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Biomass for Energy in Developing Countries

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Abstract: Biomass, like fossil fuels, can provide cooking and heating energy, electricity, chemicals and liquid fuels. Today about 14 % of the worldwide primary energy supply is provided by biomass resources – equivalent to 1000 million tons oil each year. Most of this biomass use occurs in rural areas of developing countries where half the world's population lives. For example Kenya derives about 75 %, India 50 %, China 33 % and Brazil 25 % of their total energy from biomass. A number of industrialized countries also derive a considerable amount of energy from biomass, such as Finland 18 %, Ireland 16 %, Sweden 9 % and USA 3 %. World expenditure on biomass programmes exceeds S2 bn/yr; several national biomass energy programmes are discussed. Biomass resources and conversion technologies are described, as are the factors necessary for successful regional implementation of biomass energy schemes.

Introduction

As more detailed energy information became available in recent years it has become increasingly evident that biomass already contributes a significant part of the world's energy. Fuels such as firewood, dung, charcoal, peat, residues, methane and alcohol are important sources of energy to very many people. But how much biomass will contribute in the future will depend very much on decisions that are made both at the local level and at the national level, in addition to international policy making. Decisions that are made over the next few years will significantly influence the level of biomass energy use in the future.

The oil/energy problem of the 1970s has had three clear effects on biomass energy developments. Firstly, in a number of developed countries large research and development programmes have been instituted which have sought to establish the potential, the costs and the methods of implementation for energy from biomass. The prospects look far more promising than was thought even three years ago. Demonstrations, commercial trials and industrial projects are being implemented. Estimated current expenditure is over a billion dollars per annum in North America and Europe. Secondly, in at least two countries, viz. Brazil (which currently spends over half of its foreign currency on oil imports) and China with over 7 million biogas digesters, large scale biomass energy schemes are being implemented – the current investment is about 1.3 billion dollars per annum in Brazil. Thirdly, in the developing countries as a whole there has been an accelerating use of biomass as oil products have become too expensive and/or unavailable.

Biomass

(Coombs 1980, Hall 1979a + b, 1981a, 1982a, UK-ISES 1976, Zaborsky 1981)

Biomass is a jargon term used in the context of energy for a range of organic products which have been derived from photosynthesis; the products are familiar ones such as wastes from urban areas, residues from forestry and agricultural processes, specifically grown crops like trees, starch, oil and sugar-bearing crops, hydrocarbon plants and aquatic

	Tons coal Equivalent	
1. Proven reserves		
Coal	5×10^{11}	
Oil	2×10^{11}	
Gas	1×10^{11}	
	8×10^{11} t	= *25×10^{21} J*
2. Estimated resources		
Coal	85×10^{11}	
Oil	5×10^{11}	
Gas	3×10^{11}	
Unconventional gas and oil	20×10^{11}	
	113×10^{11} t	= *300×10^{21} J*
3. Fossil fuels used so far (1976)	2×10^{11} t carbon	= *6×10^{21} J*
4. World's annual energy use (5×10^{9} t carbon from fossil fuels)		= *3×10^{20} J*
5. Annual photosynthesis	8×10^{10} t carbon	
(a) net primary production (2×10^{11} t organic matter)		= *3×10^{21} J*
(b) cultivated land only	0.4×10^{10} t carbon	
6. Stored in biomass		
(a) total (90 % in trees)	8×10^{11} t carbon	= *20×10^{21} J*
(b) cultivated land only (standing mass)	0.06×10^{11} t carbon	
7. Atmospheric CO_2	7×10^{11} t carbon	
8. CO_2 in ocean surface layers	6×10^{11} t carbon	
9. Soil organic matter	$10\text{-}30 \times 10^{11}$ t carbon	
10. Ocean organic matter	17×10^{11} t carbon	

Tab 1 Fossil Fuel Reserves and Resources, Biomass Production and CO_2 Balances

plants such as water weeds and algae. Thus everything which has resulted from the process of photosynthesis is a potential source of energy. We are talking essentially about a solar energy conversion system, since this is what photosynthesis is. The problem with solar radiation is that it is diffuse and also intermittent, so that if we are going to use it we have to capture a diffuse source of energy and then store it – this is a problem that plants solved a long time ago.

