is to reduce emissions at the source, especially by exploiting alternative sources of energy, substituting electricity or liquid fuels for direct combustion of coal and other solids. As regards motor vehicle traffic, developing countries should strive to encourage alternative means of personal and goods transport through pricing and tax policies and promotion of efficient mass transit.

As regards the social and health costs of air pollution, there are few if any data from the developing world. However, estimates by four different groups, for U.S. conditions, using various methodologies, have estimated health and other social costs c. 1990 arising from air emissions as follows [Gadgil 1994]:

SO_2: \$600 - \$2500 per metric ton
NO_x: \$200 - \$6500 per metric ton
Total Small Particulates (TSP): \$300 - \$4000 per metric ton

It should be noted that the lowest estimates in all cases were made on behalf of an electric power utility, New England Electric Co., in regulatory hearings. The damage estimates by other groups, in almost all cases, were several times higher.

It is not clear how applicable U.S. damage estimates would be for developing countries, given the income differentials. Monetary damage estimates are largely attributable to health-related costs. On the one hand, as Summers pointed out in his famous World Bank memo cited earlier, developing countries with limited financial resources appear to set a lower implicit value on human life and health — as imputed from public and private expenditure patterns — than richer countries do. Expenditure on health related problems is obviously limited by income.

On the other hand, it must also be pointed out that aggregate health costs also depend on the number of people exposed to pollution. Thus population density in polluted areas is also a key factor. Extremely densely populated areas, such as East and South Asia, will experience greater damages than less densely populated areas at comparable income levels. Taking both income per capita and density into account, it may not be unreasonable to assume that damage costs per ton of pollutant would be of the same order in magnitude in Asia as in the U.S. (In any case, more rapid economic growth in Asia would narrow the income differential over time).

On this basis, the following calculation is suggestive. Coal consumption in China is now about 1.5 billion metric tons. Assuming 14% ash content, this implies around 200 million metric tons of ash. Assuming 70% of this is fly ash and 10% of the latter consists of small particulates that are not removed at the source, implies TSP emissions of 14 million metric tons (which is roughly the official Chinese estimate). Assuming a median damage figure of \$2000/metric ton, this would amount to \$28 billion, a very significant figure in relation to current Chinese GDP. While the current damage figure is obviously disputable, there is no doubt that it would increase at a much faster rate than either total population or GDP. In fact, it would increase roughly in proportion to the product of GDP per capita and *urban* population.

In China, urban population in 1950 was 61 million; currently it is around 330 million; by 2050 it is expected to be around 1 billion, according to the UN's population projections. The situation in India is, of course, comparable if not worse. This urbanization will, among other things, remove very significant amounts of land from cultivation. In China, for instance, cities, towns, and infrastructure took 324,000 km^2 of land in 1994, as compared to 1,364,000 km^2 that was cultivated [Heilig 1995, Table 3]. In 1988/89 alone 174,000 hectares (1740 km^2) was lost to cultivation and converted to urban or industrial use [ibid, Table 4]. Assuming this modest rate of conversion continues unabated, only about 100,000 km^2 more land would be lost to cultivation in China by 2050. But if population increases as projected and the density of cities does not increase, urban area would have to increase by a factor of 3, i.e. to about 1 million km^2, mostly at the expense of nearby land, which is mostly cultivated at present. So the potential loss of cultivated land could be as much as 650,000 km^2 or close to half of the current total.

A closely related local/regional problem associated with urbanization and economic development is groundwater shortages. The cause of the water shortages now plaguing much of northern China is debatable, but the most likely cause is too many wells and too-intensive pumping of groundwater for industrial and municipal purposes. Wet rice cultivation and fish farming have both been abandoned in this region of China. The Heaven River no longer exists, and canals that formerly brought water to Beijing are now dry. In late 1993, the water resources minister of China (Niu Maosheng) said that 82 million rural Chinese were suffering water shortages, along with 300 Chinese cities. of which 100 were suffering extreme shortage [Tyler 1993].

Apart from loss of farmland and sources of food supply, urbanization of this magnitude brings with it enormous problems of water treatment, sewage treatment, air pollution and waste disposal. As it happens, these local problems are the ones most likely to have a direct impact on human health and welfare in the industrializing (and urbanizing) countries. Sewage treatment and air pollution are already extremely serious problems in most developing countries; these problems can only get much worse.

Human waste is still collected (in traditional "honey buckets") in some smaller Asian villages and towns and recycled to local farms where it is spread directly on the soil. But this practice is not only unhealthy (because of bacterial contamination of locally grown foodstuffs) but logistically impossible in large urban areas.

As it happens sewage has also been recycled successfully through fish farms in some large Asian cities, notably Calcutta. The system, developed about a hundred years ago, consists of a series of shallow ponds in which sewage— 700 million liters/day — is biologically converted in several stages [Mukerjee 1995]. The sludge from the sewage ponds is also mixed with organic solid wastes, composted, and returned to the cities' market gardens. At the final stage, algae grow and are fed on by carp and tilapia which can be harvested and safely consumed by humans. This complex system produces 20 tons of fish and 150 tons of produce each day [ibid]. Unfortunately, this successful recycling system is currently under severe threat by the State government, which created a township east of the city (in the 1960s), started filling in the ponds and selling the land to real estate developers. Among other consequences, the sewage canals, which formerly flowed east, now back up during monsoon season and flood the city itself.

A combination of sewage and waterborne industrial wastes from chemical manufacturing, textile processing, pulp and paper manufacturing, food processing, leather tanning, electroplating and other industries are rapidly converting most rivers in former USSR, India and China into large sewers. The Volga, once the home of the giant sturgeon (source of black caviar), is nearly sterile today, and the sturgeon population in the Caspian Sea has fallen to the point where the species is in danger. The rivers of China formerly supported numerous fish-farmers and produced fish in significant quantities. This formerly contributed significantly to the Chinese diet. Many of these fishermen have been effectively deprived of their livelihood in recent years due to the effects of river pollution. (The main rivers of the Indian subcontinent, the Indus and the Ganges, has been too polluted by sewage, for a long time, to support a population of edible fish). What is now happening in the rivers of China can be expected to happen in coming years to the Brahmaputra and the Mekong.

In poor countries, at present, solid waste is not a major problem, because there is relatively little to begin with and because sorting, separation, and recovery of useful materials constitutes a local source of employment. For example, there are 25,000 "ragpickers" in Calcutta, who separate and recover all paper, plastic and metals from municipal wastes [Mukerjee op cit]. However, increasing consumption-based prosperity along western lines would both increases the quantities of this sort of waste, but also make recycling more difficult.

Technological Opportunities

At present, the OECD country political establishments, under the influence of large multinational firms, are still promoting and protecting conventional technologies for petroleum and gas exploration, refineries, mining, coal-burning (and nuclear) electric power plants, together with all of the associated infrastructural investment. Yet, at the same time, environmentalists almost universally deplore these technologies, pointing out that large-scale investments in them are, in effect, commitments to a future pattern of industry and transportation similar to the present pattern in the OECD countries. But the countries that formerly industrialized on this basis have a non-increasing present total population of less than a billion people.

By contrast, the more densely populated Asian countries now embarking on this course already have a total population two and a half times greater. Moreover, unlike Europe and Japan, this population is still growing and urbanizing. However, the dominant economic interests in the OECD countries are still promoting a form of 19th century industrialization that may not be sustainable for Asia, even in the unlikely even that the industrialized world could voluntarily agree to cut back very sharply on the use of fossil energy. (Obviously such a cutback would also be opposed by these same economic interests). Sadly, the international organizations promoting industrial development (IBRD, UNDP, regional development banks) have largely promoted the same centralized, capital-intensive and technologically obsolescent technologies. They are heavily staffed by consultants from the same industries.

For instance, the nuclear power industry, together with a number of governments (such as France) with nuclear capabilities, promote nuclear power as a "clean" alternative to fossil fuels. Given the potential for military (or terrorist) use and lack of any agreed solution to the nuclear waste disposal problem in any country, public opinion in Europe and America is largely unconvinced. Nevertheless, support for nuclear power among a significant portion of the scientific establishment siphons off financial support that could otherwise greatly accelerate the development and use of newer technologies, especially photovoltaic (PV) power. The latter is by far the most promising long-term solution to the energy problem, especially for countries that do not yet have large investments in conventional systems in most rural areas.

