Food, Feed and Fuel from

BIOMASS

EDITOR

D. S. CHAHAL

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Preface

The theme of this book is to present up-to-date information about the application of biotechnology to meet the ever-increasing demand of food, feed and fuel (FFF). It has been especially addressed to businessmen, policy-makers, researchers and students working on, or interested in this field all over the world. Although the term *biomass* includes every organic matter (living or dead including fossil fuel), here it refers to lignocelluloses (crop residues, and wood and wood residues) and animal manures. Since this type of biomass is a renewable source of organic carbon, there is no fear of its exhaustion by its continuous bioconversion into FFF. While biomass is not the answer, it is one of the major sources to alleviate the shortages of FFF in the world.

Biomass is composed of mainly cellulose, hemicelluloses and lignin (lignocelluloses) and it also contains starch, protein and useful nutrients (animal manures). Since the recognition of shortage of liquid fuel cellulose has been considered as the only renewable resource for its conversion into liquid fuels (ethanol and methanol). During the last 15 years there have been numerous national and international conferences on food/feed (single-cell protein—SCP) and fuel organised in various parts of the world and as a result, a number of books appeared in the form of proceedings of such conferences. Besides such proceedings voluminous literature has been published in this field. In such publications only certain aspects of the whole subject matter have been discussed while other aspects and their interactions have been neglected.

The first two international conferences on SCP held in 1967 and 1973 dealt mainly with the production of SCP as food/feed from hydrocarbons, and from starchy and sugary materials by using mostly bacteria and yeasts (single-celled microorganisms) while ignoring altogether the use of lignocelluloses and animal manures as substrates as well as the most potential filamentous fungi as the agents of bioconversion. All of this work now has become obsolete because of shortage of hydrocarbons as well as starchy and sugary substrates which could otherwise be easily used as energy source for human and animals without any bioconversion. Because of high costs of such substrates and some of the undesirable characteristics of the product (especially from hydrocarbons) some of the SCP-producing plants are being shut down.

Similar is the case with fuel (ethanol) production wherein all the efforts were directed towards the utilisation of pure cellulose, the most expensive substrate. Because of the high cost of preparing pure and reactive cellulose and some other factors, no economical process for ethanol production from biomass is available so far.

In the field of ethanol production numerous proceedings and books have been published and nowhere has biomass been considered as one unit and nowhere has the production of FFF been discussed as an integrated process for the complete utilisation of biomass. A book dealing with an integrated approach for the production of FFF by complete utilisation of biomass is the need of the day for businessmen and policy-makers to exploit its commercialisation and for researchers and students for further improvements. To meet these requirements the present work has been compiled with the help of various experts in their respective disciplines wherein biomass has been taken as one unit and production of food/feed (SCP) and fuel (ethanol and methanol) has been dealt as an integrated process so that no fraction of biomass is left unutilised.

The first eight chapters deal with the availability of biomass, its chemical composition, structures and pretreatments to make it easily accessible by the microorganisms for conversion into FFF. The ninth to fourteenth chapters deal with production of food/feed (SCP) from biomass as well as the nutritive evaluation of SCP. The fifteenth to twenty-fourth chapters deal with production of fuels and chemicals from biomass. No treatise on bioconversion of biomass into FFF has discussed "Pretreatments of Lignocelluloses"; "Production of Cellulases and Hydrolysis of Lignocelluloses"; and "Production of Protein-rich Animal Feed from Lignocelluloses, Hemicellulose Fraction and Manures" in such detail as given in this book. Another outstanding feature of this book is that the "biomass" has been treated as one unit throughout the text of each chapter.

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Ralph P. Overend

INTRODUCTION

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 that is land is only 29% (14,900 Mha) and only 13170 Mha (10^6 ha) is ice free, and of this almost 50% is neither arable nor grazeable. At the current world population of five billion people this allows only 1.3 hectares 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 forces the development of new lands and technologies in biomass.