The process of photosynthesis embodies the two most important reactions in life. The first one is the water-splitting reaction which evolves oxygen as a byproduct; all life depends on this reaction. Secondly is the fixation of carbon dioxide to organic compounds. All our food and fuel is derived from this CO_2 fixation from the atmosphere. When looking at an energy process we need to have some understanding of what the efficiency of this process will be; one needs to look at the efficiency over the entire cycle of the system, and in the process of photosynthesis we mean incoming solar radiation converted to a stored end-product. Most people agree that the practical maximum efficiency of photosynthesis is between 5 and 6 %. This might not seem very good but remember that it represents *stored energy.*

The photosynthetic efficiency will determine the biomass dry weight yields. For example, in the UK with 100 Wm^{-2} incoming radiation a good potato crop growing at 1 % efficiency (usually not higher than this in temperate regions), will yield 20–25 t dry weight per annum per ha. Obviously if we can grow and adapt plants to increase the photosynthetic efficiency the dry weight yields will

Country	Commercial Energy	Biomass Energy – GJ/Capita/Year –	Total Energy	Percentage of Energy from Biomass
Bangladesh	1.2	3.0	4.2	71 %
Niger	1.1	8.0	9.1	88 %
Gambia	3.1	7.0	10.1	69 %
Morocco	8.4	2.3	10.7	21 %
India	5.2	6.0	11.2	54 %
Ethiopia	0.6	11.7	12.3	95 %
Nepal	0.3	13.5	13.8	98 %
Somalia	2.9	15.0	17.9	84 %
Bolivia	10.7	8.3	19.0	44 %
Sudan	5.0	20.0	25.0	80 %
Thailand	9.6	16.5	26.1	63 %
Tanzania	1.9	25.5	27.4	93 %
China	24.5	10.0	34.5	29 %
Brazil	23.2	11.7	34.9	34 %
Mexico	40.5	4.0	44.5	9 %
Libya	55.3	3.0	58.6	5 %
Developing Countries (Average)	17.3	13.1	30.1	43 %

Tab 2 Summary of Selected National Energy Consumption Surveys (Hall, Barnard, Moss 1982)

increase and of course alter the economics of the crop. One of the very interesting areas of research is to try to understand what the limiting factors are in photosynthetic efficiency in plants, both for agriculture and for biomass energy.

There is another aspect of photosynthesis that we should all appreciate. That is that the health of our biosphere and our atmosphere is totally dependent on the process of photosynthesis. Every 300 years all the CO_2 in the atmosphere is cycled through plants. Every 2,000 years all the oxygen and every 2,000,000 years all the water. Thus the three key ingredients in our atmosphere are dependent on recycling through the process of photosynthesis.

World Energy Use

(Hall 1979a, 1981a + 1982a)

How much photosynthesis actually occurs on the earth? Tab 1 shows that the world's total annual use of energy is only one tenth of the annual photosynthetic energy storage, i.e. photosynthesis already stores ten times as much energy as the world needs. The problem is getting it to the people who need it. Secondly, the energy content of stored biomass on the earth's surface today, which is 90 % in trees, is equivalent to our fossil fuel reserves. In other words the energy content of the trees is equivalent to the commercially extractable oil, coal and gas. Thirdly, during the Carboniferous Era quite large quantities of photosynthetic products were stored, but in fact they only represent 100 years of net photosynthesis. The overall photosynthetic efficiency during the Carboniferous Era was less than 0.0002 % (Moore 1983). Our total possible fossil fuel resources thus only represent 100 years of "stored" photosynthesis. Fourthly, the problem of CO_2 cycling in the atmosphere. Many people are rightly concerned about the problem of build-up of CO_2 in the atmosphere if we continue to burn fossil fuels. It is a problem of cycling between two or three pools of carbon. The amount of carbon stored in biomass is approximately the same as the atmospheric CO_2 and the same as the carbon as CO_2 in the ocean surface layers; there are three nearly equivalent pools. The problem is how is the CO_2 distributed between these pools, and how fast does it equilibrate into the deep ocean layers. However, we should appreciate that increasing CO_2 concentrations in the atmosphere may be good for plants since CO_2 is a limiting factor in photosynthesis and plants have better water use efficiency at higher CO_2 concentrations. Plants could also act as CO_2 sinks if photochemical means for fixing CO_2 were not available to alleviate the problem.