There are good reasons for believing that the new technologies such as photovoltaic (PV) power will eventually displace the older ones without heavy promotion by governments (i.e. contrary to the interests of established industrial sectors). However, at the present time even a modest boost from the public sector could make a considerable difference in terms of the *rate* of penetration of the new technologies. The newly industrializing countries have a difficult choice to make. On the one hand, they can adopt the "tried and true" older technology with all its environmental disadvantages. This is the approach that is normally recommended (even insisted upon) by bankers, whether local or western. The consequence of this conservative approach can be that they will be left behind, once again, when the technology inevitably becomes obsolete, whether or not the facilities built with borrowed money have been amortized.

On the other hand, developing countries can adopt a "leapfrogging" strategy. This means taking the lead in adopting and implementing a newer technology that is at the beginning of its life cycle, as Japan did so successfully with the Basic Oxygen Process for steelmaking (developed in Austria) and with the transistor as a substitute for vacuum tubes in radios and TV's. Of course, this means taking all of the financial risks of cost overruns, delays and even possible failure. But, private risks of this kind can be minimized with government help. The potential gains from a successful gamble, such as the above, can be enormous, as they were in the Japanese case. The Japanese became world technology leaders in both steelmaking and consumer electronics.

In particular, photovoltaic (PV) power seems to offer such an opportunity now. While it cannot substitute totally for conventional central station power, at least in the short term (i.e. until better storage means are developed), it could nevertheless be combined very beneficially with hydroelectric power plants by permitting the latter to operate mainly at night, thus conserving water. It also has enormous advantages for rapid rural electrification (at least for daytime uses) in countries without a fully interconnected national grid. In addition, there are obvious environmental benefits, especially in contrast to coal or nuclear power.

Trade and Competitiveness

Another area where the Summers argument that was summarized briefly in the introductory section of this article is relevant is in regard to concerns about the competitive effects of "clean technology". Newly industrializing countries have argued at times that they should not be forced to meet the same standards enforced in OECD countries. Here, the economic argument for allowing lower standards in developing countries is essentially that set forth by Summers. Some leaders of newly industrializing countries — notably Malaysia — even argue that pressure from the West to adopt "clean" manufacturing technology (including end-of-pipe treatment technology) is another form of neo-colonialism.[14] The argument is that this would require the LDC to buy the technology from the more industrialized countries, or to pay royalties, thus (it is asserted) constituting a "competitive disadvantage".

However, the Summers line of argument is considerably complicated by concerns about international competitiveness and free trade. Assume the case of an exporter competing in the same export market as an OECD competitor but producing in an LDC with weak environmental legislation, or weak enforcement, and using a "dirty" process. Assume both competitors are subject to the same environmental standard (in that market), which requires some "end-of-pipe" pollution controls. Both have to purchase the treatment technologies from the producers of that equipment and from consulting engineering organizations (which are *firms*, not countries). Unless the newly industrializing country imposes a high tariff on the imported equipment, it pays the same price as its western competitor for the equipment, while retaining the advantage of lower labor costs. It suffers no competitive disadvantage. The same conclusion applies if the anti-pollution device is attached to a product (i.e. an automobile) that is exported.

Developing countries particularly fear that environmental policy will be used as a trade barrier to deny them entry into markets. GATT rules do not permit countries to restrict market access on the basis of domestic environmental policies or practices in the exporting countries. The issue is being considered by the WTO, but firm guidelines do not yet exist. Developing country exporters take the view that lack of environmental regulation is a comparative advantage no different in principle from a comparative advantage based on the possession of skills and technology. Environmentalists differ sharply, especially in cases where global threats or loss of species are involved. But it is also true that protectionists with more mundane interests can use these arguments.

The relationships between environmental policy, trade and competitiveness are too numerous and complex for a concise summary at the level of specific industries. Needless to say, such relationships do exist. A useful compendium of case studies has been prepared by the UNIDO secretariat [Kumar 1995]. The author of that study remarks: "It is shown that there may be short term adverse effects on certain sectors or industries in developing countries, but the impacts at the macro level are insignificant. In the medium to long term the competitive position of *efficient* firms in export markets will most likely improve due to improved quality and environmental standards" [ibid p. 1].

International Regulatory Policy

Setting trade and economic issues aside, there remains the problem of environmental regulation in the international arena. This is a very difficult area. Libertarians, who believe that government's role should be minimized, tend to argue that the best way to deter pollution is for victims to sue polluters for infringing property rights. Apart from a host of practical objections, it must be pointed out that this is hardly feasible at the international level. A private party in Austria, for instance, can hardly expect to obtain relief from a polluter in Slovakia through either the Austrian or the Slovakian courts.

International law and the World Court in the Hague offer no way out of this fundamental difficulty. Cases are referred to the World Court only by prior international agreement, and then rarely. Moreover the Court has no legal power of enforcement over sovereign states, except when an overwhelming majority of other states (i.e. the UN Security Council) is willing to impose sanctions in support of the decision. It has moral authority, to be sure. This could be of some value in the event one or two small and weak countries were flouting an international convention (such as fishing rights), but it is inconceivable that a major power would allow the world court to void a domestic policy perceived as important to its national interest.

At the national level there are two alternatives to case-by-case litigation. One is for a centralized government agency (e.g. EPA) to take on the responsibility — under a legislative mandate — for setting general rules, namely regulations or standards. One condition for the viability of such rules and regulations is that they can be enforced, either by inspectors or auditors, or by the courts. Some agency must have the power to impose punitive sanctions (such as fines) on violators.

The other alternative for government is to use fiscal measures (taxes, subsidies) to accomplish the same thing. (See below). The first approach is, by far, the predominant one in most countries at present. It need hardly be said, however, that the regulatory approach cannot be applied *directly* with any hope of success at the international level. It would mean piling another supra-national regulatory bureaucracy on top of the existing national ones, which are already being heavily criticized for inefficiency. The notion of an international agency (analogous to the World Trade Organization, WTO) whose function is only to coordinate and "harmonize" national environmental regulations makes somewhat more sense. Such an agency is in the process of being created for Europe.

However, to extend this approach to the world scale seems to be very remote, at least for the present. At present, the only feasible route to international control seems to be via negotiations between national governments. This route is fraught with difficulties, since virtually every national government (no matter how corrupt or unrepresentative) has an effective veto over any proposal at the negotiating stage. Even when the agreement is so watered down as to be virtually meaningless, it is likely to be disregarded. This is because the diplomats who negotiate on behalf of most countries do not have the authority to make binding long term commitments. They can only operate within general guidelines. Only legislatures can ratify treaties, and (in the U.S. case, for instance) they are very likely to refuse to do so on a matter on which there is partisan disagreement. This seems to have been the fate of the so-called "Rio Accord" internationally agreed on at the Rio de Janeiro Environmental Summit in 1992, calls for stabilization and modest reductions in greenhouse gas — mainly CO_2 — emissions by the year 2000. (More stringent requirements were vigorously opposed both by petroleum exporters and by the U.S. government). The U.S. Congress has failed to take any action to achieve even this modest commitment.

The most that can be hoped for — and it is usually a vain hope — is for international agreement on generalized objectives (such as the Montreal Protocol on CFCs) to be implemented at the national level by either regulatory or fiscal means.

It is only in regard to ozone-destroying substances (CFCs) that any true global environmental policy can be said to exist. The so-called "Montreal Protocol" calls for voluntary phase-out of the use of certain long-lived chloro-fluoro-carbons (CFC 11, CFC 12 and CFC 21). This phaseout, which involves the substitution of another class of chemicals, with hydrogen in the molecule, is already under way. It has been accepted by the western chemical companies that manufacture the products, and is not being opposed by any significant group.

