Biomass for Energy

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This paper provides a broad overview of the use of plant material as a source of usable energy. The problem of gathering and interpreting data on the use of biomass is discussed. From the limited data available it is inferred that bioenergy contributes about 15% of the global energy budget. The paper deals with a variety of other major topics: the role of biomass in the energy system, differences in that role in industrialized and developing countries, conversion technologies, environmental considerations and the multiple uses of biomass (food for people, feed for animals and fibre for construction material and other uses as well as energy sources). The ability of the biosphere to provide adequate amounts of primary energy is limited, especially if forecasts of population growth, and associated increases in the demand for food, feed and fibre, turn out to be accurate. By improving the efficiency of bioenergy use, which is currently very low, it should be possible to deliver more tertiary energy for the same primary energy input.

Cet article offre une vue d'ensemble de l'utilisation de matériaux végétaux comme source d'énergie utilisable. On y discute les problèmes posés par le recueil et l'interprétation des données. A partir des informations disponibles, il apparaitrait que la bioénergie contribue à environ 15% du budget de l'énergie globale. L'article traite un variété d'autres sujets majeurs: le rôle de la biomasse dans le système d'énergie, les différences dans ce rôle entre les pays industrialisés et les pays en voie de développement, les techniques de conversion, les considérations d'ordre environnemental et les emplois multiples de la biomasse (alimentation pour les humains, fourrage pour les animaux et fibre pour les matériaux de construction ainsi que d'autre usages en plus des sources d'énergie). La capacité de la biosphère de produire une quantité suffisante d'énergie primaire est limitée, surtout si les prévisions de la croissance de la population, et des augmentations relatives dans la demande de nourriture, de fourrage et de fibre s'avèrent exactes. En améliorant l'efficacité de l'utilisation de la bioénergie, qui est actuellement très faible, il devrait être possible de dégager plus d'énergie tertiaire par rapport à la même puissance d'énergie primaire.

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Biomass, or more correctly phytomass, the plant material generated from solar energy by means of photosynthesis, is the most important of the renewable energy forms in terms of its current and projected consumption on a world scale. In fact, it ranks fourth in importance as an energy source with only oil, coal and gas contributing more energy to the world. Unlike the fossil fuels, biomass is bulky and has a fraction of the energy content of these fuels on a mass and volume basis. Its use is therefore based on regional considerations since it cannot be economically transported much more than 200 km. Biomass for energy is grown on land, land which may be needed for food or fibre production, and this results in competition for land and water between foodstuffs, fibre and fuel production. Photosynthesis does not store a large fraction of the solar input. Instantaneous efficiencies of energy capture into biomass have been measured at 6-8%. On a seasonal basis, an efficient tropical crop such as sugar cane may reach 2% efficiency in storing sunlight if no other growth factors are limiting. The boreal forest in contrast, may be capable of fixing only a fraction of one percent of the incident solar energy into biomass over its 60-80 year harvest cycle.

Biomass for energy, or bioenergy, has been the subject of numerous studies since the first of the

1970s energy crises. These studies have been conducted within the scope of two distinct economic and geographical models: the first based on development in the Third World, the second based on oil substitution in the industrialized economies. In spite of this distinction, statistics show that per capita consumption of bioenergy in both the developing and industrialized world is equivalent to between 0.5 and 1 tonne of woodfuel per annum (t/a), though, as will be discussed, the mode and efficiency of use vastly differs between the two areas. The bioenergy use systems are inherently different because in developing countries the application occurs predominantly in rural settings while in developed countries it is in the industrial and urban milieu. This distinction is now blurring because the Third World is following a path towards increasing industrialization, with an associated acceleration of urbanization.

Bioenergy Use Statistics

Use of biomass for energy often occurs in circumstances which do not permit accurate measurement of consumption. In industrialized countries most consumption is in the raw materials sector where, for example, process residues in the pulp and paper industry are used as fuel for the process itself. Such internal transfers of captive residues rarely lead to accurate accounting. In much of the Third World, especially in rural areas, biomass fuel is harvested at the cost of human labour and records of the type and quantity of fuel used are not kept. As I will discuss below, the current contribution of bioenergy to the global energy budget is estimated at about 15%. The quality of this estimate is important in terms of assessing the impact of shifts from traditional to commercial fuels and in establishing the extent of unfilled demand, since in reality there are no energy shortages but rather shortfalls that are reflected in poor nutrition or reduced performance of agriculture or industry.