Developing Countries

(Earl 1975, Eckholm 1979, Hall et al. 1982, Moss and Morgan 1981, Unasylva 1982)

Another very important aspect of biomass energy use in the world is that at least half the world's population are

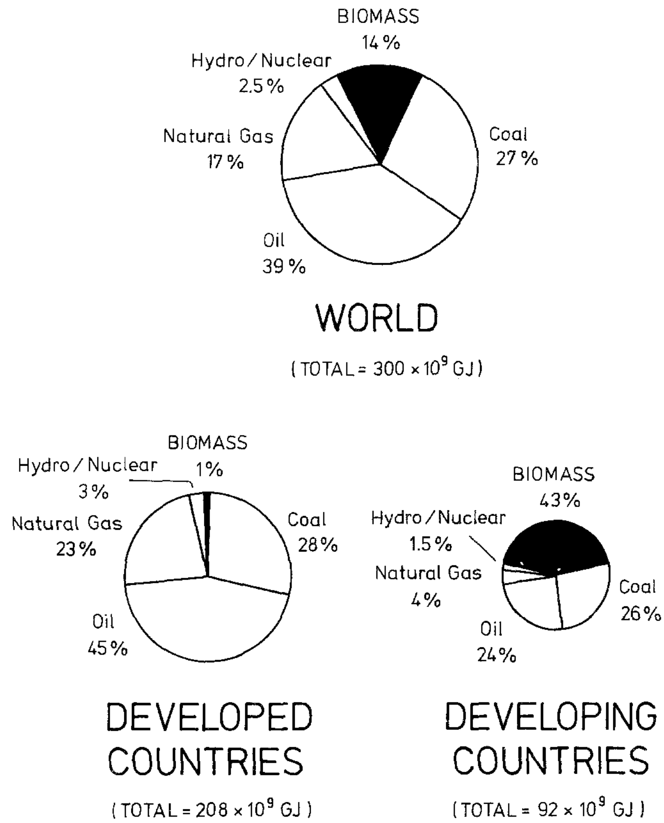

Fig 1 Global Distribution of Energy Use (1978)
(Hall, Barnard, Moss 1982)

primarily dependent on biomass as their main source of energy. A realization of this has only occurred widely in the last few years – it has been called the "fuelwood crisis" or the "second energy crisis". There is no doubt that half the people in the world have a much more serious energy problem than most of us who are primarily concerned about the price of petrol or what the heating or cooling bill is going to be. About 14 % of the world's annual fuel supplies are currently derived from biomass (Fig 1 from Hall, Barnard and Moss 1982). The average person in the rural areas of the developing world uses the equivalent of about one tonne of wood every year (Tab 2 + 3). This is mainly for cooking and heating but also for small-scale industry, agriculture, food processing, and so on. The use of wood and charcoal in urban areas and for industry is often much greater than is realized. 14 % of the world's energy use represents the equivalent of 1000 million tons of oil a year, which is slightly more than tutal USA oil use. Many people did not realize the importance of this largely because the statistics were not available to show this significance, and because the consequences of biomass overuse were not readily evident. Until a few years ago world energy supply statistics listed biomass at 3–4 %, if at all. It is now known that about half of all the trees cut down in the world today are used for cooking and heating. Of

Tab 3 Traditional Fuel Consumption in the Village Sector (Hall, Barnard, Moss 1982)

Country	Village	Number of persons, families or households	Energy Source	% of total from biomass	Fuel use (per person per year) (GJ)	Tons equivalent wood
Bangladesh	Ulipur	48 families, 330 people	Crop residues *plus firewood*	100	7.5	0.5
Bolivia	Quebrada	6 people	Fuelwood	100	30.0	2.0
Botswana	Matsheng		Firewood		16.5	1.1
Cameroon	Ngaoundere		Firewood		18.0	1.2
Chad	N'Djamena (City)		Firewood		44.0	2.9
China	Peipan	1000 people, 200 households	Mostly firewood	87	21	1.5
India	Ungra	932 people, 149 households	Fuelwood, residues	95	9.0	0.6
Iran	Semnan, Kavir	150 people	Firewood		18.0	1.2
Kenya	Machakos District		Wood and charcoal		15.0	1.0
Lesotho	Malefiloane		Wood, dung	98	8.2	0.6
Mali	Sanzana		Wood		12–14	.8–.9
Mexico	Arango	420 people, 80 households	Residues	33	13.0	0.9
Nepal	Hill	250 people, 48 households	Fuelwood	97	11.0	0.7
Nigeria	8 villages		Firewood		18–27	1.2–1.8
Peru	Nunoa	15 families studied	Dung	87	165 fam./yr.	11 fam./yr.
Senegal	Dakar (City)		Charcoal		22.0	1.5
South Africa	Mashunka		Wood	99	17.0	1.1
Sri Lanka	Village nr. Anuradhapura	203 people, 34 households	Firewood		5.3	0.4
Sudan	Bara	10,000 people, 1600 households	Mostly charcoal	90+	62.0	4.1
Tanzania	Kilombero	100 people	Biomass	100	23.0	1.5
Upper Volta	Boulenga		Wood, millet stalks		12.0	0.8