Another area of potential international agreement (where the Summers argument is particularly relevant) concerns the shipping of wastes from industrial countries to low wage countries for disposal. This sort of trade would seem at first glance to be economically beneficial to both, assuming the disposal method itself were safe and assuming the agreement to be voluntary and "arms length". In particular, discarded manufactured objects like cars, personal computers, TV sets, refrigerators and the like could be economically disassembled in low wage countries, for the recovery of remanufacturable items like bearings, pistons, pumps, and motors, or materials like antifreeze, CFC refrigerants, copper wire, aluminum, precious metal contacts or catalysts, rubber, glass, or stainless steel. This would both provide employment, reduce western waste disposal problems and reduce the need for virgin materials and the pollution problems associated with extraction and processing.

Unfortunately, the most visible trade in wastes has not been remanufacturable items of the type noted above. Toxic and hazardous wastes have been shipped routinely — although often illegally — from industrial countries to neighboring countries for disposal. For a long time, West Germany shipped its industrial wastes to East Germany, in exchange for hard currency. Now that Germany is unified, many of the waste dump sites have been uncovered, creating a whole new set of disposal problems. The biggest flow currently seems to be from Germany to Poland (or perhaps beyond). The German "Green Dot" program has also created a mountain of potentially recyclable packaging waste, but (as yet) no recycling industry has arisen to use the material. As a consequence of the supply-demand imbalance, established waste recycles in neighboring France, the Netherlands and Britain were undercut. To ameliorate this problem, shiploads of the German packaging wastes were sent to Indonesia as "raw materials". But there, too, the impact was to undercut the established ragpickers and deprive them of a livelihood.

Environmental groups in the west, like Greenpeace, have strongly opposed the practice of trading wastes of any kind, essentially moral grounds. The moral "high ground" seems to be that the "rich" should not have the right to ship their wastes to "the poor", even for a suitable fee. In 1991 17 African countries signed a convention on hazardous waste movement and management, in part due to Greenpeace revelations of secret deals to dump some toxic wastes in some countries. In effect, environmentalists argue that free trade principles should be suspended for wastes; each country should be required to dispose of its own. The same principle is already being applied *within* some western countries, at the state or municipal levels. This makes it extremely difficult (for instance) to create a viable disposal or recycling system for small volume wastes on a national basis. The question of waste trading should be re-examined.

At present, most of the pressure for environmental regulation comes from the most industrialized countries, especially the Protestant countries of Europe and North America. It seems to be driven mostly by health concerns, some of them exaggerated, and concerns about threats to the survival of exotic species and "nature". Much of the Rio conference was devoted to arguments on the recognized problem of protecting biodiversity. Among the arguments often used in support of the proposed biodiversity convention was (and is) that drugs to cure cancer, AIDS or other ailments might be found in plants or other life forms threatened with extinction. Most of the unexploited biological "potential" in this regard is (probably) in the tropical rainforests. Unfortunately, this argument in defense of protecting biodiversity resulted in a bitter squabble on the ownership of such organisms, should they be discovered. Governments and NGOs representing tropical countries insisted that any such discovery on their territory would constitute a part of its national wealth, and that pharmaceutical companies should pay royalties for the use of any such drug. At first sight this idea seems reasonable enough. But as soon as the details are considered, the problem quickly spins out of control.[15]

However, if economic development and industrialization continue at the present pace in Asia, especially, the health problems characteristic of too-rapid, unregulated industrialization will soon become acute — as they already are in parts of Russia and eastern Europe. Once the causes are understood, the coming environmental crisis (in Asia, especially), is likely to bring about a much stronger demand for environmental regulation than anything yet seen in the West.

At first, this demand for regulation may be resisted by economic interests on the grounds that it is "anti-growth". But, there is another possibility. In fact, it might encourage (much needed) technological innovation. Regulations that are intelligently drawn can actually encourage economically beneficial technological innovation.[16] For instance, Michael Porter of Harvard Business School has argued that regulation-induced innovativeness can constitute a national competitive advantage [Porter 1991, Bonifant *et al* 1995]. Porter believes that both Japan and Germany have exploited such an advantage, at least to the extent of developing an export sector in the area of "end-of pipe" pollution treatment equipment. In fact, this argument has much to recommend it. But, at least for the present, the "induced innovation" viewpoint has few proponents in the business community.

Fiscal Policy Approaches

It is really because of the pragmatic objections to administrative regulation that environmental economists have long argued for greater use of fiscal devices like effluent taxes, subsidies (and, more recently, tradeable emissions permits). Economists generally oppose subsidies of any kind, and there are very few in the environmental domain. The elimination of environmentally unfriendly subsidies (such as subsidies to coal mining) is universally recommended and generally ignored.

As regards taxes and tradeable permits, environmentalists have traditionally opposed such solutions on the ground that they are *immoral*. This argument is superficially simple: both "sin" taxes and tradeable permits seemingly permit the "rich" to buy the "license to pollute". The phrase "license to pollute" has become a pejorative in the vocabulary of many environmental activists, who have been the strongest supporters of the centralized regulatory approach, notwithstanding its demonstrable inefficiency and high administrative costs.

Effluent taxes are, in principle, far more efficient than administrative regulations, insofar as they "steer" behavior in the desired direction while allowing maximum discretionary choice to economic decision-makers who are affected. Again, this is a fairly well-understood advantage (at least among economists). The economists' answer to the moral argument against allowing the rich to buy the right to pollute is strictly pragmatic: first, the rich can buy more of everything than the poor, so the issue appears to be a question of social justice, not environmental protection. Second, since society has limited resources available to apply to a variety of social purposes (including providing assistance to the poor) it makes sense to use these resources as cost-effectively as possible.

Public finance economists traditionally oppose the use of taxes for "social engineering" purposes. The idea is that social problems should be addressed directly, by the elected representatives of the people, and that professional economists have no business in the game. From this perspective taxes should be socially neutral, economically optimal, and used only to generate needed revenue. This notion is somewhat idealistic. As a practical matter, taxes have always been determined largely on the basis of political and administrative feasibility, not economic efficiency. Historically, governments have taxed whatever was easiest, mainly trade, regardless of impact on economic activity. Later, governments (influenced by economists) have shifted taxes away from trade to producers and finally to consumers and workers. The dominant forms of taxation today, however, are actually indirect taxes on individuals collected by employers. By the same token, governments have avoided taxing things (like pollution) that are hard to measure. This is partly for administrative simplicity and partly to keep the tax burden as "invisible" as possible.

Moreover no tax is really socially neutral and some are much better (or worse) than others, depending on one's point-of-view. It seems more sensible to acknowledge that taxes do have social (and environmental) effects, and that an effort should be made to design tax schemes that minimize harm. From this perspective, "sin" taxes (including effluent taxes) are very attractive.

Apart from other possible objections, however, enforceability is again a salient issue. A carbon tax might be feasible in the OECD countries, where it could be enforced by existing agencies and collected from primary producers or processors of carbon-based fuels. But who is going to enforce a carbon tax on dung or charcoal gatherers in Kenya, India or Nepal? Worse, if the price of fossil fuels is driven up by a tax applied only to large scale fossil fuel producers, it would have the perverse effect of driving up the price of charcoal and, arguably, the rate of tropical deforestation. Only an alternative and cheaper form of generally available energy can have the desired effect. This would involve a much more complex program including subsidies and other kinds of interference by the government.

The libertarian objection to using effluent taxes as a means of correcting for market failures challenges the economists' assumption of authority to decide when, or whether, a market is not working correctly. It doubts that economists are able to decide (by means of CVM) what the "right" price — or tax — for each good or service should be [e.g. Sagoff 1993]. However, the counter-argument is simple and powerful: taxes must be collected to finance government functions. Why not tax obvious "bads" rather than "goods"? There can be no good moral reason for taxing labor while subsidizing coal mining or tobacco growing.

Nor is there any real need to engage in endless debate as to relative goodness or badness. There are several criteria that would be widely acceptable. For instance, unemployment is bad, so taxes on labor should be reduced if possible to encourage more job creation. Pollution is bad, so if taxes are needed (for revenue) they should be imposed on the extraction and use of materials that eventually become pollutants.