A glance at the newspapers shows that the world biomass supply question 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. Currently policies to reduce these surpluses are being developed in the OECD nations (Organisation for Economic Cooperation and Development) which 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 food exports and aid from producing regions to consumers. Since the Second World War the tonnage of food traded internationally has increased by at least a factor of 5. At least 10% of the world's cereal production is traded internationally, most of it from North America.

A recent FAO study (*Potential population supporting capacities of lands in the developing World*) has examined the carrying capacity question in detail and has concluded that with increasing technological inputs the World as a whole has the capability to feed the anticipated population of 6.1 billion (10^9) in about the year 2000. Such a global view, however, conceals large regional disparities. In 1975 it was reckoned that 55 out of the world's 117 developing countries were critical 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 Magnitude of Biomass Use

The biosphere not only provides food and feed, it also furnishes construction materials and energy. Quantitatively the mass of the biosphere used in non-food pursuits is probably greater than the food consumption. Man's impact on the biosphere in terms of food, feed and fuel withdrawals probably amounts to about 5 – 6 Pg/a (10^{15} g/year) or 4-5% of the primary productivity (estimated to be of the order of 130 Pg/a).

However, man's impact on the biosphe e 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, urbanisation 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 or Gt. The prefix G is 10^9 the North American billion. The major food harvest is grains, probably 70% 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. Industrial wood is about 0.5 Gt, with roughly 50% going into paper and board products. The industrial wood harvest generates both forest residues and process residues of about the same quantity. Fuelwood withdrawals as such are about 0.5 Gt. The total of all of these is about 6 Gt with residues and fuelwood totaling 3.5 Gt.

Table 1 describes in approximate terms the current production and consumer price of different biomasses. Bioenergy clearly is first in rank in quantity but is last in terms of consumer price.

TABLE 1
Relative production and price of biomass

Biomass Source	Production Gt	Price $/t	Total Value G$
Food (Veg)	2	200	400
Livestock Products	0.2	5000	250
Fibre	0.5	500	250
Bioenergy	3.5	45	160

These numbers are indeed order of magnitude estimates but they highlight that there is 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. This places increasing burdens on the sustainable yield of the biosphere, year after year, and it is already evident that in some instances the effect of human pressure has already 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 consumption rate of resources is already much less than is required and as will be seen the growth rate in the less developed part of the world is considerably greater than that of the industrialised countries.

Population Statistics

In 1986 it was estimated that the world population had passed 5 billion persons. Starting from 1950 the population of the developed World: Europe, North America, Australia, New Zealand, Japan and the U.S.S.R., 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 projection to 2000 (approximately 10 years from now!) (UN, 1985), shows that the total World population estimate is 6.1 billion with the developed country 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 that 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 which has a bearing on the future use of resources such as biomass, namely urbanization. Thus, while in the Third World the 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 only forecast to be another 0.5 billion. Thus it can be assumed that one out of every two of the population increase in the Third World will be an urban dweller.

These population trends indicate that transportation of food and energy is increasingly going to 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 with a predominantly rural society.

LAND FOR FOOD, FEED AND FIBRE

The population of 6.1 billion forecast for 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 2100 could also be fed. These dreams are not reflected in the cold facts of today; a World Bank study (World Bank, 1985) identified 87 developing countries in which the proportion of the population lacking sufficient calories to have an active working life were anywhere between 10% and 50% with an average of 34 per cent. Sixteen per cent were at a level less than 80% of the FAO/WHO minima, a level known to stunt growth and to create serious health risks.

Land Usage

The global land use is as follows:

Category	*Mha*	*%*
Arable Land	1469	11.2
Grass Land	3172	24.3
Forest Land	4090	31.3
Other Land	4346	33.2
Total	13077	100.0

Source: FAO, 1983

The total area of the land including rivers and freshwater lakes is 13,400 Mha. The term "other land" includes ice caps, deserts and mountains. It is also important to consider where the different types of land are situated all in units of Mha:

Region	*Arable Land*	*Grass Land*	*Forest*
Africa	182.7	783.9	693.7
N&C America	273.0	354.5	282.3
S. America	137.3	454.4	936.7
Asia	457.7	649.1	552.0
Europe	140.8	86.1	155.2
Oceania	44.9	470.4	150.2
USSR	232.2	373.6	920.0

Source: FAO 1983.