course the problem of deforestation with its consequent flooding, desertification and agricultural problems is not solely due to over-cutting of trees for cooking and heating. There are obviously other factors involved such as commercial and illegal cutting, absence of replanting, and so on.

Recently there have been a few good papers published on studies in Southern and East Africa which show that in an average family of six or seven, one person's sole job is to collect firewood and they will often have to walk great distances, which of course has other deleterious consequences. In urban locations households can spend up to 40 % of their income on fuelwood and charcoal. Another example which has been highlighted in Tanzania is the curing of tobacco; for each hectare of tobacco the wood from one hectare of savannah woodland is burned in the curing process. There are many examples to show that it is not only domestic fuelwood use but also agricultural, urban and small scale industrial uses which are having deleterious long-term consequences. Serious attempts are being made by a number of international and national groups to attempt to reverse this problem of deforestation by vigorously promoting reforestation, village fuelwood lots or community forestry, agroforestry, and other solutions. One study which has just been published (NAS 1981a) is a long overdue manual for tree species especially suited for fuelwood in the humid tropics, the arid tropics and temperate regions. Another study from ICRAF in Nairobi (Nair 1980) promotes the concept of agroforestry where one can derive both food and fuel from replanting schemes. In 1980 the

Tab 4 Some Advantages and Problems Foreseen in Biomass for Energy Schemes

Advantages	Problems
1. Stores energy	1. Land and water use competition
2. Renewable	2. Land areas required
3. Versatile conversion and products with high energy content	3. Supply uncertainty in initial phases
4. Dependent on technology already available with minimum capital input; available to all income levels	4. Costs often uncertain
5. Can be developed with present manpower and material resources	5. Fertilizer, soil and water requirements
6. Large biological and engineering development potential	6. Existing agricultural, forestry and social practices
7. Creates employment and develops skills	7. Bulky resource; transport and storage can be a problem
8. Reasonably priced in many instances	8. Subject to climatic variability
9. Ecologically inoffensive and safe	9. Low conversion efficiencies
10. Does not increase atmospheric CO_2	10. Seasonal (sometimes)

World Bank concluded that if one was to reverse the deforestation problem we would need to spend 6.75 billion dollars over the next five years in order to start reforesting 50 million hectares (World Bank 1980). There is little hope that this will happen, but that was what was realistically thought to be needed. There are a number of reasons why this won't be possible; one barrier is the very low status that foresters have in developing (and also developed) countries. It is all very well advocating reforestation schemes to help solve the energy crisis but unless you have people with the experience and knowledge to do the fieldwork there is no way that these schemes can be implemented.

Biomass Attributes

Biomass as a source of energy has problems and it has advantages. Like every other energy source one must realize that it is not the universal panacea. Some advantages and disadvantages are listed in Tab 4. One advantage that is very interesting is the large biological and engineering development potential which is available for biomass (Rabson, Rogers 1981). Presently we are using knowledge and experience which has been static for very many years; the efficiency of production and use of biomass as a source of energy has not progressed the way agricultural yields for food have increased. Thus there is an undoubted potential to increase biomass yields. The most obvious problems that immediately come to mind are land use in competition with food production (Brown 1980). Existing agricultural, forestry and social practices are also certainly a hindrance to promoting biomass as a source of energy whether in a developing or a developed country.

Biomass Projects

(Barnard and Hall 1982; Hall 1979a + b, 1981a, 1982; Bio-Energy Council 1981)

Here follow some examples of biomass programmes around the world.