However, for historical reasons, extractive resources are relatively undertaxed — mostly because of worries about international competitiveness — while labor and income are over-taxed. The social consequence of overtaxation of labor is that the price of labor is too high *vis a vis* the price of materials and energy. As a direct (if not immediate) consequence, businesses in countries with high labor costs tend to concentrate their efforts in increasing labor productivity — which means cutting jobs and employment. As long as other, newer jobs are being created by technological innovation, this is no problem. But where new jobs are *not* being created in sufficiently large numbers (as in Europe) unemployment rises to unsustain-able levels and social problems become acute.

While effluent taxes, as such, may not be an attractive possibility except in special cases (because of enforcement problems), taxes on extractive resources that *become* effluents later in the life cycle would pose little or no enforcement or administrative problem. The mechanisms already exist. The real problem is competitiveness: if any singe country chose to tax the use of natural resources it would raise the prices of domestically manufactured products, making imports more attractive and making exports less competitive. This is anathema in today's competitive world.

Yet, if only because other policies have failed, a consensus appears to be building gradually (though it may require another decade) among western economists and governments, to the effect that excessive taxation of labor — mainly to finance social security — is the main root cause of rising unemployment. This implies that either social security protection must be sharply cut, or taxation in the OECD countries *must* be shifted away from labor and income, to reduce the existing disincentives for job creation. (Probably, in the end, both policies will be needed, despite the political pain).

The revenue gap can (and should) be met in principle by taxing effluents, congestion and other "bads". In practice, however, the most likely compromise will be increasing taxes on consumption of non-renewable natural resources, especially fossil fuels and metals. This would change the ratio of labor costs to resource costs, thus favoring more use of labor and less use of non-renewable resources. It would also be a strong signal to encourage re-use and recycling and the development of technological alternatives to conventional fossil energy sources. The economic development strategies of newly industrializing countries should take these future developments into account.

The fact that a global resource tax would make sense compared to command & control environmental regulation (in an ideal world) does not make it a feasible proposal in the real world. Even the OPEC cartel has been consistently undermined by cheaters, despite the obvious self-interest of its members in cooperating. National tendencies to maximize perceived national short-term interests — even to the extent of "beggar thy neighbor" — are not about to be supplanted by global cooperation on any except the most basic of principles.

National governments have a potential answer to the competitiveness problem. They can impose equivalent taxes on imports and rebate the taxes on exports. But this tactic, though widely used in other contexts, is also condemned as "protectionism", and not without reason. (It is a tactic that old-school protectionists would certainly try to exploit). There is a real danger that a such a policy of "border adjustment", however well-intentioned, would be politically abused for protectionist purposes. The risk might be worth taking if a better solution cannot be found. However, there may be another solution (tradeable import quotas), discussed below.

Tradeable Emission Permits

The tradeable permit (to emit some pollutant, such as SO_2) is a useful idea. There are two versions. In both versions the total allowable emissions would be determined at the national level or, eventually, at the world level. In one version, "rights" to emit the pollutant would be allocated to existing polluters in proportion to past activity levels, perhaps with some allowance for prior attempts to reduce emissions. This would minimize transitional problems. It would also create a "property right" with some market value. Owners of permits would have an incentive to maintain, or even increase their value. Thus permit-owners would have an incentive to identify and prosecute cheaters. (While this is unlikely to be effective in practice, at least the permit owners would presumably by willing to assist the government in its enforcement efforts).

In the other version, the rights would not be allocated free to past users, but auctioned off to qualified entities (much the way rights to offshore petroleum exploration, or use of unallocated portions of the electromagnetic frequency spectrum are currently allocated in the U.S.) In this case, the government, or the international agency, would receive the income from sale of rights, which could be applied to environmental protection, R&D, or to any other designated public purpose.

The theoretical virtues of tradeable permits are greater than the virtues of effluent taxes or resource-taxes in another respect. First (from a libertarian perspective), once the markets are established, the government's opportunity for interference is automatically minimized, especially if the total "lifetime emissions" permitted could be fixed in advance, allowing markets to optimize resource use in the temporal dimension as well as the horizontal one. This is a subtle point, but extremely important. This is because it is actually optimal to *plan* the transition far ahead but to make most of the actual investments toward the end of the transition period. This minimizes costs, because it allows for the maximum of technological progress in the alternative technologies before they need to be standardized for large-scale use.

The major difficulty with tradeable emission permits is that, in most cases, viable auction markets for them cannot be created easily, if at all. The reason is that tradeable permits will have market value if, and only if, there is some authority (probably centralized) capable of detecting unauthorized emissions and penalizing the polluters with sufficient certainty and severity to deter cheaters. Realistically, the scheme in its simple form can only be applied in a very few cases.

It takes very little imagination to see the limiting factor: if there are more than a few potential polluters, the enforcement system will be either very expensive and cumbersome, or it will be honored mostly in the breach.[17] Thus it was feasible to create a tradeable permit system for sulfur dioxide emissions (in the U.S.) because most of the polluters are large electric power producers, of which there are only a few hundred and which are already fairly tightly regulated. By similar logic it would be feasible to create a tradeable permit system applicable to petroleum refineries, steel mills, or chlor-alkali plants. It would *not* be feasible to create such a system for smokers or drinkers or private cars or backyard barbecues. What about NO_x emitters? What about CFC or N_2O emissions? The more, and the more diverse, the sources of emissions, the more difficult and less feasible the enforcement.

Apart from enforceability issues, both variants of the tradeable permit concept are subject to the same moral objection as the effluent tax, namely that the "rich" can buy a "license to pollute". (This applies also to countries). On the other hand, the first variant (rights allocated to prior users) would presumably be acceptable to libertarians, given that they accept the need to reduce emissions. Libertarians would presumably object to the second variant (rights auctioned by the government) on grounds that it would increase the revenue and power of government.

Tradeable Consumption Quotas

Is there a way around the inherent difficulty (namely, enforcement) of implementing tradeable emissions permits? Setting aside the problem of international competitiveness (discussed later), there is an alternative. It is analogous to the imposition of taxes on materials (including fuels) at the extraction stage rather than taxes on effluents. Briefly, the scheme in question would be to set national quotas for aggregate consumption of certain *physical* commodities, allocate those quotas equally to all adult individuals residing in the country, and allow trading of unused quotas in regulated (but untaxed) auction markets. The major technical problem is to devise a medium of exchange that is effectively immune to counterfeiting. The medium of exchange could be printed paper, like paper money or "bearer bonds". But, in modern conditions, it could also be personal bank accounts accessible only to the individual, accessible by means of a personal code. The code could be magnetically imprinted in plastic cards, e.g. in small ROM chips embedded therein.[18]

The rationing principle is applicable quite generally to all marketed products, subject to one critical condition: the existence of a rational physical measure — "pollution indicator" — suitable both for setting national quotas and for determining the "pollution potential" of each product. There are various possibilities for a choice of indicator. This is not the place for comprehensive discussion of the possibilities and the limitations. However, one candidate would be potential carbon dioxide emissions, which are the basis on which a carbon tax would be determined. Potential sulfur dioxide emissions would be another possibility, given that the sulfur content of most fuels is quite accurately known. A more general measure, such as "exergy-content", could also be used.[19]

The first step, which necessarily involves government, is to determine the maximum total quantity of the selected pollution measure (e.g. carbon dioxide emissions) that is to be permitted within the country in the next year. The total quantity, divided by the adult population, is the allowable individual quota, or ration.

The next step is to ascertain the technical "pollution potential" of each unit of each final product. This task could be very difficult for some possible choices of measure (e.g. human toxicity) or if extreme accuracy is desired. However, for the three specific pollutants mentioned above and some others, given a standardized methodology, the detailed implementation could largely be delegated to manufacturers subject to occasional government audits.