The problem of energy demand analysis in countries that have large traditional fuels sectors has been addressed by Bhatia (1987) as part of the activities of the Energy Research Group of IDRC. The methodology required has to be based on survey activity at the micro level, which is then accumulated for a region and eventually summed on a country basis. Checks on this can be performed at the macro level using other knowledge of crop and forest production and animal stock data. Such surveys are time-consuming and must be carried out over several seasons in order to satisfactorily reflect real use. The earliest survey data for biomass was based on the use of fuelwood and was the basis of Eckholm's now-famous declaration of a fuelwood crisis (Eckholm, 1976). As a result of this, a major effort on data gathering for fuelwood consumption was undertaken by the FAO. This survey was primarily based on data from forestry departments and identified wood usage as amounting to only about 1 Gt or 15 EJ (WRI, 1986).

The problem with this viewpoint of bioenergy use is that it neglects entirely the use of plant residues, dung, bioethanol and biogas. The data for India are a salutary correction; it is reckoned that dung and plant residues add another 100% to firewood consumption (CSE, 1982; WEC, 1986). Further corroboration of this is given by Reddy and Ravindranath (1987) who tabulate the importance of dung cake and agrowaste relative to firewood in several village economies. A comparison (Overend, 1986) of FAO fuelwood data for Latin America with the OLADE user survey data for bioenergy use, again showed discrepancies of almost 100% for many countries. A final disposition would be to assume that for the developing world, in agriculture and forest based economies the usage of biomass in general is about 1 t/a per person. In Brazil, despite its high degree of urbanization (72% as against the average for Latin America of 65.3% (WRI, 1986)), utilization of biomass is 0.95 t/a per person (Goldemberg *et al*, 1988). This stems partly from the very large role that charcoal manufactured from wood plantations plays in steel manufacture. Even for China, Wu and Chen (1983) have provided data to suggest that 800 million rural Chinese utilize about 1 t/a per person of fuelwood equivalent.

A particularly good example of the degree of

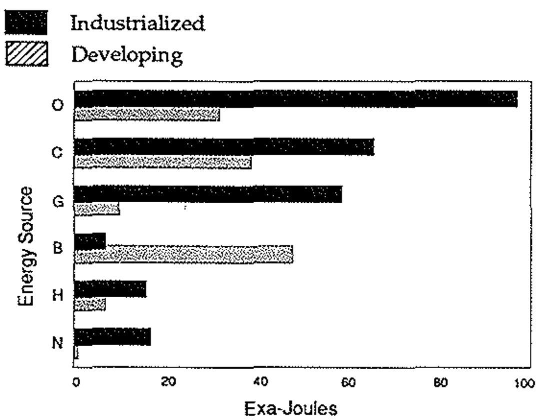

Figure 1: World Energy Sources: Developing and Industrial Countries
O: oil; C: coal; G: gas; B: bioenergy; H: hydroelectricity; N: nuclear. Hydroelectricity at 10.8 MJ/kWh.

resolution required to make an estimate of biomass fuel usage has recently been given by Wijesinghe (1988) for the island of Sri Lanka. This small tropical island (65,610 km^2) with a population of 15.6 million has a primary energy input of 71% biomass. Of these 9 Mt of biomass, 7.9 Mt are used by households. Fuelwood (see below) constitutes 72%, while agricultural wastes amount to 28% of the total biomass used. The majority of agricultural wastes used come from coconut plantations. The fuelwood component includes rubber wood, which is a by-product of the management of rubber plantations and comprises 18% of the total bioenergy contribution. Of the remaining fuelwood less than half comes from the forest, the majority is gathered from waste and scrub land.

David Hall (1988), using data from several sources (CSE, 1982; WEC, 1986; WRI, 1986; IEA, 1987; WCED, 1987; BP, 1988), has generated a table of world energy use incorporating as far as possible the revised data on biomass contributions. In developing this data set, the biomass data were estimated from the available survey data. While less accurate than data on fossil fuel use, the global value is probably reliable to within 25%. The data from this table have been summarized in Figure 1 and are classified according to developing and industrialized countries.