Brazil. The largest biomass programme in the world is in Brazil (Trindade 1981, Lima Acioli 1981) which is spending about 1.3 billion dollars of government money a year on subsidizing the production of alcohol primarily from sugar cane. The large scale of the programme which started in 1975 is due to the fact that Brazil currently spends about two-thirds of its total foreign income (or about $11 billion) on importing oil, in order to provide the petroleum to run its transport system. Brazil does not have an extensive railway system and so is very much dependent on the internal combustion engine. Interestingly enough, it still derives about 25 % of its energy from biomass; in fact its steel industry uses charcoal as a fuel. Brazil is trying to greatly reduce this huge dependence on imported petroleum by increasing the production of alcohol; currently they produce about 4 billion litres per year and this is proposed to be expanded to about 11 billion litres by 1985. Presently, all the petrol sold in Brazil is a blend containing 20 % alcohol. On Sundays such gasohol is not sold but one can buy alcohol – about half a million cars now run on hydrated alcohol which is 95 % by volume. The price of alcohol – engine cars is less than ordinary cars that run on gasohol, and the hydrated alcohol is about 10–20 % cheaper than the gasohol. Thus there are subsidies to the producers, to the car buyer and to the car user. There are advantages and disadvantages to this system, but the Brazilians' argument is that they have to "get off the oil hook". They calculate that each barrel of oil does not cost them $34, it eventually costs them $100 a barrel when taking into account financing charges and opportunity costs.

In 1987 production is anticipated to be 14 billion litres when they hope to replace half their petroleum imports with alcohol. Everything is not perfect with this programme. In fact the Brazilians have recently published an assessment of the programme which shows their own great awareness of the problem (Ministry of Industry 1981). But as someone in Brazilia has said, if any government has to spend $6 bn in six years it can make mistakes! One problem which was immediately evident is pollution in rivers. Most of the alcohol currently being produced comes from sugar cane plantations in the South West of Brazil, where the stillage, a byproduct from the distillation of the alcohol, has often been put into rivers. For every litre of alcohol produced about 8–10 litres of stillage is produced and this has a very high chemical and biological oxygen demand. There are certainly ways of countering this pollution problem. Stillage has a high protein content and can be a valuable food when dried. It can also be fermented to methane, or be put into lakes to grow water hyacinths and algae for fermentation or cattle fodder.

Zimbabwe

(Grundy 1980, Hall 1982b)

You don't have to be a country the size of Brazil in order to have a successful alcohol programme. Zimbabwe, in 1980 opened an alcohol distillery in the Triangle area of the South East lowlands which saves them $10–12 million of foreign currency per annum. They produce 40 million litres of ethanol a year from sugar-cane which is blended into petrol by the oil companies at a 15 % blend; it is planned to increase this up to 25 % blend when a new refinery/distillery is opened. The yields of sugar-cane are high at about 120 t/ha per annum. Using the stillage from the fermentation as a fertilizer on the sugar plantations increases the yields by about 6 % and this increase allows for the extra installations to be paid for within one year.

USA

(OTA 1980, Bio Energy Council 1980, Lipinsky 1981)

The biomass resources of the US are indeed quite large. About 3 % of their total energy requirements are now met by biomass, which is equivalent to one million barrels of oil a day. The energy content of the standing forests of the US are at least 50 % greater than the oil reserves and about equivalent to the gas reserves. The Americans have a gasohol programme which blends 10 % alcohol, primarily derived from corn (maize), with unleaded gasoline to provide a high octane fuel (US-DOE 1980). You can buy gasohol in over 11,000 gasoline stations at a recent count. A gasoline pump often has an advertisement on it as follows: "Gasohol: the home grown fuel, the high octane fuel that is good for your car and good for your country". It is a bit of useful propaganda because it often costs a few cents more to buy the gasohol than it does to buy other unleaded gasoline.

Another aspect of the US energy programme is called "Silviculture Biomass Plantations", which are essentially forests! Species have been selected which grow in specific sites, with close spacing and short rotation. Coppicing ability is important i.e. after cutting down, new shoots immediately resprout from the stump (Steinbeck 1981). One is trying to obtain the maximum amount of energy per hectare per annum in such demonstration schemes. Pines, willows, oaks, maples and sycamores are some of the species undergoing trials.