The third step is to label *each* product in terms of its "X" equivalence. The system would work as follows: Each producer would be required to specify both the X-content ("X" being carbon, sulfur, or exergy) of all of its inputs and the X-content of all of its products. The first (larger) number is the *indirect* X-content, which takes into account X used in the process; the second (smaller) number is the *direct* X-content of the product itself. Both figures would be included on the product label. The producer must then subtract the direct X-content of its own marketed products from the X-content of all purchased inputs and "pay" for the difference in terms of purchased emission quota points. This would, of course, add an increment to the product price, exactly as if it had been taxed.

Each subsequent intermediate processor along the product value-added chain to final consumer would be required to do the same thing, i.e. add up the (direct) X-content of *all* purchased inputs, and subtract the X-content of products it sells, treating the difference as a loss for which quota points are needed. For reasons discussed hereafter, it would also be necessary to calculate a new indirect X-content for its products, by adding the indirect "X"-contents of all purchased inputs. This must also be included on the product label for the next consumer to see. Firms would be required to report to a government authority (possibly the tax authority) the X content of both purchased inputs and marketable outputs, together with evidence of purchase of quota points sufficient to account for the difference, which is presumably lost as emissions.

The problems of implementation are essentially technical. The use of credit cards is already widespread. The administrative mechanisms for auditing already exist (having been put in place throughout Europe to implement the VAT). To check whether a particular firm (say) is reporting correctly, the auditor need only compare the X-content of inputs, as reported by the firm in question with the X-content of the same commodities as reported by the sellers. In the event of a discrepancy, the auditor would have several optional ways to proceed, depending on whether the discrepancy were indicative of fraud or merely error. Given the large and growing capacity for information processing in our society, solutions to these problems should not be beyond the realm of feasibility.

It is obvious that the actual X-content of the final product may be much less than the X consumed along the chain. In fact it could even be zero. Yet, for the three measures identified above (fuel carbon, fuel sulfur and exergy) it is safe to say that, at each stage, the pollutant is *either* emitted *or* embodied in the main product or a by-product and carried to the next stage of processing. There is no significant third possibility, such as conversion to a harmless form. This would also be true for some heavy metals, like, mercury. It is very nearly true for arsenic despite the existence of at least one long-lived and probably harmless form, namely gallium arsenide. It is partially true for cadmium, again excepting its use in nickel-cadmium batteries. For copper, lead and zinc, the structural uses are generally harmless, whereas the chemical uses are dissipative and potentially harmful. Other pollutants which are not simply passed along the chain, but may be created or transformed along the way, include NO_x, chlorinated hydrocarbons, CFCs and most toxic organic and inorganic chemicals.

The final step is the requirement that each purchase of any product — whether by a business or an individual — be accompanied by an appropriate purchase of "X-quota ration points" or a corresponding deduction of points from the customer's credit account. In the case of individuals the deduction can be done automatically, as it is with debit cards in wide use today (e.g. telephone cards). The only difference is that, whereas the money cost of the product is transferred from the buyer to the seller, the "ration points" are purchased through the bank or simply deducted from the buyer's X-quota account.

Unlike traditional historical rationing systems, however, this one would actively encourage trading. In particular, under-users would be encouraged to sell their surplus (for cash) while over-users — including all businesses — would have to buy needed ration points. There are various alternative ways to accomplish this, but one possible scheme is as follows: Each individual's monthly ration credit would be deposited automatically in a special account in a commercial (or savings) bank of the individual's choice. If unused, the credit in the account would accumulate, month by month. If used, the account is debited. Of course, a significant percentage of most emissions are generated by businesses, not individuals. This means individual needs would be generally be considerably smaller than the average annual individual quota. Most individuals would therefore be able to sell a significant fraction of their emission quota rights to businesses. However, this would increase the cost base of polluting businesses, which would naturally pass their higher costs on to consumers through higher prices — exactly as if emissions were taxed directly. There would be a similar incentive effect on businesses to reduce costs by minimizing emissions.

Both selling and buying of emission quota rights would best be done through commercial bank(s). Banks would maintain internal markets among their customers and also buy and sell from each other through a central exchange. (Emission rights could be exchanged like shares, through brokers). Apart from a small service charge, the value of underused quotas becomes a fairly predictable cash income to individuals who consume relatively little. Since poor and elderly people are likely to be low consumers, this market incidentally functions as an automatic income redistribution mechanism.

What about the international competitiveness problem? As in the case of resource-based taxes, the net result of imposing quotas on resource use would be to raise the effective prices of some goods and services *vis a vis* others. For instance, petroleum-based fuels and petrochemicals would almost certainly be rationed as western countries become more serious about protecting the environment. This would make them more expensive, just as a tax would. Since foreign competitors would not have to pay these higher costs, they would have a competitive advantage. To compensate for this in domestic markets, there would have to be border adjustments so as not to discriminate against domestic producers in favor of importers. (Exporters would be exempt in any case).

To be sure that they are treated in a manner equivalent to domestic products, the indirect, as well as direct, X-content of imported as well as domestic goods and services should be assessed. Importers of semi-finished or finished goods would have to provide this information, and to acquire the necessary "pollution quota points" on the market. (Importers unable or unwilling to provide such data could be assessed pollution quota points at a rate equal to that of the worst-case domestic producer.)

The national government, or international agency, role would be to determine the overall X emissions quota, to audit the determination of X-equivalences of commodities and basic products, to audit exporters allowances, and to monitor the bank's exchange operations.

Concluding Remarks: Is There a Need for a Global Authority?

Given that there are some environmental threats, such as climate change, that are both global in scope and potentially far beyond the marginal in severity, there would seem, at first glance, to be a strong argument for creating centralized supra-national authority for countering such threats. Even libertarians agree that national defense is the province of central government. Surely, it can be argued, the same argument must hold for global environmental threats?

A central global authority could theoretically eliminate the competitiveness problem by harmonizing taxes across national boundaries. It would be possible, then, to finance many global governmental activities by taxing exhaustible resource extraction, which is currently undertaxed, and using the revenues, in part, to subsidize environmentally friendly "renewable" alternatives and economic conversion programs for affected workers. It need hardly be added that a truly effective global authority would also sharply reduce the need for armaments and *ipso facto* for the taxation that pays the costs of arms. These savings would compensate in large measure for the costs of global governance.

However the practical possibility of a centralized global authority, in the present state of the world, is probably nil. Moreover, even if such an authority could be created by some *deus ex machina*, how would it function? Clearly the UN is no model of global governance, and there is no other model on the horizon. This may be a problem that has to be solved some day, but it will not be solved in time to protect the environment.

The primary problem for supra-national solutions is national sovereignty. A sovereign nation, by definition, is not subject to any higher authority unless it allows itself to be. International law exists, no doubt, but there is a limit to the effectiveness of UN resolutions or trade embargoes. There is no competent international court system nor any international agency with police power of enforcement. Nations may agree to reduce emissions of CFCs, or CO_2, but if they decide, for reasons of national interest, to ignore their agreements, or if they fail to enforce their international commitments internally, there is no effective recourse except "international opinion", which is not always effective. For instance, international opinion strongly opposed French nuclear tests (as did French public opinion), but the tests went on regardless. Similarly, international opinion strongly opposed Serbian "ethnic cleansing" with no noticeable impact on moderating Serbian behavior.

For this reason, economists have generally concluded that the most effective device is likely to be "side payments" in exchange for performance. For instance, Germany or Sweden might agree to pay neighboring Poland to cut its sulfur emissions. One problem with this strategy is that it contradicts the "polluter pays" principle that has been widely agreed upon. Indeed, it creates opportunities, at least in theory, for countries to profit by polluting. But even if the recipient of the side payment has no intention to cheat, the verification of performance remains very difficult and probably very expensive.

The question can be rephrased: *absent* an omnipotent (and not necessarily benevolent) global authority, is there any way to reconcile national sovereignty as a fact of life with the need to solve global environmental problems? The minimum requirement of such a path would seem to be that any country can undertake to make incremental progress on its own without either international agreement or major national sacrifice in terms of international economic competition.