The Biomass and Energy Framework

In the Third World approximately 35% of the primary energy supply is derived from biomass and over 2 billion people are almost totally reliant on this source for their energy needs. As a measure of the importance of bioenergy, it is interesting to note that if kerosene were to replace all biofuels, the world oil demand would increase by 20%. It is dangerous to generalize about the nature of Third World energy use since each country has its own infrastructure in terms of biomass resource base and the energy demands of the urban, rural, industrial and domestic sectors. However, on the basis of a number of studies it is possible to provide some ranges of the contribution of bioenergy in each sector of the economy: approximately 50-80% is used in domestic applications, predominantly for food preparation; 10-20% is used in the commercial sector such as bakeries, restaurants and in pre-cooked food preparation; industrial uses such as crop drying (tea, coffee and tobacco), brick, tile, charcoal production and lime manufacture represent 5-40%. It should be noted that these are almost all applications of solid fuel combustion in size ranges of 5, 20 and 100 kW for domestic, commercial and industrial applications respectively. In industrialized and urbanized countries, the use of bioenergy has become concentrated in industries (e.g., foodstuffs, fodder and fibre) in which residual biomass from a production process is used as the primary fuel for the process. In the northern hemisphere, the USA, USSR, Scandinavia and Canada all have major energy contributions from their pulp and paper industries through the use of wood residues and pulping liquors. Canadian bioenergy use (representing 7% of the total energy economy) is distributed as follows: 63% in the pulp and paper sector, 32% as domestic woodfuel, and 5% in the saw mill sector. Usage proportions in the industrial and domestic sector are inverted in comparison with the Third World and are accompanied by a dramatic increase in scale of combustors. The size range is from 1 to 300 MW in industry and 50-100 kW in domestic space heating.

In the chain from the resource to the energy service required by the consumer, there are several distinct stages: cultivation, harvest, fuel distribution, conversion and delivery of energy. The primary energy (P) harvested is not all delivered to the consumer. Some is lost during conversion to a secondary form (S) and there are further losses in distribution and conversion to heat, power or light delivered at the tertiary level (T). Each transformation has an efficiency which can be defined as the ratio of energy input to the output for that stage. For woodfuel in Canada and Kenya, the ratios of S/P are 95% and 71%, and of T/S 48% and 19% in Canada and Kenya respectively. Clearly, the use of bioenergy in the developing country is significantly less efficient. The existence of a large charcoal industry in Kenya explains the low value of S/P, whereas in Canada almost all of the woodfuel use is direct to end use. Even in the end use application the efficiency of industrial burners is at least 2-3 times better than the domestic stoves which burn the majority of fuel in Kenya.

Fuelwood/Woodfuel

Taking woodfuel to mean both fuelwood and charcoal, it is possible after almost two decades of research and the gathering of statistics, to see that the situation is complex and very dependent on whether, for example, you are in the Sahel or the Punjab. Where population density is low, woodfuel needs are easily met without affecting the standing stock of trees. Woodfuel supplies are normally drawn by women and children for a modest investment of time and effort. The land used varies; sometimes the wood lot belongs to the family, elsewhere there may be legal or customary use of national forests, while in other places waste land and roadsides or neighbour's land may all be used. Most often dead wood is utilized; it is lighter, burns better and is easier to cut than live wood. Increasing population density initially increases the radius of collection and the concomitant cost in terms of the labour of women and children. Nevertheless, the system can remain in balance. Eventually the walking distance becomes unreasonable and then increasing demand is placed on a limited area. Dead wood is no longer enough. Live trees are felled, all available twigs and other fallen materials are utilized and the forest is lost. The impacts depend upon the land holding pattern. The poor and landless are left with the denuded commons while the land holders may still be quite well supplied. This phase frequently leads to commercialization of the woodfuel system, particularly if the population growth is accompanied by urbanization. The effects of this can be both positive and negative. Purchasers of woodfuel are more frugal in its use and may invest in improved stoves or even undertake fuel substitution to LPG and kerosene for some of their activities. Wood production may be stimulated and trees planted. On the debit side the poor will be encouraged to cut trees (poaching) for a cash income and the urban demand thus accelerates loss of the forest. Urban demands must be distinguished from local rural demand if appropriate solutions to a shortage are to be found. While industrial demand is frequently only a fraction of the total woodfuel demand, it too can have enormous local impacts. Baking, brickmaking, salt and lime manufacture, use 0.5 to 2.0 t woodfuel/t product, while consumption in crop drying ranges from 5 to 50 t/t. Traditional drying barns in Malawi use as much as 48 t woodfuel/t tobacco leaf produced. Or more dramatically, one hectare of tobacco requires 42 ha of forest to dry the leaves. Modern kilns (Barnard, 1987) should be able to reduce the demand to around 5 t/t which is still four times the theoretical requirement.