Europe

(Palz et al. 1980; Chartier, Palz 1981; Moss, Hall 1983)

Nearly all the countries in Europe have energy-from-biomass schemes. Currently the EEC derives over half its total energy requirements from imported oil, so for Europe as a whole some substitution of imported liquid fuels makes biomass look interesting. The EEC programme examines the use of agricultural resources, forestry resources, algae, the digestion of biological materials to produce methane, and thermochemical routes such as gasification to produce methanol. A recent study indicated that the EEC could produce about 75 million tons of oil equivalent, which is 1 1/2 million barrels of oil a day, providing about 6 % of our estimated 1985 energy demand or more than is used in agriculture (Palz, Chartier 1980). Agriculture unfortunately often has a bad name because it is thought to be energy intensive, but there is no doubt that if ever there is an energy shortage this 3–4 % of energy requirement by agriculture is the most important. The study also showed that if a crash programme was required, a maximum disturbance to agriculture and forestry could possibly achieve a 20 % provision of our energy requirement in the EEC. It is highly unlikely that this will happen. Thus a 6 % energy provision is there for the taking, with minimal disturbance to current agricultural and forestry practices.

Some points about the land area, afforestation and agriculture in the EEC countries seem warranted. Italy, Germany, France and the UK have the same population – about 55 million. Germany is 28 % forested, France 27 %, Italy 21 %: the UK is only 8 % forested. France has twice the land area as the UK, Germany and Italy (which are equal). The EEC currently spends about 2/3 of its budget on the Common Agricultural Policy and most of this goes on subsidizing animals. To provide the food for these animals we devote a very large percentage of our land area to growing grains, and also import large quantities of grains from the United States and other countries. We produce milk, butter and cheese – it is a problem getting rid of these mountains, so very often they are fed back to animals. Since 90 % of the energy in the food is lost every time you go through the animal, it seems rather an unusual way of doing things!

Even two years ago it was unthinkable to mention the possibility that we could use some of our agricultural land and our agricultural surpluses to produce something different, such as energy. Consider that the EEC is the world's second largest exporter of sugar. It is also the second biggest meat exporter in the world, has the biggest wine lakes, and has the biggest olive oil lakes in the world. The problem in Europe is not food shortage, it is overproduction.

The French renewable energy programme, which is now over S200 million dollars a year, devotes about 40 % of its budget to production of "petrol from the earth" (COMES 1980) and various schemes are being implemented. One is "carburol" blending into petrol. "Carburol" can be acetone-butanol mixtures or other alcohols derived from fermentation processes. Ireland has a short-rotation forestry scheme, primarily using exhausted peat bogs in order to grow rapid-growing trees like willows and alder (Neenan, Lyons 1980). The UK Department of Energy study indicated that Britain could derive about 9 % of its total energy requirements from biofuels (King 1983). Sweden currently derives about 9 % of its total energy requirements from biomass. They have a very interesting series of advanced biomass trials (Heden 1982) in which fast-growing willows have been selected. Every year in Sweden there is a contest to find the tallest-growing shoot of willow. It is very successful because they now have nine clones which they call "super willows" which have twice the yield of those previously used. The Swedes conclude that if it was so desired they could derive half their energy requirements from biomass: they have the land and a low population. So, the energy is there for the taking especially from urban, agricultural and forestry wastes; the question is, can it be done economically and can it be done in the present circumstances.

Vegetable Oils

(Bio Energy Council 1981, Hall 1981b, IUCEM 1981, Lipinsky et al. 1981)

It has been known for quite a long time that vegetable oils of all types can be used as fuel in diesel engines. In 1911 Diesel wrote an article in which he advocated the use of vegetable oils in his engines in agricultural regions of the world, and predicted that it would become important in the future. Studies in Zimbabwe, South Africa, Australia, Brazil, Philippines, United States, Austria, Germany and others, show for example that in the sunny countries if a maize farmer devoted 10 % of his land area to growing sunflowers or peanuts he could fuel all the diesel-powered machines that he uses in his farming operation. It is not generally advocated that these vegetable oils are used pure. Probably a blend of from 10–30 % is preferable. The question is whether to spend money on refining the oil or to use it unrefined – if used unrefined, you have to make sure that oil filters and jets are cleaned frequently. There is also much interesting work on the esterification of sunflower oil as methyl or ethyl esters; the esterified oil has fuel properties very close to those of diesel and the esterification can be done on the farm. The Brazilians are devoting most of their effort to extraction of oil from peanuts and carefully evaluating the use of palm oil as a 6 % blend into diesel. Oils from soyabean, castor seeds and indigenous plants such as malmeleiro and babassu nut are also being investigated.