In this context, the adoption of consumption quota schemes at the national level, with tradeable allowances (or permits) to emit pollutants of global environmental significance, applicable to imports as well as domestic producers (but exempt for exports) would eliminate any trade distortion and thence any adverse competitiveness effect. For instance, Germans could decide unilaterally to cut energy consumption or carbon emissions, without adversely affecting German exporters. Importers would be treated the same as domestic producers. Other countries could follow suit, in the same way. Trade would eventually decline, but competitiveness would not be adversely affected.

The problem of international equity could also be attacked via a rationing system. For instance, the UN financing system could be completely reformed by agreeing to a global *per capita* X-quota. (X could be any universally traded commodity, but let us take carbon emissions as the example). Countries wanting to emit more than their per capita share would have to purchase excess carbon emission rights from under-users, via an auction market (which would have to be created for the purpose). Payments for the underlying commodities, such as petroleum and gas, would go to the sellers, as at present. But payment for the consumption quota rights, in hard currencies, could go into a centrally administered fund and redistributed on behalf of under-users according to a formula. A plausible redistribution formula might be: (1) hard currency to pay UN membership (including peace-keeping) dues (2) to pay off existing IMF debts and World Bank debts — thus reducing debt service — (3) to increase the capital of the World Bank (4) to finance the International Environment Fund and (5) to co-finance a new international venture capital fund earmarked for developing countries.

Many will argue that such schemes are too visionary to be seriously considered. On the other hand, it may be argued that thinking visionary thoughts is cheaper than correcting problems that result from thoughtless action. The UN itself was once a vision.

Endnotes

1. For instance, Montrose Chemical Co., the last DDT producer in the U.S. was sold to Indonesian investors in 1983 and literally moved to from California to Indonesia, where it has become a notorious local polluter.

2. Significant extracts of the memo were published by *The Economist* (Feb 8 1992).

3. Deposition consists of nitrates resulting from neutralization reactions between alkaline ammonia (volatilized from animal urine and manure) and nitric or sulfuric acids produced by atmospheric oxidation of NO_x and SO_X. The end results of these acid-alkali reactions are ammonium sulfate and ammonium nitrate.

4. Worldwide, about 87% of synthetic ammonia production is used for fertilizer [*Informations Chimie* **346**, 1993].

5. The crop yield per unit of fertilizer input is anomalously low for North Africa and the Mid-East, but the explanation for this is almost certainly related to water scarcity. That is to say, yield could be increased sharply without more fertilizer input, if more water were available.

6. This is roughly consistent with other estimates. For example, the U.S. National Academy of Sciences estimated global N_2O output for 1988 at 1.5 MMT [NASNRC 1992].

7. The rate of deforestation in the Amazon has apparently slowed down since the late 1980s, thanks to the withdrawal of subsidies to cattle ranchers.

8. The Comecon countries consisted of eastern Europe (including E. Germany) and the USSR (now CIS).

9. There is one major exception, a relatively new blast furnace in the Amazon basin of Brazil (Carajas) financed by the World Bank, using charcoal from wood. In principle this might be regarded as a "renewable resource" but in practice it is virgin tropical forest that is being consumed and the land that is cleared is not being replanted, but used for cattle raising.

10. In the U.S. 247 metric tons of mercury was consumed in producing about 1.5 million metric tons of chlorine (16 % of the total) in 1990 [USBuMines 1991]. Assuming the same rate of use, European chlorine production would have consumed about 4 times as much mercury, or around 1000 tons, while chlorine production elsewhere in Asia (excluding Japan) and Latin America could have consumed another 500 tons, assuming a significant fraction of production using the de Nora cell. In any case, this industry is almost certainly the largest user of mercury in the world (total world production being about 5000 metric tons in that year).

11. Over 1 million peasants will be displaced by the Three Gorges project alone.

12. For a recent review of the literature, see [Frey 1995].

13. Except in the case of very efficient large-scale modern power plants utilizing electrostatic precipitators, which can be up to 99.5% efficient. However, such equipment adds significantly to capital (and operating) costs and is rarely employed in developing countries.

14. In a 1993 address to an International Conference on Human Resources, attended by 150 international experts, Prime Minister Mahathir bin Mohamad accused western countries of perpetuating colonialism and failing to help poorer countries to develop. He said "All the cares and concerns for human rights and democracy are laudable except that the obvious results of applying western standards would be to knock out the competitiveness of the manufactured products of these countries". Mahathir was specifically referring in this instance to western concerns about production based on child labor, but he has also criticized the use western environmental standards to restrict imports of (for instance) tropical hardwoods.

15. Suppose the drug was originally discovered by an indigenous people (quite likely) and brought to the attention of a European researcher by an anthropologist or similar intermediary. Who deserves to get the royalty? Should it be paid to a corrupt national government that has been harassing the same indigenes? Suppose the source of the drug is a rare species that can only be exploited in the near term by harvesting (i.e. killing) it? Should then it be collected? Or should it be cultivated in plantations, like rubber? Wouldn't that destroy more rainforest? Suppose that, to avoid these problems, the decision is to synthesize the molecule. Suppose that a pharmaceutical company has to spend $100 million learning how to synthesize the drug and testing it. But suppose that, in the process, it discovers that a variant of the natural product is more effective. Should it still have to pay the royalty? Needless to say, a system that could resolve all these problems equitably would be difficult to design, and still more difficult to obtain international agreement on.

16. On the other hand, regulations that are too detailed or too specific can inhibit technological innovation and perpetuate the very problems that prompted the regulation in the first place. For instance, the introduction of catalytic convertors for automobiles has been a bonanza for the catalyst industry, but has probably inhibited the development of alternative "clean burn" engines, even though the latter would be both cheaper and more effective over the life of the engine.

17. Prohibition (of alcoholic beverages) failed in the 1920s and 1930s because it was far too easy to distil alcoholic spirits in backwoods stills ("moonshine"), or to smuggle them. Prohibition of marijuana, cocaine and heroin fails for similar reasons, despite fairly widespread and well-financed enforcement efforts. The major results of attempts to do so is the creation of highly profitable opportunities for criminals.

18. All Visa credit cards in France ("Carte Bleue") have been using this system for a number of years. Each card is issued by a bank, with a 4-digit personal code known only to the owner. The owner uses his code (rather than his signature) to verify his/her identity each time the card is used. Theft and fraud have been virtually eliminated.

19. The exergy of a material is the amount of "useful work" that can theoretically be extracted from it by utilizing motion differentials (if any), gravitational field differentials (if any), temperature differentials (if any), pressure differentials (if any) and chemical composition differentials (if any) with respect to the average motion, gravitational field, temperature, pressure and chemical composition of the environment. In most cases of practical importance, it is the chemical differentials that matter. The exergy-content of a

material (or a waste) is directly proportional to the "potential entropy" that would result when the material in question reaches thermodynamic equilibrium (with its environment). It can be argued that this may be the most general measure of potential for causing harm to the environment [Ayres & Martinás 1995].

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Table I: Ammonia capacity, production & consumption 1991; kMT(N)

	Capacity[c]	*Production*		*Consumption*
	IC	*BoM*	*IC*	*IC*
World	**117 985**	**103 308**	**92 500**	**91 700**
W. Europe	13 400	13 590	11 300	13 500
Germany		*2123*		
E. Europe	34 500	6 010	21 800	18 300
CIS		18 850		
N. America[a]	17 080	21 691	15 800	17 000
U.S.		*13 991*		
S. America	6 364	1 695	5 300	3 500
Brazil		*875*		
Africa	3 591	1 330	3 591	2 600
S. Africa		*504*		
Middle East	4 102		2 700	2 300
Asia[b]	33 400	39 415	33 400	34 400
Japan		*1 712*		
China		*19 840*		
Oceania		537		

Data Sources: BoM = [USBuMines 1994], IC = Informations Chimie, various issues

a. Informations Chimie includes US & Canada only

b. Informations Chimie includes Oceania; Bureau of Mines includes Middle East

c. Capacity is 1992

Table II: Fossil fuel production & consumption 1991/1992 (MMT)