Conversion Technology

The most important biomass conversion technology is combustion, which probably accounts for 95% of all end use applications at the tertiary level of the energy economy. The conversion of biomass into other energy forms such as gas (producer gas and biogas) and liquid fuels (ethanol, methanol), and the generation of electricity or the production of solid fuels (charcoal), constitutes only a fraction of total woodfuel use. Of these other conversion technologies, electricity and charcoal production are the most important transformations to secondary energy forms. Biotechnological conversions to biogas and ethanol are in existence but as yet are relatively minor in relation to thermochemical conversions. The large scale state-subsidized ethanol programs in the USA (maize) and Brazil (sugar cane) are clear demonstrations that significant quantities of liquid fuels can be obtained from biomass while also demonstrating that such a policy can aid in regulating agricultural production.

The Supply of Biomass

Whether for food, feed or fuel, the major part of the biomass used is drawn from the land. The fraction of the world's surface composed of land is only 29% (14,900 Mha), only 13,170 Mha (10^6 ha) is ice free, and of this almost 50% is neither arable nor grazeable. With a current world population of 5 billion people this provides only 1.3 ha to support each person in almost all of their food requirements. Thus, one concern that has existed since Malthus is the carrying capacity of the land for a growing population. Population growth is one of the driving forces that increase pressure on the environment and force the development of new lands and technologies in biomass. A glance at the newspapers shows that the question of world biomass supply is quite complex. In North America and Europe one reads of concerns about agricultural surpluses that have led to complex subsidy regimes for farmers growing wheat or other foodstuffs, in order to maintain farmer income at a time of considerable overproduction. Policies currently being developed in the OECD nations (Organization for Economic Cooperation and Development) to reduce these surpluses include taking land out of productive use. Elsewhere in the same newspaper one can read of famine and malnutrition in Africa's Sahel region, where climate has reduced the productive capacity of the land to such an extent that large populations are migrating to other regions. Fortunately, one thing that has ameliorated this disturbing feast and famine disparity between regions has been the large increase in aid and food exports from producing regions to consumers. Since the Second World War the tonnage of food traded internationally has increased by more than a factor of 5. At least 10% of the World's cereal production is traded internationally, most of it from North America. An FAO study: "Potential population supporting capacities of lands in the developing world" (FAO, 1983a), has examined the carrying capacity question in detail and concluded that with increasing technological inputs the world as a whole has the capacity to feed the anticipated population of 6.1 billion in about the year 2000. Such a global view, however, conceals large regional disparities. In 1975 it was reckoned that 55 of the world's 117 developing countries were in a state of crisis in that they could not satisfy their own food demands; by 2000 this number is projected to be 64, and would include the entire Southwest Asian region.

The Magnitudes of Biomass Use

The biosphere provides not only food and feed, but also furnishes construction materials and energy. Quantitatively, the mass of the biosphere used in non-food pursuits is probably greater than that used for food production. Man's impact on the biosphere in terms of food, feed, fibre and fuel withdrawals probably amounts to about 5-6 Pg/a (10^{15} g/annum) or 4-5% of the primary productivity (estimated to be of the order of 130 Pg/a). However, man's impact on the biosphere is much greater than a simple addition of food, feed, fibre and bioenergy would suggest. At any given moment: land is being set aside; forests are cleared by slash and burn agriculture; and land is lost to desertification, salination, urbanization and energy projects. Other productive capacities of the land base are being affected by both local pollution and that deposited by long range transport such as acid rain in North America and Europe (Vitousek *et al*, 1986).

It is useful to generate an order of magnitude estimate of the size of the biomass withdrawals and their use in order to guide the later discussion. The units that I will use are giga tonnes (Gt). The prefix G is 10^9, the North American billion. The major food harvest is grains; probably 70%