Hydrocarbon Plants

(Hall 1980, Sonalysts 1981, Stewart et al. 1982)

Proposals to use plants directly to produce gasoline have been around for quite some time with the main recent proponent being Calvin of the University of California. He advocates growing *Euphorbia lathyrus* for the extraction of hydrocarbons which have molecular weights very close to those of petroleum (Calvin 1980). There are large trials, mostly in Arizona, to establish whether this is economically viable (Johnson, Hinman 1980, 1981). Unfortunately the initial claims of high yields were not substantiated, but recent studies show yields of about 10 barrels (1.5 tons) of oil per hectare per annum under irrigation (Bioenergy Council 1981). The question is whether such yields are sustainable in arid environments (Kingsolver 1982). There are at least five other trials in various parts of the world to see if this is economically viable.

Another important product of oil is synthetic rubber. Guayule, *Parthenium argentatum*, which grows naturally in N Mexico and the S USA can be used as a source of rubber with properties which are indistinguishable from that coming from the rubber tree (CIQA 1978). By 1910 Rockefeller and Vanderbilt had made fortunes supplying a large part of the world's rubber from such guayule bushes. There exists a pilot plant of one ton a day in Saltillo, Mexico, and a 50 ton a day plant is now being proposed for N Mexico.

An alga, *Botryococcus braunii* has been shown in Australia to yield 70 % of its extract as a hydrocarbon liquid closely resembling crude oil. This has led to the idea in France of immobilizing these algae in solid matrices and using a flow-through system to produce hydrocarbons (Casadevall 1981). A green alga called *Dunaliella* discovered in the Dead Sea produces glycerol, beta-carotene, and protein. This alga does not have a cell wall and it grows in these very high salt concentrations; thus to compensate for the high salt externally it produces glycerol internally. A recent publication showed that if glycerol, beta-carotene and protein are produced this can be an economically viable system (Ben Amotz, Avron 1981).

Biogas

(Barnett et al. 1978, Hughes et al. 1982, NAS 1981b, UN-ESCAP 1981)

There are many energy problems which cannot be solved just by technology. For example, cow-dung is gathered in the areas surrounding cities and towns in India and then sold as a fuel. The removal and burning of dung has serious consequences to agriculture. There are however means of obtaining energy from cow-dung, and at the same time producing fertilizer as a by-product. The process is fermentation in biogas digesters and could be very useful in many parts of the world. There is unfortunately no universal prescription in advocating biogas as an energy source. In China biogas digesters, mostly single family units, have been built at about the rate of one million a year. Seven million have been constructed so far, mostly in Szechwan Province in S China (Chen 1981). They are cheap and not very efficient, generally do work but are abandoned if not functioning. In India 90,000 efficient biogas digesters have been built, with steel domes and concrete bases, but they require a minimum of about five cows in order for them to work efficiently (Ghate 1979). Unfortunately, there are not many families in India with five cows. Thus ideally these biogas digesters would be best suited to a community or village; but there are social problems which must be understood before putting this type of system into an Indian village, and in other parts of the world (Reddy 1981).

Aquatic Plants and Algae

(Beneman et al. 1977, CSC 1981, Richmond et al. 1979, NAS 1976, Shelef and Soeder 1980, Sheshadri 1979, Chin, Goh 1978)

The potential biomass yields from freshwater and marine plants are great. However, the extremely high water content of many of these plants when harvested, and the difficulty in drying them, may preclude their use as a fuel by direct combustion techniques. Anaerobic fermentation of aquatic plants and wet agricultural wastes appears to be a most appropriate technology for processing algae into fuel, fertilizer, and feed. Waterweeds thrive on sewage, clean the water effectively, and grow rapidly in the process. Thus, they may serve a dual role of improving the environment and providing a significant source of energy.

The production of biogas from water hyacinth has been carried out in a number of countries. They were selected as a feedstock because of their prolific growh rate and because, as floating plants, they can be easily harvested. Alternatively, algal ponds which incorporate the use of organic wastes seem promising in many of the sunnier parts of the world where there are often problems with liquid waste disposal.

Arid Lands

(Campos-Lopez 1980, Manassah and Briskey 1981)

Deserts cover about 30 % of the earth's land area. There are also large areas of semi-arid lands and savannah. Such areas often have serious energy, fuelwood and ecological problems. With proper management the vegetation of these areas could provide renewable resources for the future, such as energy, food, fibre and chemicals. A few institutes devoted to research in arid areas exist, but generally, the required research and development in these regions have been sadly neglected. Attempts to integrate arid and semi-arid regions into general economic development have always remained outside the plans of any government or international organization. There is a need to rescue the deserts, preserve their ecological characteristics, and use them in the search for plants as renewable sources of industrial materials and chemical products, which cannot be produced in regions with potential for food production.