Region	*Hard coal*		*Brown coal*		*Petrol.*	*Gas*
	output	*consumption*	*output*	*consumption*	*production*	
World	**3456**	**3456**	**1048**	**1048**	**2972**	**1983**
W. Europe	193	324	420	420	202.5	195
ex-Comecon	568	591	428	428	509.3	745
N. America	861	742	111	111	596.8	652
Latin America	21	21			227.6	63.5
Africa(S)	178	130			314.2	68
Middle East	—	—			1094.1	235.5
Asia	1303	1395			(in ME)	(in ME)
Oceania	160	40	50	50	27.3	26.5

Data Source: [WEC 1994]

Table III: Atmospheric emissions of carbon, sulfur & nitrogen 1990/2020

	Carbon[1] *GT*		*Sulfur[2]* *MT*		*Nitrogen[2]* *MT*	
Region	***1990***	***2020***	***1990***	***2020***	***1990***	***2020***
World	**5.90**	**8.37**	**64.6**	**66.1**	**24.0**	**27.0**
W. Europe	1.00	1.06	10.4	4.5	3.7	2.3
E. Europe	0.25	0.23	3.9	2.2	1.0	0.7
CIS	1.08	1.03	12.4	7.4	4.0	2.9
N. America	1.55	1.49	12.1	5.8	5.5	3.2
Latin America	0.26	0.68	3.2	7.1	1.4	2.7
Sub-Saharan Africa	0.11	0.31	1.9	4.4	0.7	1.6
N. Africa + Middle East	0.22	0.59	2.2	4.9	1.0	2.0
Asia + Oceania	1.47	2.98	18.5	29.7	6.8	11.5
Centrally planned	*0.72*	*1.56*	*6.9*	*14.4*	*3.2*	*6.3*
Asia, South	*0.20*	*0.55*	*3.4*	*7.5*	*1.1*	*2.4*
Other Asia + Oceania	*0.55*	*0.87*	*8.2*	*7.8*	*2.5*	*2.8*

Data Source: [WEC 1994]

1. *The emissions are calculated as 1000 million metric tons (GT) of elemental C*
2. *The emissions are calculated as million metric tons of elemental S and elemental N*

Table IV: Iron, steel and coke production (MMT)

Metal	*Iron ore*		*Iron content*		*Pig iron for steel*		*Crude steel*		*Coke*	
year	***1991***	***1994***	***1991***	***1991***	***1988***	***1991***	***1988***	***1991***	***1988***	***1991***
source	***BoM***	***R***	***BoM***	***Grade (%)***	***UN***	***BoM***	***UN***	***BoM***	***UN***	***UN***
World	**952 (R)** **901**	**956(R)**	**611.0 (R)** **526.1**	**58.5**	**523.75** **539.6(BoM)**	**508.7**	**730.4**	**733.7**	**370.6**	**339**
W. Europe	37.3	28	19.8	53	100.3	98.9	140.6	148.1	59.8	53.5
E. Europe	8	1.3	2.3	29	35.6	23.1	60.8	35.6	36.4	25.5
CIS	200	135	110	55	114.6	91	163.0	132.7	86	64.4
N. America	104.7	105	64.4	61.4	64.3	55.4	113.3	101.3	35.6	27.8
U.S.	*59.6*	*58.2*	*33.3*	*56*	*49.7* *50.6(BoM)*	*44.1*	*90.6*	*79.7*	*29.1*	*21.8*
S. America	188.5	198	123.6	72	27.9	25.3	33.9	30.2	9.7	9.8
Brazil	*155*	*166.5*	*103*	*67.5*	*23.6* *23.4(BoM)*	*22.7*	*24.5*	*22.6*	*8.1*	*8.1*
Africa	47.5	37	30.3	64.5	7.9	9.8	12.4	14.5	3.1	3.6
S. Africa	*29.1*	*32.3*	*19*	*65*	*6.3* *6.2(BoM)*	*7*	*8.5*	*9.4*	*1.8*	*1.8*
Asia	200.8	320	105.8	52^{est}	168.9	199.5	200.0	252.9	135.9	150.1
Japan	—	—	—		*78.4* *79.3(BoM)*	*80.0*	*105.0*	*109.6*	*47.7*	*45.5*
China	*119*	*229*	*59.5*	*50^{est}*	*57.0*	*67.0*	*59.4*	*70.6*	*59.1*	*73.5*
Oceania	119	137	69.8	59	5.5 5.7(BoM)	5.6	6.3	6.2	4.1	4.2

Data sources: BoM = [USBuMines 1994], R = [Roskill 1995], UN = [UNIS 1988, UNIS 1993]

Table V: Bauxite, alumina & aluminum production (MMT)

Metal Region	*Bauxite* 1991	*Bauxite* 1994 (R)	*Alumina* 1988	*Alumina* 1991	*Primary Aluminum* 1991	*Primary Aluminum* 1994
World	**115.3(UN)** **109.2(BoM)**	**114**	**36.8(BoM)**	**39.8(BoM)**	**19.0(UN)** **18.2(BoM)**	**19.0(R)**
W. Europe	2.34	2.4	4.55	4.8	3.41	2.97
E. Europe	5.11	0.1	2.55	2.0	1.55	0.32(?)
CIS	3.8	6.5[est]	3.5	3.0	2.0	3.0
N. America	11.89	11.6	7.3	9.4	6.0	5.55
U.S.	—	—	*4.8*	*5.2*	*4.12*	*3.30*
S. America	15.75	17.0	4.4	4.4	1.94	1.99
Brazil	*2.6*	*9.5*	*1.5*	*1.6*	*1.14*	*1.18*
Africa	18.75	18.8	0.6	0.6	0.62	0.58
S. Africa	—	—	—	—	*0.17*	*0.17*
Asia	9.42	15.6	3.1	3.9	2.01	2.97
Japan	—	—	*0.4*	*0.44*	*0.03*	*0.017*
China	*2.6*	*8.0[est]*	*1.3*	*1.6*	*0.86*	*1.45*
Oceania	41.83	41.7	10.5	11.7	1.50	1.31

Data sources: BoM = [USBuMines 1994], R = [Roskill 1995], UN = [UNIS 1993]

N. B. Both Roskill and BoM report no production of aluminum in Korea; however UN does report a small output (13.6 kMT in 1991. Sources also differ on Japanese output.

Table VI: Copper production

Metal / Region	*Copper ore (MMT) (assuming 0.9%) 1991*	*1994*	*Copper content (kMT) R 1991*	*R 1994*	*Smelter (primary) (kMT) UN 1988*	*BoM 1991*	*Refinery (primary) (kMT) UN 1988*	*BoM 1991*
World	**1014.3**	**1061.0**	**9130.0(R) 8819.5(BoM)**	**9550**	**8727**	**8008**	**9225**	**8410.4**
W. Europe	33.3	25.6	300.1	230	557	490.9	1195	815.1
E. Europe	65.2	60.0	586.6	540	784	517.5	701	522.5
CIS	61.1	97.8	550	880	1120	700	1380	750
N. America	303.3	302.2	2730	2720	1730	1831	2065	2074
U.S.	*324.7*	*200.0*	*1631*	*1800*	*1043*	*1123*	*1406*	*1577.4*
S. America	250.0	291.1	2250	2620	1214	1725	1180	1624
Brazil	*4.1*	*5.0*	*37*	*45*	*132*	*160*	*148*	*140*
Africa	102.4	76.0	922	684	1103	814	780	723
S. Africa	*21.4*	*20.4*	*193*	*184*	*180*	*170*	*139*	*139*
Asia	110.3	156.5	993	1409	2039	1703	1738	1988
Japan	*1.3*	*0.0*	*12*	—	*1270*	*968*	*898*	*968*
China	*33.3*	*48.0*	*300*	*432*	*350*	*360*	*400*	*560*
Oceania	57.2	51.9	515	467	180	197	186	252

Data sources: BoM = [USBuMines 1994], R = [Roskill 1995], UN = [UNIS 1988]

N. B. Copper ore processed in the U.S. in 1991 was actually 324 MMT, according to BoM; this means the U.S. ore grade was considerably lower than the world average, viz. about 0.5%; on the other hand both Chilean and African ores were higher in grade than the world average, meaning that somewhat less ore had to be processed than the calculated figures.