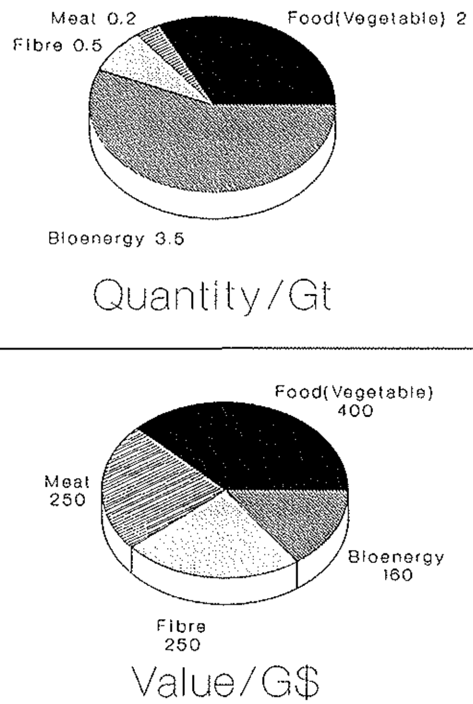

Figure 2: Biomass Utilization: Quantity And Price

of all crops. From FAO statistics it is possible to estimate that the food system generates about 2 Gt of food stuff and 2.5 Gt of associated residues such as straw and stover. About 0.5 Gt of industrial wood are used annually, approximately 50% for paper and board products. The industrial wood harvest generates about the same quantities of both forest and process residues. Direct fuelwood withdrawals are in the order of 0.5 Gt. The total of all of these is about 6 Gt, with residues and woodfuel totalling 3.5 Gt. The quantities and their values are summarized in Figure 2.

Bioenergy clearly ranks first in quantity, but last in terms of consumer price. Although these numbers are order of magnitude estimates, they highlight a large area of opportunity in the use of wastes and residues associated with the economically essential areas of food and fibres/solid products. Currently much of this is used in low efficiency bioenergy applications and in terms of added value and substitution potential, could probably be better utilized elsewhere.

Population

The ever present driving force for development is population growth. It places increasing burdens on the sustainable yield of the biosphere year after year, and already it is evident that in some instances the effect of human pressure has led to loss of ecosystems. The effect of population change on resource demand is difficult to project. The simplest model would be to assume that present per capita consumption will be maintained. There are dangers in this approach since it is evident that for much of the Third World the current resource consumption rate is already much lower than required and, as will be seen, the growth rate in the less developed part of the world is considerably greater than in industrialized countries.

Population Statistics

In 1986 it was estimated that world population had surpassed 5 billion people. From 1950 to 1986 the population of the developed world (Europe, North America, Australia, New Zealand, Japan and the USSR) grew from 0.8 to 1.2 billion (an annual growth rate of 1.6%). The Third World (Africa, Asia, Latin America and Oceania) grew from 1.7 to 3.8 billion (3.1 %/a). The United Nations projection to 2000 (UN, 1985) shows the total world population estimate at 6.1 billion, with the developed countries total having increased at a rate of 1.2 %/a to about 1.3 billion and that of the developing countries at 2.4 %/a to 4.8 billion. Such a global perspective conceals countries such as Sweden which are in negative growth and those undergoing explosive growth such as Kenya with a current growth rate of 4.1 %/a.

The rapid world population growth is accompanied by another phenomenon, namely urbanization, which has a bearing on the future use of resources such as biomass. Thus, while Third World rural populations have increased in the last five decades from 1.5 to 2.5 billion; according to El-Shakhs (1983), the increase to the year 2000 is forecast to be only another 0.5 billion. It can thereby be assumed that one out of every two additional people in the Third World will be an urban dweller. These population trends indicate that transportation of food and energy will increasingly be required even in countries with large productive land capacities per capita. If the population is predominantly urban it will not be possible to use biomass for food, feed and energy in the same way as in a predominantly rural society.

Land for Food, Feed and Fibre

The population of 6.1 billion forecast for the year 2000 could easily have enough food, feed and fibre. In fact the theory has been advanced that, under ideal conditions of adequate fertilizer and water inputs along with a global transportation network for foodstuffs, the forecast stabilized world population of 11 billion in the year 2100 could also be fed. These dreams are not reflected in the cold facts of today; a World Bank study (WB, 1985) identified 87 developing countries in which the proportion of the population lacking sufficient calories to have an active working life was anywhere between 10 and 50 percent, with an average of 34 percent. Sixteen per cent were at a caloric intake level less than 80% of the FAO/WHO minima, a level known to stunt growth and to pose serious health risks.

Land Usage

Global land use (FAO, 1983b) is shown in the table below. Total land area including rivers and freshwater lakes is 13,400 Mha. The term "Other" includes ice caps, deserts and mountains. It is important to consider where the different types of land are situated, as is shown in Table 1.