There are many plants which have a CAM-type photosynthetic metabolism which enables them to thrive in arid zones, e.g. Guayule, *Euphorbia* and *Yucca*. Such plants make optimum use of water. Their dry matter production per unit of water used is high compared to other types of photosynthesis. They can also function well at high temperatures and light intensities, as well as under other types of physiological stress. Sustainable yields in such environments is the important criterion. The production of oils, rubbers, waxes, and energy on a sustainable basis from plants able to grow in stressful environments may be valuable in the future.

Energy Ratios

(Khan and Fox 1982, Leach 1976, OTA 1980, Pimentel and Pimentel 1979, TRW 1980)

In an ideal world the main factors to be considered in adopting a specific biomass scheme would relate to the energy gain and the economics. The benefit in converting plant material to ethanol, for example, can be expressed as the net energy ratio (NER) which is obtained by dividing the final yield of energy in useful products by the total energy inputs derived from sources other than the biomass itself. In computing the inputs, in addition to fuel, fertilizer, and irrigation, a value has to be assigned to the farm and process machinery and to ongoing maintenance. In general, a net energy gain is seen where the fermentation and distillation is powered by the burning of crop residues, as in the case of sugarcane, or by burning of wood obtained from close by – as for a cassava alcohol-distillery powered using *Eucalyptus* wood. Reported NER values for such systems vary from about 2.4 to over 7. For most starch crops and sugar beet the values are close to or below one, i.e., more energy is used than is produced. However, this may still be worthwhile if the fuel source is, for instance, cheap coal or poor quality wood or residues, etc., which are in effect converted to a high quality liquid fuel.

Implementation

(Arnon 1981, Hall 1982c, Mabbutt 1980)

One problem with biomass energy is that it is such a diverse "technology" and source of energy that actually implementing or improving biomass-for-energy schemes is often extremely difficult. They are part of the overall development requirements of rural areas of developing countries. One of the first things that must be done is a realistic local energy analysis. One needs to establish what the current and future needs (energy and other) of the people are, what biomass resources are available and which are already being used, what infrastructure exists to implement new schemes, what are the land and tree tenure patterns,and so on. This should be done by multi-disciplinary groups, with the involvement of local leaders, social workers, women's groups and so on, to establish exactly what is needed and what is available. Adequate initial financing from central or regional governments is the next stage; demonstrations and pilot schemes in the country itself are important incentives in raising funds. Similar schemes in other countries should be carefully analysed.

In our opinion, the following six factors are very important in the successful implementation of renewable energy on a regional basis. A top-level, highly visible commitment must be obtained, and facilities and PRESTIGE created to persuade people of adequate caliber to work towards biomass implementation. Appropriate INCENTIVES such as credits, guaranteed purchase and salaries should be made especially in the initial stages. Regional development staff should be given certain "perks" to prevent their posts becoming "hardship posts". TRAINING is necessary to provide extension workers, engineers, agriculturalists, foresters and other people who can implement pilot and R & D programmes. INFRASTRUCTURE, in the form of an adequate number of full-time posts, with adequate auxillary fundings, is necessary for the maintenance, extension and administration of the programme. MONITORING during the implementation phase assesses progress and the attitudes of local people and leaders. Finally, DEMONSTRATION SCHEMES and REALISTIC TIMING should be built into the scheme from the beginning. People should have employment and other forms of income during the initial stages and expectations should not be excessive, either by the local population or central planners, otherwise disillusionment can set in. Schemes which are well integrated into local work patterns and social habits will be most acceptable and successful.

The following is a suggested timetable for biomass energy programmes:

Next 10 years:	fuels from residues, trees and existing crops; use of existing biofuels; demonstrations and training.
10–12 years:	increased residue and complete crop utilization with recycling; local energy crops and plantations in use.
After 20 years:	energy farming; improved plant species. Artificial photobiology and photochemistry may become feasible for energy production.

Conclusion

Photosynthesis is the key process in the living world and will continue to be so for the continuation of life as we know it. The development of large- and small-scale biomass conversion systems has long-term implications. We might well have new and alternative ways of providing ourselves with food, fuel, fiber and chemicals in the future. In the meanwhile, we must try to correct the serious agricultural, forestry and ecological problems that overuse of biomass energy resources in rural areas (plus urban and industrial use) has already created and is continuing to create at an alarming rate.

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