Table VII: Lead production

Metal Region	*Lead ore (MMT) (assuming 3.3%)* *1988*	 *1991*	*Lead content (kMT)* *1991 (BoM)*	 *1994 (R)*	*Lead refinery output* *1991 (BoM)*
World	**100.5**	**80.3**	**3318**	**2650**	**3029**
W. Europe	7.0	7.0	230	230	760
E. Europe	6.2	3.6	203	120	190
CIS	12.1	6.1	400	200	380
N. America	26.5	21.5	875	710	606
U.S.	*14.5*	*11.2*	*477*	*370*	*346*
S. America	7.8	7.0	257	230	125
Brazil	*0.3*	*0.1*	*9*	*4*	*35*
Africa	5.3	5.5	175	180	100
S. Africa	*2.3*	*2.7*	*76*	*90*	—
Asia	18.4	14.5	606	480	642
Japan	*0.5*	*0.3*	*18*	*10*	*220*
China	*11.5*	*10.3*	*380*	*340*	*265*
Oceania	17.3	15.8	571	520	220

Data sources: BoM = [USBuMines 1994], R = [Roskill 1995]

Table VIII: Zinc production

Metal Region	*Zinc ore (MMT) (assuming 4.4%)* *1991*	 *1994*	*Zinc content (kMT)* *1991 (BoM)*	 *1994 (R)*	*Zinc smelter output* *1991 (BoM)*
World	**165.5**	**152.3**	**7282**	**6700**	**4443**
W. Europe	19.1	13.6	841	600	2063
E. Europe	6.2	5.6	272	247	284
CIS	18.4	11.1	810	est490	700
N. America	46.3	45.1	2035	1986	1103
U.S.	*12.4*	*13.3*	*547*	*585*	*253.3*
S. America	21.8	21.2	958	934	341
Brazil	*3.1*	*3.2*	*135*	*140*	*150*
Africa	5.2	5.4	227	236	140
S. Africa	*1.5*	*1.7*	*67*	*76*	*91.5*
Asia	28.4	30.5	1250	1344	1761
Japan	*3.0*	*2.3*	*132*	*101*	*640.6*
China	*14.8*	*21.3*	*650*	*938*	*526*
Oceania	23.8	21.9	1048	963	324

Data sources: BoM = [USBuMines 1994], R = [Roskill 1995]

Table IX: Nickel production

Metal / Region	*Nickel ore (MMT) (assuming 2.5%)* 1991	1994 (R)	*Nickel content (kMT)* BoM 1991	R 1994	*Nickel production (kMT) (FeNi, Ni, oxide)* 1991 (BoM)
World	**36.9**	**32.0**	**923**	**800**	**876**
W. Europe	1.1	1.0	27	24	128.8
E. Europe	0.4	0.1	11	1.5	7
CIS	10.0	7.6	250	190	257
N. America	10.4	8.5	259	212	161.2
U.S.	*0.2*	*0.0*	*5.5*	—	*7.1*
S. America	1.6	1.5	41	37	32
Brazil	*0.9*	*0.7*	*23*	*16.5*	*13*
Africa	2.4	2.5	60	62	38.3
S. Africa	*1.2*	*1.2*	*30*	*30*	*26.9*
Asia	4.6	5.1	115	128	171.8
Japan	*0.0*	*0.0*	—	—	*116.7*
China	*1.1*	*1.2*	*27.5*	*30*	*27.5*
Oceania	6.4	5.8	160.5	146	79.4

Data sources: BoM = [USBuMines 1994], R = [Roskill 1995]

Table X: Gold production

Metal / Region	*Gold ore (MMT) (assuming .03%)* 1991	1994	*Gold (MT)* BoM 1991	R 1994
World	**6.333**	**6.78**	**2111**	**2260**
W. Europe	0.0585	0.0465	19.5	15.5
E. Europe	0.0444	0.024	14.8	8^{est}
CIS	0.72	0.66	240^{est}	220^{est}
N. America	1.434	1.431	478	477
U.S.	*0.87*	*0.954*	*290*	*318*
S. America	0.513	0.597	171	199
Brazil	*0.225*	*0.21*	75^{est}	70^{est}
Africa	1.989	2.091	663	697
S. Africa	*1.803*	*1.752*	*601*	*584*
Asia	0.588	0.939	196	313
Japan	*0.0249*	*0.0288*	*8.3*	*9.6)*
China	*0.36*	*0.45*	*120*	150^{est}
Oceania	0.933	0.993	311	331

Data sources: BoM = [USBuMines 1994], R = [Roskill 1995]

Table XI: Uranium production

Metal Region	*Uranium ore (MMT) (assuming .05%)* *1988*	 *1991*	*Uranium content (MT) UN* *1988*	 *1991*
World	**18.379**	**13.576**	**36758**	**27152**
W. Europe	1.922	1.974	3844	3948
E. Europe	0.04		80(a)	—
CIS			(a)	(a)
N. America	8.725	5.595	17450	11190
U.S.	*2.525*		*5050*	
S. America	0.071	0.0275	142	55
Brazil			—	—
Africa	5.74	3.7405	11480	7481
S. Africa	*1.925*		*3850*	
Asia	0.115	0.13	230(a)	260(a)
Japan			—	—
China			*(a)*	*(a)*
Oceania	1.766	1.888	3532	3776

Data source: UN = [UNIS 1988, 1993]

a. Uranium data from eastern Europe, CIS (former USSR) and China is not included; never published. However, it is likely that production in the USSR and China would be comparable to that in North America, if not greater.

Table XII: Inorganic chemical production 1991 (kMT)

Chemical	*Phosphates*		*Sulfur*		*Chlorine*	
	Phosphate Ore	*Phosphoric acid P_2O_5*	*Crude S*	*Sulfuric acid*	*Production*	*Capacity 1992*
Region	*BoM*	*UN*	*BoM*	*UN*	*UN*	*IC*
World	**146859**	**31500**	**55592**	**150 000[est]**	**35 701(T)** **47 318(UN)**	
W. Europe	500	2930	7728	21148	9 244	11 197
Germany	—	*280*	*1990*	*3064*	*3 254[a]*	*4 074*
E. Europe	—	1 071	6006	4142	1 541	2 000
CIS	30000	5 000[est]	8100	24115	20 298[a]	3 000
N. America	48691	11516	19905	40106	13 470	14 230
U.S.	*48096*	*10936*	*10816*	*36486*	*11 421*	*12 444*
S. America	3543	863	955	9329	1 069	1 282
Brazil	*3309*	*863*	*282*	*3579*	*1 030*	*830*
Africa	33980	3091	806	6500	35	502
S. Africa	*3050*	*520[est]*	*517*	*1 600[est]*	*232*	*232*
Asia	30701	8 000[est]	11915	27247	1 748	5 869
Japan	—	*164*	*2754*	*7057*	*1 027*	*3 136*
China	*20000*	*4 000[est]*	*5470*	*13329*	*3000*	*3000*
Oceania	534	74	213	1206	315	315

Data sources: BoM = [USBuMines 1994], IC = Informations Chimie, various issues, T = Tecnon Ltd, UN = [UNIS 1993]

a. 1990

N.B. Phosphoric acid production for China and Asia has been estimated on the basis of 5 t ore per t of fertilizer grade P_2O_5. In the case of China, this would require 10000 t of sulfuric acid for processing, or 75% of total sulfuric acid production in that country.

N.B. UN data on chlorine production is very unreliable incomplete; for example, production of more than 20,000 t has consistently been reported for the (former)USSR, whereas industry sources put the production capacity of the former USSR at only 3000 t; UN reports no production is reported for Australia, South Africa, China or Taiwan. However the Chlorine Institute lists 30 plants known to be in operation in China and another 30 in Taiwan. Thus for South America, Africa, Oceania and Asia we have also indicated 1989 capacity as reported by Informations Chimie no. 310, Nov. 1989. In the case of Brazil, at least, 1989 capacity appears to be less than 1991 production.. The world total for 1989 has been reported by an industry consulting service, Tecnon Ltd. (T).