These statistics of land availability (Table 1) show that just over one half of the world's cropland (or potential cropland) is located in the developing countries which presently hold 3/4 of the world population. Cropland is defined as land under permanent or temporary crops and includes market and kitchen gardens. The current cropland area of 1.47 Gha represents 0.39 ha/person. The total area of current and potential cropland is 4.15 Gha. Potential cropland has yet to be created from grasslands and forests. It is generally considered that little of the potential area will be converted to crops. This is because areas that are not currently used as cropland have one or more major drawbacks, for example, the thin soils of the Andes, the near desert soils of the southern Sahel, and the tsetse fly regions in Central Africa. In any case the majority of the developing countries with food supply problems are land-short; the potential areas for conversion are in the wrong places. The majority of the forecast increase in food production needed to meet anticipated population growth must therefore come from increasing land productivity. Much of the capacity to keep growth in food production in line with population increase has come from high input agriculture. The so-called Green Revolution took the US agricultural model and applied it to the developing world by breeding high-yielding wheat, rice and maize to better utilize the water, fertilizer and bio/herbicide methods of the industrial countries in a development setting. India is a stellar example of the success of this revolution. In the 20 years from 1964 to 1984 (FAO, 1983b), grain productivity increased from 904 kg/ha to 1626 kg/ha, irrigation increased by 20% and fertilizer inputs

Table 1: Global Distribution Of Land Categories By Region

Region	Land Area (Mha)			
	Arable	Grassland	Forest	Other
Africa	182.7	783.9	693.7	—
North & Cent America	273.0	354.5	282.3	—
South America	137.3	454.4	936.7	—
Asia	457.7	649.1	552.0	—
Oceania	44.9	470.4	150.2	—
USSR	232.2	373.6	920.0	—
World Totals	1469.0	3172.0	4090.0	4346.0
(%)	11.2	24.3	31.3	33.2

climbed from an average of 5 kg/ha to 34 kg/ha. While total food production increased by 75%, per capita consumption increased by only 17%, due to a concomitant growth in population.

Feed

Roughly half of the world's grain production is used as animal feed to provide animal protein. However, the majority of the feed for ruminant livestock comes from rangeland. Globally, rangeland accounts for about 80% of all meat production, while in developing countries this value is probably close to 95%. Most rangelands are lands that are too dry to support rain-fed agriculture and about 2.3 Gha (i.e. half) of these lands are in developing countries. The world's livestock herds (cattle, buffalo, sheep, goats, pigs) amount to a population of about 4 billion. In developing countries meat animals are often also beasts of burden and provide motive power for pumping and milling; a considerable portion of village energy input in parts of India according to Reddy and Ravindranath (1987). The productivity of many of the developing world's rangelands is declining, according to the World Resources Institute (WRI, 1986). Most are probably producing less than 20% of their potential forage due to overgrazing. Though it is unfair to compare European rangeland with that of arid Africa, it is worth noting that although the area of pasture in the African continent is at least 6 times greater than in Europe, Europe produces 75% more cattle and sheep — a productivity difference of 25 times. As with caloric input, protein intake is a function of region, state of development and national income. FAO statistics show that the per capita consumption varies widely (FAO, 1983b). Animal protein consumption appears to be associated with income level as evidenced by the spectacular growth in meat consumption in OPEC countries of the Middle East during the 1970's. The lowest animal protein consumption occurs in the Far East at around 7 g/day per person.

Fibre

Wood is the most important fibre crop. Annual harvest of natural vegetable fibres such as jute, sisal, hemp and cotton amounts to about 20 Mt, with cotton representing about 3/4 of the total. This compares with an annual wood usage of about 1 Gt. Thus the last major land base to consider is the forest base and its relationship to biomass supply. Prior to the rapid population growth of the last century, the area of forested lands of the world was probably well in excess of 6 Gha. By 1882 this was already down to 5.2 Gha. The intervening century has seen a collapse to only 4 Gha. The majority of the forested land has been lost to arable land and grassland. This loss of what is frequently primary forest continues unabated. It is estimated (FAO, 1982), that each year 6-8 Mha of closed forest and 4 Mha of open woodlands are lost to agriculture. The majority is tropical forest; in Europe the area of forested land is increasing as agricultural land is passed back for reforestation. The prognosis for the year 2000 is that the world's forest area will be down to 3.6 Gha, a loss rate of about 1 %/a. The productivity and growing stock of the forest base is also precarious. UNEP reported Buringh's observation that only 10% of the world's forest area is sufficiently well stocked to meet its productivity potential (UNEP, 1982). Eighty per cent is estimated to be at less than 20% of its potential due to poor stocking, erosion and site degradation. The current harvest of wood is considerably underestimated in the developing world because much of it does not come from forests but rather from woodlots and other small scale production means. The current roundwood production rate is about 3.15 Gm^3 of which 1.4 Gm^3 is industrial wood, the rest being fuelwood and charcoal. Over half of the world's industrial wood production is from boreal countries, based mainly on coniferous species in the USA, Canada, Scandinavia and the USSR. Paper and board production comprises a major fraction of the consumption of industrial wood. For the last decade such use has grown at about 2 %/a. It is anticipated that this will increase over the next few decades as a result of the growth in population, literacy and income of the developing countries. Between 1970 and 1980 the developing countries' share of paper and board consumption increased from 11 to 16%, while production in the developing world increased from 7.8 to 12.4%. Current per capita consumptions in the Third World are often less than 10 kg/a while in the USA they are about 400 kg/a. As in the discussion on food and protein the two forces of population growth and increased per capita consumption could result in very large increases in demand for paper and board products.