Crop Availability

The statistics of land availability above show that just over one half of the world's cropland (or potential cropland) is in the developing countries that presently have three-fourths of the world's population. The current and projected areas along with the per capita cropland availability are as follows:

Region	Current Gha	Projected Gha in 2000	Per capita ha	ha (2000)
World	1.47	1.54	0.39	0.25
Industrialized Countries	0.40	0.40	0.55	0.46
Centrally Planned Countries	0.41	0.42	0.35	0.26
Developing Countries	0.66	0.72	0.35	0.19

Cropland is defined as land under permanent or temporary crops and includes market and kitchen gardens. The total of current and potential cropland has an area of 4.15 Gha. The potential cropland has yet to be created out of grasslands and forests. It is generally not considered that much of the potential area will be converted to crops. This is because the areas that are not currently cropland have one or more major drawbacks. These range from 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 in any case land short, the potential areas for conversion are in the wrong places.

The majority of the forecast increase in food production to meet anticipated population growth has therefore to come from increasing land productivity. Much of the capacity to keep food production increases 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 bioherbicide 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, grain productivity increased from 904 kg/ha to 1626 kg/ha, irrigation increased by 20% and the fertilizer inputs went from an average of 5 kg/ha to 34 kg/ha (FAO 1983). While the total food production increased by 75% the per capita consumption was only improved by 17% due to a concomitant growth in population.

Feed

Roughly half of the world's grain production is used as a animal feed to provide animal protein, 70% of this consumption is in 10 countries: the U.S.A., the U.S.S.R., China, Canada, France, Brazil, Japan, Poland, the F.R.G. and Spain. Nevertheless the majority of the feed for ruminant livestock comes from rangeland and forage fed animals. Globally this accounts for around 80% of the meat production, while in the developing countries it is probably close to 95%. The majority of the rangelands are lands that are too dry to support rainfed agriculture and about 2.3 Gha, or 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 part of village energy input in parts of India according to Reddy and Ravindranath (1987).

The productivity of much of the developing world's rangelands is declining (WRI, 1986). Most are probably producing less than 20% of their potential forage due to overgrazing. Although it is unfair to compare the European rangeland with that of arid Africa, it is worthwhile noting that although the area of pasture in the African continent is at least six times greater than Europe's, 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 (FAO 1983, table 104) that the per capita consumption varies widely. 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 1980 figures are as follows:

Region	*Vegetable Protein*	*Animal Protein*	*Total Protein*
	g/(d. caput)	g/(d.caput)	g/(d.caput)
WORLD	45.6	23.8	69.4
Developed	39.9	57.9	97.8
Central planned Economies:			
U.S.S.R. + E. Eur.	49.7	50.7	100.4
Asian	52.8	12.0	64.8
Developing countries	43.6	12.2	55.8

The lowest animal protein consumption is in the Far East at around 7 g/d per person.

Fibre

The most important fibre crop is wood. Natural vegetable fibres such as jute, sisal, hemp and cotton amount to about 20 Mt with cotton representing about three-fourth of the total. This compares with an annual wood usage of > 1 Gt. Thus the last major land base to consider is the forest base and its relationship to biomass supply. The forested lands of the world prior to the rapid population growth of the last century were probably well in excess of 6 Gha. By 1882 they were already down to 5.2 Gha. The intervening century has seen a collapse to only 4 Gha. The majority of this loss of forested land has been to arable land and to grassland. This loss of what is often 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 of this 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 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. The UNEP (1982) reported Buringh's observation that only 10% of the world's forest area is sufficiently well stocked to meet its productivity potential. Eighty per