Environmental Considerations

Environmental impacts of biomass use are associated with production and harvest of the vegetable raw materials and with their use and conversion into other energy forms.

The most common use of biomass is for combustion processes, the majority taking place in developing countries. There is widespread evidence that a considerable amount of air pollution is caused by biomass use. The combustion process is one in which thermal energy is released by oxidation of the biomass, with the carbon and hydrogen in the fuel theoretically converted to carbon dioxide and water. Ideally, only the stoichiometric quantity of air (or oxygen) is required. In reality, there is always an excess of air either by design or by the inability of the user to control the air supply. Industrial scale units have good control systems and operate with minimum excess air to avoid water vapour condensation in flue gas handling systems. Their efficiencies, as a consequence, can be in the high 80s percent, the emissions of carbon monoxide and unburnt hydrocarbons are low, and with scrubber and filter technology particulate emissions can also be minimized.

The open fire or small cooking stove meets none of the prerequisites for good combustion: the air-to-fuel ratio is impossible to control; the hot flames are quenched on the cold surfaces of cooking pots; and there is an extensive loss of unburnt hydrocarbons and particulates in the form of smoke. At best, the three-stone fireplace can have an efficiency of 30% but this is more frequently in the range of 5-10%. Vast quantities of emissions are produced including particulates and gases containing known carcinogens such as benzo(a)pyrene. Evidence from Nepal for enclosed kitchens, has shown that indoor levels of carbon monoxide and dioxide, particulates and hydrocarbons are well in excess of those in heavily industrialized cities. Epidemiological evidence exists for a causal link between chronic bronchitis, which affects 20% of all rural adults in Nepal, and the use of open stoves (Pandy, 1984).

There has been a significant effort to ameliorate this situation, particularly by non-governmental organizations in developing countries. This has resulted in new stoves having much improved performance with respect to fuel consumption and emissions. The diffusion of these stoves and their acceptance into the target communities has, however, been slow.

The environmental impacts of intensive use of the biosphere are evident and have already been alluded to above. Intensive crop production demands fertilizer, insecticide and herbicide inputs. These draw on the overall energy and materials supply system, create pollution in manufacture and all too often create pollution and damage when used, due to run-off into water supplies. Irrigation, while boosting production, also runs the risk of transporting salts to the soil surface and reducing the productive capacity of the land. Multiple cropping is often unsustainable and leads to soil depletion and erosion. Conversion of land to cropland creates other environmental risks due to loss of soil in tropical forest environments and the loss of habitat for wildlife. In any case, land conversion is not a leading choice since it will further reduce the forest lands which are also required for the production of fibre and fuel. As if these environmental insults associated with the direct management of the land resource were not enough, the biosphere now has to contend with other more noxious and insidious aspects of modern man's urban existence. In the Northern Hemisphere the long range transport of acid gases has resulted in nitric and sulphuric acid deposition that is affecting vulnerable soils with no pH buffering capacity. Concerns are being expressed about the depletion of the ozone layer as a result of the transport of halogen-containing compounds to the stratosphere. Increased UV radiation at the earth's surface will damage plants in addition to its obvious effects on fair skinned people. The other long range problem involving the biosphere is the question of infrared-absorbing gases in the atmosphere. The major component of these gases is carbon dioxide, which has risen in the last century from 295 ppm to the present 350 ppm. These infrared-absorbing gases have been called the greenhouse gases and in a postulated greenhouse effect it is anticipated that there will be significant global warming. The sum of atmospheric alterations related to infrared-absorbing gases could lead to:

- increased soil erosion
- shifts and uncertainties in biomass productivity
- changes in distribution/seasonality of fresh water
- accelerated species extinction
- reductions in yield and diversity of ecosystems, especially of forests.

These changes will obviously reduce the prospects for sustainable development and reduction of poverty in the Third World and will decrease political stability. The biosphere is implicated in many of these changes as both source and sink for carbon dioxide. Reduction of forested areas and replacement by poorly managed low productive rangelands reduces the capacity of the biosphere to absorb carbon dioxide and, at the time of clearance, contributes to the CO_2 burden. Bad agricultural practice, particularly with fertilizer use, can lead to increased loss of other greenhouse gases including nitrous oxides and methane. The changes in climate induced by warming are not easily forecast. Indeed, we are in the midst of a very large scale and irreversible experiment on our environment. There is likely to be an increase in sea level with enormous implications for many world cities. The increased temperature of the atmospheric heat engine is likely to increase the magnitude and frequency of tropical storms, hurricanes and typhoons. Given the current hard won competition between food security and population growth, these uncertainties decrease the resiliency of the world community and its capacity to guarantee adequate food, shelter and energy for everybody.

The conference "The Changing Atmosphere: Implications for Global Security," sponsored by Environment Canada in 1988, made a number of recommendations for immediate action by governments and industry. These centre on the need to reduce emissions of both CO_2 and trace gases with the goal of stabilizing carbon dioxide in particular. With the current model for the carbon cycle, this implies a 50% reduction in carbon dioxide emissions. A goal of 10% is proposed for the year 2005. This will require large augmentations in efficiency of use of fossil and biomass fuels; large scale shifts to non-carbon dioxide-emitting sources; and conservation measures to reduce demand. Each of these has to involve technology which is already in existence! Given the proposed time scale, a switch to lower CO_2-emitting fuels would include increased use of natural gas and both hydro and nuclear electricity. The conference recommended that renewable energy strategies, especially for bioenergy, be reviewed due to the potential of these technologies to better manage the circulation of carbon between the biosphere and the atmosphere without adding to the existing pool.

Prospects

Biomass energy is an integral part of the management of the biosphere, and is the largest component of man's use of the biosphere. The data presented in this paper show that the ability of the biosphere to provide more bioenergy as primary energy is limited, especially if population growth-driven demand for food and fibre products is as forecast. The data available on bioenergy use also show that the efficiency of current use is quite low, thus it should be possible to deliver more tertiary energy for the same primary energy input. This is unlikely to be achieved merely by manufacturing a better woodstove for the Third World. A much more rational solution will be to focus on improvements in the efficiency of biomass production and utilization. Since food and feed applications are essential to human survival, attention has to be focused on the utilization of residues and wastes associated with their production and processing. At present, many of these are used in relatively inefficient combustion processes and by changing to new technologies (e.g., improved combustion, gasification, and biotechnological processes such as anaerobic digestion and alcohol fuel production) energy needs could be satisfied while meeting food and feed demands. While there have been many technical advances in bioenergy conversion, all of which it has not been possible to describe, the point has forcibly to be made that only technologically facile processes having low capital and operating costs and reasonable efficiency are of interest in the development context. Even in the industrialized countries these same criteria apply, since competition from superior fuels (i.e., those that are cleaner, of higher energy density and needing less capital investment in conversion and use) constrains the bioenergy market potential.

Given this, emphasis needs to be placed on direct combustion, the preparation of transportable solid fuels, such as charcoal, and on applications of these fuels that lead to shaft power and electricity generation. Biotechnological processes, such as biomethanation and ethanol production, are currently of minor importance relative to direct combustion and, as a consequence of the technological and capital investment requirements associated with them, will only emerge in the context of industrialized countries or those in the process of industrialization.

The provision of biomass, unlike conversion of biomass (which is governed by universal principles that apply widely), is very much a consideration of biome, climate and population. The rural and peri-urban woodfuel problem is likely to be addressed by multiple purpose trees in the context of changes in crop practice to agroforestry and other systems. Those countries with surplus crop production (or land) will clearly be able to look to agri(silvi)-industrial complexes to generate materials and energy along with foodstuffs and traditional products. In addition, increasing efficiency will lead to the solution of some of the problems of wastes and residue utilization and can address the environmental problems which continue to be associated with the primary industries in both developing and industrialized countries.

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